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Can the name *Mugil cephalus* (Pisces: Mugilidae) be used for the species occurring in the north western Atlantic?

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Abstract

Menezes *et al.* (2010) show that *Mugil cephalus* Linnaeus, 1758 is different from *Mugil liza* Valenciennes 1836, the latter being the mullet found along the Atlantic coast of South America. They also suggest that individuals identified as *M. cephalus* from the northwest Atlantic could represent a population of *M. liza* in this region, since they doubt the presence of *M. cephalus* in waters colder than the ones of the West Indies. In order to clarify the presence of *M. cephalus* in the northwest Atlantic, this study compares meristic and morphometric measurements of *M. cephalus* and *M. liza* from the Gulf of Mexico with those obtained by Menezes *et al.* (2010) for *M. liza* from South America and for *M. cephalus* in the Mediterranean Sea. Results show that there are differences in both morphometric and meristic data between the two species. The morphometric measure that differentiates these species is the distance from the snout to the dorsal fin, which is positioned backwards in *M. liza* compared with *M. cephalus*. The body width is consistently greater in *M. cephalus* than *M. liza*. The meristic character that discriminates between both species is the number of scales in the longitudinal series that, in *M. cephalus*, ranges from 38 to 43 while in *M. liza* between 32 to 39. The information presented in this work confirms the presence of *M. cephalus* in the Gulf of Mexico and the sympatric presence of *M. liza* is established, even if its abundance is quite low.

Key words: grey mullet, taxonomy, Gulf of Mexico, mullet distribution, sympatric species

Introduction

According to Briggs (1960), Thomson (1966), and Castro-Aguirre *et al.* (1999), *Mugil cephalus* Linnaeus, 1758 is a cosmopolitan species found in oceanic, coastal, and inland waters in temperate and sub-tropical regions around the world mainly between latitudes 42˚ N and 42˚ S. This has been considered the species with the widest distribution range among the Mugilidae (Eschmeyer and Fricke, 2009). *Mugil cephalus* inhabits coastal areas and its reproductive migrations to spawn in open seas may help to explain the extensive worldwide distribution (Anderson, 1958; Arnold and Thompson, 1958; Chang *et al.*, 2004). Recently, it has been recognized that this species has a discontinuous distribution in both hemispheres, and has been successfully introduced in areas such as the Caspian Sea (Whitehead *et al.*, 1986).

Considering its wide distribution and the similar morphometric characteristics of those found in other closely related mullets, not surprisingly *M. cephalus* has been confused with other species such as *M. liza* Valenciennes 1836 (Menezes *et al.* 2010; Fraga *et al.* 2007; González-Castro *et al.* 2008 and Heras *et al.* 2009). Recently, Fraga *et al.* (2007) and Heras *et al.* (2009) showed that *M. platanus* Günther 1880 should be considered a junior synonym

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of *M. liza* (González-Castro and Minos, 2016). Menezes (1983, 2003) and Figueiredo and Menezes (1985) did not consider *M. cephalus* to be the appropriate name for the mullets found in the coastal waters of southeastern Brazil and Argentina. They proposed that *M. liza* and *M. platanus* are two allopatric species distributed throughout South America. Furthermore, recent studies suggest that *M. cephalus* throughout its distribution range may be a complex of several species (Heras *et al.*, 2009; Shen *et al.*, 2011) and there is a possibility that at least 14 species within *Mugil* form that complex (Durand *et al.*, 2012).

According to Menezes *et al.* (2010), the identification and distribution of the lebranche or striped mullet in the Atlantic waters of South America has long been controversial. Thomson (1963) considered *M. cephalus* to be widely distributed in tropical and subtropical zones of all seas, but did not confirm its presence along the Atlantic coast of South America. Menezes (1983, 2003) and Menezes & Figueiredo (1985) did not consider *M. cephalus* the appropriate name for the striped mullet found in coastal waters from southeastern Brazil to Argentina. Rather they proposed that *M. liza* and *M. platanus* were two allopatric species distributed respectively north and south of Rio de Janeiro that should be recognized in the western south Atlantic.

In order to clarify the identity of the mullets present in the western coasts of South America, Menezes *et al.* (2010) used meristic and morphological data to show that *M. cephalus* is different from *M. liza*, the latter being the mullet found along the Atlantic coast of South America. Also, they suggest that individuals identified as *M. cephalus* in the northwest Atlantic could be part of a population of *M. liza*.

To clarify the presence of *M. cephalus* in the northwest Atlantic, this work compares meristic and morphometric data constituting evidence of the presence of *M. cephalus* in the Gulf of Mexico. Meristic and morphometric data from 341 specimens of *Mugil cephalus* and seven of *M. liza* are compared to those reported by Menezes *et al.* (2010) for *M. liza* from South America and for *M. cephalus* from the Mediterranean. Finally, variations in the scale pattern of the *M. cephalus* (flathead mullet) along the Gulf of Mexico are analyzed allowing us to identify valid records of *M. liza* in waters colder than those of the West Indies.

