

Diversity of ichthyoplankton in Tampamachoco Lagoon, Veracruz, Mexico

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Resumen. Muestras de ictioplancton fueron tomadas en otoño de 1987, y en invierno, primavera y verano de 1988 en nueve estaciones en la Laguna de Tampamachoco. Se registró la temperatura y salinidad superficial del agua. La estructura de la comunidad ictioplanctónica fue analizada considerando los índices de diversidad, dominancia y equidad; el valor de importancia y un análisis de asociaciones fueron calculados usando el índice de disimilitud de Bray-Curtis. Esta laguna es poli-hipersalina, con variaciones en la salinidad de 20-38 ups. Fueron identificadas 31 especies pertenecientes a 17 familias. Las especies dominantes fueron *Anchoa hepsetus*, *Bathygobius soporator*, *Lupinoblennius nicholsi*, *Gobiosoma bosc*, *Dormitator maculatus* y *Membras martinica*. La diversidad fue mayor en primavera y otoño con valores de 3.1 y 2.9, y el más bajo en invierno cuando *A. hepsetus* fue dominante. La laguna tiene una gran variedad de habitats que favorecen la presencia de seis grupos de especies, y es utilizada como área de alimentación y crianza por especies marinas que desovan en el mar. *Bathygobius soporator*, *L. nicholsi*, *G. bosc*, *A. mitchilli* and *M. martinica* son residentes permanentes de la laguna.

Palabras clave: larvas de peces, comunidad ictioplanctónica, laguna costera, Golfo de México.

Abstract. Ichthyoplankton sampling took place in autumn of 1987, and in winter, spring and summer of 1988 at nine stations throughout Tampamachoco Lagoon. Water temperature and salinity were recorded. Ichthyoplankton community structure was analysed considering the diversity, dominance and evenness indices. The species Importance Value and an association analysis were calculated using the Bray-Curtis dissimilarity index. This lagoon is poly-hyperhaline, with variations in salinity of 20-38 psu. A total of 31 species of 17 families were identified. The dominant species were *Anchoa hepsetus*, *Bathygobius soporator*, *Lupinoblennius nicholsi*, *Gobiosoma bosc*, *Dormitator maculatus* and *Membras martinica*. Diversity was greatest in spring and autumn with values of 3.1 and 2.9,

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and lowest in winter when *A. hepsetus* was markedly dominant. The lagoon has a variety of habitats that favour the presence of six groups of species, and it is used as a feeding and nursery area by marine species that spawn at sea. *Bathygobius soporator*, *L. nicholsi*, *G. bosc*, *A. mitchilli* and *M. martinica* are permanent residents of the lagoon.

Key words: fish larvae, ichthyoplankton community, coastal lagoon, Gulf of Mexico.

Introduction

Estuaries and lagoons are important nursery areas for many fish species (Weinstein 1979, Rozas & Hackney 1984, Peterson & Ross 1991). These include resident fish together with those that use the systems only during their juvenile stages, while taking advantage of an abundant food supply, as well as of the protection provided against physical forces and predators (Reis & Dean 1981, Bennett & Branch 1990, Tito de Moraes & Tito de Moraes 1994).

Recruitment into estuaries has been widely studied, particularly with regard to species that spawn at sea during the autumn and winter, as is the case of the Sciaenidae (Lewis & Judy 1983, Cowan & Shaw 1988, Hoss *et al.* 1988, Norcross 1991, Flores-Coto & Warlen 1992), and some species of Clupeidae, Sparidae, Ophichthidae, Bothidae and Elopidae (Warlen & Burke 1990). The passage from the sea into these nursery areas is restricted to the inlets between the barrier islands (Lyczkowski-Shultz *et al.* 1990). There is also a group of resident estuarine fish representative of these regions, of Gobiidae, Engraulidae, Cyprinodontidae, Atherinidae and Soleidae, that spawn mainly during the spring and summer (Flores-Coto *et al.* 1983, Warlen & Burke 1990).

