Comparative morphometrics of two populations of *Mugil curema* (Pisces: Mugilidae) on the Atlantic and Mexican Pacific coasts*

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SUMMARY: A population of *Mugil curema* in the Gulf of Mexico was compared with one in the Pacific Ocean using nine morphometric variables. The allometries of each measurement were estimated in relation to total length. Morphometric variations were analyzed using the normalization of the individuals of each group and two multivariate methods: correspondence analysis, used to explore the information, and discriminant analysis. Results indicated that the diameter of the eye differentiated the populations of both coasts, the Atlantic population showed a larger eye diameter. However, other than this and the body width (which can be strongly influenced by sexual maturation) there was no difference between the shapes of both populations. We discuss the larger morphometric variability of the Atlantic population which may be due to the presence of more than one population unlike the Pacific population.

Keywords: mullets, fish, morphometry, relative growth, *Mugil curema*, Gulf of Mexico, Mexican Pacific.

RESUMEN: COMPARACIÓN DE LA MORFOMETRÍA DE DOS POBLACIONES DE *MUGIL CUREMA* (PISCES: MUGILIDAE) EN LAS COSTAS DEL ATLÁNTICO Y PACÍFICO MEXICANOS. – Se comparó la forma de *Mugil curema* entre una población del Golfo de México y otra del Pacífico Mexicano. Fueron usadas nueve variables morfométricas, se estimaron las alometrías de cada variable con respecto a la longitud total. Las variaciones en la forma fueron analizadas utilizando la normalización de los individuos de cada grupo. Se emplearon dos análisis multivariantes: el análisis de correspondencias, empleado para explorar la información, y el análisis discriminante. El diámetro del ojo fue la variable que diferenció a las dos poblaciones siendo los ejemplares del Atlántico los que mostraron un mayor diámetro de ojo. Sin embargo, además de ésta y la anchura del cuerpo (la cual puede estar fuertemente influenciada por la madurez sexual) no se encontraron diferencias entre la forma de las dos poblaciones. Se discute la mayor variabilidad morfológica de los especimenes del Atlántico, atribuida a la presencia de más de una población.

Palabras clave: mugílidos, morfometría, crecimiento relativo, *Mugil curema,* Golfo de México, Pacífico mexicano.

INTRODUCTION

Mugil curema Valenciennes 1836 has been reported as an eminently American species distributed from Cape Cod, USA to Brazil in the Atlantic and from Magdalena Bay, Mexico to the coasts of Chile (Jordan and Everman, 1896). However, Fischer *et al*. (1995) recorded *M. curema* off the western coast of Africa. The available literature in Mexico on this species is scarce. There are some

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studies on age analysis, growth, mortality and reproduction (Ibáñez and Gallardo-Cabello 1996a, b; Ibáñez *et al.*, 1999; Ibáñez and Gallardo-Cabello, 2004; Ibáñez and Gutierrez-Benítez, 2004). There are only two studies on morphometric analysis or relative growth (Pérez and Ibáñez, 1992; Ibáñez and Lleonart, 1996), which describe relative growth and morphometrics between *M. curema* and *Mugil cephalus* (L.) along the coasts of the Gulf of Mexico. Morphometric analysis has been very useful for separating species, populations and races. It is of vital importance to identify the study population in order to understand its dynamics.

With the rise of the land known now as Central America during the Pleistocene around two million years ago (Hallam, 1981), a geographical barrier was formed which separated the Atlantic and the Pacific oceans, eliminating the possibility of genetic recombination of the species. Isolation over time could have been the cause of morphometric modifications among related populations. The interest in analyzing the possible differences in morphology between both populations of *M. curema* found in the Pacific and Atlantic oceans was the origin of the present study.