Material and methods

Morphological and meristic data were obtained from the left flank of each specimen. Measurements of individuals belonging to the smaller size classes were taken with calipers while large specimens were measured with a ruler in millimeters. The following data were obtained: body depth, measured vertically downwards from the origin of the first dorsal fin (spiny); head length, measured from the tip of the premaxilla to the tip of the operculum, including its membranous margin; head depth, measured at the wider rear portion; head width, measured at the wider rear portion; length of the upper jaw, measured from the tip of premaxilla to the posterior section of the maxilla; horizontal diameter of the eye, taken as the distance from the anterior edge to the margin of the orbit, excluding the adipose eyelid; snout length, measured from the tip of the premaxilla to the anterior margin of the orbit; interorbital distance, as the shortest distance between the edges of the frontal bones; depth of the caudal peduncle, as the minimum length measured vertically; length of the pectoral fin, measured from the base of the upper radius to the tip of the longest radius; pelvic fin length, taken from the base of the spine to the tip of the longest radius; tip of the snout to the origin of the second dorsal fin (curved); tip of the snout to the origin of pectoral fin; tip of the snout to the origin of the pelvic fin; tip of the snout to the origin of the anal fin.

Meristic counts included the number of longitudinal scales, the number of oblique rows counted from the scale located immediately above the insertion of the pectoral fin to the caudal bend; the number of transverse scales, counted vertically from the origin of the first dorsal fin (spiny) to the line passing through the origin of the pelvic fin; gill rakers, counted in the first gill arch. Box plots and / or frequency tables were used to compare meristic data. Significant differences were tested at $p < 0.05$. The number of gill rakers was analyzed as a function of the standard length.

Samples were obtained at the following locations (marked with an asterisk in Figure 1): Florida: Charlotte Harbor, Tampa Bay, Cedar Key (collected by WFS 613 class) and Apalachicola Bay (collected by RW Yerger and class); Alabama: Baldwin (collected by Suttkus, Smalley and Rohmann); Mississippi: Jackson (collected by Suttkus, D. Norriss and Biol. of Fishes class); Louisiana: West Feliciana (collected by Rios, Todaro and Coste); Texas: Sabine Lake, Aransas Bay (collected by WFS 312 and class) and Corpus Christi Bay (collected by Pacheco-Almanzar); Veracruz: Tamiahua Lagoon (collected by HE Winn and CL Smith), Rio Rancho Nuevo (collected by

RR Miller, RJ Schultz and natives) and Boca del Rio (collected by Miller, Carranza, Schultz and García) and Yucatán: Sisal (collected by Chiappa and Badillo). To compare the results, data were grouped by location and plotted following that order. The comparison between our samples and the ones for *M. liza* and *M. cephalus* from Menezes *et al.* (2010) were not statistically tested since data from Menezes *et al.* (2010) were not available.

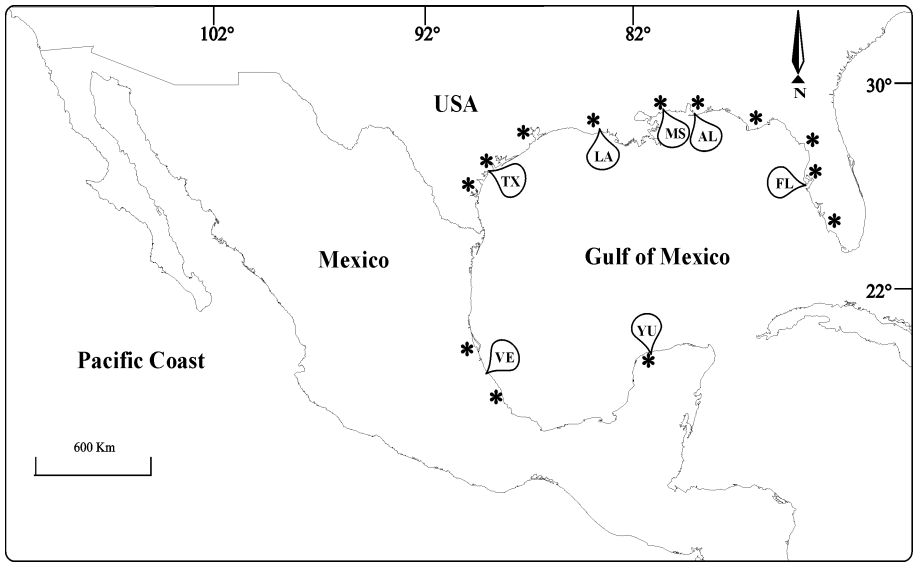

FIGURE 1. *Mugil cephalus* sampling areas (*), State names: FL = Florida; AL = Alabama; MS = Mississippi; LA = Louisiana; TX = Texas; VE = Veracruz and YU = Yucatán. Asterisk in Figure 1. Charlotte Harbor; 2. Tampa Bay; 3. Cedar Key; 4. Apalachicola Bay; 5. Baldwin; 6. Jackson; 7. West Feliciana; 8. Sabine Lake; 9. Aransas Bay; 10. Corpus Christi Bay; 11. Tamiahua Lagoon; 12. Rio Rancho Nuevo; 13. Estero Mandinga; 14. Sisal.

