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Relative growth and comparative morphometrics of *Mugil cephalus* L. and *M. curema* V. in the Gulf of Mexico*

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SUMMARY: The morphometric differences between two congeneric species, *Mugil cephalus* and *M. curema*, and their sexes are studied through ten measurements. The allometries of each measurement are estimated in relation to total length. Morphometric variations are analysed using three transformations: (i) logarithmic transformation, (ii) division of each variable by total length, and (iii) normalization of the individuals of each group; and three multivariate methods: (a) reciprocal averaging, (b) principal component analysis and (c) canonical analysis of populations. Results indicate that the morphology of both species is different, male and female *M. cephalus* were clearly discriminated into two groups, while no important differences were found between the sexes of *M. curema*. The separation of the groups, due to differences in "shape" rather than "size" was observed through analysis of reciprocal averaging and canonical analysis of populations by normalization of the individuals in each group. The morphometric variables that differentiated the four groups were thickness at maximum width, length to anal fin and cephalic length.

Key words: Relative growth, morphometrics, *Mugil cephalus*, *Mugil curema*, Gulf of Mexico

RESUMEN: Se estudian las diferencias morfométricas entre dos especies congenéricas, *Mugil cephalus* y *Mugil curema*, y sus sexos empleando diez medidas somaticas. Las alometrías de cada medida se estiman en relación a la longitud total. Se analizan las variaciones morfométricas mediante tres transformaciones: (i) transformación logarítmica, (ii) división de cada variable por la longitud total y (iii) normalización de los individuos de cada grupo; y tres análisis multivariantes: (a) anál-sis de correspondencias, (b) análisis de componentes principales y (c) análsis canónico de poblaciones. Los resultados indican diferencias en la morfología de ambas especies. Los machos y las hembras de *M. cephalus* quedan claramente discriminados en dos grupos, mientras que para *M. curema* los sexos no presentan diferencias importantes. La separación de los grupos, debida a diferencias en la forma y no en el tamaño, se pone de manifiesto mediante el análisis de correspondencias y del análisis canónico de poblaciones de los datos normalizados. La variables morfométricas que diferencian los cuatro grupos son anchura máxima, longitud hasta la aleta anal y longitud cefálica.

Palabras clave: Crecimiento relativo, morfometría, *Mugil cephalus*, *Mugil curema*, Golfo de México.

INTRODUCTION

In Mexico, *Mugil cephalus* and *Mugil curema* make up two of the ten most important fisheries given the high volume of capture, higher than 10 000 tonnes per year (Polanco *et al.*, 1987). Most of the lifecycle of these species is clearly associated with coastal lagoons and 99% of the total catch is registered in the northwestern part of the Gulf of Mexico. They are the main source of income in the Tamiahua lagoon. This is basically due to the high commercial value of the "roe" or gonad. Inspite of the importance of these species, there are very few studies publis-

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hed on the subject in Mexico and they refer mainly to *M. cephalus*. Among the most important, we find those that deal with aspects such as mortality and growth (Márquez, 1974), age-length ratio reproduction and fertility (Díaz and Hernández, 1980) and space-time distribution in Tamiahua lagoon, Mexico (García, 1980). There is a study concerning relative growth of *M. cephalus* and *M. curema* carried out in the area of study (Pérez and Ibáñez, 1992) that refers to allometric ratios regarding size. Several papers are found on morphometric analysis of mugilids: Grant and Spain (1975), Drake and Arias (1984) and Rojo and Ramos (1985). However, none of the mentioned studies refers to the "shape" of these species; they rather deal with the various adaptations conferred by the allometries regarding total (or standard) length.

Particular interest in carrying out an analysis exclusively of the "shape" of these two mugilids lies in the great resemblance between both of them. They present, among other similar characteristics, the same number of scales from the dorsal origin to the tip of the mouth, forked caudal fin, as well as having their eyes hidden by a thick adipose membrane (anterior and posterior). One of the main distinctive characteristics between these two species is colour and pigmentation, since only *M. cephalus* shows conspicuous black lines along each row of scales. However, this feature can be easily detected in adult specimens while it is barely noticeable in small ones. No apparent sexual dimorphism occurs in either species, making dissection necessary in order to distinguish the sexes.

