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Research Article

Patterns of distribution, temporal fluctuations and some population parameters of four species of flatfish (Pleuronectidae) off the western coast of Baja California

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ABSTRACT. We examined the spatial and temporal abundance as well as some biological features of the four Pleuronectidae species living in the shallow and deep marine waters off the western coast of Baja California: spotted turbot *Pleuronichthys ritteri* (Starks & Morris, 1907); hornyhead turbot *Pleuronichthys verticalis* (Jordan & Gilbert, 1880); slender sole *Lyopsetta exilis* (Jordan & Gilbert, 1880), and Dover sole *Microstomus pacificus* (Lockington, 1879). Flatfishes were sampled by otter trawls during six cruises, between October 1988 and September 1990. The area sampled covers three geographic regions (Southern, Central and Northern) and three depths (inner, middle and outer shelf). The data were analyzed to quantify the ecological variation in environmental factors and spatial assemblages. Spatial patterns of the Pleuronectidae assemblages were determined by depth, sediment type and geographical region. The distribution of Pleuronectidae species across the shelf also varies in time depending on the oceanic regimes. The sex ratio was approximately 1:1 for all four species. Standard length ranged from 45 to 261 mm, with the most frequent sizes ranging from 90 to 130 mm. For turbots, the length-weight relationships varied between sexes, geographical regions and seasons of the year.

Keywords: Pleuronectidae, flatfish, distribution, population parameters, Baja California, Mexico.

Patrones de distribución, fluctuaciones temporales y algunos parámetros poblacionales de cuatro especies de lenguados (Pleuronectidae) frente a la costa occidental de Baja California

RESUMEN. Se examinó la abundancia espacial y temporal, así como algunas características biológicas de cuatro especies de la familia Pleuronectidae que habitan en aguas someras y profundas frente a la costa occidental de Baja California: platija moteada *Pleuronichthys ritteri* (Starks & Morris, 1907); platija cornuda *Pleuronichthys verticalis* (Jordan & Gilbert, 1880); lenguado delgado *Lyopsetta exilis* (Jordan & Gilbert, 1880), y lenguado resbaloso *Microstomus pacificus* (Lockington, 1879). Los peces planos se muestrearon con redes de arrastre durante seis cruceros entre octubre de 1988 y septiembre de 1990. El área muestreada cubrió tres regiones geográficas (sur, centro y norte) y tres profundidades (plataformas interna, media y externa). Los datos se analizaron para cuantificar la variación ecológica en cuanto a factores ambientales y asociaciones espaciales. Los patrones espaciales de asociación de los pleuronéctidos fueron determinados por profundidad, tipo de sedimento y región geográfica. La distribución de las especies de pleuronéctidos en la plataforma, varió en el tiempo dependiendo de los regímenes oceánicos. La proporción de sexos fue aproximadamente 1:1

para las cuatro especies. La longitud estándar abarcó desde 45 a 261 mm, siendo las longitudes más frecuentes entre 90 y 130 mm. Para las platijas, la relación longitud-peso varió entre sexos, región geográfica y estación del año.

Palabras clave: Pleuronectidae, lenguados, distribución, parámetros poblacionales, Baja California, México.

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INTRODUCTION

Fishes of the family Pleuronectidae are widely distributed in subtropical & boreal oceans (Eschmeyer, 1998; Love *et al.*, 2005), and some species constitute important fishery resources in several countries. Of these, *Lyopsetta exilis* (slender sole) and *Microstomus pacificus* (dover sole) are among the most abundant flatfishes in the demersal communities of the northwest Pacific Ocean (Alton, 1972; Demory & Hosie, 1975). From the Oregon to Baja California coast, Pleuronectidae are the most abundant soft-bottom flatfishes caught in otter trawls (Allen, 1982). The available reports on bottom-trawl surveys off southern California lack information on size-specific abundance of soft-bottom species (Allen, 1982; De Martini & Allen, 1984; Love *et al.*, 1986) and most of these surveys sampled depths greater than 12 m.

Besides changes in overall abundance, fish communities can respond to fluctuations in oceanic regimes by showing changes in their geographic or bathymetric distributions (Allen, 2008). These changes in the geographical distribution have been observed often during warm El Niño events. Water depth directly affects the community structure in the continental shelf and slope in coastal waters that potentially serve as nursery areas (Abookire & Norcross, 1998), and depth also plays an important role in determining the distribution of flatfish (Rogers, 1992; Gibson, 1994; Norcross *et al.*, 1995). There is little information about changes in the structure and distribution of flatfish communities during the above mentioned El Niño (Lea & Rosenblatt, 2000; Allen *et al.*, 2004).

Few studies have been reported on Baja California Pleuronectidae, providing general information on the zoogeography (Castro-Aguirre *et al.*, 1992; Eschmeyer, 1998; Rodríguez-Romero *et al.*, 2008) and distribution (Kramer, 1991; Rosales-Casián, 1996; Rábago-Quiroz *et al.*, 2008).

Flatfish species contribute with an account for 88% to demersal fishes captures in Baja California, with more than 500 ton per year (Balart, 1996). Most incidental flatfish captures are taken by otter trawls and such figures indicate the importance of several flatfish species caught in exploratory fishing surveys in Baja California (Ehrhardt *et al.*, 1982; Aurioles-Gamboa *et al.*, 1993).

In the Pacific waters off California and Baja California coasts 22 species of Pleuronectidae have been recognized (Miller & Lea, 1972; Fischer *et al.*, 1995; Eschmeyer, 1998). Exploratory surveys off the western coast of Baja California collected around 20 flatfish species of the families Pleuronectidae, Bothidae, Paralichthyidae and Cynoglossidae (Martínez-Muñoz & Ramirez-Cruz, 1992) on the soft bottoms of the continental shelf and slope.

The objectives of this study were: 1) to describe the temporal and spatial patterns in the distribution and abundance of Pleuronectidae; 2) to assess the relationship between abundance and environmental variables that structure flatfish populations; and 3) to determine the population structure for sizes and the characteristics of the size-weight relationships for each of the species studied.