MATERIAL AND METHODS

Data collection

Morphometric measurements were taken from individuals belonging to *Mugil curema* collected from the commercial catch in the Tamiahua lagoon (located in the mid-western portion of the coast of the Gulf of Mexico: 21°06' to 22°06' N and 97°23' to 97°46' W) and in the Cuyutlan lagoon (located in the middle portion of the Mexican Pacific Coast: 18°57' to 19°50' N and 103°57' to 104°19'W).

All body measurements were obtained to the nearest 1 mm with the help of an ictiometer, except the following measurements: maximum height (Max h), peduncle height (P. h), cephalic length (Cl), ocular diameter (Oc d) and width at the maximum body height (Max g), which were taken with a caliper to the nearest 0.01 mm (Fig. 1). These measurements were selected according to the criterion followed by Drake and Arias (1984). Sampling lasted a year with monthly periodicity from April 1990 to March 1991 for the Gulf of Mexico, and from March 1997 to February 1998 for the Pacific Ocean. The organisms were sexed and measured fresh. Those whose sex was not determined were discarded for this analysis. The data were organized into four matrices according to ocean and sex, with ten columns (one per variable) and different numbers of rows (one per individual) (Table 1).

Data analysis

The parameters of the allometric ratios between total length (*Tl*), taken as an independent variable, and each of the remaining nine variables taken as dependent variables according to the allometric model:

$$Y_{ij} = a_i Tl_j^{b_i} \quad (1)$$

where: Tl_j is the total length of the individual *j*, Y_{ij} is the *i* variable of the individual *j* and a_i and b_i are the

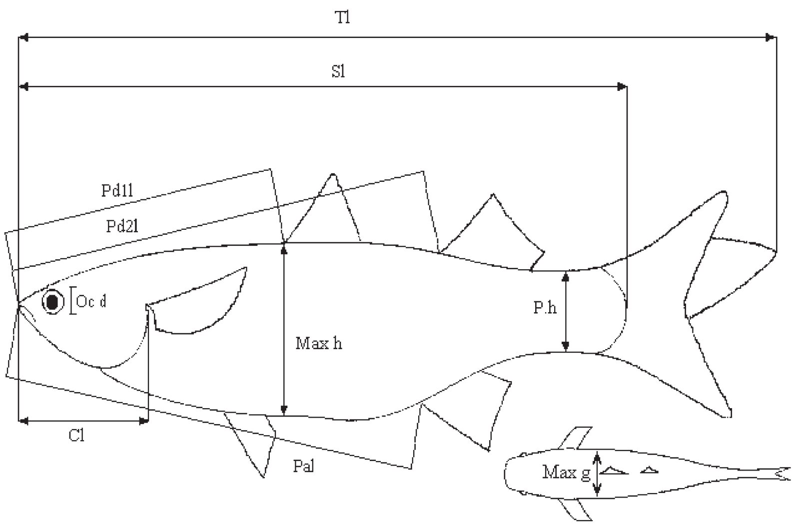

FIG. 1. – Morphometric measurements taken of *Mugil curema*. Total length (Tl); standard length (Sl); maximum height (Max h); peduncle height (P. h); distance to the first dorsal fin (Pd1l); distance to the second dorsal fin (Pd2l); length to the anal fin (Pal); cephalic length (Cl); and ocular diameter (Oc d). Body width at maximum body height (Max g.) is showed in the upper view of the fish.

TABLE 1. – Size of sample, average, variance and size range (*Tl* in cm) of *Mugil curema* from the Atlantic and Pacific Ocean, their sexes and the organisms of undifferentiated sex.

Sample	n	average	variance	size range
Pacific				
Females	368	27.1	5.0	22.0-35.2
Males	232	25.2	2.7	20.8-32.4
Undifferentiated	12	22.1	4.3	17.9-26.8
Atlantic				
Females	179	27.8	8.7	20.8-37.0
Males	130	25.4	8.0	17.6-33.9
Undifferentiated	21	24.2	7.7	16.3-27.9

parameters of the allometric ratio between total length and variable *i* which were calculated by the previously log-linearized lineal regression of the allometric model.