The object of the present study was to analyse the morphology of *Mugil cephalus* and *M. curema* and to answer the following question: are there any differences in "shape" between these two species?

MATERIAL AND METHODS

Data collection

The morphometric measurements were taken (Fig. 1) on individuals belonging to the *M. cephalus* and *M. curema* species collected from the commercial catch in the Tamiahua lagoon (located in the mid-western portion of the coasts of the Gulf of Mexico: N 21°06' to 22° 06' W 97° 23' to 97° 46'). The measurements: total length (Tl), standard length (Sl), distance to the first dorsal fin (PD1l), distance to the second dorsal fin (PD2l) and length to the anal fin (PAl), were obtained to the nearest 1 mm, with the help of an ictiometer. The remaining measurements, maximum height (Max.h), minimum height (Min.h), cephalic length (Cl), ocular diameter (Oc.d) and thickness at maximum width (Max.g), were taken with a calliper to the nearest 0.01 mm. These measurements were selected according to the criterion followed by Drake and Arias (1984). Sam-

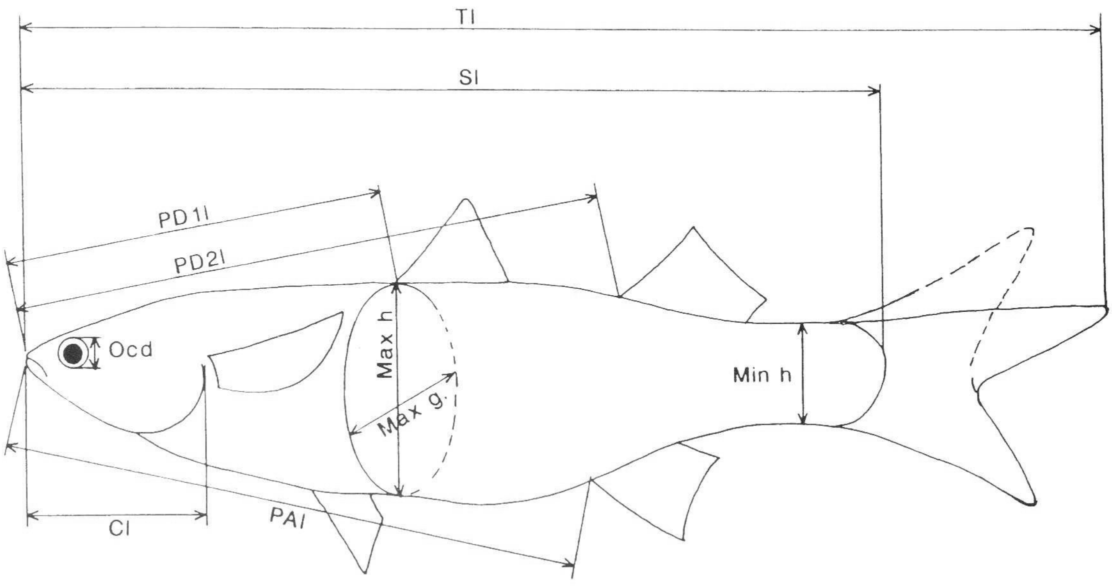

FIG. 1. – Morphometric measurements taken to *Mugil cephalus* and *Mugil curema*. Total length (Tl), standard length (Sl), distance to the first dorsal fin (PD1l), distance to the second dorsal fin (PD2l), length to the anal fin (PAl), maximum height (Max h), minimum height (Min h), cephalic length (Cl), ocular diameter (Ocd) and thickness at maximum width (Max g.)

pling lasted a year with monthly periodicity from April, 1990 to March, 1991. The organisms were sexed and measured fresh. Those whose sex was not determined were discarded for this analysis.

The data were organised in four matrices by species and sex, each with ten columns (one for each variable) and a different number of rows (one for each individual). A summary of data can be found in 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, were calculated in the following way:

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

where: Tl_j is the total length of individual j, Y_{ij}, is the i variable of individual j and a_i and b_i are the parameters of the allometric ratio between total length and variable i.