MATERIALS AND METHODS

Study area and data collection

Fishes were collected from April 1988 to September 1990 from nine cruises aboard the R/V El Puma and R/V Marsep XVI. One hundred and five sampling stations were located off the western coast of Baja California, from Boca del Carrizal (23º00'N) to Vizcaíno Bay (28º51'N) (Fig. 1). Many hours were spent searching for suitable bottoms during the first cruises. Echosonic exploration to detect stations of positive (not risky) trawling, according to bottom outline, was made using a Simrad sounder. Once the geographic position of the stations was established and recorded, the bottom suitability was verified by sampling the type of substrate with a Smith-McIntyre grab. Ships were positioned on the same stations on subsequent trips with a satellite navigator. Samples were taken during day and night. All fishes were collected using an otter trawl 20 m wide and 9 m high at the mouth and, 24 m in length. The nets, in both cases, were those used in the typical shrimp fishery with a stretched mesh size of 3 cm. The mean speed

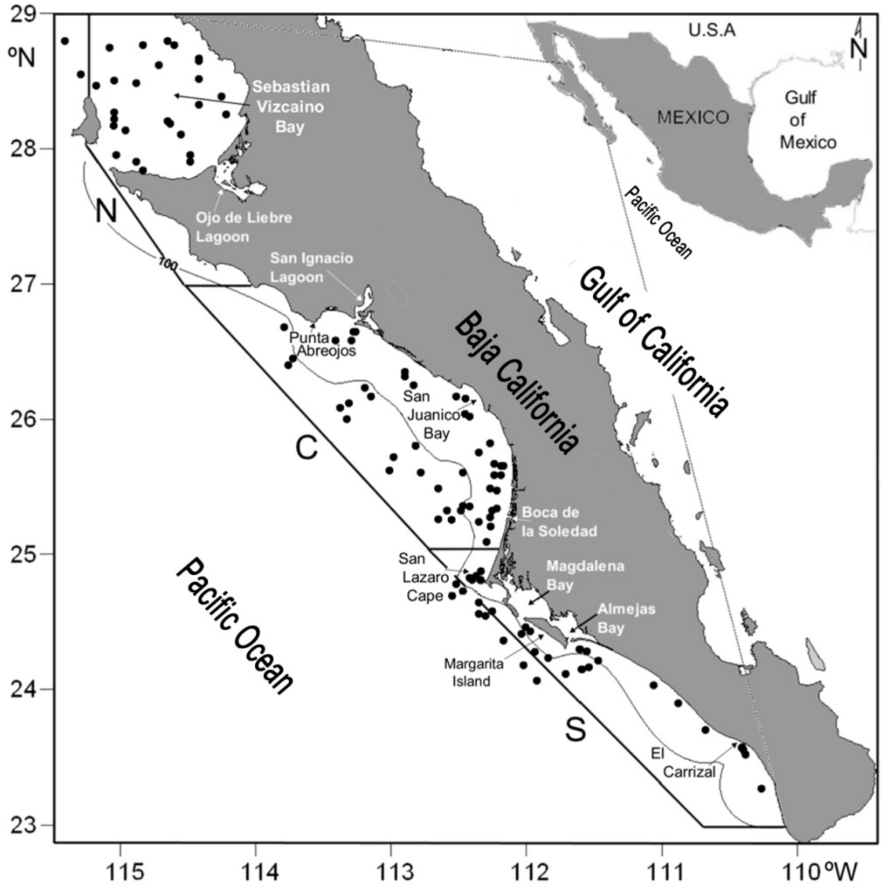

Figure 1. Sampling stations off the western coast of Baja California, México. Northern (N), Center (C) and Southern (S) regions.

was 2.5 knots. Trawling time and speed were recorded to estimate the area swept by the net (Sparre & Venema, 1997). The trawls were towed for 30 min at depths of 10 m to 250 m.

Temperature and salinity data were recorded after each trawl by using an internally recording conductivity-temperature-depth sound (CTD). The sediment types for the stations were characterized by the percent distribution of sand, silt and clay (Table 1).

Samples were collected according to a random stratified design to cover different depths and geographic regions. Depth sampled comprised inner shelf (10 to 50 m), middle shelf (51 to 100 m) and outer shelf (100 to 250 m depth). Samples were also randomly distributed along geographical regions: Southern (23-24ºN), Central (25-26ºN) and Northern (27-29ºN).

Statistical analysis

In order to assess both spatial and temporal variations, species abundance data were averaged by sampling region and depth stratum. Bottom water temperature, salinity and bottom sediment composition data were also included in the analysis as a covariable data matrix.

The records of the catches were transformed by area swept, standardized to units of abundance (ind ha^{-1}) and biomass (kg ha^{-1}). Analysis of variance (ANOVA) was used to describe the variability in abundance and biomass by length class, season, region and depth of the stratum. Differences were considered significant where $P < 0.05$. The Tukey test was used to determine whether there were significant differences among zones and seasons on both fishes and environmental data.

Fishes and environmental data were log (x+1) transformed previously to fulfill homoscedasticity and normality requirements, in order to validate assumption for parametric analyses applied to the univariate and multivariate tests, to reduce the weighting of abundant species, and to balance the effect of different units of measurement of the environmental parameters.

Table 1. Cruises (month, year), season (Spr = spring; Sum = summer), number of trawls with Pleuronectidae (trawl/sp), depth range (m), surface temperature (ST), bottom temperature (BT), salinity (psu), type of sediment (%), abundance (Abun), biomass (Biom), during the study period 1988-1990, off the western coast of Baja California.

Cruises Month/Year	Season	Total trawl	Nº trawl/sp	Depth (m)	Temperature (ºC)		Salinity (psu)	Sediment (%)			Abun	Biom
					ST	BT		Sand	Silt	Clay	(ind ha^{-1})	(kg ha^{-1})
Apr-Jul-1988	Spr-Sum	16	11	13-56	-	-	-	78.3	12.1	9.7	745	49.2
Oct-1988	Fall	16	4	31-180	21.2-28.0	14.0-19.2	28.0-34.2	79.0	13.3	7.6	32	3.1
Feb-1989	Winter	17	3	25-168	16.0-28.0	12.5-15.1	30.2-35.0	70.6	20.7	8.9	31	1.0
Jul-1989	Summer	19	17	31-197	13.5-24.0	11.0-22.0	31.0-34.5	64.5	25.1	10.6	2013	61.0
Mar-1990	Winter	18	15	37-237	13.8-19.0	11.0-18.0	30.5-34.6	65.2	23.3	11.6	193	13.5
Sep-1990	Summer	19	16	42-312	16.0-32.0	11.5-24.6	33.5-39.2	57.2	28.0	15.1	152	16.0

We used redundancy analysis (RDA) to explore species distribution patterns. This technique is a powerful tool to identify patterns of community structure. This ordination analysis technique allows for the establishment of relationships between the community structure pattern and the environmental data pattern and is designed to extract synthetic environmental gradients from ecological data sets (Ter Braak, 1988). The gradients are basic to describe differential habitat preferences of the species via ordination diagrams (Ter Braak & Verdondchot, 1995).

A forward selection of environmental variables was used to select a minimum set of environmental variables that best explained the distribution and abundance of fishes (Ter Braak & Juggins, 1993). The explanatory variables are represented by vectors pointing towards the maximum change in the value of the associated variable. Species and sample sites marked with points would represent the optimum distribution for a given species. The length of each vector on the biplot would indicate the relative importance of the environmental variable in the ordination. The position and direction of each vector indicates how it is correlated with the other vectors and with each axis. To test the advisability of adding variables, Monte Carlo permutation simulations were conducted. Variables were added as long as their addition contributed significantly to explain variance ($P < 0.05$). Additionally, the Spearman rank correlation coefficient was used to determine the significance of the relationship between each environmental variable and fishes abundance (Zar, 1996).