Sample sizes are distributed as follows: from the United States: Levy, Florida (41 specimens collected at Lat: 29.14639—Long: -83.03944 (TCWC 294.14) and 15 specimens taken from Lat: 29.15778—Long: -83.04667 (TCWC 565.15)) provided by the Texas Cooperative Wildlife Collection (TCWC)—Ichthyology Specimens. Four specimens were collected in Escambia River, Florida (UF 154959), and 20 specimens collected in Franklin, Florida (UF 63571), were provided by the Division of Ichthyology, Florida Museum of Natural History, and University of Florida (FLMNH) at Gainesville, Florida. Twenty-four individuals from Baldwin, Alabama (TU 108680), 27 from Jackson, Mississippi (TU 142412), and 21 specimens collected in West Feliciana, Louisiana (TU 192232), were provided by the Tulane University (TU) Museum of Natural History—Royal D. Suttkus Fish Collection. Thirty specimens from Aransas Bay, Texas, captured at Lat: 28.05—Long: -96.99139 (TCWC 1598.02) were provided by the Texas Cooperative Wildlife Collection (TCWC)—Ichthyology Specimens. From Mexico: 9 specimens collected in Rio Rancho Nuevo, Veracruz (19º50'N–96º30'W) (UMMZ 184469), 21 specimens collected in Tamiahua lagoon (21º28'N–97º40'W) (UMMZ 167545) and 1 individual captured in Estero Mandinga (19º8' N–96º8' W) (UMMZ 184498) were provided by the Collection of Fishes of the University of Michigan Museum of Zoology (UMMZ); finally, 15 specimens captured in Sisal, Yucatán (21º09' N–90º02' W) were captured by the authors. Specimens of *M. liza* are from the National Collection of Fishes, two specimens were captured off San Juan de Ulúa, Veracruz. (IBUNAM CNPE 757), three from Sabancuy, Yucatán (IBUNAM CNPE 20686) and two from Celestún, Campeche, Mexico (IBUNAM CNPE 20688).

Results and discussion

Diagnostic characters of Mugil cephalus

The morphometric data obtained are shown in Table 1. Adults have a thick layer of adipose tissue around the eye, covering most of pupil; hind edge of preorbital does not extend beyond the corner of the mouth. Preorbital extends almost to the end of the maxilla (Figure 2). Both the second dorsal and anal fins have small scales on the basal parts. Anal fin has 3 spines and 8 soft rays in adults (the first spine is very short, and may be hidden under

the overlapping scales). Juvenile fish, especially those ≤ 30 mm standard length, usually have 2 spines and 9 soft rays. Pectoral fin with 1 spine and 15 to 16 (rarely 17) soft rays; its length does not reach the origin of the first dorsal fin. The number of scales of the longitudinal series is generally 38–43 (mean 40) for the samples analyzed (reported range worldwide is 36 to 44), and from 12 to 15 in the transverse series (Table 1). The number of gill rakers on the first gill arch is 53–89, showing a positive relationship with standard length.

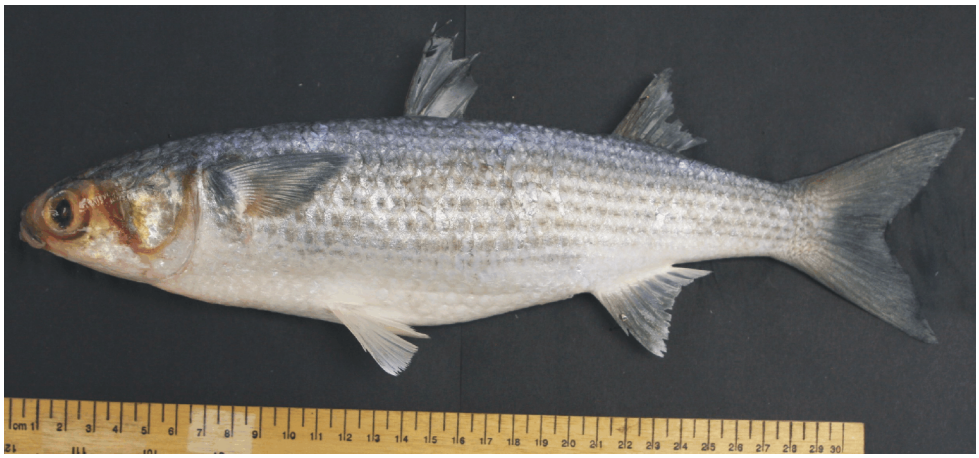

FIGURE 2. *Mugil cephalus*, Madre Lagoon, Tamaulipas, Mexico 376 mm total length.