Several studies have been carried out in Tampamachoco Lagoon on adult fish, among which are those of Kobelkowsky-Díaz (1985), Castro-Aguirre *et al.* (1986), Résendez-Medina & Kobelkowsky-Díaz (1991), López-López *et al.* (1991) and Cota-Fernández & Santiago-Bravo (1994). Few studies in coastal lagoons have looked to establish the species composition, abundance, variation in diversity and fish larvae assemblages, which are of particular importance to the knowledge of the ichthyoplankton community structure, and ultimately to enable an adequate management of the fishery resources.

It is important to mention that this study was completed before the thermoelectric plant "Adolfo López Mateos" started operations in 1991. This plant is located north of Tuxpan, on the Barra Norte de Tuxpan that separates Tampamachoco Lagoon from the sea. This and other studies will thus be of value for future evaluations of the impact of this plant on the lagoon and the adjacent littoral area. This research aims to establish the ichthyoplankton community structure throughout the year.

Study area

Tampamachoco Lagoon is located in northern Veracruz, between $20^{\circ} 55' - 21^{\circ} 02' N$, and between $97^{\circ} 15' - 97^{\circ} 23' W$. It is a shallow water body with a maximum depth of 4 m, a surface area of 15 km^2 (Reguero *et al.* 1991) and no particular bathymetric features except for an artificial navigation canal that traverses the lagoon in a north-south direction. Its greatest length and width are about 11 and 1.3 km respectively; it is separated from the sea by the Barra Norte de Tuxpan. It is connected with Tamiahua Lagoon to the north through a canal, with the sea through the artificial inlet of Galindo, and with the Tuxpan River to the south through a small estuary (Fig. 1).

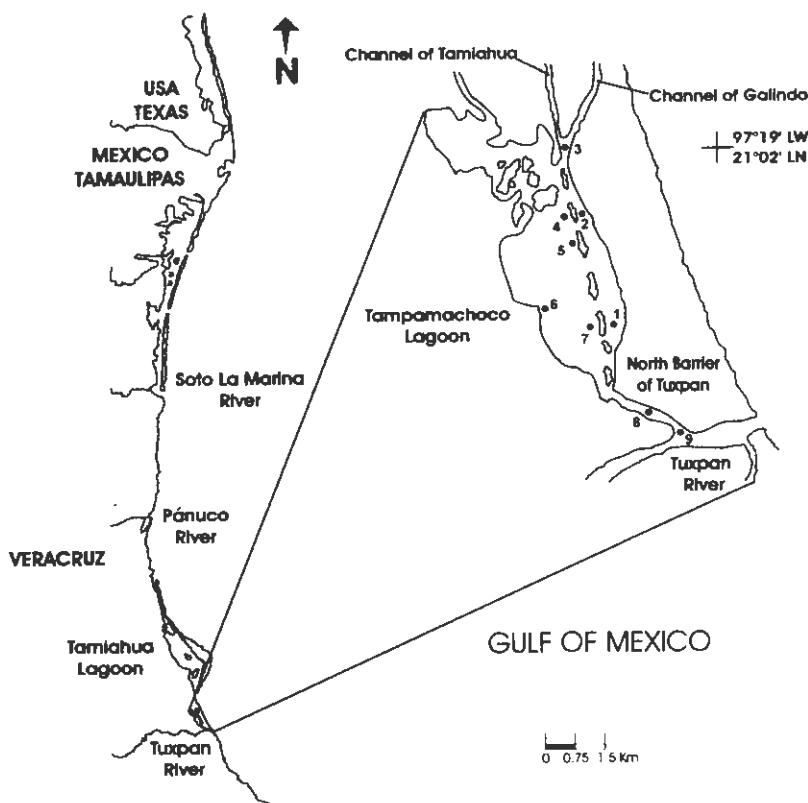


Fig. 1. Study area and ichthyoplankton sampling stations in the Tampamachoco Lagoon, Mexico.