Environmental characterization of the sampling stations was done through correlation-based Detrended Redundancy Analysis (RDA) using CANOCO 4.5 software (Ter Braak, 1988).

Individual flatfish were identified, counted, measured to the nearest millimetre standard length (SL), weighed (g) and classified into length classes. The relationship between length and weight of fish is described as follows (Wooton, 1990; Anderson & Neumann, 1996):

$$W = a\ SL^{b}$$

where W is weight in grams, SL is the standard length (mm), a-values is the y-intercept and b is the slope.

The length-weight data were grouped by sex, region and shelf stratum and analyzed for possible differences for these factors. To perform the statistical analysis, the length and weight data were logarithmically-transformed (base 10), linear regressions were fitted to pairs of observations by each species and the slopes of the length-weight relationships for these groupings were compared by an analysis of covariance (ANCOVA) to test for equality of slopes among groups.

RESULTS

The surveys represent different oceanic periods: 1988 (ENSO, very warm), 1989 (cold regime), and 1990 (warm regime). These seasonal and interannual fluctuations in the study area were observed in the patterns of temperature, salinity and organic matter concentration (Table 2). The temperature showed values between 13 and 32ºC at the surface, and between 11 and 24ºC at the bottom.

The surface temperature during the fall of 1988 ranged between 21 and 28ºC while it varied between 13 and 24ºC for the summer of 1989 and between 16 and 32ºC for the summer of 1990. The bottom temperature recorded values of 14 to 19ºC, 11 to 22ºC and 11.5 to 24ºC for 1988, 1989 and 1990 respectively.

Table 2. Means (standard deviation) of environmental variables and comparison among years in the three regions and strata of the continental shelf off the western coast of Baja California. Surface temperature (Surf. T.), bottom temperature (Bott. T.), salinity, and organic matter (O. Mat).

	Region								
	Southern			Center			Northern		
	1988	1989	1990	1988	1989	1990	1988	1989	1990
Surf. T.	24.1 (1.9)	17.7 (1.2)	20.9 (4.4)	22.6 (0.7)	19.2 (3.6)	23.1 (5.1)	-	17.1 (1.4)	19.9 (3.3)
Bott. T.	13.7 (0.7)	14.1 (1.0)	15.3 (3.2)	16.9 (1.4)	14.6 (2.1)	14.5 (3.0)	-	12.2 (2.0)	13.3 (2.2)
Salinity	31.7 (2.0)	31.7 (0.3)	35.3 (1.9)	31.9 (0.3)	32.1 (1.0)	34.4 (0.2)	-	33.1 (0.1)	33.7 (0.1)
O. Mat.	0.67 (0.2)	0.3 (0.2)	0.91 (0.3)	1.14 (0.3)	1.30 (0.6)	2.1 (1.1)	-	1.9 (0.7)	1.86 (0.4)
	Shelf								
	Inner			Middle			Outer		
	1988	1989	1990	1988	1989	1990	1988	1989	1990
Surf. T.	23.1 (00.2)	18.5 (2.6)	21.0 (4.3)	22.9 (0.7)	18.3 (3.2)	22.2 (4.6)	23.9 (2.4)	17.6 (1.2)	21.2 (4.9)
Bott. T.	18.8 (0.4)	15.9 (2.7)	16.3 (3.1)	16.0 (1.0)	13.5 (1.9)	15.5 (3.3)	15.2 (0.9)	12.9 (1.1)	13.0 (1.7)
Salinity	31.6 (0.2)	32.2 (0.5)	34.0 (0.4)	32.2 (1.0)	32.1 (1.2)	34.1 (0.4)	31.4 (1.8)	31.8 (0.3)	34.8 (1.4)
O. Mat.	0.8 (0.0)	1.0 (0.2)	1.3 (0.3)	1.0 (0.3)	1.5 (0.7)	1.6 (0.7)	0.91 (0.3)	1.1 (0.8)	1.8 (1.2)

When ANOVA was applied to the annual values of surface temperature, significant differences between years were found (F = 67.4, df = 8, $P < 0.05$). Significant differences between the inner and outer shelf were also detected for bottom temperatures (F= 4.21, df = 8, $P < 0.05$). The Tukey test showed also significant differences between the Central and Northern regions.

The temporal variation of salinity recorded the lowest values in the fall of 1988 (28.0 psu) and in the winter of 1988 (30.2 psu), while the highest values were observed in the summer of 1990 (39.2 psu). Statistical analysis showed significant differences (F = 43.6, df = 8, $P < 0.05$) between the years 1988-1990 and 1989-1990.

Organic matter of the sediments registered the lowest concentrations in the southern region, ranging between 0.3 and 0.9%. In the central region between Punta Abreojos and Magdalena Bay, organic matter concentrations ranged between 0.5 and 4.0%, with a maximum detected near the 100 m isobath. In Vizcaino Bay, the organic matter values ranged between 0.4 and 2.8%.

ANOVA analysis showed that sediment organic matter values were significantly different between the years 1988 and 1990 (F = 6.93, df = 8, $P < 0.05$). Differences were also significantly different between the north-southern and southern-central region (F = 10.6, df = 8, $P < 0.05$).

The total abundance of Pleuronectidae was 3166 ind ha^{-1} and biomass was estimated at 143.9 kg ha^{-1}. Four species of the family Pleuronectidae were found: *Pleuronichthys ritteri* (spotted turbot); *P. verticalis* (hornyhead turbot); *Lyopsetta exilis* (slender sole) and *Microstomus pacificus* (Dover sole).

The most abundant species was spotted turbot accounting to 78.1% in abundance and 73.8% in biomass of the total catches, being present in more than 60% of the samples. Second in abundance was slender sole with 16% in numbers and 18.5% in biomass, with an ocurrence of 10.6%. Hornyhead turbot and dover sole showed values less than 3% of the abundance and 6% biomass, respectively, but the former accounted for 20% occurrence in the sampling.

Spotted turbot was widely distributed throughout the three regions off the western coast of Baja California. Spatial and temporal relative abundances changed throughout the three-year studied period. During 1988-1989 fishes were more abundant in the southern (1653 ind ha^{-1} and 63.0 kg ha^{-1}) and central (663 ind ha^{-1}and 36.8 kg ha^{-1}) regions. The northern region recorded the minimum abundances with a mean of 156 ind ha^{-1}and 6.4 kg ha^{-1} (Figs. 2a, 2c).