In order to eliminate size correlation the data were transformed with the normalization of individuals of each group proposed by Lleonart *et al.* (2000), which has been successfully used in previous analyses (Lombarte and LLeonart, 1993; Senar *et al.*, 1994 and Ibáñez and LLeonart, 1996). This normalization is a theoretical generalization of the technique used by Thorpe (1975), which was recorded as one of the most efficient methods in the empirical evaluation done by Reist (1985), hence:

$$Z_{ij} = Y_{ij}\,(Tl_0 / Tl_j)^{b_i} \qquad (2)$$

where: Z_{ij} is the value of the variable Y_{ij} once it has been transformed, Tl_0 represents a reference value of size to which all individuals are reduced (or amplified; Lombarte and Lleonart, 1993). This normalization completely removes all the information related to size, not only scaling all individuals to the same size, but also adjusting their shape to the one they would have in the new size according to allometry (Lleonart *et al.*, 2000). The Tl_0 used was 26.53 cm, which was the average of the total length of the four matrices and it was very similar to the median value (M= 26.43 cm). A correspondence analysis (CA) was used to explore the data by sex and discriminant analyses (DA), also applied to the normalized data, were used to analyze the oceans.

The boxplot by groups was made for each of the nine variables using the normalized data: standard length (Sl); distance to the first dorsal fin (Pd1l); distance to the second dorsal fin (Pd2l); length to the anal fin (Pal); maximum height (Max h); peduncle height (P. h) and cephalic length (Cl); body width at maximum body height (Max g.); and ocular diameter (Oc d).

RESULTS

The results of the parameters of allometric relationships are presented in Table 2. Isometric growth is more common in the population of the Gulf of

TABLE 2. – Parameters of the allometric ratios and comparison between sexes of *Mugil curema*.

	Female					Male					
	a	b	r	Allom.	t_b	a	b	r	Allom.	t_b	t_s
Pacific											
Sl	0.806	1.000	0.97	=	0.000	0.917	0.961	0.93	=	1.589	3.113*
Max h	0.239	0.951	0.88	=	1.833	0.289	0.894	0.84	-	2.771*	5.055*
P. h	0.113	0.913	0.90	-	3.741*	0.131	0.864	0.82	-	3.469*	3.054*
Pd1l	0.348	1.022	0.96	=	1.451	0.361	1.009	0.95	=	0.410	1.968*
Pd2l	0.605	0.981	0.96	=	1.361	0.634	0.964	0.97	-	2.315*	9.897*
Pal	0.434	1.070	0.97	+	4.689*	0.408	1.087	0.96	+	3.922*	2.344*
Cl	0.237	0.932	0.94	-	3.868*	0.232	0.940	0.90	-	2.011*	0.666
Max g.	0.116	1.033	0.91	=	1.320	0.149	0.955	0.82	=	1.028	4.144*
Oc d	0.129	0.659	0.73	-	10.46*	0.160	0.601	0.72	-	6.132*	1.785
Atlantic											
Sl	0.805	1.000	0.98	=	0.000	0.827	0.990	0.97	=	0.481	0.385
Max h	0.252	0.917	0.78	=	1.488	0.260	0.906	0.78	=	1.469	0.120
P. h	0.112	0.915	0.68	=	1.139	0.053	1.140	0.82	+	1.994*	2.196*
Pd1l	0.368	1.010	0.95	=	0.385	0.446	0.951	0.93	=	1.485	1.404
Pd2l	0.518	1.030	0.98	=	1.744	0.555	1.007	0.97	=	0.324	0.832
Pal	0.534	1.006	0.96	=	0.256	0.524	1.009	0.95	=	0.307	0.080
Cl	0.226	0.942	0.94	-	2.189*	0.525	0.689	0.76	-	12.44*	4.297*
Max g.	0.031	1.191	0.90	+	4.505*	0.047	1.098	0.87	=	1.753	1.323
Oc d	0.030	1.417	0.98	+	19.128*	0.078	1.124	0.78	=	1.570	3.574*

Key: t, t statistic (level of significance $P < 0.05$). *; significant value of t; t_s = t between sex; t_b = t of the b = 1 parameter. Standard length (Sl); maximum height (Max h); peduncle height (P. h); distance to the first dorsal fin (Pd1l); distance to the second dorsal fin (Pd2l); length to the anal fin (Pal); cephalic length (Cl); body width at maximum body height (Max g.); and ocular diameter (Oc d).

