Geographic differences and annual stability in length-weight relationships of fish mullets (Pisces: Mugilidae)

Diferencias geográficas y estabilidad anual en la relación peso-longitud de peces mugílidos (Pisces: Mugilidae)

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ABSTRACT

Length-weight relationships are essential in fisheries science since they are used to calculate fish yield. Even though spatial and temporal differences in length-weight relationships are known to exist, it is frequently understood that length–weight relationships do not vary within near stocks. In order to probe this, we analyze the length–weight relationships for 384 *Mugil cephalus* and 652 specimens of *M. curema* from commercial captures on two locations of the Mexican Pacific coast and seven along the Gulf of Mexico including the US. In the locations of the Mexican Gulf of Mexico coast contiguous years were sampled. Results show that the parameter *b* ranged from 2.15 to 3.87 for *M. cephalus* and from 2.39 to 3.11 for *M. curema*. No significant differences were found between regions. Even though the b values for *M. cephalus* are higher in northern locations (USA samples) while for *M. curema* *b* values increase in low latitudes with more tropical characteristics. Most of the results showed negative allometric values, which seems to indicate that commercial captures are mainly represented by young adults. No significant differences between years were detected for both species. Plot of log a vs *b* showed no significant differences between species form pointing out that both are similar-looking with fusiform shape. This resemblance demonstrates that the species of the genus *Mugil* are characterized by much conserved morphological features, which noticeably obstruct taxonomic determination.

Key words: Gulf of Mexico, length-weight relationship, Mexican coasts, *Mugil cephalus, Mugil curema.*

RESUMEN

Las relaciones talla-peso son importantes en la ciencia pesquera porque generalmente se emplean para obtener rendimientos pesqueros. Aunque se sabe que existen diferencias de dicha relación entre diferentes zonas geográficas frecuentemente se piensa que la relación talla-peso no varía entre zonas cercanas. Así, para analizar la variación espacial y temporal de esta relación se estimó la relación talla-peso para 384 y 652 ejemplares de *Mugil cephalus* y *M. curema* respectivamente, provenientes de la captura comercial en dos localidades de las costas mexicanas del Pacífico y siete del Golfo de México incluyendo las de E.U.A. Para el Golfo de México se realizaron colectas durante dos años contiguos. Los resultados mostraron que el parámetro *b* varió en un intervalo de 2.15 a 3.87 para *M. cephalus* y de 2.39 a 3.11 para *M. curema.* No se encontraron diferencias significativas entre las diferentes localidades de colecta. Sin embargo, los valores de b en *M. cephalus* fueron mayores para las localidades de EUA, mientras que para *M. curema* el valor de *b* se incrementó en las latitudes menores de ambientes más tropicales. La mayoría de los resultados mostraron relaciones de alometría negativa, lo que parece indicar que las capturas comerciales están representadas fundamentalmente por adultos jóvenes. No se presentaron diferencias significativas entre los años de recolecta para ambas especies. La relación entre el logaritmo de *a* sobre *b*, mostró que no hay diferencias significativas entre la forma de las especies: ambas son fusiformes. Este resultado nuevamente prueba lo conservador de la morfología del género *Mugil* lo que dificulta notoriamente la determinación taxonómica de las especies debido a la similitud entre ellas.

Palabras clave: Costas mexicanas, Golfo de México, *Mugil cephalus, Mugil curema*, relación talla-peso.

The striped mullet *Mugil cephalus* Linnaeus 1758 is distributed in all oceans from 42°N to 42°S (De Silva & Silva, 1979), whereas *Mugil curema* Valenciennes in Cuvier and Valenciennes 1836, the white mullet, is basically an American species with recent reports in western African waters (Durand *et al.*, 2012). In Mexico, both fish mullets represent one of the 10 most important fisheries, based on their high catch volumes, which surpass 12,500 t yr^{-1} (Conapesca-Sagarpa, 2012), 67% of the total catch is registered in the northwestern lagoons of the Gulf of Mexico.

According to Petrakis and Stergiou (1995) the weight-length relationship is a practical index of the condition of fish and also is useful for between-regions life-history comparisons. In addition, this relationship can be used to estimate weight at a given length since to get the length of a fish is more easy and accurate that the weight. Even though spatial differences in length-weight relationships are known to exist, it is frequently understood that length–weight relationships do not vary within near stocks. In order to probe this we analyze the length–weight relationships for 384 *Mugil cephalus* and 652 specimens of *M. curema* on two locations of the Mexican Pacific coast and seven along the Gulf of Mexico including the USA. Also time variation on length-weight relationship was analyzed since contiguous years were sampled on locations of the Gulf of Mexico coast.