Dorsally, specimens are gray-olive or grayish brown colored. Flanks are silver and the abdomen is whitish; 7 to 10 dark longitudinal stripes are visible along the sides. Dorsal and caudal fins are dark; pelvic and anal fins are pale. The pectoral fins have a dark spot at the origin (Figure 2).

Interspecific comparison

The morphometric measures of *M. cephalus* and *M. liza* are shown in Table 1. The mean values of all measurements are similar between the two species except the distance from the snout to the origin of the dorsal fin, which is much larger for *M. liza*. In this case, the beginning of the dorsal fin is located towards the distal zone while in *M. cephalus* the beginning of the dorsal fin has an anterior location. Also, the body width is greater in *M. liza* than in *M. cephalus*, which appears more robust. This fact has also been recognized by Harrison (2002) who mentions that the ratio of body depth to standard length in *M. liza* ranges from 17 to 23% while values of 24 to 28% are common in *M. cephalus*. Even if the majority of the mean values of the morphometric variables are similar, ranges are generally wider in *M. cephalus*. In *M. liza*, adipose tissue around eye is almost absent and the hind edge of the preorbital extends beyond the corner of the mouth. The preorbital ends before the end of maxilla (Figure 3). The second dorsal and the anal fin of *M. liza* have no scales in the basal parts. Anal fin has 3 spines and 8 soft rays in adults; usually 2 spines and 9 soft rays in juveniles about 30 mm or less in standard length in both species.

Although the number of transverse, circumpeduncular, and longitudinal scales overlap between the two species, it is possible to distinguish *M. cephalus* captured in the Gulf of Mexico from *M. liza* (according to Menezes *et al.*, 2010) using scale counts. Figures 4 to 6 show that, in general, *M. cephalus* has a higher number of scales that *M. liza; M. cephalus* has between 12 and 15 transverse scales with a mode set at 13, while the number of these scales in *M. liza* ranges from 11 to 14. The number of scales on the circumpeduncular series of the *flathead mullet* goes from 18 to 23 with a mode at 20, while in the longitudinal series counts range from 38 to 43, with a mode of 40. In *M. liza*, scales in the circumpeduncular series range from 16 to 20 and in the longitudinal series from 32 to 39. There is almost no overlap between the number of scales in the longitudinal series of both species; only specimens of *M. liza* with 39 scales could be confused with *M. cephalus.*

TABLE 1. Morphometrics of *Mugil liza* and *Mugil cephalus*. Length expressed in mm; measurements through head length are percentage of standard length; last seven entries are percentages of head length. Data for *M. liza* were taken from Menezes *et al.* (2010).

	Mugil liza				*Mugil cephalus*			
Characters	n	Range	Mean	SD	n	Range	Mean	SD
Standard length	155	24.0–412.0	179.3		341	24.0–412.0	138.1	101.0
Body depth	132	22.0–32.5	26.0	2.8	341	18.8–27.2	25.8	3.0
Snout to dorsal-fin origin	156	70.0–79.0	74.7	1.6	341	45.8–52.2	50.9	2.0
Snout to pectoral-fin origin	156	25.3–32.7	28.2	1.9	341	20.8–44.8	29.4	2.7
Snout to pelvic-fin origin	156	35.2–45.3	40.6	2.1	341	33.3–40.0	41.7	3.0
Snout to anal-fin origin	156	69.0–74.7	72.5	1.4	341	56.1–83.3	71.2	2.8
Caudal peduncle depth	156	9.0–11.8	10.6	0.5	341	6.0–17.9	10.3	1.1
Pectoral-fin length	155	16.4–21.7	18.5	1.1	341	8.3–20.7	17.4	2.1
Pelvic-fin length	155	13.6–19.1	16.4	1.0	341	8.0–20.0	14.5	1.6
Head length	155	24.0–30.8	27.3	1.9	341	20.8–35.8	27.7	2.4
Head width	155	60.0–71.7	66.6	2.5	341	28.6–81.3	62.2	7.4
Head depth	155	60.0-70.0	64.8	2.8	Data not available			
Horizontal orbital diameter	153	16.5–26.6	22.0	1.9	341	10.3–50.0	24.7	4.1
Least interorbital width	155	20.0–25.5	22.3	1.3	341	9.2–40.0	24.7	3.7
Snout length	155	32.5–38.8	35.7	1.6	341	14.3–52.2	36.9	5.2
Upper jaw width	155	27.0–32.0	29.6	1.1	341	10.0–60.0	30.6	4.8
Mouth width	155	20.0–25.0	23.4	1.0	292	16.7–33.0	26.4	3.9

In the species identification keys of Thomson (1997) and Harrison (2003) the criterion to differentiate between *M. cephalus* and *M. liza* is the number of scales in the longitudinal series, being 34 or fewer for *M. liza* (Thomson, 1997) and greater than 34 for *M. cephalus* (Harrison, 2003). Misidentification of these two species may be due to the fact that among the mullets of the Western Atlantic, these are the largest and attain similar sizes: *M. cephalus* reaches 120 cm and *M. liza* reaches 100 cm.