Methods

Ichthyoplankton sampling was carried out in autumn of 1987, and in winter, spring and summer of 1988 at nine stations throughout Tampamachoco Lagoon (Fig. 1). A conical plankton net was used with a mesh size of 250 μm and a 50 cm diameter mouth, to which a flowmeter was attached. Surface plankton tows were circular and had a duration of five minutes each. Surface salinity (psu) and temperature ($^{\circ}\text{C}$) were recorded at each sampling station. Samples were fixed with 4% formalin neutralised with sodium borate. Laboratory work included the separation of fish eggs and larvae, the quantification of organisms, and their conservation in 70% alcohol. Identification of the organisms was carried out to the lowest possible taxon.

The number of specimens collected was used to calculate the density (organisms/100 m^3) of fish eggs and larvae, and the average density values for each season were used for the analyses. Only the density of the organisms identified to species level was considered. Species richness (Margalef 1968), diversity (Shannon-Weaver 1963; $\log_2$), dominance (Simpson 1949), evenness (Pielou 1975), and the species Importance Value (IV) (Krebs 1985) were calculated using the relative densities and frequencies in order to identify the dominant species. The Bray-Curtis dissimilarity index was used for the multifactorial analysis of the agglomerative classification that describes the formation of groups between species, with a flexible link cluster (β coefficient = -0.25). This was carried out with the Anacom programme (De la Cruz-Agüero 1994).

Results and discussion

Hydrology. Salinity varied during the autumn between 29 and 32 psu, except for the area between the lagoon and the estuary (station 9) where it remained at 24 psu (Fig. 2). During the winter, salinity varied only between 29 and 30 psu. It increased markedly in the spring throughout the whole lagoon to 34-38 psu, with lower values in the south at stations 8 and 9 of 30 and 28 psu respectively. It decreased markedly in the summer to 20-28 psu as the result of an increase in freshwater from the river Tuxpan that coincided with the rainy season recorded for the region by García (1973). In view of these data and in accordance with Gómez-Aguirre's (1987) classification for Mexican coastal lagoons, Tampamachoco Lagoon is classified as a polyhaline estuarine system. The surface water temperature varied between 20 and 24 $^{\circ}\text{C}$ in autumn-winter (the northerly season) and increased considerably to 27-34 $^{\circ}\text{C}$ between the spring and summer (the warm rainy season) (Fig. 3).

Ichthyoplankton. A total of 17,290 fish eggs and 12,138 fish larvae were collected. The taxa present included 17 families, 29 genera and 31 species. In terms of spe-

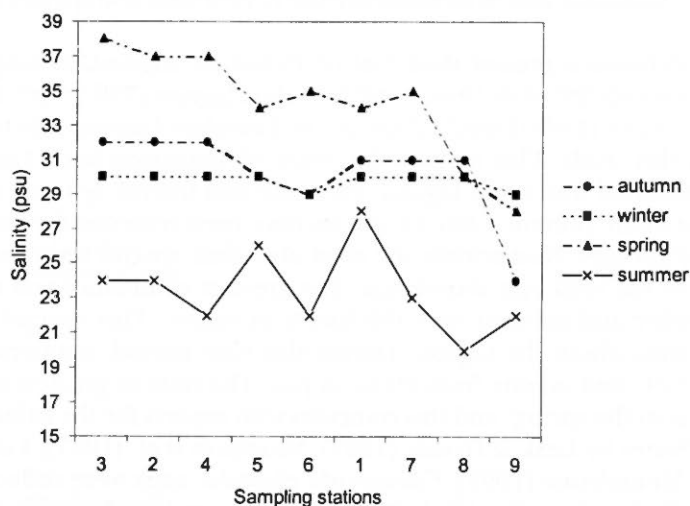


Fig. 2. Surface salinity (psu) at each sampling station in autumn of 1987, and in winter, spring and summer of 1988 in Tampamachoco Lagoon, Mexico.