The hypotheses test that the condition factor “b” will be the same in all locations sampled and as well this “b” factor is the same between contiguous sampled years.

Field studies were conducted from commercial captures during the fishing season of both species from November to February of 2009–2011 (Fig. 1, Table 1). For all Mexican locations in the Gulf of Mexico two contiguous years were sampled on similar days each year. Tamiahua Lagoon had also a third collection during year 2011.Total individuals were 384 and 652, captured from commercial samples with gill net of 76-89 mm and 51-64 mm mesh size for *M. cephalus* and *M. curema*, respectively. Samples were identified and measured for total length (TL) to the nearest 0.1 cm and weighed (total weight, W) to the nearest 0.1 g.

The parameters of the allometric ratios between total length (TL), taken as the independent variable, and total weight (W) taken as the dependent variable was calculated by the equation: $W = a\,TL^b$.

Where: W = Total weight, TL = total length and *a* and *b* are the parameters of the allometric ration between W and TL. The hypothesis of isometric growth was tested by Student’s *t*-test (level of significance $\alpha < 0.05$):

Where t_s is the value of t, *b* is the slope of the length/weight relationship and S*b* is the error standard of the slope. Also t-test was used

$$t_s = \frac{b - 3}{S_b}$$

to determine whether the slope b differ between years from the same location. For *M. curema* information from one-way ANOVA was used to determine whether locations differ. For *M. cephalus* comparisons were done by Kruskal-Wallis analysis since homoscedasticity was not achieved.

In order to detect outliers in weight–length relationships a robust regression analysis of log a over *b* (Froese, 2006) was estimated for each species and the regression lines were compared by ancova. Twenty four and sixteen estimates of weight–length relationships were available from Binohlan and Pauly (2013) at Fishbase for *M. cephalus* and *M. curema*, respectively; they were used to do a comparison with current data from this study.

Length–weight relationships of *M. cephalus* and *M. curema* are summarized in Table 1. The parameter *b* ranged from 2.15 to 3.87 for *M. cephalus* and from 2.39 to 3.11 for *M. curema.* The *b* values for *M. cephalus* are higher in northern locations (Texas samples) while for *M. curema b* values increase in low latitudes. For both species most of the results showed negative allometric values (Table 1). No significant differences between years (data not showed) and locations were detected ($F(4,5) = 0.597$, $p = 0.681$ for *M. curema* and $\chi^2(3, N = 7) = 4.571$, $p = 0.206$ for *M. cephalus* analysis).

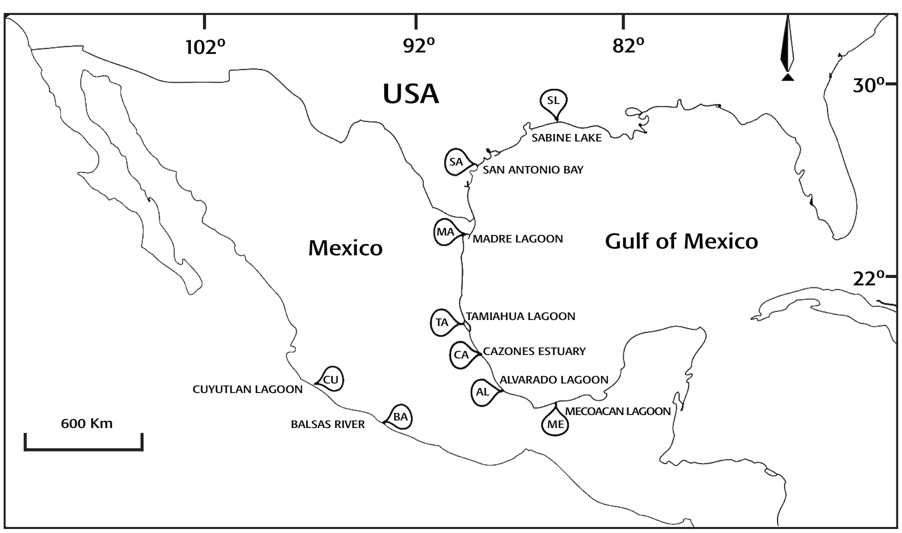

Figure 1. Sampling locations in the Gulf of Mexico and Pacific coast. Gulf of Mexico locations: SL = Sabine Lake; SA = San Antonio Bay; MA = Madre Lagoon; TA = Tamiahua Lagoon; CA = Cazones Estuary; AL = Alvarado Lagoon; ME = Mecoacan Lagoon. Pacific coast locations: CU = Cuyutlan Lagoon; BA = Balsas River.

