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RESEARCH PAPER

# Relationships between Sagittal Otolith Length and Fish Size for 14 *Mojarra* Species (Gerreidae: Perciformes) in Mexico

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**Abstract**

The relationships between fish length and weight and sagittal otolith length have not been studied in many families of fish that inhabit the coastal waters of Mexico, such as the Gerreidae family. Fish in this family are a valuable local fishery resource in Mexico and important prey for higher trophic level piscivores. The relationships between fish length and weight and otolith length were investigated for 14 species of Gerreidae. The relationship between fish length and otolith length was linear ($r^2 \geq 0.83$ for 12 of 14 species; 0.87 mean), while the relationship between fish weight and otolith length was exponential ($r^2 \geq 0.85$ for 11 of 14 species; 0.88 mean). Mean percent prediction errors (*mPPE*), which indicate the strength of individual bivariate relationships, were 5.6% for otolith length against fish length and 12.9% for otolith length against fish weight. Hence, predictive regression equations developed herein can be used to back-calculate the size and weight of prey from recovered otoliths. Several factors can limit the back-calculation of parameters based on otolith length; however, the present results indicate that accurate predictions are possible. Nevertheless, regression equations should not be applied to fish and otoliths beyond the size range examined.

*Keywords*: Gerreid fish, otolith morphometry, regression equations, Mexico.

## Introduction

Fish of the family Gerreidae, known as mojarras or silver biddies, live in shallow coastal waters of tropical and sub-temperate regions, preferentially in areas with sandy and muddy bottoms, and often show a sympatric distribution (De La Cruz-Agüero *et al.* 2011). In Mexico, although they are not exploited on a large scale, mojarras are a valuable resource among local fishermen as food or bait, with catches reaching approximately 1200 t per year (CONAPESCA 2012). Internationally, they are an abundant resource of commercial and industrial importance, particularly in Southeast Asia, with annual catches reaching approximately 9000 t (FAO, 2011).

Mojarras are important in the trophic web owing to their role in energy transfer between primary consumers and top piscivores. They prey on primary consumers of the benthic macrofauna (Kerschner *et al.* 1985), and in turn, they are important prey ingested by top predators (Fogarty *et al.* 1981; Cortes and Gruber 1990; Barros and Wells 1998; De Oliveira *et al.* 2002; García-Rodríguez and Aurioles-Gamboa 2003; Moreira *et al.* 2003; Reeve *et al.* 2009; Torres-Rojas *et al.* 2010).

Otoliths function in balance and hearing; they are composed of calcium carbonate and are located in the inner ears of bony fishes (Campana 2004). They are often found in the stomach contents and scat of piscivorous predators. These paired structures (*e.g.* sagittae, lapilli and asterisci) are particularly useful for determining the composition of prey owing to their interspecific variation in shape and resistance to digestion; accordingly, they are used to estimate the size and identity of prey (Battaglia *et al*., 2010; Yilmaz *et al*., 2015).

In fisheries' analyses of finfish, the saccular otoliths (*i.e.* sagittae) are the most studied because they are the largest of the three ear bones in bony fishes (Harvey *et al*. 2000; Campana 2004; Mehanna *et al.* 2016), except for those of members of Cypriniformes (minnows) and Siluriformes (catfish), in which asterisci are the largest otolith (Hecht 1977; Yilmaz *et al*. 2014; 2015).

In studies of the feeding habitats of top predators, in addition to morphological analyses of the otolith (De La Cruz-Agüero *et al*. 2012; Rivera-Félix, *et al*. 2013), it is necessary to develop specific equations to reconstruct the original size and mass of prey fish in the stomach content (Morat et al. 2008;

Yilmaz *et al*. 2014; Zengin *et al*. 2015). When the relationships between otolith length and fish length or weight are determined, the total length, standard length or weight of a fish can be estimated based on its otolith length, or vice versa (Battaglia *et al*. 2010; Yilmaz *et al*. 2014; Zengin *et al*. 2015). This reconstruction of prey fish characteristics in the stomach contents of top predators is a necessary step in understanding the feeding ecology of piscivorous animals (Yilmaz *et al*. 2014).

To the best of our knowledge, the relationships between size parameters in fish and otolith length for species of the Gerreidae family that inhabit the coast of Mexico have not been investigated, except for three species: the Irish mojarra *Diapterus auratus* Ranzani 1842, the short-nosed mojarra *D. brevirostris* (Sauvage 1879), and the yellowfin Mojarra *Gerres cinereus* (Walbaum 1792) (Rivera-Félix *et al*. 2013; Gallardo-Cabello *et al.* 2014; Espino-Barr *et al*. 2015, respectively). In contrast, these relationships have been examined in other fish families (*e.g*., Aurioles-Gamboa, 1992; Espino-Barr et al. 2013). However, in these studies, the relationship between gerreid fish and otolith sizes was not used to back-calculate the size and weight of specimens, rather it was used to investigate growth and age.