The number of transverse, circumpeduncular, and longitudinal scales of *M. cephalus* from the Mediterranean coincide with specimens from the Gulf of Mexico (Menezes *et al.*, 2010). The exception is the upper limit of the range of the number of longitudinal scales, which is greater in individuals caught in the Mediterranean, reaching 38 to 46 (Figures 4 to 6).

The number of gill rakers is similar between these two mullets. Within the same length range, the number of gill rakers of *M. cephalus* varies from 50 to 90 while for *M. liza* counts fall between 53 and 81. The relationship between the number of gill rakers and standard length was linear, which differs from Menezes *et al.* (2010) because in this study small specimens of sizes between 10 and 100 mm, which have fewer gill rakers (Figure 7), were analyzed.

Harrison (2003) illustrates the presence of *M. cephalus* in the Gulf of Mexico, which is supported by data presented here; Álvarez-Lajonchere (personal communication) does not accept that its distribution range reaches the Caribbean Sea. The presence of *M. liza* in the Caribbean has been shown by Álvarez-Lajonchere (1978a; 1978b), and its presence is confirmed in the Gulf of Mexico with specimens catalogued as CNPE-IBUNAM 757 captured in the coastal waters of Veracruz, Mexico, as well as other evidence documented by Castro-Aguirre *et al.* (1999).

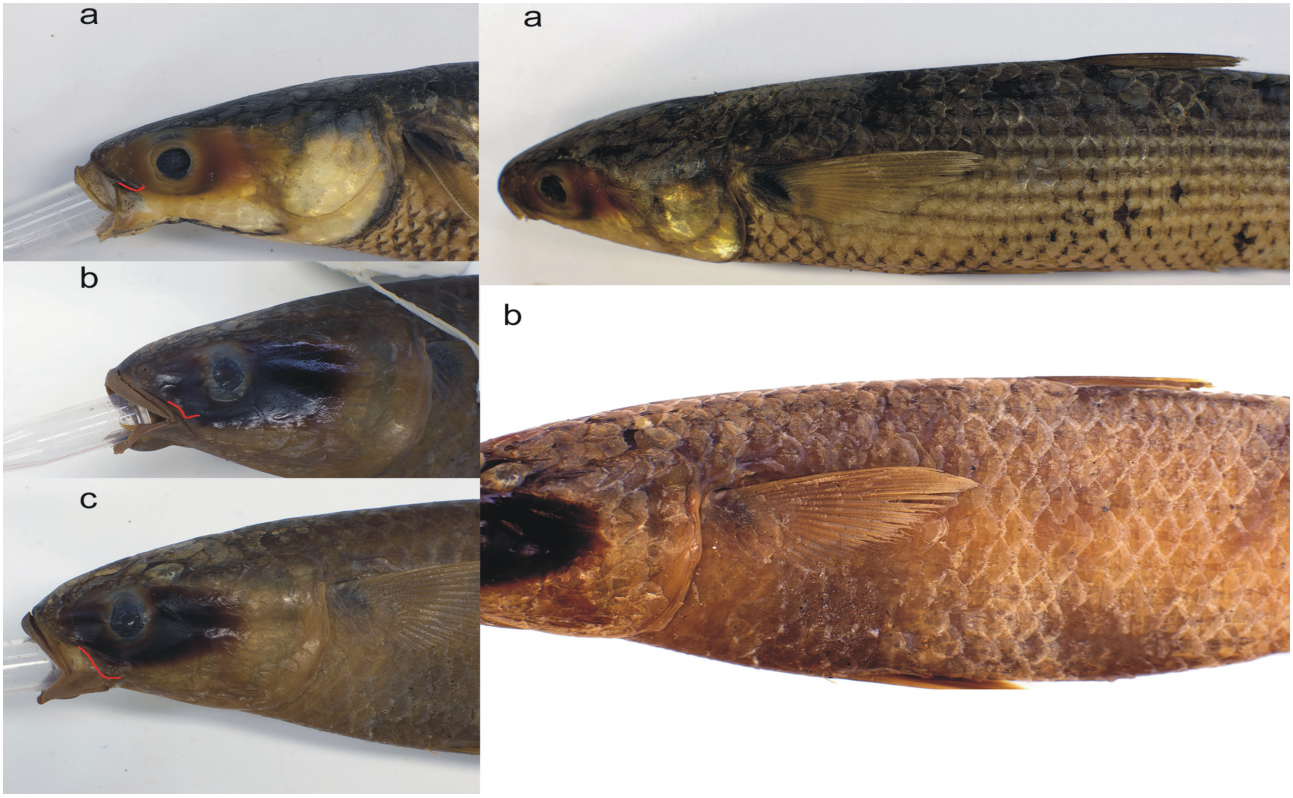

FIGURE 3. a) *Mugil cephalus* showing preorbital extending beyond corner of mouth and size of the scales. b and c) *M. liza* preorbital position and bigger size of the scales.