The data were transformed according to three criteria:

(i) logarithmic transformation of each measurement, justified by the existence of the potential ratios (eq. 1) between variables, that are linealized with the logarithmic transformation.

(ii) the ratios of the measured variables for an individual by one of them (total length in this case) in order to eliminate size differences.

(iii) normalization of individuals of each group according to the equation:

$$Z_{ij} = Y_{ij} \left[\frac{Tl_0}{Tl_j} \right]^{b_i} \quad (2)$$

where: Z_{ij} is the value of variable Y_{ij} once it has been transformed, X_0 represents a reference value of size to which all individuals are reduced (or amplified) (Lombarte and Lleonart, 1993). With this transformation both size differences and changes in shape related to it are eliminated.

Among the different multivariate analysis that may be carried out, the following have been chosen: (a) reciprocal averaging, (b) principal component analysis, (c) canonical analyses of populations.

Reciprocal averaging has been applied to the transformed data according to the three mentioned procedures. Given that the normalization procedure (iii) is more efficient, principal component analysis and canonical analysis of populations have been carried out only on transformed data according to this criterion.

TABLE 1. – Size of sample, average, variance and size range (Tl in cm) of the species, their sexes and the organisms of undifferentiated sex.

Mugil cephalus	n	average	variance	size range
Females	126	38.7	32.1	25.8 – 53.0
Males	123	34.4	11.8	21.7 – 45.6
Undiff.	32	24.8	5.48	20.8 – 28.4

Mugil curema	n	average	variance	size range
Females	179	27.8	8.7	27.8 – 37.0
Males	130	25.4	8.0	17.6 – 33.9
Undiff.	21	24.19	7.7	16.3 – 27.9

RESULTS

The results of parameter calculations of the allometric ratios are presented in Table 2. Relative growth of variables is different for each species. In both sexes of *M. curema* most variables grow isometrically, while allometric growth is more common in the case of *M. cephalus*.

The t test pointed out a greater discrepancy between allometries of the *M. cephalus* sexes (with seven different variables) and those of *M. curema* (with three significantly different variables).

It is to be noticed that, in reciprocal averaging using the logarithmic transformation (i) and the ratios of variables measured for an individual by total length (ii) (Figs. 2 and 3), the disposition of specimens is highly related to size. A horizontal gradient (from left to right, Table 1) can be observed, where the smaller individuals (of the *M. curema* males) come first, followed by female *M. curema*, *M. cephalus* males and females, the latter being found preferably towards the right margin of the graph. Evidently the greatest cloud of points is found in sizes with higher frequency values.

In the reciprocal averaging with normalization of individuals of each group (iii), the species and sexes of the *M. cephalus* are clearly discriminated (Fig. 4). This agrees with the results obtained in the parame-

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

Mugil cephalus.

	Females					Males					
	Parameters					Parameters					
Var.	a	b	r	allom.	t_b	a	b	r	allom.	t_b	t_s
2	0.892	0.972	0.97	–	1.346	0.994	0.938	0.95	–	2.220*	0.968
3	0.185	1.013	0.91	+	0.313	0.068	1.295	0.98	+	12.826*	5.941*
4	0.170	0.815	0.81	–	3.510*	0.033	1.266	0.97	+	9.236*	7.515*
5	0.332	1.041	0.98	+	2.135*	0.495	0.928	0.91	–	1.930	2.688*
6	0.516	1.031	0.99	+	2.039*	1.027	0.834	0.94	–	5.866*	6.121*
7	0.471	1.047	0.98	+	2.749*	0.879	0.870	0.95	–	4.962*	5.646*
8	0.284	0.895	0.89	–	2.606*	0.354	0.820	0.93	–	6.020*	1.497
9	0.015	1.328	0.98	+	14.709*	0.004	1.759	0.96	+	16.536*	8.442*
10	0.115	1.023	0.88	+	0.470	0.034	1.355	0.93	+	7.505*	4.873*