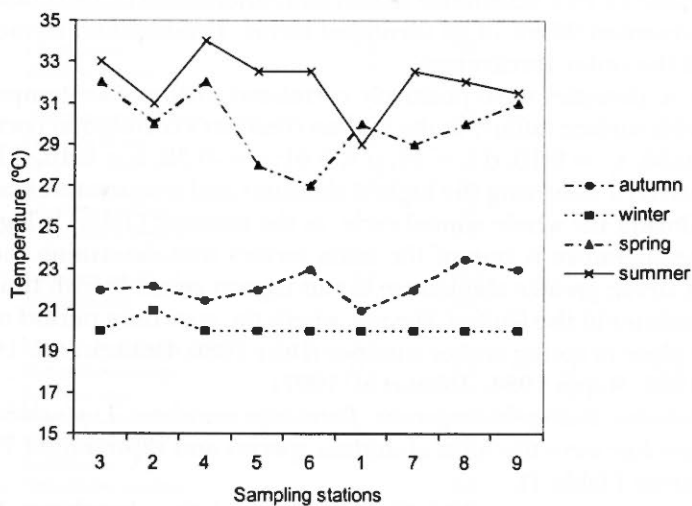


Fig. 3. Surface water temperature (°C) at each sampling station in autumn of 1987, and in winter, spring and summer of 1988 in Tampamachoco Lagoon, Mexico.

cies richness, Gobiidae and Sciaenidae are the richest with five species each (Table 1).

Species richness is greater than that of Tamiahua Lagoon, although the surface represents only 2% of the surface of Tamiahua lagoon (750.3 km², Flores-Coto 1988). Flores-Coto (1988) found 22 species in Tamiahua Lagoon, whereas 31 were recorded in this study. This may be the result of Tampamachoco Lagoon being well communicated with other lagoon, estuarine and marine systems, where a variety of habitats are present. Only 11 species have been recorded for both lagoons. *Abundance of fish eggs.* Numerically the most abundant species was *Anchoa mitchilli* with 83.9% of the total egg abundance. The greatest abundance was recorded in spring, summer and autumn, and the lowest in winter. This species was widely distributed throughout the lagoon. During this time period, temperature varied from 20 to 34°C and salinity from 20 to 38 psu. The time of greatest spawning of this species is in the spring, and this coincides with reports for the Atlantic coast of the United States by Leak & Houde (1987), Vouglitois *et al.* (1987), Luo & Musick (1991) and Monteleone (1992). *Cetengraulis edentulus* eggs were collected only in the spring, in the central area of the lagoon, at very low densities and at high temperatures (28-29 °C) and salinities (34-35 psu). Eggs of Soleidae were widely distributed throughout most of the lagoon during the autumn and spring, when temperatures ranged from 22 to 32°C and salinities from 29 to 37 psu.

Abundance of fish larvae. The family with most fish larvae was Engraulidae (54.2%), followed by Gobiidae (18.8%), Eleotridae (6.9%), Blennidae (4.3%), Clupeidae (3.6%), Sparidae (3.1%), Sciaenidae (2.8%) and Atherinidae (2.1%) (Table 1). These families represented 95.8% of all identified larvae. Unidentified larvae were yolk-sac larvae of the order Perciformes.

Fish larvae densities were positively correlated with surface temperature and negatively with surface salinity at the lagoon (Pearson's correlation coefficient, Zar 1999), ($r = 0.34$, $s_r = 0.16$, d.f. = 34, $p < 0.01$; $r = -0.32$, $s_r = 0.16$, d.f. = 34, $p < 0.01$, respectively), observing the highest densities and temperatures, also the lowest salinity during the whole annual cycle, in the summer (Table 1; Figs. 2 and 3). Therefore temperature is one of the main factors that determine the spawning period. Fish larvae greater abundance in this lagoon coincide with those reported for other localities in the Gulf of Mexico, where the spawning period of many fish species take place in spring and/or summer (Ditty 1986, Dokken *et al.* 1984, Flores-Coto *et al.* 1983, Ruple 1984, Tolan *et al.* 1997).