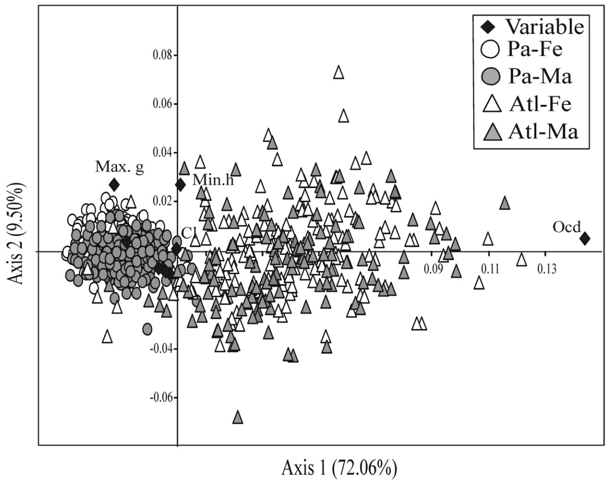

FIG. 2. – First two axes of the transformed data (normalization of individuals of each group) with the correspondence analysis (CA) using all the morphometric variables for *Mugil curema*. Key: Circles= Pa: Pacific coast; Triangles= Atl: Atlantic coast. White = Fe: females; Grey = Ma: males. Rhombus= Variables.

TABLE 3. – Factorial matrix of the CA with the normalized data for all the variables.

Variable	Factor 1	Factor 2	Factor 3
Standard length	-0.0052	-0.0071	0.0006
Maximum height	-0.0183	0.0041	-0.0060
Peduncle height	0.0010	0.0268	0.0321
Distance to the first dorsal fin	-0.0029	-0.0091	-0.0005
Distance to the second dorsal fin	-0.0046	-0.0075	0.0010
Length to the anal fin	-0.0065	-0.0073	-0.0004
Cephalic length	-0.0003	0.0008	0.0066
Body width at maximum height	-0.0225	0.0272	-0.0233
Ocular diameter	0.1440	0.0050	-0.0083

Mexico. The *t* test showed higher discrepancies among the sexes of the Pacific population, while only three variables were significantly different among the sexes of the Gulf of Mexico's population.

The correspondence analysis provides higher variance values for the first two axes (81.56%) and the correlation matrix showed positive and negative values, a pattern that expresses variations in shape but not size (Cuadras, 1991). The graphic representation of the first two axes with the CA showed separation of the organisms by area, but no differences between sexes. Nevertheless, in general, females showed wider variability than males (Fig. 2). The factorial matrix of the CA with the normalized data indicated that the variables needed to differentiate the two populations were most importantly the ocular diameter (Oc d,) and with a smaller influence, the width at maximum body height (Max g; Table 3).

The DA analysis performed with the normalized data and the nine variables showed 95.16% of the classification with a Wilks' lambda of 0.2470 (Table 4); the graphical result of this analysis showed the combined histogram for the canonical scores (Fig. 3a). Two groups can be identified from the two distinct modes, the left one for the Pacific organisms

TABLE 4. – Results of the discriminant analysis classification with normalized data showing the percentage of specimens classified in each ocean using 9 variables (total length was excluded as a result of the normalization). Wilks' lambda: 0.2470