Accordingly, to assess the contribution of gerreids to the diet of marine piscivores, we determined the relationships between otolith length and fish size using regression models for 14 species of gerreids found along the coasts of Mexico. These results can be used to back-calculate the size and weight of gerreids using otoliths and thus may improve our understanding of their role as prey in trophic ecology studies.

## Materials and Methods

### Sample Collection

Fish were captured from February 2009 through November 2011 along the coast of Mexico, on the Atlantic side (including the Gulf of Mexico and the Caribbean Sea; Figure 1): 1. Off Tamaulipas State (23.883333 N – 97.483333 W); 2. La Mancha beach, Veracruz (19.6 N – 96.383333 W); 3. Términos lagoon, Campeche (18.6 N – 91.55 W), and 4. Chetumal bay, Quintana Roo (18.516667 N – 88.283333 W). Additional samples were obtained on the Pacific side (including the Gulf of California): 5. Magdalena bay, Baja California Sur (24.666667 N – 110.9 W); 6. La Paz bay, B.C.S. (24.233333 N – 110.316667 W); 7. Espíritu Santo island, B.C.S. (24.45 N – 110.366667 W); 8. Santa Rosalía harbour, B.C.S. (27.333333 N – 112.25 W); 9. Mazatlan harbour, Sinaloa (26.216667 N – 106.433333 W); 10. Off Nayarit State (21.033333 N – 105.45 W); 11. Acapulco bay, Guerrero (16.816667 N – 105.45 W), and 12. Puerto Escondido harbour, Oaxaca (15.866667 N – 97.1 W).

The species were selected based on their availability and frequency of occurrence in the commercial and artisanal fisheries. Species were identified following Castro-Aguirre *et al*. (1999) and Vergara-Solana *et al*. (2014). The specimens were captured by local fishermen and occasionally by the authors and were immediately placed on ice until their lengths and weights were recorded. For each specimen, standard length (SL, to the nearest 0.1 mm) and total weight (Wt, to the nearest 0.1 g) were recorded, and the sagittal otoliths were removed. Fish specimens and bone material are catalogued in the fish collection of CICIMAR-IPN in La Paz, Baja California Sur, Mexico and are available upon request (http://coleccion.cicimar.ipn.mx).

### Otolith Extraction, Measurement and Image Analysis

Otoliths were removed, cleaned and photographed in the laboratory, and no preservative was used before extraction. We excluded otoliths that were damaged or broken during removal and those that were considered statistical outliers (see below). Digital images of each pair of otoliths were recorded with a stereomicroscope (model SZ61, Olympus) with a digital camera (SP-320, Olympus), 3× optical zoom and a transmitted light source (SZ2-LGBST, Olympus) to highlight the edges of the structures. Otoliths were photographed on their concave inner side (*i.e.* they were positioned systematically with the sulcus acusticus facing up and the rostrum pointing to the right), and images were obtained as bright objects on a dark background (De La Cruz-Agüero *et al*. 2012).

The otolith length (OL) was estimated as the maximum linear distance from the rostrum to the postrostrum (Figure 2). Length measurements were made on the otolith images using ImageJ 1.49a (http://imagej.nih.gov/ij/index.html), with an accuracy of 0.01 mm.

### Data Analysis

All data were checked for outliers using the three-sigma rule (for which $P<0.05$) (Pukelsheim 1994), homogeneity of variances (according to Zuur *et al*. 2010), and for normality using the Lilliefors test. Differences between the lengths of the left and right otoliths for each species were tested using paired Student’s *t*-tests. The relationships between fish length and weight and otolith length for the 14 species were calculated using least squares regression equations to predict the standard length and weight of the original fish from otolith lengths (*e.g.* Longenecker 2008). Linear regressions were fitted to the data to describe the relationships between otolith length and fish standard length ($SL = a + b \times OL$) and non-linear (exponential) regressions were fitted to determine the relationships between otolith length and