Anchoa hepsetus, *Bathygobius soporator*, *Dormitator maculatus*, *Lupinoblennius nicholsi* and *Gobiosoma bosc* were the most abundant species and represented 71.5% of the identified larvae (Table 1).

Anchoa hepsetus represented 48.4% of the total relative abundance. It is also the most abundant in Laguna Morales, Tamaulipas (Guerrero-Lucio 2001). The other species of Engraulidae, *A. mitchilli*, represents only 3.1%, in contrast with results recorded for other Gulf of Mexico coastal lagoons including Términos, Alvarado,

Table 1. Fish egg and larval mean densities (number/100 m³) and species Importance Value (IV) for Tampamachoco Lagoon, Mexico

Family	Genus/species	Autumn	Winter	Spring	Summer	IV
EGGS						
Clupeidae				0.6		
Engraulidae				8.7		
	<i>Anchoa mitchilli</i>	975.6	133.1	1555.59	95.1	
	<i>Cetengraulis edentulus</i>			0.4		
Achiiridae		1.8		2.7		
Undetermined		181.7	10.5	50.2	447.8	
TOTAL		1159.1	143.6	1618.0	1442.9	
LARVAE						
Elopidae	<i>Elops saurus</i>		0.9			1.9
Ophichthidae	<i>Myrophis punctatus</i>		0.2			1.7
Clupeidae			0.6			
	<i>Brevoortia</i> spp		10.2			
	<i>Harengula jaguana</i>		2.6			2.4
Engraulidae	<i>Anchoa hepsetus</i>	20.3	141.0	1.3	16.3	59.8
	<i>A. mitchilli</i>	2.7		7.8	1.0	8.3
	<i>A. lamprolaria</i>			7.1		3.8
	<i>Anchoa</i> spp			2.1	0.9	
Atherinidae	<i>Membias martinica</i>	2.8	1.7	3.0	0.3	8.9
Syngnathidae	<i>Syngnathus scovelli</i>	0.2			0.3	3.4
Gerreidae		0.3				
	<i>Ulaena leproyi</i>	1.1	0.2	1.9	0.4	7.6
	<i>Diapterus rhombus</i>	1.7				2.2
Sparidae	<i>Lagodon rhomboides</i>		11.6			5.1
Sciaenidae	<i>Micropogonias undulatus/furnieri</i>		0.7			1.9
	<i>Bairdiella chrysoura</i>	0.2		1.3	0.4	5.5
	<i>Cynoscion nebulosus</i>			1.1		2.0
	<i>C. arenarius</i>	0.2	1.6	0.5	0.7	7.5
	<i>Leiostomus xanthurus</i>		3.6			2.7
Polynemidae	<i>Polydactylus octonemus</i>		0.2			1.7
Bleenniidae	<i>Lupinoblennius nicholsi</i>	3.0	8.9	2.0	1.9	11.3
Eleotridae	<i>Dormitor maculatus</i>	3.8	21.0			10.7
	<i>Eleotris pisonis</i>		0.8			1.9
Gobiidae		2.7	2.2	0.7	13.9	
	<i>Gobioides broussoneti</i>	0.3				1.7
	<i>Bathygobius soporator</i>	17.0	1.0	0.8	11.1	15.5
	<i>Gobiosoma bass</i>	3.8	0.9	1.4	8.7	11.0
	<i>Evarthodius lynceus</i>		1.8		0.3	3.9
	<i>Gobionellus hastatus</i>	1.2	0.9			3.9
	<i>G. boleosoma</i>	0.7				1.9
Paralichthyidae	<i>Citharichthys arcifrons</i>		0.8			1.9
	<i>C. spilopterus</i>		0.9			1.9
Achiiridae	<i>Achirus lineatus</i>	0.8		1.0	3.5	6.5
	<i>Trinectes maculatus</i>	0.6				1.8
Undetermined		146.7	4.9	21.5	3011.4	
TOTAL		210.3	219.5	53.6	3071.1	

Tamiahua (Flores-Coto 1988), Pueblo Viejo (Ramírez-Orta 2001) and Madre (Guerrero-Lucio 2001), where it has been recorded as the dominant species in the fish larvae community.