Mugil curema

	Females					Males					
	Parameters					Parameters					
Var.	a	b	r	allom.	t_b	a	b	r	allom.	t_b	t_s
2	0.805	1.000	0.98	=	0.000	0.827	0.990	0.97	–	0.481	0.385
3	0.252	0.917	0.78	–	1.488	0.260	0.906	0.78	–	1.469	0.120
4	0.112	0.915	0.68	–	1.139	0.053	1.140	0.82	+	1.994*	2.196*
5	0.368	1.010	0.95	+	0.385	0.446	0.951	0.93	–	1.485	1.404
6	0.518	1.030	0.98	+	1.744	0.555	1.007	0.97	+	0.324	0.832
7	0.534	1.006	0.96	+	0.256	0.524	1.009	0.95	+	0.307	0.080
8	0.226	0.942	0.94	–	2.189*	0.525	0.689	0.76	–	12.440*	4.297*
9	0.031	1.191	0.90	+	4.505*	0.047	1.098	0.87	+	1.753	1.323
10	0.030	1.417	0.98	+	19.128*	0.078	1.124	0.78	+	1.570	3.574*

Key: Var., variables: 2, Sl.; 3, Max.h; 4, Min.h; 5, PD1l; 6, PD2l; 7, PAl; 8, Cl; 9, Oc.d; 10, Max.g; t, t statistic (level of significance $P < 0.05$). *; significative value of t; t_s= t between sex; t_b= t of the b =1 parameter.

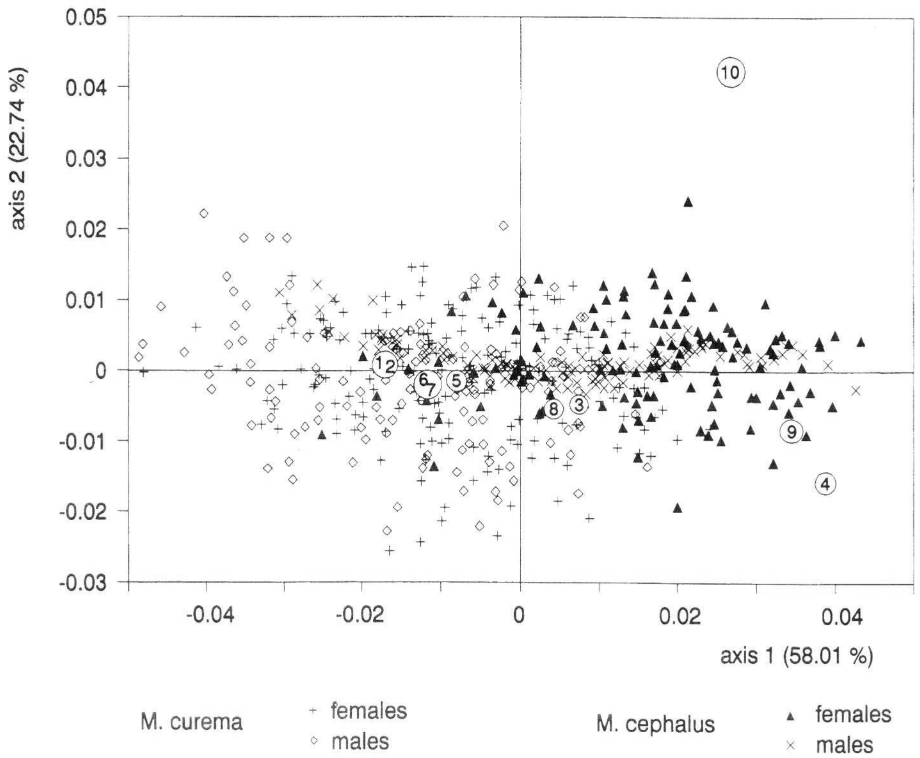

FIG. 2. – Reciprocal averaging analysis of the logarithmic transformation of each of the measurements (transformation (i)).