The depth distribution of spotted turbot had the highest abundances in the inner and middle stratum, with 904 ind ha^{-1}and 1033 ind ha^{-1}, respectively, with the corresponding biomass values ranging between 62.3 and 31.2 kg ha^{-1}. The minimum values were found in the outer shelf with 505 ind ha^{-1} and 12.6 kg ha^{-1} (Figs. 2b, 2d).

The contours of highest abundance (Fig. 3a) ranged between 156 and 786 ind ha^{-1}, in April-July

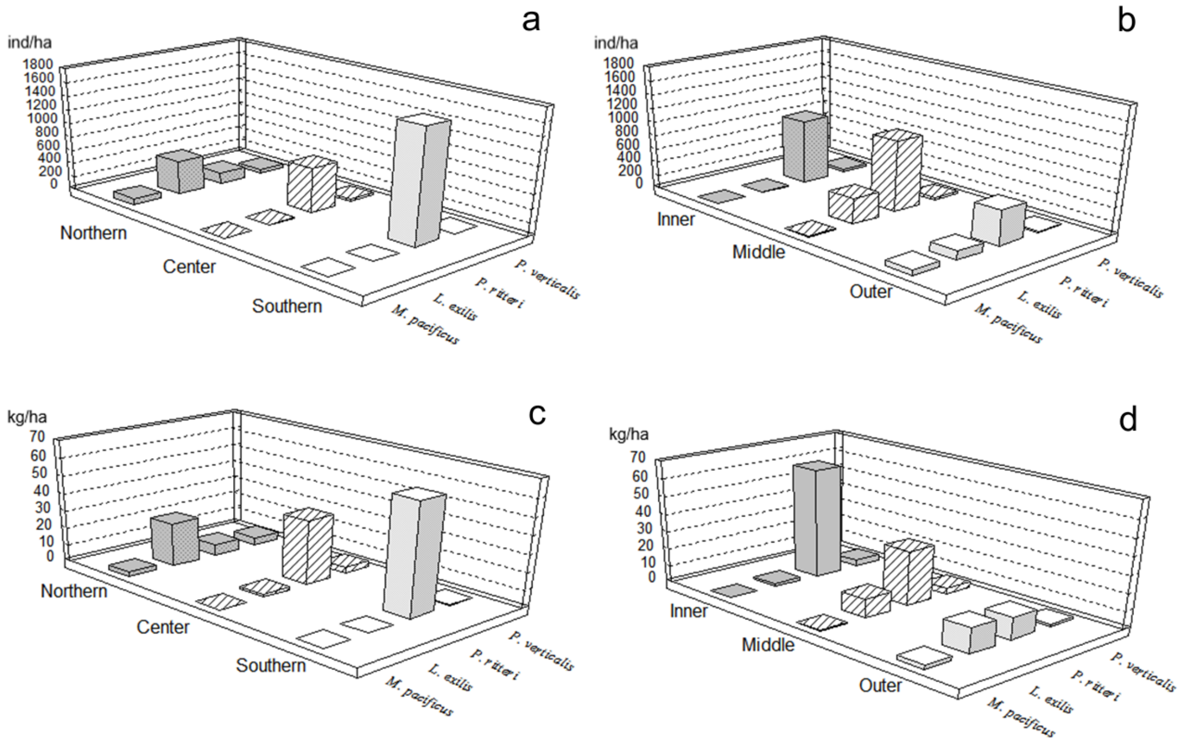

Figure 2. Distribution of abundance and biomass of Pleuronectidae species during 1988 and 1990, by region (a, c) and strata of the continental shelf (b, d).

1988 and 1989 respectively, in the localities of San Ignacio Lagoon and San Juanico Bay, and the waters adjacent to Cape San Lazaro and Margarita Island (center).

In the middle and shallow strata of Vizcaino Bay hornyhead turbot (Fig. 3b) recorded the highest abundances in March 1990, with 61 ind ha^{-1} and 4.6 kg ha^{-1}. Lower values were found between the localities of Bahia San Juanico and San Ignacio Lagoon with 32 ind ha^{-1} and 3.4 kg ha^{-1} respectively. The lowest values of biomass and abundance were found close to Magdalena Bay 3 ind ha^{-1} and 0.21 kg ha^{-1} (Figs. 2a-2d).

Slender sole record their peak abundance of 500 ind ha^{-1} and a biomass of 130 kg ha^{-1} in Vizcaino Bay, at depths between 90 and 200 m (Figs. 2a-2d). The highest abundance values ranged between 8 and 12 ind ha^{-1} in September 1990. The minimum abundance was 6 ind ha^{-1} in San Juanico Bay and Vizcaino Bay, at depths less than 50 m in March and September 1990 (Fig. 3c).

The highest abundance of Dover sole was found in Vizcaino Bay: 93 ind ha^{-1}, with a biomass of 2.8 kg ha^{-1} (Figs. 2a-2d).). The highest values of abundance of 79 ind ha^{-1} were observed in July 1989, at depths between 80 and 134 m. The lowest abundance was 2 ind ha^{-1} in March and September 1990 (Fig. 3d).

Dominant Pleuronectidae fishes showed average sizes ranging from 45 to 261 mm. Species composition varied spatially, with the most abundant species shifting in rank depending on the zone. Turbots were more abundant in the inner zone, while slender and dover sole were more abundant in the outer zone. The correlation coefficients between the environment variables and the ordination axes reflect the relative importance of each environmental variable in determining the structure of the Pleuronectidae assemblages. Using the Monte Carlo permutation test, we selected explanatory variables of region, shelf strata, salinity, sediment type (clay, sand, and silt), organic matter, surface and bottom temperature, at the 99% ($P < 0.01$) significance level.

Thus, Axis 1 corresponds to the northern region, inner and external shelf, surface and bottom temperature, sand, silt and clay, while Axis 2 corresponds to the salinity gradient. The species and environment correlation coefficients were 0.48 for Axis 1 and 0.4 for Axis 2 (Table 3).