Table 1. Parameters of length-weight relationship for *Mugil cephalus* and *M. curema* from locations in the Gulf of Mexico and Pacific coast.

Location	Code	Country/Geographic area	Year	N	Total length (cm) mean ± Std	Min-Max	a	Parameters of length-weight relationship 95% CI of a	b	95% CI of b	r^2	t_b	Allometry
Mugil cephalus													
Sabine Lake	SL	USA/ Gulf of Mexico	2009	50	34.1±2.1	30.5-50.0	0.0072	0.0039-0.0132	3.11	2.94-3.28	0.96	1.31	=
San Antonio Bay	SA	USA/ Gulf of Mexico	2009	22	34.3±3.2	31.0-40.5	0.0005	0.0001-0.0037	3.87	3.31-4.44	0.91	3.21*	+
Madre Lagoon	MA^1	Mexico/ Gulf of Mexico	2009	50	31.1±2.1	27.0-35.9	0.1625	0.0492-0.5370	2.15	1.80-2.50	0.76	-4.91*	-
Madre Lagoon	MA^2	Mexico/ Gulf of Mexico	2010	56	35.4±2.3	30.9-42.7	0.0270	0.0073-0.1006	2.71	2.34-3.08	0.80	-1.57	=
Tamiahua Lagoon	TA^1	Mexico/ Gulf of Mexico	2009	51	37.1±5.6	29.1-48.0	0.0280	0.0138-0.0567	2.70	2.49-2.88	0.94	-3.07*	-
Tamiahua Lagoon	TA^2	Mexico/ Gulf of Mexico	2010	52	32.9±2.7	28.1-41.8	0.0151	0.0066-0.0344	2.86	2.62-3.10	0.92	-1.17	=
Tamiahua Lagoon	TA^3	Mexico/ Gulf of Mexico	2011	51	31.3±2.0	26.6-36.4	0.0198	0.0038-0.1026	2.78	2.30-3.26	0.74	-0.91	=
Cuyutlán Lagoon	CU	Mexico/ Pacific Coast	2009	52	41.0±1.8	37.5-46.4	0.0934	0.0177-0.0492	2.39	1.94-2.84	0.69	-2.74*	-
Mugil curema													
Madre Lagoon	MA^1	Mexico/ Gulf of Mexico	2009	49	28.6±1.2	24.9-31.2	0.0694	0.0209-0.2302	2.43	2.07-2.79	0.79	-3.19*	-
Madre Lagoon	MA^2	Mexico/ Gulf of Mexico	2010	52	29.8±1.4	25.8-32.4	0.0135	0.0022-0.0834	2.91	2.37-3.44	0.70	-0.35	=
Tamiahua Lagoon	TA^1	Mexico/ Gulf of Mexico	2009	43	30.1±1.9	26.7-35.0	0.0359	0.0117-0.1096	2.62	2.29-2.95	0.86	-2.33*	-
Tamiahua Lagoon	TA^2	Mexico/ Gulf of Mexico	2010	51	29.7±2.3	24.8-34.5	0.0292	0.0117-0.0728	2.66	2.39-2.93	0.89	-2.55*	-
Tamiahua Lagoon	TA^3	Mexico/ Gulf of Mexico	2011	52	28.8±1.3	25.8-31.6	0.0328	0.0118-0.0910	2.64	2.33-2.94	0.86	-2.41*	-
Cazones Estuary	CA^1	Mexico/ Gulf of Mexico	2009	49	30.8±1.7	27.6-34.7	0.0795	0.0208-0.3039	2.39	1.20-2.78	0.76	-3.14*	-
Cazones Estuary	CA^2	Mexico/ Gulf of Mexico	2010	52	31.1±2.7	23.5-36.0	0.0065	0.0025-0.0165	3.11	2.84-3.38	0.91	0.80	=
Alvarado Lagoon	AL^1	Mexico/ Gulf of Mexico	2008	46	27.6±2.5	22.4-33.9	0.0078	0.0035-0.0173	3.06	2.82-3.30	0.94	-0.50	=
Alvarado Lagoon	AL^2	Mexico/ Gulf of Mexico	2009	52	29.8±2.3	24.6-35.7	0.0094	0.0042-0.0215	2.98	2.74-3.22	0.92	-0.18	=
Mecoacan Lagoon	ME^1	Mexico/ Gulf of Mexico	2008	51	28.8±4.4	22.3-40.5	0.0237	0.0156-0.0359	2.75	2.63-2.88	0.98	-4.01*	-
Mecoacan Lagoon	ME^2	Mexico/ Gulf of Mexico	2009	52	29.6±2.0	25.6-34.8	0.0097	0.0035-0.0268	2.96	2.66-3.26	0.89	-0.27	=
Cuyutlan Lagoon	CU	Mexico/ Pacific Coast	2009	52	22.5±1.0	20.0-25.1	0.0388	0.0134-0.1123	2.58	2.24-2.92	0.82	-2.46*	-
Balsas River	BA	Mexico/ Pacific Coast	2009	51	32.8±2.3	26.1-37.2	0.0165	0.0077-0.0353	2.84	2.63-3.06	0.93	-1.44	=