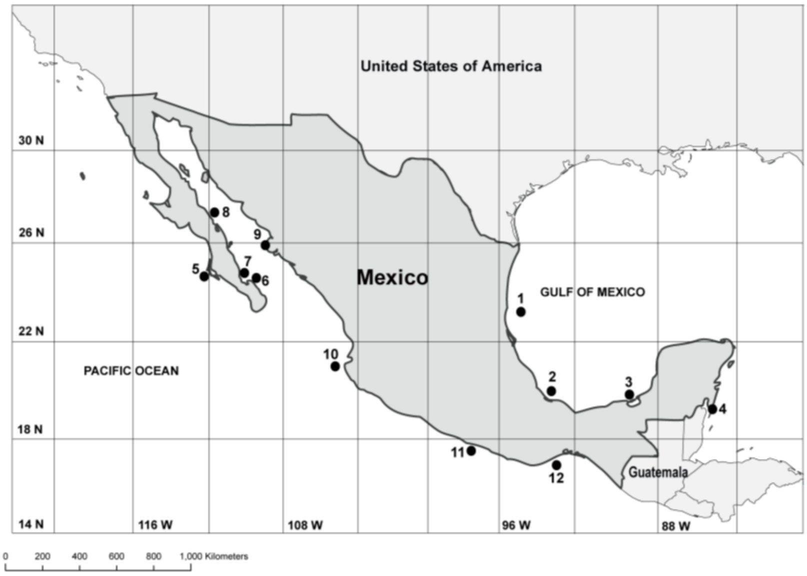


**Figure 1.** Locations (black dots) of Gerreidae species along the Mexican coasts for analysis of otolith sagittae length and fish size. See the coordinates and denomination of the sites in text.

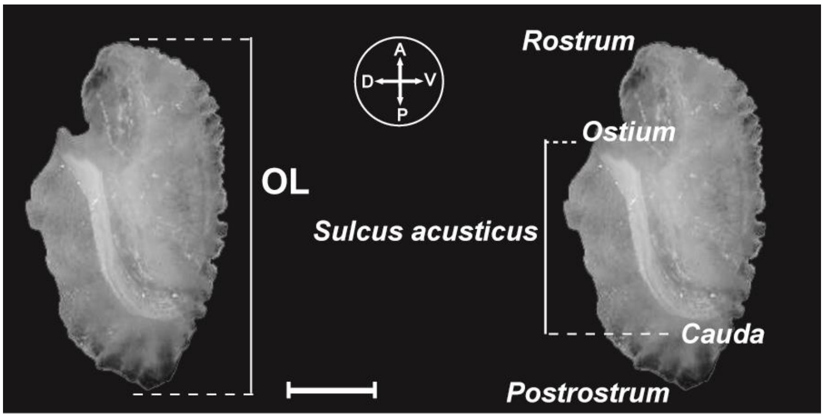


**Figure. 2**. Lateral view of sagittal otolith (left otolith, inner side) showing measurement and terminology (exemplified in *Deckertichthys aureolus*). The sulcus acusticus is facing the observer and the rostrum pointing upwards. Circles and crosses indicate the margins and orientation of the otoliths in the body plan: D = dorsal; V = ventral; A = anterior; P= posterior. OL = otolith length. Scale bar = 1 mm.

fish weight ($Wt = a \times OL^b$), where the term "*a*" is the intercept of the regression curves and "*b*" is the regression coefficient (slope). The second model is a traditional allometric equation, where the weight of a fish is approximately equal to its length elevated to the third power (Harvey *et al*. 2000).

The slopes of the regression equations were assessed by Student's *t*-tests. When the slope of the regression line was significantly different from zero, we concluded that there was a significant relationship between the independent and dependent variables (Rivera-Felix *et al*. 2013). We used the Durbin–Watson statistic to assess the null hypothesis that the residuals from the least-square regressions are not auto-correlated at $P < 0.01$ (Kutner *et al*. 2004). We also calculated confidence limits (95%) and the standard error for the regression line of model parameters (Zar 2010).

To further assess the strength of individual bivariate relationships and to demonstrate the applicability of the regression models, mean percent prediction errors (*mPPE*) were determined for each regression (Smith 1980) by averaging the *mPPE* calculated for each observation as follows:

$mPPE = [(\text{observed} - \text{predicted}) / \text{predicted}] \times 100$.

All statistical analyses were performed with the MS Excel© plug–in Winstat 2009.1. Statistical significance was set at $P<0.05$ for all tests.

## Results

A total of 1254 otoliths of 627 individuals representing 14 species ranging from 17 to 293 mm in standard length and from 0.90 to 330 g were used in the analysis (Table 1). The otolith lengths ranged from 2.01 mm, observed in *D.rhombeus* (Cuvier 1829), to 8.37 mm in *E. lineatus* (Humboldt 1821) (Table 2), or 3.6–5.4% of the fish standard length. The general fish and otolith size parameters for each species are shown in Table 1 and Table 2, respectively.