The ordination diagram from the first two axes (Fig. 4), with samples coded by depth stratum, showed

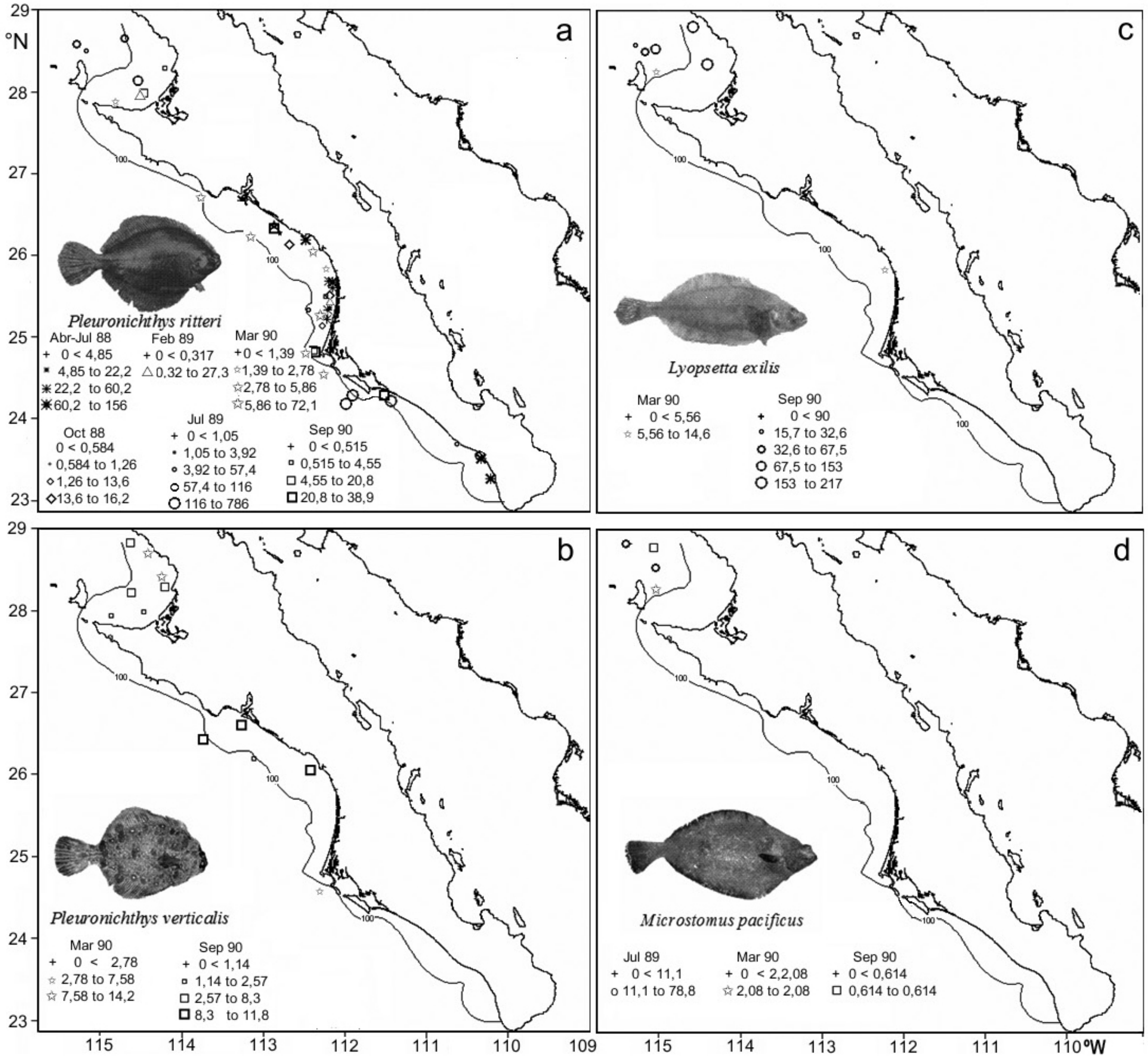

Figure 3. Spatial distribution and relative abundance of the studied species during the period 1988-1990. The estimated abundances are ind ha^{-1} per cruise. Solid line corresponds to the 100 m isobath. a) *Pleuronichthys ritteri* (spotted turbot), b) *Pleuronichthys verticalis* (hornyhead turbot), c) *Lyopsetta exilis* (slender sole), d) *Microstomus pacificus* (dover sole).

changes in the Pleuronectidae assemblages from the inner to the outer zone. Axis 1 explained 80.4% of the variance of the relationship between species and environment parameters (region, sediment type and depth gradient). The outer shelf associated with the deeper stations and, sediments with high concentrations of silt and organic matter. By contrast, the inner shelf was associated with sandy sediments.

Species associated with Axis 1 were slender sole and dover sole, while spotted turbot is located on the right side. Axis 2, explains 95.3% of the variance for the relationship between species and the environmental factors salinity and surface and bottom temperatures. Spotted turbot, related to Axis 2, is associated with stations located in the cold waters of the middle and outer shelf.

The spotted turbot population of 1988 included juveniles and adults within a wide range of sizes between 55 mm to 270 mm SL (Fig. 5a). Sizes ranged between 90 and 175 mm standard length (SL) in the southern region and between 75 to 180 mm in the central region. For 1989, the sizes ranged between 70 and 261 mm SL in the southern region and between 45 and 188 mm in the northern region.

Table 3. Summary of the ordenation axes and intra-set correlation of environmental variables with the first two axis of redundancy analysis (RDA) in the western coast of Baja California (1988-1990).

	Axes	
Summary of ordenation axes	1	2
Eigenvalues	0.171	0.032
Species-environment correlations	0.482	0.404
Cumulative percentage variance		
Of species data	17.1	20.3
Of species-environment relation	80.4	95.3
Sum of all canonical eigenvalues		0.213
Sum of all eigenvalues		1.000
Correlation of environmental variables		
Northern	-0.4606	0.1452
Inner shelf	0.7546	-0.0235
Outer shelf	-0.4654	0.1167
Surface temperature	-0.6543	-0.4695
Bottom temperature	-0.5792	-0.5321
Salinity	-0.4084	-0.5989
Organic matter	-0.3510	0.0052
Silt	-0.4472	0.1255
Sand	0.3972	0.0511

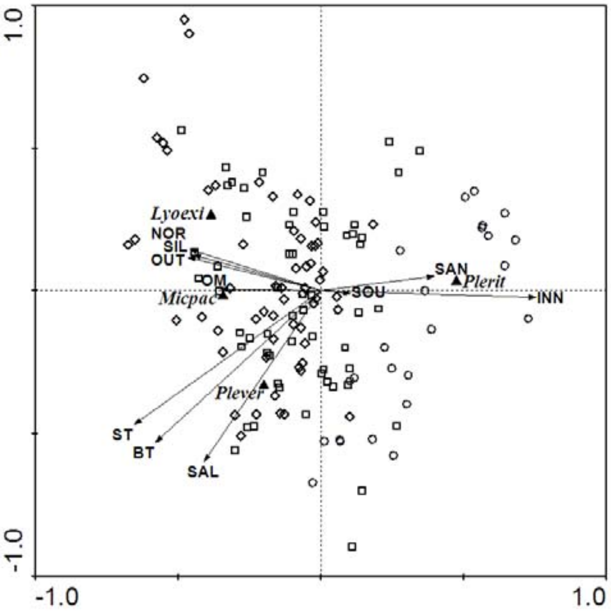

Figure 4. Ordination diagram from overall redundancy analysis (RDA) on Pleuronectidae abundance and environmental variables represented by arrows. Stations: Continental shelf stratum: Inner (circles), Middle (squares), Outer (diamonds). Codes of environmental variables: Northern (NOR), Southern (SOU), Inner (INN), Outer (OUT), Surface temperature (ST), Bottom temperature (BT), Salinity (SAL), Sand (SAN), Silt (SIL), Organic matter (OM). Codes of species in triangles: *Pleuronichthys ritteri* (Plerit); *Pleuronichthys verticalis* (Plever); *Lyopsetta exilis* (Lyoexi); *Microstomus pacificus* (Micpac).