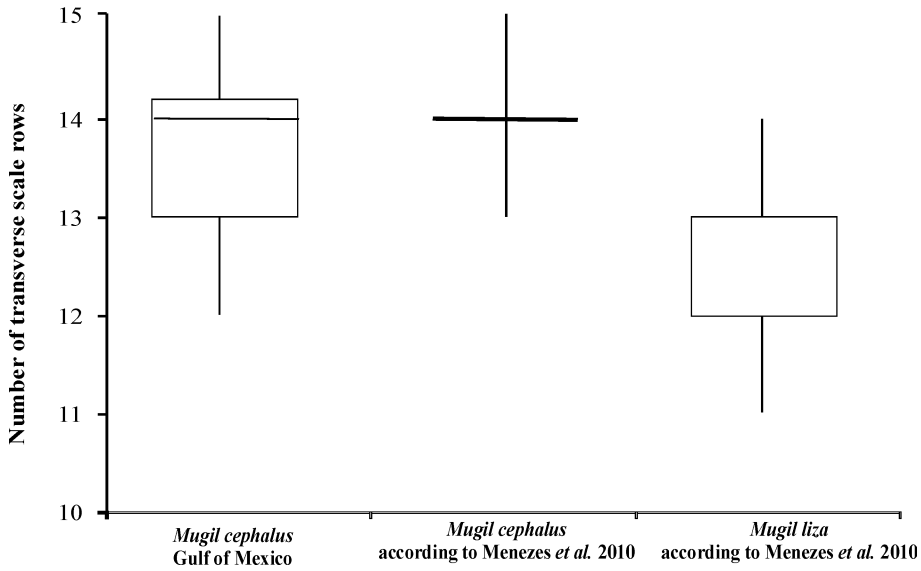

FIGURE 4. Comparative plots of number of transverse scale rows among *Mugil cephalus* from the Gulf of Mexico, *Mugil cephalus* and *Mugil liza* according to Menezes *et al.* (2010).

The meristic and morphometric measures of *M. liza* from the Gulf of Mexico are contained within the ranges showed by Menezes *et al.* (2010). No comparison of Mexican samples was included in figures and tables here since only seven specimens were reviewed in the Gulf of Mexico and this could bias the information.

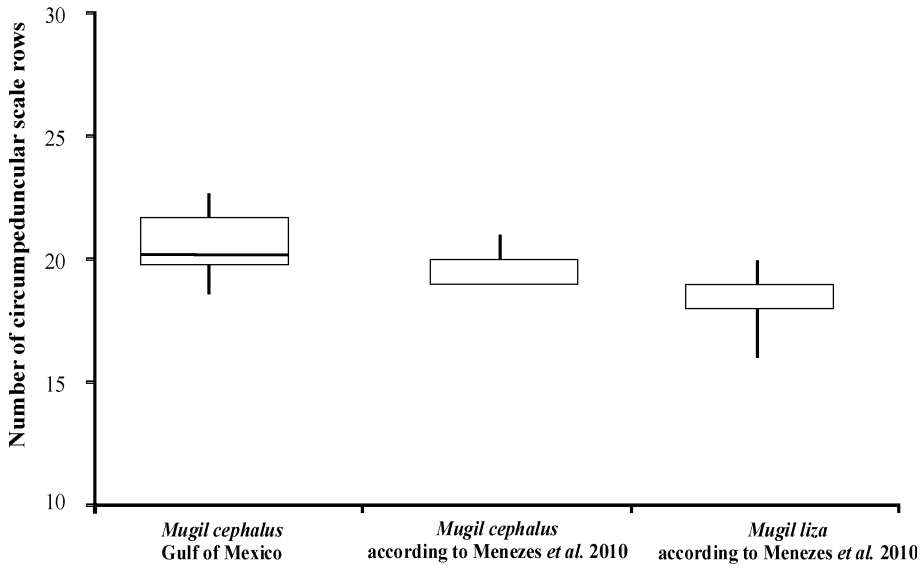

FIGURE 5. Comparative plots of number of circumpeduncular scale rows among *Mugil cephalus* from the Gulf of Mexico, *Mugil cephalus* and *Mugil liza* according to Menezes *et al.* (2010).