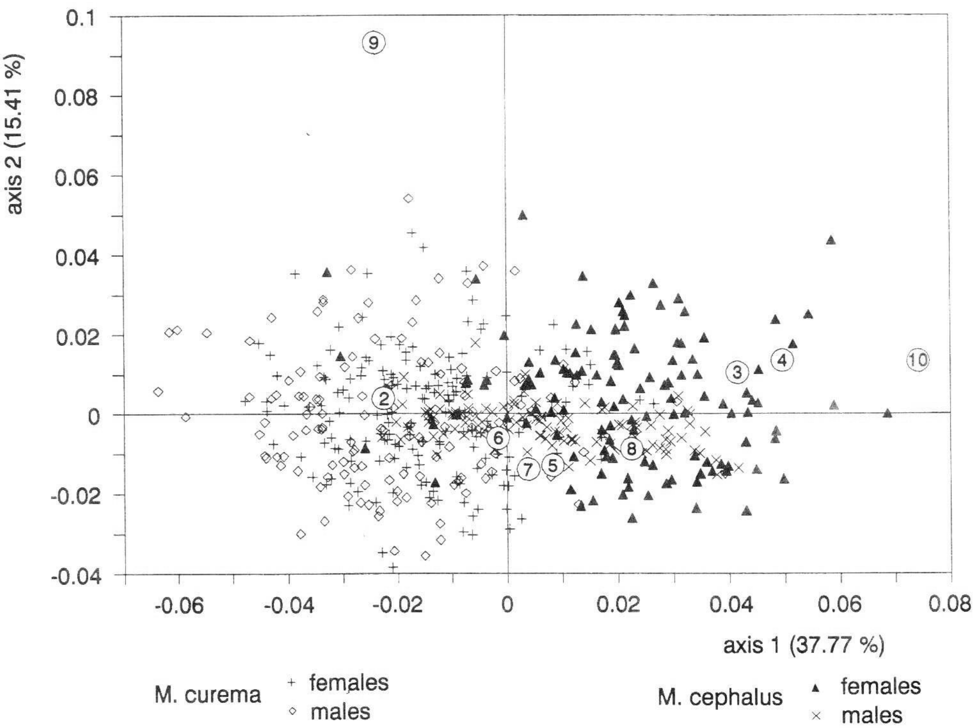

FIG. 3. – Reciprocal averaging analysis of the ratios of the variables of an individual by total length (transformation (ii)).

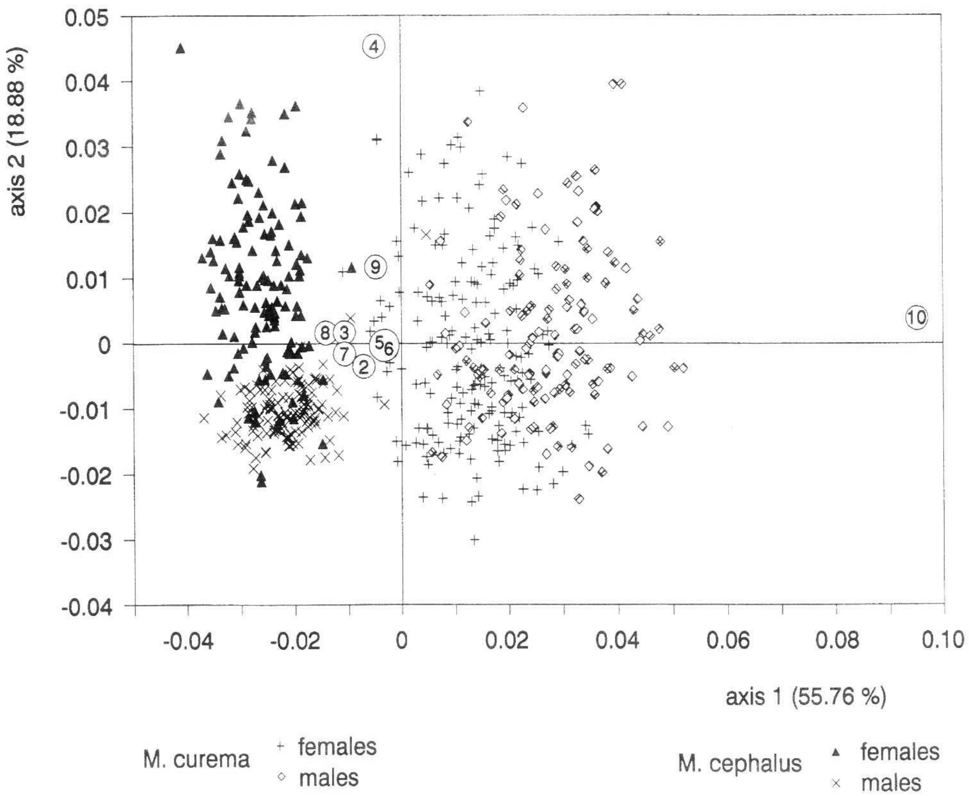

FIG. 4. – Reciprocal averaging analysis of the normalization of individuals of each group (transormation (iii)).