For 1990, the corresponding values were 100-210 mm in the south and 140-155 mm in the north. ANOVA was applied to compare size classes according to the region, resulting in significant differences (F = 37.4, df = 420, $P < 0.05$). However, the Tukey´s test did not show significant differences between regions.

The length of hornyhead turbot ranged between 100 and 187 mm SL. The record was wider in the summer of 1990 and included juveniles and adults (Fig. 5b). The narrower range (150-180 mm) was recorded during the winter of 1989. The sizes observed in slender sole ranged between 75 and 200 mm, and included many juveniles during summer 1989 (Fig. 5c). Dover sole was represented mainly by juveniles in the range 90 to 185 SL mm (Fig. 5d).

The sex ratio of Pleuronectidae was close to 1:1, except for spotted turbot (1:1.4). Length-weight equations for all species were highly significant ($P < 0.001$) for combined sex, male and female samples (Table 4).

Males showed an exponent (b) greater than females, except in hornyhead turbot. For the overall sample of Pleuronectidae, the exponent exceeds the value of 3, except for dover sole, which showed a slightly lower value.

The weight-length relationship for the flatfish in the study area showed significant correlation between these parameters ($r^2 = 0.9$), as shown in Table 4.

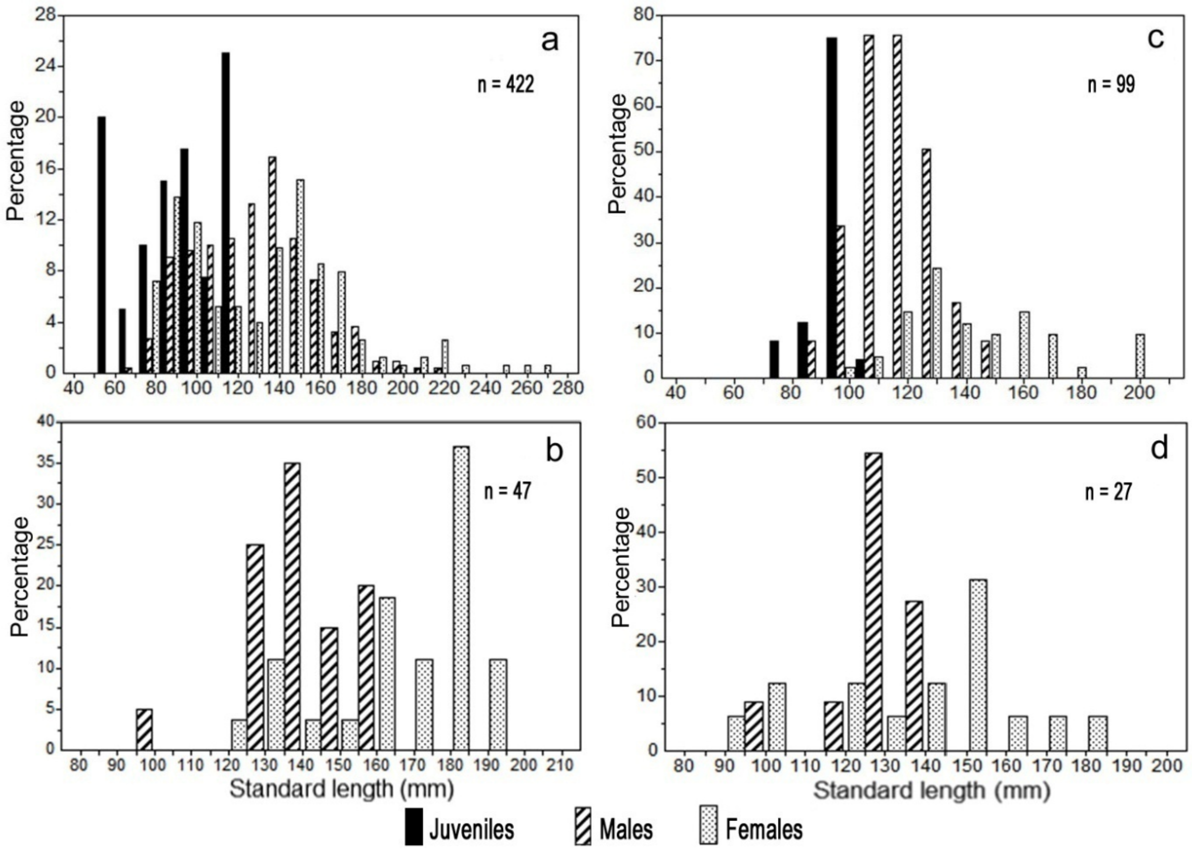

Figure. 5. Length-frequency distributions, composition of juveniles, female and male of Pleuronectidae species off the western coast of Baja California, México. a) *Pleuronichthys ritteri*, b) *Pleuronichthys verticalis*, c) *Lyopsetta exilis*, d) *Microstomus pacificus.*

Table 4. Summary of the parameters of the weight-length relationship and sex ratio of the species of Pleuronectidae off the western coast of Baja California. *Statistical difference at $P = 0.05$.

Species	n	A	b	r^2	Ratio sex
Pleuronichthys ritteri					
♀	133	$3.24*(10^{-6})$	3.3718	0.97	
♂	185	$2.83*(10^{-6})$	3.4231	0.94	
All	422	$3.97*(10^{-6})$	3.3443	0.96	1:1.4*
Pleuronichthys verticalis					
♀	20	$4.38*(10^{-6})$	3.3597	0.97	
♂	14	$1.13*(10^{-5})$	3.1561	0.95	
All	47	$4.59*(10^{-6})$	3.3474	0.97	1:0.7
Lyopsetta exilis					
♀	43	$2.87*(10^{-5})$	2.8576	0.80	
♂	32	$1.06*(10^{-5})$	3.0858	0.65	
All	99	$2.28*(10^{-6})$	3.3808	0.89	1:0.8
Microstomus pacificus					
♀	17	$3.08*(10^{-5})$	2.8120	0.93	
♂	10	$2.18*(10^{-7})$	3.7887	0.92	
All	27	$1.29*(10^{-5})$	2.9748	0.88	1:0.7

The hypothesis of isometric growth for this species was discarded, as the allometric index value (b) was significantly different from 3 (Student's t-test, $P < 0.05$). Length and weight were closely correlated with the determination coefficients ranging from 0.80 to 0.97 in both sexes, which indicated a strong relationship between these two variables except for males of slender sole.