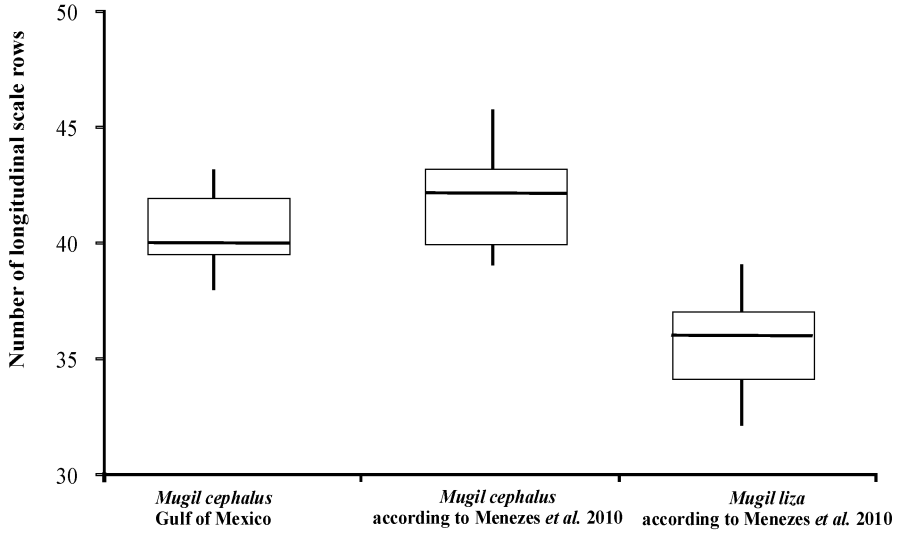

FIGURE 6. Comparative plots of number of longitudinal scale rows among *Mugil cephalus* from the Gulf of Mexico, *Mugil cephalus* and *Mugil liza* according to Menezes *et al.* (2010).

Variation in the number of scales of Mugil cephalus *in the Gulf of Mexico*

Morphometric measurements were not significantly in different individuals from different sites along the coast of the Gulf of Mexico. However, the number of scales of the transverse and longitudinal series ($p < 0.05$) was significantly different among sites. Although the median number of scales in the longitudinal series is identical in six of the seven sites, there is a pattern that emerges considering specimens obtained from sites in Florida (FL), Alabama (AL), and Mississippi (MS) and those caught in Louisiana (LA), Texas (TX), and Veracruz (VE). Differences seem to be determined geographically by the coastal areas east and west of the Mississippi River. The number of scales in the longitudinal series of specimens caught in Yucatan (YU) is different from the others (Figure 8).

The number of scales in the transverse series shows differences in individuals obtained east and west of the Mississippi River. The most frequent number of scales in the transverse series for individuals from locations in Louisiana, Mississippi, Alabama, and Florida was 13 scales, found in 62.8 to 79.2% of the specimens analyzed. In

the southern areas, such as Texas, Tamaulipas, and Veracruz, 14 transverse scales were counted in 77.2%, 91.1%, and 69.5% of analyzed specimens. In individuals from Yucatán, 13 transverse scales were counted more frequently (Table 2).

TABLE 2. Percentage frequency of transverse scale number for *Mugil cephalus* from the Gulf of Mexico. Higher values in bold.

		Transverse scale rows			
Sample zone	N	12	13	14	15
Florida, USA	164	9.1	**62.9**	25.0	3.0
Alabama, USA	24	20.8	**79.2**	0.0	0.0
Mississippi, USA	27	37.0	**63.0**	0.0	0.0
Louisiana, USA	21	19.0	**76.2**	4.8	0.0
Texas, USA	114	3.5	16.7	**77.2**	2.6
Tamaulipas, MEX	56	0.0	0.0	**91.1**	8.9
Veracruz, MEX	82	2.4	24.4	**69.5**	3.7
Yucatán, MEX	15	0.0	**80.0**	20.0	0.0

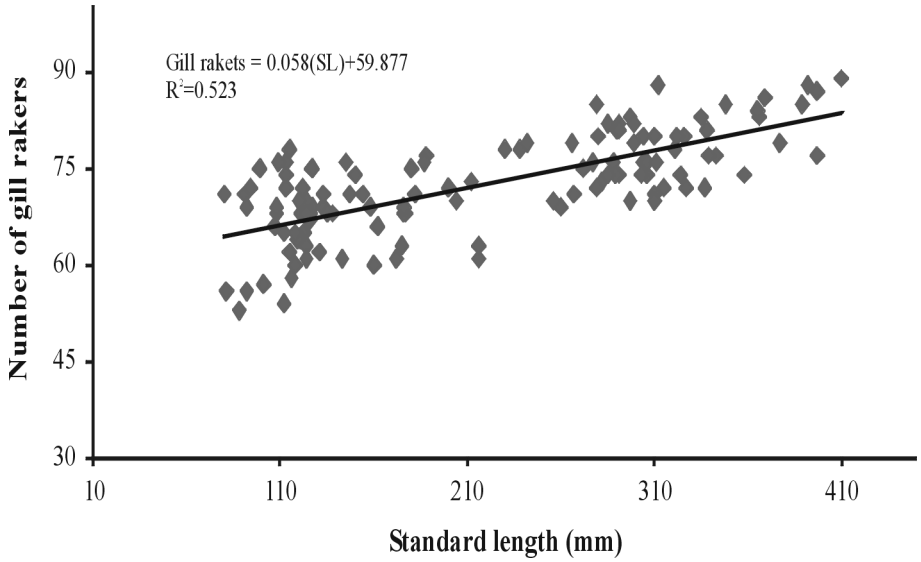

FIGURE 7. Regression of number of gill rakers *vs*. standard length for *Mugil cephalus* specimens from the Gulf of Mexico.