Among all samples, eight outliers were detected for otolith and fish measurements according to the

**Table 1.** Minimum, maximum, mean and standard deviation values of length and the total weight of Gerreidae fish caught along the Pacific and Atlantic coasts of Mexico. n = sample number; SD = standard deviation; SL = standard length (mm); Wt = total weight (g); B = Basin: P = Pacific; A = Atlantic. Species listed according to nomenclature and common names in Froese and Pauly (2016) and Vergara-Solana *et al*. (2014). *See text for these species

| Species | Common names | B | n | SL | | Wt | |
|---|---|---|---|---|---|---|---|
| | | | | Min-Max | Mean±SD | Min-Max | Mean±SD |
| *Deckertichthys aureolus* (Jordan et Gilbert, 1882) | Golden mojarra | P | 51 | 62-121<br>121 | 84.6±16.6<br>16.6 | 7.3-21.2<br>21.2 | 12.8±2.9<br>2.9 |
| *Diapterus auratus* (Ranzani, 1842) | Irish mojarra | A | 33 | 85-119<br>119 | 104.8±8.7<br>8.7 | 17.9-47.7<br>47.7 | 32.8±7.6<br>7.6 |
| *D. brevirostris* (Sauvage, 1879) | Short-nosed mojarra | P | 44 | 93-150<br>150 | 124.7±17.8<br>17.8 | 22.1-124.<br>124.7 | 62.1±29.1<br>29.1 |
| *D. rhombeus* (Cuvier, 1829) | Rhombic mojarra | A | 76 | 33-101<br>101 | 78.1±21.1<br>21.1 | 0.9-34.4<br>34.4 | 19.4±10.2<br>10.2 |
| *Eucinostomus argenteus* (Baird et Girard, 1855) | Silver mojarra | A | 33 | 52-100<br>100 | 76.3±14.3<br>14.3 | 2.8-24.7<br>24.7 | 11.8±7.1<br>7.1 |
| *E. currani* (Zahuranec, 1980) | Pacific flagfin mojarra | P | 28 | 67-106<br>106 | 87.5±11.3<br>11.3 | 6.9-28.2<br>28.2 | 15.6±7.3<br>7.3 |
| *E. dowii* (Gill, 1863) | Dow's mojarra | P | 66 | 84-114<br>114 | 94.8±7.6<br>7.6 | 14.8-40.4<br>40.4 | 22.3±6.4<br>6.4 |
| *E. entomelas* (Zahuranec, 1980) | Dark-spot mojarra | P | 56 | 80-194<br>194 | 154.4±31.3<br>31.3 | 13.8-151.<br>151.6 | 88.9±38.5<br>38.5 |
| *E. gula* (Quoy et Gaimard, 1824) | Jenny mojarra | A | 62 | 40-108<br>108 | 84.7±17.9<br>17.9 | 1.4-37.2<br>37.2 | 19.1±8.9<br>8.9 |
| *E. melanopterus* (Bleeker, 1863) | Atlantic flagfin mojarra | A | 45 | 40-110<br>110 | 81.9±19.8<br>19.8 | 1.5-35.5<br>35.5 | 15.2±8.7<br>8.7 |
| *Eugerres lineatus* (Humboldt, 1821) | Streaked mojarra | P | 37 | 52-200<br>200 | 143.2±45.2<br>45.2 | 61-280<br>280 | 173.4±58.7<br>58.7 |
| *E. plumieri* (Cuvier, 1830) | Striped mojarra | A | 29 | 79-216<br>216 | 142.5±42.5<br>42.5 | 15-200<br>200 | 110.8±66.6<br>66.6 |
| *Gerres cinereus* (Walbaum, 1792)* | Yellowfin mojarra | P | 45 | 17-293<br>293 | 169.4±63.3<br>63.3 | 100-330<br>330 | 190.1±40.5<br>40.5 |
| *G. cinereus* (Walbaum, 1792)* | Yellowfin mojarra | A | 22 | 125-195<br>195 | 155.9±17.1<br>17.1 | 63-182<br>182 | 131.8±46.1<br>46.1 |