Group	1	2
Pacific	99.83	0.17
Atlantic	86.08	13.92

TABLE 5. – Results of the discriminant analysis classification with normalized data showing the percentage of specimens classified in each ocean using 8 variables (excluding ocular diameter). Wilks' lambda: 0.6109

Group	1	2
Pacific	96.00	4.00
Atlantic	63.11	36.89

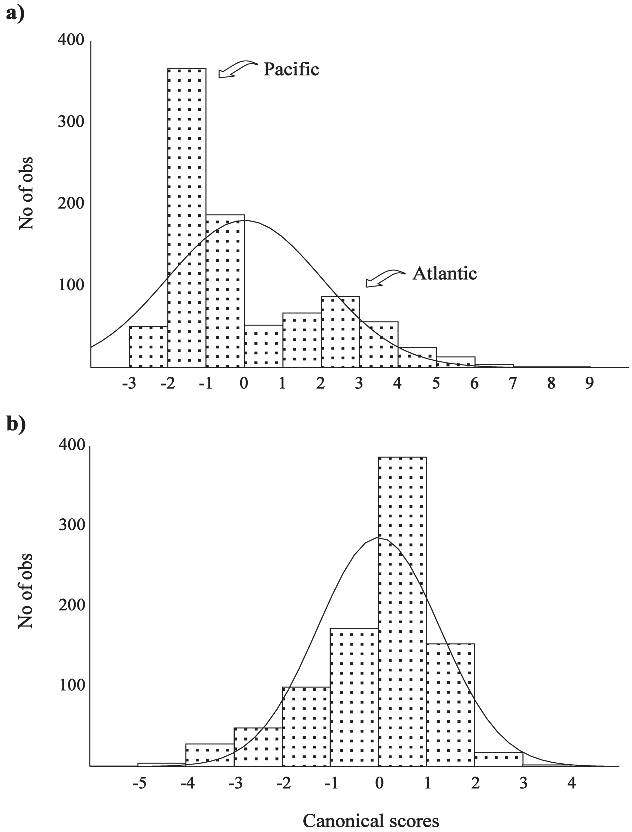

FIG. 3. – Discrimination analysis with the normalization of individuals of each group: a). Combined histogram for the canonical scores for the Pacific and Atlantic groups using nine morphometrics variables and b) Combined histogram for the canonical scores for the Pacific and Atlantic groups using eight morphometrics variables (without ocular diameter) for *Mugil curema*. Continuous line is the expected normal.