Superscript on Code indicate 1= first, 2 = second and 3 = third sample year. Level of significance $\alpha < 0.05$; * significant differences to b = 3 parameter. N=sample size; Min=minimum; Max=maximum; CI=coefficient interval.

Since the mullet fishery develops during the same time of year each year then no seasonal variation could be analyzed. Size was similar for different locations with the exception of Cuyutlán lagoon that in *M. cephalus* showed the highest and in *M. curema* lowest values of total length, respectively.

In order to provide a more species-specific overall relationship, data from all locations were plotted in Figure 2. It is evident that every decrease in the slope of the regression line will lead to an increase in the intercept, and vice-versa. Most of the results show negative allometric or isometric values with exception of San Antonio Bay ($b = 3.87$ for *M. cephalus*, Fig. 2 symbols in grey). Values from the Fishbase (Fig. 2 symbols in white) data depict similar performance with mixed results with current data from this study and between species. When comparing parameters of the plot of log a over *b* no differences were found between species ($p = 0.134$).

Gerritsen and McGrath (2007) found that a bias of up to 10% could occur in biomass estimates as a result of applying length–weight relationships of one neighboring stock with different relationship. In this sense we recommend to do the L-W estimation by location if possible even though no statistical differences were found since small (non significant) variation could lead to biomass bias considering the low expense of obtaining precise length–weight relationships.

As Froese (2006) mentioned the expected range of $2.5 < b < 3.5$ for fish is confirmed here and also in the River basin at the south east of the Iberian Peninsula where *M. cephalus* showed isometric growth ($b = 3$) (Andreu-Soler *et al.*, 2006) and positive allometric growth ($b = 3.36$) at Mar Menor coastal lagoon (Western Mediterranean Sea) (Verdiell-Cubedo *et al.*, 2006). The b values for *M. cephalus* are bigger in northern locations (USA samples) while for *M. curema b* values increase in low latitudes. One explanation could be that specimens sampled for this study come from over-exploited fisheries with exception of the USA samples; as well colder waters could favor the striped mullet condition. On the other hand, *M. curema b* values increase in low latitudes, thus suggesting that this species adapt better to tropical environments (Moore, 1974).

Lowest values of *b* coincide with samples with small sizes specimens that might contain more young adults, younger specimens less robust. At least this is visibly correct for the lower *b* value from *M. cephalus* from Madre Lagoon (1st year) and for *M. curema* of Madre Lagoon (1st year), Cazones (1st year) and Cuyutlán, Colima. Inferring ages from Ibáñez-Aguirre *et al.* (1999) for Tamiahua Lagoon, fishermen appear to be catching mainly specimens of ages between 3 and 5 years for *M. cephalus* and from 1 to 3 years for *M. curema*. According to Ibáñez-Aguirre and Gallardo-Cabello (2004), the first sexual maturation in Tamiahua Lagoon was at 3 yr and 1 yr of age for *M. cephalus* and *M. curema*, respectively. Consequently the commercial specimens are mainly based in young adults. Different growth stanzas have been experimentally studied since 1949 by Martin. He found that while in most species of fish the exponent b is close to 3 this index could change by strong changes in temperature or by starvation. Safran (1992) theoretically analyzed the weight-length relationship in fish juveniles and its possible linkage with the fractal theory and the saltatory ontogeny. Also, Stergiou and Fourtouni (1991) explored growth stanzas of *Zeus faber* Linnaeus 1758 and found them to be correlated with ontogenetic shifts in diet.