The period of maximum reproduction does not overlap in the case of the engraulid species. *Anchoa mitchilli* was not collected during the winter when *A. hepsetus* had high larval densities, and its greatest values of egg and larval density were recorded in the spring, summer and autumn. These dates coincide with the season of greatest reproduction of *A. mitchilli* reported for Términos lagoon, in contrast with the spawning of *A. hepsetus* which was not very abundant, with a slight peak in winter and with its eggs distributed mainly in marine influence zones (Ocaña-Luna *et al.* 1987, Flores-Coto *et al.* 1988). Therefore it is considered that *A. hepsetus* spawns at sea and its larvae get into the coastal lagoons, a fact observed by Ogburn-Matthews & Allen (1993) in an estuary of South Carolina, USA. It can be said that it is probable that the low abundance of the larvae of *A. mitchilli* is due to a high predation since it is the main source of food for predatory fish along its distribution range (Baird & Ulanowicz 1989, Juanes *et al.* 1993).

Larval abundance of *B. soporator*, *G. bosc* and *L. nicholsi* (16.4%) in the lagoon may be favoured by the 29 oyster banks in Tampamachoco, found in several phases of production (Reguero *et al.* 1991), inasmuch as it has been observed that the adults of some species of Gobiidae and Blennidae are closely associated with the American oyster *Crassostrea virginica*, as its empty shells provide protection against predation and substrate for the deposition of eggs (Dahlberg & Conyers 1973, Résendez-Medina 1973, Crabtree & Middaugh 1982, Harding & Mann 2000).

Dormitator maculatus has been recorded in other studies, as in this one, as the most abundant Eleotridae in the coastal lagoons of Términos, Alvarado, Tamiahua (Flores-Coto, 1988), Pueblo Viejo (Ramírez-Orta 2001), Madre and Morales (Goitia-Fabian 2000). It is widely distributed as it tolerates salinities ranging from fresh to hypersaline values of 75‰ (Nordlie & Haney 1993).

Larvae of *Elops saurus*, *Myrophis punctatus*, Clupeidae, *Brevoortia* spp., *Harengula jaguana*, *Lagodon rhomboides*, *Micropogonias undulatus/furnieri*, *Leiostomus xanthurus*, *Polidactylus octonemus*, *Eleotris pisonis*, *Citharichthys arcifrons* and *C. spilopterus* were collected exclusively in winter in narrow ranges of temperature (20–21°C) and salinity (29–30 psu). With the exception of *H. jaguana*, *P. octonemus*, *E. pisonis* and *C. arcifrons*, these have been reported as species that spawn at sea and enter estuarine-lagoon systems as larval/early juvenile fishes to complete their life cycles (Warlen & Burke 1990).

Ichthyoplankton community structure. Diversity was greatest in spring and autumn with index values of 3.1 and 2.9 respectively which coincides with the average values of high salinity (34.2 y 30.2 psu). It was lowest in winter with a value of 1.8, when the lowest evenness value of 0.42 was recorded. Dominance was low in general (0.16–0.24), with the exception of winter when it reached a value of 0.51. The

low diversity recorded in winter was the result of the greater abundance of *A. hepsetus* that caused a greater dominance at that point during the cycle. Species richness was highest in autumn and winter (2.54 and 2.53) with 17 and 20 species respectively, after which it decreased during spring-summer (1.97-1.83) with 12 species in both seasons (Fig. 4; Table 1).

The heterogeneity of habitats in the lagoon favours a great diversity of species that make up various groups (Fig. 5). According to the cluster analysis and the Bray-Curtis index, these groups are:

Group I. *E. saurus*, *M. undulatus/furnieri*, *E. pisonis*, *C. spilopterus* and *C. arcifrons* that reproduce at sea and enter the lagoon only in winter with low abundance.

Group II. Two low-abundance species considered incidental, *M. punctatus* and *P. octonemus*, with the lowest Importance Value (Table 1).