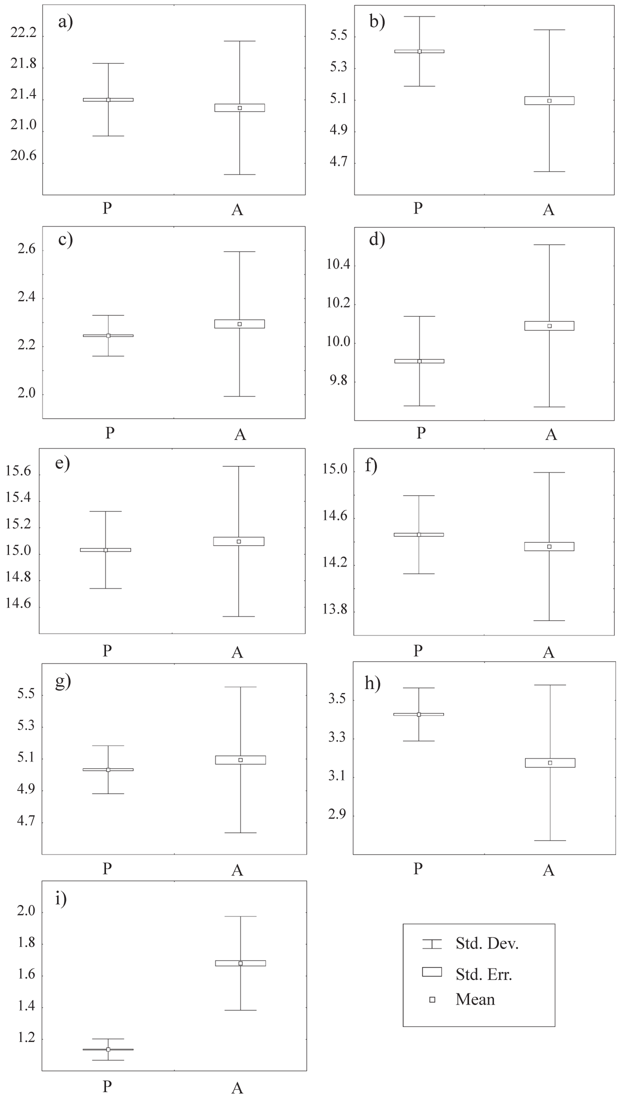

FIG. 4. – Mean ± standard error and standard deviation of nine normalized variables of *Mugil curema*: a) standard length (Sl); b) maximum height (Max h); c) peduncle height (P. h); d) distance to the first dorsal fin (Pd1l); e) distance to the second dorsal fin (Pd2l); f) length to the anal fin (Pal); g) cephalic length (Cl); h) width at the maximum body height (Max g); and i) ocular diameter (Oc d).

with more abundance and a leptokurtic distribution and the right mode with a platycurtic distribution containing the Atlantic sample. When we eliminate the variable ocular diameter an 84.82% classification can be seen but with a Wilks' lambda value of 0.6109 (Table 5) and the two modes of the combined histogram have disappeared (Fig. 3b).

Averages, standard error and standard deviation of the nine mentioned variables in Figure 4 show the similarity in the distribution from each variable, except for the ocular diameter (Oc d), the width at maximum body height (Max g) and maximum height (Max h). The Atlantic population showed a larger diameter of the eye and in general, it is noticeable that the sample of the Atlantic has larger variability than the one from the Pacific.

DISCUSSION

The size averages for both populations of *Mugil curema* were very similar, although the size interval for the population of the Gulf of Mexico is slightly larger. This fact indicates that the fishing gear is similar on both coasts, since both samples came from commercial capture. The capture volumes reported for both coastal areas show that the population of the Gulf of Mexico is larger than that of the Pacific; in fact, 87% of the national production of this mullet (according to registrations in the fishing annuals of 1983 to 1999) is captured in the north of the Gulf of Mexico. Capture of *M. curema* is significant in the fisheries of the states of Texas and Florida, USA, where according to Anderson (1957) white mullet in Florida spawn primarily from April through to June (and extremely between March and September). In the Gulf of Mexico off Texas, Moore (1974) collected white mullet with gonads in post-spawning condition in late spring and early autumn, but not in summer, and suggested the possibility of an interrupted spawning season or two populations that spawn at different times. Two spawning seasons, summer and winter, were reported for Cuban waters (Alvarez-Lajonchere, 1976). It is possible that this species recombines with other stocks during its oceanic reproduction or possibly there are two populations, so that the variability of the species in this area is larger. The allometry among sexes would not be a cause of variability in this case, since there were only three different variables among the sexes. A significant source of variability, particularity for fish thickness (Max g) is the sexual maturation of the specimens; the females from the Atlantic mature at age "1" while the females from the Pacific coast mature at age "2" (Cabral-Solis, 1999). Another factor that could produce variability in the body width is the quality of preservation of fish, since the samples came from commercial capture and the refrigeration process could vary.

Nevertheless both populations had similar lengths; the normalization used was necessary to avoid size effects (the correlation matrix showed both positive and negative values) and clearly shows the differences between the populations. The resemblance between the sizes of both populations could also cause uncertainty with the allometry parameters.