TABLE 3. – Correlation matrix with the normalization of individuals of each group (method iii).

Var\Dim.	2	3	4	5	6	7	8	9	10
Sl	1.0000								
Max.h.	0.0731	1.0000							
Min.h.	0.1831	0.1896	1.0000						
PD11	0.1380	0.1365	-.0213	1.0000					
PD21	0.2914	0.2114	0.0308	0.6538	1.0000				
PAl	0.2274	0.1344	-.0421	0.6122	0.6289	1.0000			
Cl	0.2328	0.1357	0.2573	0.1197	0.1928	0.2071	1.0000		
Oc.d.	-.0718	-.0102	0.0019	-.1594	-.1427	-.3240	-.3868	1.0000	
Max.g.	0.1561	0.3173	0.3157	0.1079	0.1289	0.0755	0.3222	0.0473	1.0000

Key: Var: variables; Dim: dimension.

TABLE 4. – Variance cumulative percentage in the three first axes of the different analyses.

Anal.	Trans.	Axis 1	Axis 2	Axis 3
CO	i	58.01	80.76	89.78
CO	ii	37.77	53.18	65.98
CO	iii	55.76	74.64	84.55
CP	iii	30.43	48.58	61.78
CANP	iii	54.74	96.21	100.0

Key: CO: correspondence analysis (reciprocal averaging); CP: principal components analysis and; CANP: canonical analysis.

ter calculations of the allometric ratios, where it was shown that there was a greater difference in allometries between the sexes of *M. cephalus*. *M. cephalus* males appeared in a compact conglomerate while females showed greater variability (Fig. 4).

The variables that influenced the most in each of the three mentioned analyses were thickness at maximum width, minimum height and ocular diameter (variables 10, 4 and 9, Figs. 2, 3 and 4).

The measurements of thickness at maximum width (Max. g.) remain highly important for recog-

TABLE 5. – Canonical analysis of populations.

1) Homoscedasticity of covariances.

χ^2	d.f.
1202.10*	108

* significant value ($P<0.05$).

2) Population comparison.

λ	F	d.f.
0.4169	23.284	24 and 1587

3) Variances-covariances matrix.

0.468930							
0.016411	0.159500						
0.027581	0.012044	0.053662					
0.040006	0.297340	0.002932	0.205601				
0.100240	0.052488	0.015883	0.138032	0.233155			
0.084595	0.040952	0.003179	0.144691	0.154280	0.298350		
0.041754	0.013257	0.014349	0.008624	0.025391	0.012966	0.092682	
0.023429	0.028423	0.013212	0.019183	0.298490	0.248730	0.247040	0.066236

4) Factorial structure of tha canonical variables. The correlations between the observable variables and the two canonical variables are:

Var.	V_1	V_2	Var.	V_1	V_2
Sl	0.03278	-0.18422	PD21	0.45133	0.05433
Max. h	-0.15751	-0.22228	PAl	0.62411	-0.20764
Min. h	-0.35885	-0.52509	Cl	0.29448	-0.80114
PD11	0.31294	-0.06271	Oc.d.	-0.35279	-0.42923

Key variables: Sl: standar length; Max. h: maximum height; Min. h: minimum heigth; PD11: distance to the first dorsal fin; PD21: distance to the second dorsal fin; PAl: length to he anal fin; Cl: cephalic length; Ocd: ocular diameter.

nising the species and the sexes (in the case of *M. cephalus*). The difference between these two species was recognised by Jordan and Everman in 1896 while describing these organisms, noting that *M. cephalus* shows a somewhat robust body, while *M. curema* is moderately elongated.