According to our data, a pattern of variation exists in individuals obtained east and west of the mouth of the Mississippi. Those from Yucatan have unique characteristics relative from specimens obtained in other Gulf sites particularly when considering the number of scales in the longitudinal series. A microsatellite study conducted by Colin (2014) suggests that there is a trend in the genetic differentiation that supports the hypothesis that, within the Gulf of Mexico, this species is structured with at least three subgroups: the Mississippi, the Caribbean, and the Gulf, possibly separated by the prevailing circulation pattern. Zavala-Hidalgo *et al.* (2003) noted that there is a seasonal current from Louisiana and Texas towards Tamaulipas and Veracruz, which is well established from September to March; a reverse direction is observed from May to August. Different counts in the scales both of the longitudinal and transverse series were found in individuals from these two areas.

In conclusion, morphometric and meristic results are evidence of the presence of *M. cephalus* in the Gulf of Mexico and clarify doubts on its distribution in the northwest Atlantic. The sympatric presence of *M. liza* is confirmed although its abundance seems to be low.

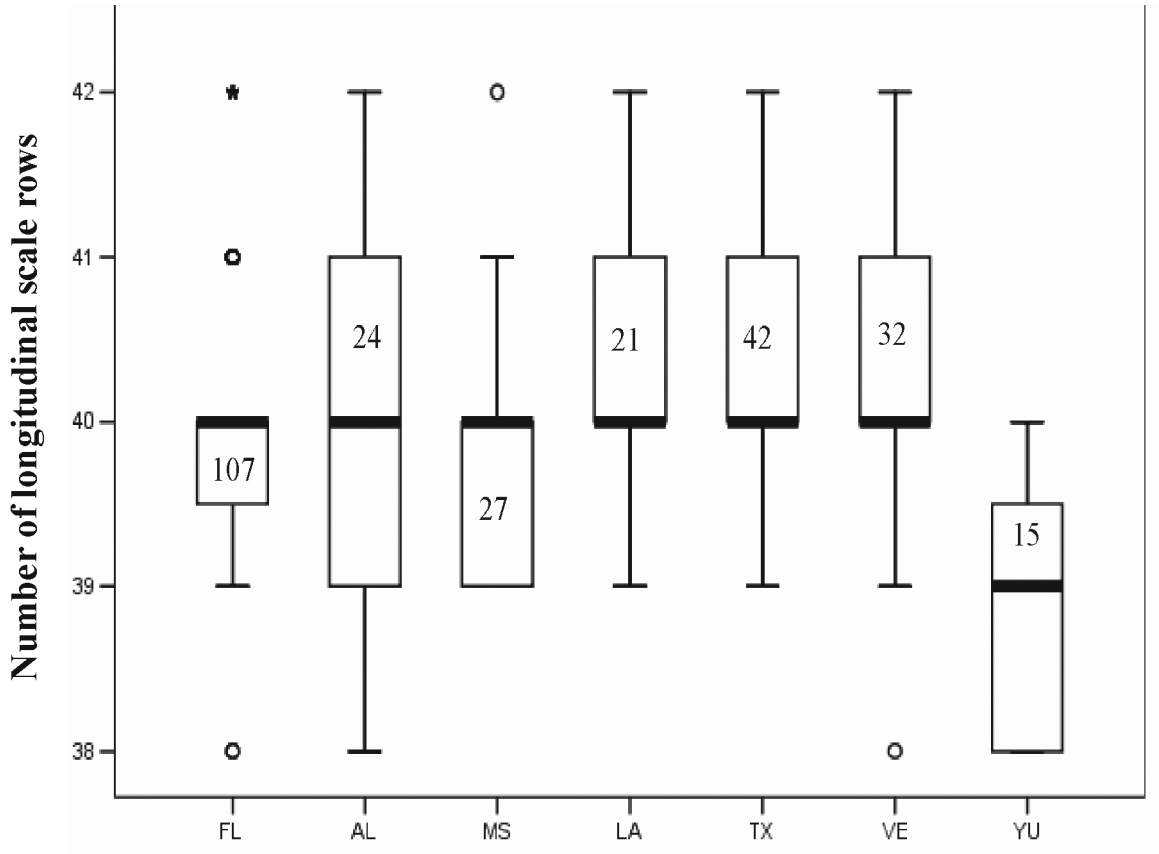

FIGURE 8. Box plot of the number of longitudinal scale rows of *Mugil cephalus* of the Gulf of Mexico. Code: Florida (FL); Alabama (AL); Mississippi (MS); Louisiana (LA); Texas (TX), Veracruz (VE); Yucatán (YU).

Acknowledgments

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