The significant differences between the two populations are given by the ocular diameter, and when eliminated from the analysis we were able to observe that the shape of this species is identical on both coasts of Mexico. It might appear that the seven selected variables associated with the body shape are not enough to discriminate groups. However, they were appropriate to separate sexes of *M. cephalus* in the Gulf of Mexico through multivariable exploratory analysis (CA) and canonical analysis of populations, where the morphometric variables that differentiated the sexes were the length to the anal fin (Pal) and cephalic length (Cl) (Ibáñez and Lleonart, 1996).

Corti and Crosetti (1996) mentioned that the morphometry of *M. cephalus* partially reflects the geographical origins of the samples. The environmental differences between the two coastal areas of Mexico are very evident: on the Atlantic coast, the continental shelf is very wide, whereas on the Pacific coast it is very narrow. In the Gulf of Mexico the rivers are perennial and in the Pacific they only have water during the rainy season, which accounts for marked differences in the environment. The large diameter of the eye of *M. curema* from the Atlantic could be related to the higher turbidity of the waters of the Gulf of Mexico. Experimental studies have shown that the African cichlid *Haplochromis burtoni* reared in darkness and in scotopic illumination has significantly larger eyes in relation to lens size in comparison with fish reared in white light (Kroger and Fernald, 1994). In addition, Kroger and Wagner (1996) reared the cichlid *Aequidens pulcher* in monochromatic illuminations and observed changes in eye size. Montgomery *et al.* (1997) showed with the Antarctic silverfish (*Pleuragramma antarcticum*) that eye growth and somatic growth are on separate trajectories, and the breaks in the relative eye diameter result from overwinter periods when somatic growth is static but the eye continues to grow. Similar results were found in the rainbow trout *Oncorhynchus mykiss* (Pankhurst and Montgomery, 1994). Moreover, carp pituitary extract together with a dopamine antagonist caused an increase in eye size and significant gonadal development in the female of *Anguilla anguilla* in wild and cultivated stocks (Muller *et al.*, 2003). As can be seen, the differences in ocular diameter are not easy to explain but the fact that the Atlantic specimens show early sexual maturation could reduce somatic growth while the eye continues to grow. In addition, the eye could grow because of the sexual hormones involved. The positive allometric relationship in females of the Atlantic area could support this idea. Finally, the explanation for the white mullet from the Atlantic having bigger eyes is still an open question since eye growth is related to different biological processes that occur throughout the fish's life.

The differences in the shape results of several authors for Mullets (Corti and Crosetti, 1996 and Mamuris *et al.*, 1998) could be due to the methods used. Nevertheless, with these seven measures it is possible to find out the difference in shape as was shown for the sexes of *M. cephalus* (Ibáñez and Lleonart, 1996) even if it is not viable to show the geometric relationships.

When the multivariate exploratory analyses provide elements that show possible differences between groups, it is advisable to use confirmatory analysis. The discriminant analysis, unlike the correspondence analysis, is focused on the interpopulation variations which maximize the differences between them (Surre *et al.*, 1986). Meanwhile, CA only explores the information without following a fixed model *a priori*. It is important to mention the statistical significance of the discriminant analysis in which the Wilkes' lambda evaluates the discriminatory capacity of the discriminant function(s). In the study by Mamuris *et al.* (1998), the statistical significance of the analysis is not mentioned. Our results showed that the discriminant analysis using normalization with nine variables showed a low value for the Wilks' lambda (0.2470), otherwise the Wilks' lambda for the eight variables showed a lambda of 0.6109. The higher the dispersion between groups the smaller the value of Wilks' lambda and the higher the significance (Hair *et al.*, 1999). The boxplot between groups showed resemblances among the two populations, except for width at maximum body height (Max g) and ocular diameter (Oc d). The maximum height (Max h) also showed some differences.

Results indicate that the diameter of the eye differentiates the populations of both coasts. However, other than this and the body width (which can be strongly influenced by sexual maturation and the preservation of fish) there were no differences between the shapes of both populations. The levels of variation in the specimens of the Atlantic may be due to the presence of more than one population in the Gulf of Mexico or else that there are different phenotypes in the same sample.

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