Group III. *H. jaguana*, *L. rhomboides* and *L. xanthurus* that reproduce at sea and enter the lagoon only in winter but with great abundance, together with *C. arenarius*, *D. maculatus* and *E. lyricus* that were present during other months but were more abundant in winter.

The greater part of the species included in groups I, II and III (Fig. 5) with exception of *P. octonemus* were recorded mostly in the lagoon inlet or in areas under marine influence, for which reason they may be considered as marine euryhaline species. Whitfield (1994) defined this marine euryhaline species as those which at

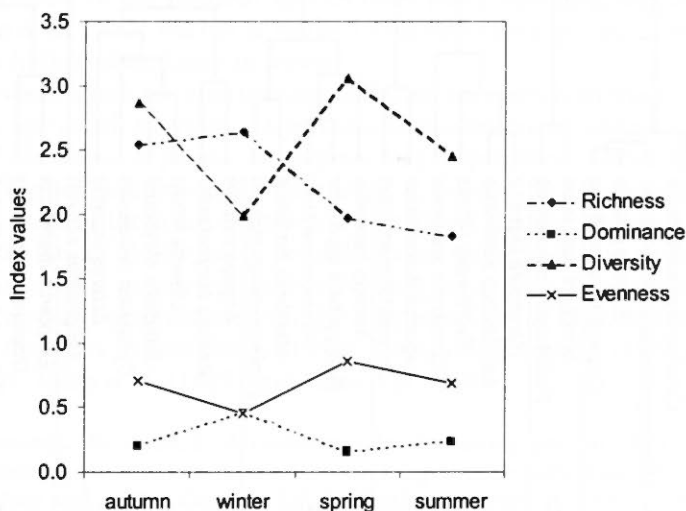


Fig. 4. Variation in species richness, dominance, diversity, and evenness in Tampamachoco Lagoon, Mexico.

least partly depend on estuarine systems, a large proportion of which could be regarded as marine/estuarine opportunists. These species spawn at sea but make extensive use of estuaries as nursery areas (Whitfield 1983, Warlen & Burke 1990).

Dormitator maculatus, *E. pisonis* and *E. lyricus* are frequent and common species in the coastal lagoons. They tolerate wide variations of salinity and are included in the euryhaline marine component (Castro-Aguirre *et al.* 1999).

Group IV. The species included in this group are *A. hepsetus*, *B. soporator*, *L. nicholsi*, *G. bosc* and *M. martinica*, and are considered lagoon resident species or most abun-