Significant differences between sexes were found for the slopes of the weight/length relationship in the cases of spotted turbot and hornyhead turbot. Females of hornyhead turbot were slightly heavier than males of the same length, whereas the spotted turbot presented the opposite pattern. No significant differences between sexes were found for slender sole ordover sole, perhaps because their populations were composed mainly of young individuals.

Comparing the slopes for different years, only spotted turbot showed significant differences between 1988 and 1990. Comparing regions, it was found that slopes were different in spotted turbot in all three regions, while slopes for hornyhead turbot were significantly different between the central and northern regions. Moreover, when the slopes were compared for depth strata, significant differences between the inner and middle shelf were found for the spotted turbot, and between the middle and outer shelf for the dover sole (Table 5).

Table 5. Comparison of slopes between sexes, years, region, and shelf areas of the species of Pleuronectidae off the western coast of Baja California. 1988-1990. *Statistical difference at $P = 0.05$.

Species	n	F	t	r^2	$P = 0.05$
Pleuronichthys ritteri					
Sexes	318	1716.84	2.619	0.92	*
88-89	358	820.19	0.099	0.87	0.920
88-90	166	526.8	1.952	0.91	*
89-90	212	450.9	0.990	0.86	0.323
Region					
South-Center	258	629.54	1.927	0.88	*
Center-North	246	634.80	6.149	0.88	*
South-North	234	627.92	6.500	0.89	*
Shelf					
Inner-Middle	269	576.11	1.954	0.86	*
Inner-Outer	340	886.47	0.561	0.88	0.574
Middle-Outer	129	307.35	1.643	0.88	0.103
Pleuronichthys verticalis					
Sexes	34	309.34	4.124	0.97	*
89-90	47	237.61	1.270	0.94	0.2107
Region					
Centre-North	47	286.32	2.254	0.95	*
Shelf					
Inner-Middle	40	184.36	1.241	0.93	0.2226
Inner-Outer	21	108.61	0.692	0.95	0.4978
Middle-Outer	33	160.65	0.037	0.94	0.9706
Lyopsetta exilis					
Sexes	75	104.94	0.8544	0.82	0.3958
Middle-Outer	99	124.91	1.591	0.79	0.1147
Microstomus pacificus					
Sexes	27	56.12	0.5330	0.88	0.5991
Middle-Outer	27	103.52	3.767	0.93	*

DISCUSSION

On the western coast of Baja California, four the Pleuronectidae species *Pleuronichthys ritteri*, *P. verticalis*, *Lyopsetta exilis* and *Microstomus pacificus* have been recorded. These species have previously been reported in the area by other authors (Castro-Aguirre *et al*., 1992; Torres-Orozco & Castro-Aguirre, 1992; Castro-Aguirre & Torres-Orozco, 1993; De la Cruz-Agüero *et al*., 1994; Rodríguez-Romero *et al*., 2011). Because they are small and difficult to catch, these flatfishes have low commercial value.

In Palos Verdes, California, these Pleuronectidae dominated the monitored demersal fish fauna in the period 1973-1993, accounting for 53-59% of the fish collected. The proportion of flatfish in the catches increased from 23 to 137 m water depths. These species accounting for the 6% of the total number of fish caught in trawls between 1973 and 1993 (Stull & Tang, 1996). Balart (1996) noted that the flatfish fishery was artisanal and multispecific, and of little relevance in Baja California, the main catches being in Vizcaino Bay. Rodriguez-Romero *et al*. (2008) recorded the presence of the same species of flatfish mentioned in this study on the west coast of Baja California, but they also included *Parophrys vetulus* and *Hypsopsetta guttulata*.

According to our results *P. ritteri* was the most abundant flatfish in the middle continental shelf, across all the study area, showing a wide range of sizes that included juveniles and adults, and with higher affinity to muddy and sandy bottoms (also recognized by Moles & Norcross, 1995). These authors mention that this species is frequent in the bycatch of the shrimp fishery, with lengths between 143 and 200 mm (within the range of sizes found in this study). Weinberg *et al*. (2002), recorded low abundance of spotted turbot in summer 2009 in Conception, California, between 72 and 90 m, and with bottom temperature about 7.2ºC.

Further, Allen *et al*. (1983) reported spotted turbot off Los Angeles, California, with abundances of 6 ind trawl^{-1}, that were mostly juveniles.

Kramer (1991) estimated abundances of 1.2 to 16.2 ind ha^{-1} for spotted turbot, mainly in shallow waters (5 to 10 m) off San Diego, California, and with a size range between 75 and 237 mm SL. Moreover, in a study conducted in San Quintin Bay, Baja California (Rosales-Casián, 1996) mentioned the presence of juveniles and adults (21-260 mm SL) of spotted turbot, in shallow waters (5-10 m), characterized by mud-sandy sediments. Both reports reflect similar results to those obtained in the present study, confirming that coastal areas with sandy sediments have high abundances of juveniles and adults of the spotted turbot. Allen (1982) considers coastal bays and lagoons as nursery areas for juvenile fish and this explanation could be valid for this species.

According to the results of this study, the highest abundance of *P. verticalis* was found around Vizcaino Bay, in the middle and outer continental shelves, which is dominated by sandy-muddy sediment and sand-silt (Chávez, 1995; Pedrín-Avilés & Padilla-Arredondo, 1999). On the other hand, this species have the lowest abundances in the Central region, a pattern observed also by Cross (1985) indicating a random distribution in the southern California coast.

In southern California, Allen *et al*. (1983) recorded low abundances of hornyhead turbot predominantly juveniles, between 10 and 65 m. Stull & Tang (1996) mentioned that this species preferred shelf depths with warm-temperate conditions and that it was more common in the mid-to-late 1980s, following El Niño. Hornyhead turbot migrated into deeper waters during the El Niño event of 1987-1988 (Allen, 2008).

Rodríguez-Romero *et al*. (2008) consider this species as very common in the west coast of Baja California, with sizes ranging between 81 and 256 mm SL. In San Quintin Bay, Rosales-Casián (1996) reported sizes between 60 and 140 mm. Kramer (1991), observed a range of 10 mm to 265 mm in southern California. Weinberg *et al*. (2002) recorded this species off Cape Mendocino (California) up to 119 m depth.

In the Gulf of California, Acevedo-Cervantes *et al*. (2009) recorded abundant populations of hornyhead turbot between 360 and 450 m, these depths characterized by low temperatures (7-9ºC) and anoxic conditions (<0.5 mL O_2 L^{-1}) into deeper waters during the El Niño event of 1987-1988 (Allen, 2008).