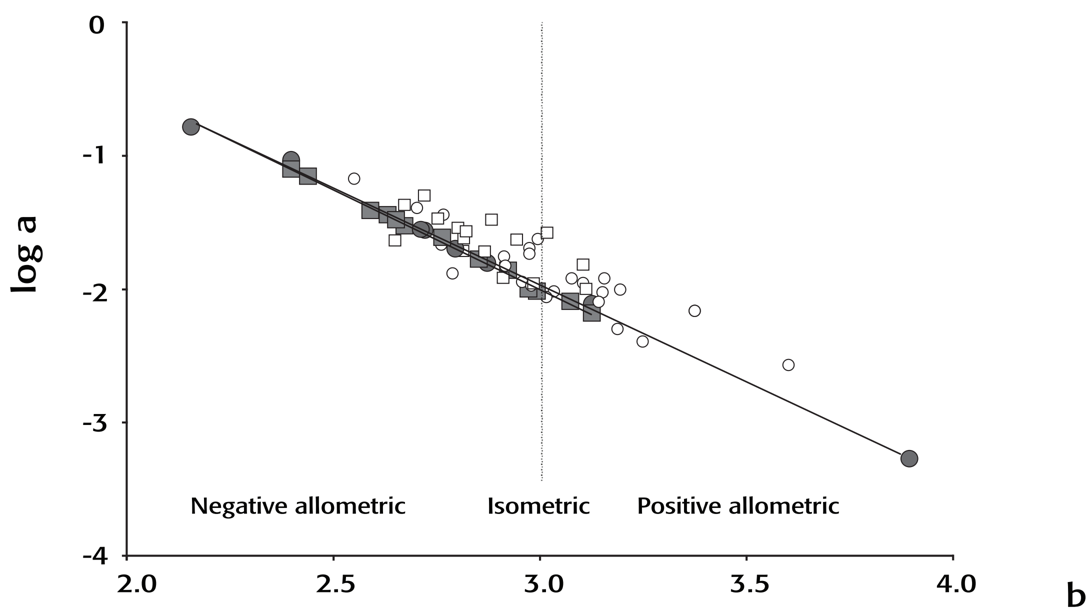

Figure 2. Scatter plot of log a over b for *Mugil cephalus* (circles) and *Mugil curema* (square), in grey current samples, white filling samples from Fishbase. *a* y *b* are the parameters of the allometric ration between W (total weight) and TL (total length). *b*= slope of the length/weigth relationship. A dotted line at $b = 3.0$ indicate the areas of negative allometric, isometric and positive-allometric growth. Regression line for *M. cephalus*: log a = - 1.4834 (b) + 2.4465, n = 8, $r^2 = 0.9978$; Regression line for *M. curema*: log a = - 1.5225 (b) + 2.5351, n = 13, $r^2 = 0.9967$.

Another cause of extreme values of *b* could be due to other characteristic of the sample. Carlander (1977) demonstrated that values of b < 2.5 or >3.5 are often derived from samples with narrow size ranges, he arrived to this results since a robust regression analysis found the slope of absolute residuals vs fraction of maximum length to be negative and significantly different from zero, i. e. residuals were becoming smaller with the increase in length-range used. In our case this is truth for the samples of the first year from Madre Lagoon for both species and for Cuyutlán and Cazones (1st year) collects for *M. cephalus* and *M. curema*, respectively.

As can be seen the allometric index is highly sensible to data sampling. If we want to analyze samples by month to detect seasonal variation data collection should include as many months as possible. In our study we sampled in the same season in the same areas during the fishing season. This gave us information on the fishery season for both species but is not representative of the different growth stanzas or between juveniles and adults. Nevertheless, this study verified that the capture is mainly represented by slim adults or young-adults since most of the results showed negative allometric values and samples of this study came from commercial capture.

Plot of log a vs *b* showed no significant differences between species form pointing out that both are similar-looking with fusiform shape. The species similarity of the parameters of the plot of log *a* over *b* points out that there are not outliers and that both species depict similar-looking fusiform shape. While exploring such relationship with several length-weight Fishbase available relationships (Binohlan & Pauly, 2013), both species follow same performance, particularly on parameter *b*. The variation in log *a* is mainly a function of the body shape of the respective populations, specimens could be slimmer or more robust probably due to age or diet conditions. This resemblance demonstrates that the species of the genus *Mugil* are characterized by much conserved morphological features, which noticeably obstruct taxonomic determination.

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