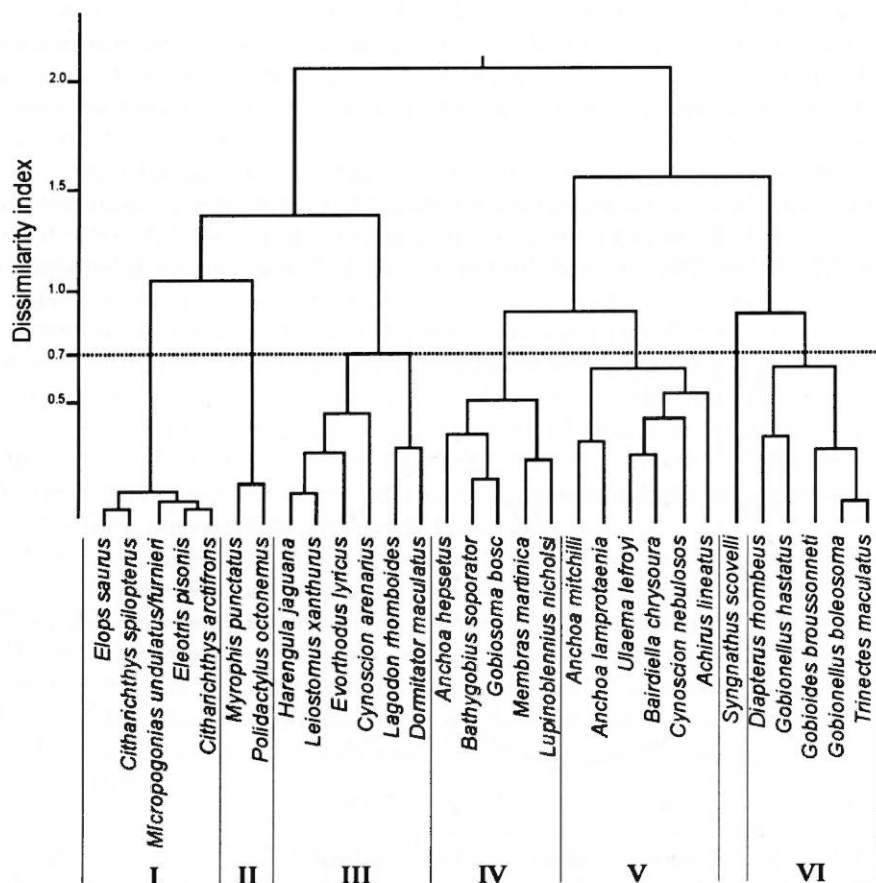


Fig. 5. Dendrogram of species groups defined by the Bray-Curtis dissimilarity index, using density data of the fish larvae for Tampamachoco Lagoon, México. Vertical line (0.7) indicates level of cluster recognition.

dant species that spend their whole life cycle within coastal lagoons. *Anchoa hepsetus* is an exception as it spawns at sea and its larvae enter the lagoon in great numbers. For their high abundance and frequency, species in this group are dominant components of the ichthyoplanktonic community in Tampamachoco Lagoon, and have Importance Values of 8.9 %.

Group V. Species that reproduce mainly during the warm season (spring or summer) and include *A. mitchilli*, *A. lamprotaenia*, *Ulaema lefroyi*, *Bairdiella chrysoura*, *C. nebulosus* and *A. lineatus*.

Group VI. These species have been recorded exclusively in the autumn and include *Diapterus rhombeus*, *Gobioides broussonneti*, *Gobionellus hastatus*, *G. boleosoma* and *Trinectes maculatus*.

The greater part of the species (64%) in groups IV and V (*A. hepsetus*, *A. mitchilli*, *M. martinica*, *B. chrysoura*, *C. nebulosus*, *G. bosc* and *A. lineatus*) are considered to constitute the basic group of the ichthyoplanktonic community in the other lagoon systems in the Gulf of Mexico, Tamiagua, Alvarado and Términos (Flores-Coto 1988). *A. mitchilli* and *G. bosc* are noteworthy for being common in these three lagoons.

Tampamachoco Lagoon is used as a residence area by *B. soporator*, *L. nicholsi*, *G. bosc*, *M. martinica* and *A. mitchilli*, the larvae of these species are commonly found throughout the year with the highest abundance in spring, summer or autumn. Its reproduction periods coincide with what is registered for other estuarine-lagoon systems of the Gulf of Mexico and the Atlantic Ocean, where it has been observed that the spawning of the resident species takes place during spring and summer (Flores-Coto *et al.* 1983, Warlen & Burke 1990) with exception of *L. nicholsi* which presented a higher abundance in winter.

On the other hand, ten species were collected exclusively in winter. These species were: *E. saurus*, *M. punctatus*, *H. jaguana*, *L. rhomboides*, *M. undulatus/furnieri*, *L. xanthurus*, *P. octonemus*, *E. pisonis*, *C. arctifrons* and *C. spilopterus*. Other species which presented a higher abundance in winter were: *A. hepsetus*, *C. arenarius*, *D. maculatus* and *E. lyricus*. All of them are considered euryhaline marine species which spawn at sea and its larvae and/or early juvenile fishes migrate to the estuarine-lagoon systems to use them as nursery and/or feeding area. This dependence of many marine species has been recorded for the northern Gulf of Mexico and the Atlantic coast of the USA by Weinstein (1979), Cowan & Birdsong (1985), Warlen & Burke (1990), Tolan *et al.* (1997) and Hoss *et al.* (1988).

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