The matrix of correlations (Table 3), shows that these were different in sign and magnitude, a pattern that expresses variation in "shape" but not in "size" (Cuadras, 1981; Corti *et al.*, 1988). Major correlations can be noted between length to the first and second dorsal fins and length to the anal fin; this is due to the relative growth of the head. According to Burdak (Aleev, 1963) in the case of the mugilids, there is a change in the size of the mouth (it is reduced) as they change from youths to adults with the head getting smaller. Ocular diameter showed, in 6 of the 8 cases, a negative correlation, thus standing out from the characteristics identified as "shape of the body". The variance explained by the first two factors in this principal components analysis was of 49% (Table 4).

As mentioned above, thickness (Max. g.) is the most important variable for the recognition of the groups, however it is influenced also by the state of sexual maturity in which the specimens are found at the moment of being measured. For this reason, it was decided to eliminate this variable and proceed with the canonical analysis of populations of the data matrix with the normalization of individuals of each group (iii).

The within-group covariance matrix was heteroscedastic (Table 5); nevertheless, after examining the covariance matrix, it was found that the signs do not change from one population to another. That is, the elipsoidal orientation of concentration does not vary much, making it possible to carry out a canonical analysis of populations (Cuadras, 1981).

The population results of the canonical variables one and two for both species of mugilids are shown in Fig. 5. The radii of confidential regions were calculated with a confidence coefficient of 90%. The first two axes account for 96% of the variance. Since the first two axes make up almost all variability, the geometric distance practically coincides with the distance of Mahalanobis (Cuadras, 1981). From this representation the similarity between male and female populations of *M. curema* can be seen, while the *M. cephalus* males and females were clearly separated in two groups. This coincides with the reciprocal averaging with normalization of individuals of each group (iii). The

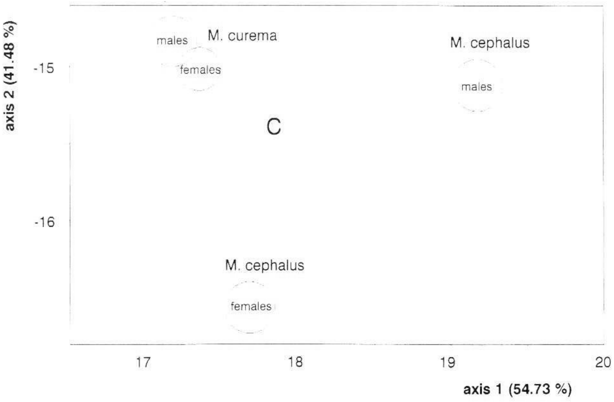

FIG. 5. – Canonical analysis of the normalization of individuals of each group (transformation *iii*) after eliminating the width variable (Max. g).

morphometric variables that influence discrimination of the populations, through canonical analysis of populations, are pre-anal length (PAl) and cephalic length (Cl) (Table 5).

DISCUSSION

The data indicate that the morphology of both species is different, with a greater difference between the sexes of *M. cephalus* while there are no important differences between the sexes of *M. curema*. The extent to which both species and their sexes differ morphometrically was illustrated by means of reciprocal averaging and of canonical analysis of populations using the Lombarte and Lleonart (1993) normalization, which defined the differences in "shape" between groups.

The thickness variable (Max. g.) was, at first, the most important measurement for group separation confirming differences in robustness between species. Once this variable had been eliminated, group recognition -through canonical analysis of populations- depended particularly on the differences of the ratio between shape of head and shape of body. These discrepancies in shape of the head have been acknowledged since 1896 by Jordan and Everman in the specific description of *M. cephalus* and *M. curema* for Central and North America. Nevertheless, these authors make no reference to the differences between the sexes of *M. cephalus*, undoubtedly because they are less striking. In the case of *M. curema* the variability is greater and, therefore, the sexes cannot be discriminated so easily.

In the literature, the differences between the sexes of mugilids refer, basically, to changes in growth (Cech and Wohlschalag, 1975; Angell, 1973; Oren, 1981), or to allometric ratios regarding size (Grant and Spain, 1975; Drake and Arias, 1984; Pérez and Ibáñez, 1992); however, we have no evidence of any study that refers exclusively to the "shape" of these species.

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