In the present study, captures of *M. pacificus* consisted mainly of juveniles inhabiting the middle shelf and outer Vizcaino Bay, dominated by sandy silt sediments with high organic matter concentrations. Hunter *et al*. (1990) described the ontogeny of this species in southern California in relation to the bathymetric gradient, noting that sexual maturity was reached in deep water with low dissolved oxygen levels and at a mean size of 310 mm SL.

The seasonal catch patterns may be due, in part, to changes in the bathymetric distribution of some of the flatfishes. Dover sole, for example, are more abundant on the shelf off southern California in spring and summer than in fall and winter (Cross, 1985). In northern California and Oregon, Dover sole move onto the shelf in summer to feed, and move back to the slope in winter to reproduce (Hagerman, 1952; Alton, 1972).

In the continental slope of southern California, Cross (1987) records the size range of Dover sole between 110 and 420 mm, and states that this species lives mostly in clay silt sediments with high organic matter content (5 to 14%) and cold water (6.5 to 8.2ºC), these results being similar to those obtained in this study.

According to our results, specimens of Dover sole were collected with an approximate age between 1 and 3 years, ranging between 220 and 290 mm SL for males and between 280 and 350 mm for females, which would correspond to juveniles which have not reached the size of sexual maturity as estimated from maturity-length curves (Hagerman, 1952; Brodziak & Mikus, 2000; Abookire & Macewicz, 2003).

In the present study juveniles and adults of *L. exilis* were found in the deep stratum (90 to 200 m), with greater occurrence during the summer of 1989. This was confirmed by the results reported by Snelgrove & Haedrich (1985), for immature individuals that they found concentrated at the shallow end of the depth range while adults distribute across all depths. Rodríguez-Romero *et al.* (2008) consider it as a common species, with sizes ranging from 127 to 222 mm SL, and inhabiting depths between 25 and 800 m on sandy bottoms. This species is more common in cold-temperate waters, where its abundance increased beyond or below 137 m, where this species feed on nektonic benthopelagic preys such as shrimp (Stull & Tang, 1996).

Pearcy (1978) recorded the highest catches of slender sole at stations with a high percentage of clay and silt on the continental shelf off Oregon. McConnaughey & Smith (2000) concluded that the sediment texture is a crucial factor in their habitat and distribution. Furthermore, Amezcua & Nash (2001) emphasize the importance of depth and temperature gradient, and type of sediment, as important factors to explain the structure and abundance of pleuronectid species.

Water depth is one of the main factors affecting the community structure in the continental shelf and slope in coastal waters (Abookire & Norcross, 1998), and depth also plays an important role in determining the distribution of flatfish (Rogers, 1992; Gibson, 1994; Norcross *et al*., 1997). Benthic community structure and composition have been related to depth (Pearcy, 1978).

Between the northern and southern stations there were differences in temperature and salinity, among other parameters, such as organic matter. Other measured variables, however, such as sediment composition, in regions adjoining each sample site, may explain the additional variance in the assemblage.

The changes in the distribution of pleuronectid species between cold and warm regimes may be due in part to differences in the magnitudes of larval recruitment between these two periods and also to movements of juvenile and adult fish across different depths (Castro-Aguirre *et al*., 1992; Lea & Rosenblatt, 2000; Funes-Rodríguez *et al*., 2002; Chávez *et al*., 2003; Allen, 2008). Changes that occur in the oceanic environment between a cold and warm regime include increased water temperature, a deeper thermocline depth, decreased plankton productivity and reduced transport of the California Current (Hayward, 2000; Juan-Jordá *et al*., 2009).

On the west coast of Baja California Pleuronectidae abundance varied from 1988 to 1990. Spatial and temporal patterns are described, and inferences are made on potentially important environmental processes that influence fish assemblages. Changes in ocean conditions during the 1988-1990 periods affected the occurrence and abundance of fish in the west coast of Baja California (Castro-Aguirre *et al*., 1992).

The conclusions of this study indicate that the distribution of Pleuronectidae species varies with depth across the shelf during different oceanic regime periods.

The sex ratio found for these species in the present work was close to 1:1, which is the usual value found for Pleuronectidae (Kramer, 1991; Minami & Tanaka, 1992; Martínez-Muñoz & Ortega-Salas, 1999, 2001, 2010).

Length-weight relationship analysis of males, females, and undetermined, shows allometric growth and differences, in the relative growth rate, between sexes of *P. ritteri* and *P. verticalis*. Such allometric growth shows similar characteristics (positive allometric growth) to those found by Hagerman (1952) and Martínez-Muñoz & Ortega-Salas (1999, 2001) in California and other regions.

We have found obvious differences between sexes for the length-weight relationships of spotted turbot and hornyhead turbot. Cooper (1994) estimated the length to weight ratio for hornyhead turbot in southern California and found, differences between the sexes; the values of the power coefficients of the equation were lower.

We present some estimates of the parameters of the weight-length relationship of species of flatfish along the US west coast in the Table 6. We have found a well-pronounced size sexual dimorphism between

Table 6. Estimated parameters of the weight-length relationship of some Pleuronectidae species along the US West coast.

Species	a	b	Locality	Source
Microstomus pacificus				
All	4.0659×10^{-3}	3.2479	Pacific northwestern	Brodziak & Mikus (2000)
Male	3.7064×10^{-3}	3.2736	US West coast	
Female	4.4149×10^{-3}	3.2254		
Male	2.440×10^{-3}	2.95	Eureka US West coast	Hagerman (1952)
Female	2.389×10^{-3}	2.97		
Pleuronichthys verticalis				
Male	0.8915	1.767	Southern California	Cooper (1994)
Female	0.3027	2.145	US West coast	
Hypsopsetta guttulata				
All	2.213×10^{-5}	3.044	Anaheim, California US West coast	Lane (1975)
Glyptocephalus zachirus				
All	8.647×10^{-4}	3.5553	Oregon, US West coast	Hosie & Horton (1977)
Male	1.026×10^{-3}	3.5598		
Female	8.158×10^{-4}	3.5112		

male and female turbot. Female were considerably larger than males, which probably relates to earlier maturation, greater longevity, and lower growth rates of females. As a result, this leads to a dominance of females among the oldest fishes that is also characteristic of many other flatfish species (Chen *et al*., 1992).

Jacobson & Hunter (1993), in their analysis of bathymetric patterns in population structure, also found that Dover sole segregated by sex. The authors attribute such differences to the fact that large Dover sole males undertake seasonal movements less frequently than females, and therefore their growth rates may be expected to be less heterogeneous than those of females that move from the continental slope to the more productive waters of continental shelf during spring.

The length-weight relationship may be influenced by sex, maturity, geographical location, and environmental condition (Bagenal & Tesch, 1978; Weatherly & Gill, 1987; Wootton, 1990; Murphy *et al*., 1991).

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