**Table 2.** Minimum, maximum, mean and standard deviation values of otolith length (OL, in mm) of Gerreidae fish caught in Mexican Pacific and Atlantic coasts. Statistical tests (*t*-tests) between left (L) and right (R) sagitta per species. (*t* / *P*; not significant differences at P>0.05 in all values); n (samples including both otoliths); SD (standard deviation). *See text for these species

| Species | L-R<br>n | L-R<br>*t*/*P* | OL (mm) | |
|---|---|---|---|---|
| | | | Min-Max | Mean±SD |
| *Deckertichthys aureolus* | 102 | 1.06 / 0.145 | 3.43-4.90 | 4.04±0.35 |
| *Diapterus auratus* | 66 | 1.13 / 0.131 | 4.54-6.60 | 5.62±0.52 |
| *D. brevirostris* | 88 | 1.06 / 0.146 | 4.04-6.78 | 5.61±0.75 |
| *D. rhombeus* | 152 | 1.0 / 0.159 | 2.01-5.36 | 4.33±1.10 |
| *Eucinostomus argenteus* | 66 | 1.06 / 0.146 | 2.54-4.60 | 3.47±0.63 |
| *E. currani* | 56 | .04 / 0.145 | 2.72-4.15 | 3.48±0.44 |
| *E. dowii* | 132 | 1.06 / 0.145 | 3.66-4.82 | 3.99±0.29 |
| *E. entomelas* | 112 | 1.11 / 0.134 | 3.77-7.17 | 5.93±0.98 |
| *E. gula* | 124 | 1.01 / 0.157 | 2.27-4.92 | 3.97±0.66 |
| *E. melanopterus* | 90 | 1.08 / 0.141 | 2.15-4.51 | 3.56±0.65 |
| *Eugerres lineatus* | 74 | 1.02 / 0.155 | 3.13-8.37 | 6.50±1.40 |
| *E. plumieri* | 58 | 1.03 / 0.153 | 3.71-8.31 | 6.20±1.50 |
| *Gerres cinereus* (Pac.)* | 90 | 1.05 / 0.148 | 3.53-7.89 | 6.19±0.96 |
| *G. cinereus* (Atl.)* | 44 | 1.31 / 0.09 | 5.33-7.02 | 6.29±0.55 |

established criterion based on standard deviations [for the eight cases in six species, the n-sigma values ranged from 3.15 (P<0.04) to 4.09 (P<0.0002)]. Homogeneity of variances was assessed by residual analyses of the regression equations, and most of the data were within the 95% confidence intervals; therefore, we assume that variation in length and weight were similar (Zuur *et al*. 2010). In a comparison between the left and right sagittal otoliths, there were no significant differences for all species (*t*-tests, P>0.05) (Table 2). Thus, the left otoliths were used in all subsequent analyses, and they were replaced with the right otolith if the latter was in better condition.

The assumption of normality was met for the otolith length distribution for all species (P>0.05), except *D. rhombeus*, *Eucinostomus gula* (Quoy and Gaimard 1824), and *E. melanopterus* (Bleeker 1863). However, these three species were included in the analysis because the linear regression is reasonably robust against violations of the assumption of normality (Zar, 2010). There was a positive linear relationship between otolith length and fish length for all 14 species. Regression equations relating otolith length to standard length were highly significant (ANOVA, P<0.0001), and all had positive slopes that differed significantly from zero (*t*-tests, P<0.0001). The Durbin–Watson test showed that in all cases, except for *E. lineatus*, the residuals were not auto-correlated (Table 3).

The coefficients of determination ($r^2$) for otolith length versus fish standard length ranged from 0.83 to 0.98 for 12 out 14 species (0.87 on average; see Table 3). Mean percent prediction errors (*mPPE*) reached an average value of 5.6%; the least accurate prediction was observed for *G. cinereus* (Pacific basin) with an *mPPE* value of 13.2%, and the highest predictive power of fish length was observed for *D. auratus* with an *mPPE* of 2.03% (Table 3). The standard error about the regression line ranged from 0.33 in *D. rhombeus* to 4.41 in *G. cinereus* (Atlantic basin) ($P$ < 0.0001), confirming the predictive power of the equations.

Regressions relating otolith length to fish weight were also highly significant ($P$ < 0.0001). The $r^2$ values ranged from 0.85 to 0.99 for 11 out 14 species (0.88 on average; see Table 3). Mean percent prediction errors (*mPPE*) reached an average value of 12.9%; the least accurate prediction was observed for *E. plumieri* (Cuvier 1830) with an *mPPE* value of 25.5%, and the highest predictive power of fish weight was observed for *Deckertichthys aureolus* (Jordan and Gilbert 1882), with an *mPPE* of 7.9% (Table 3). The standard error about the regression line ranged from 0.12 in *E. lineatus* to 0.42 in *G. cinereus* (Atlantic basin) ($P$ < 0.0001), which also confirmed the predictive power of the equations.

Comparatively, the results of the mean percent prediction errors for the regression equations indicated that fish length estimates were more precise (ranging 2.03%–13.2%) than estimates for fish weight (7.9%–25.5%). The relationships between gerreid fish length and weight and otolith length are summarized in Table 3.

## Discussion

As far as we are aware, this is the first application of the relationship between sagittae length and fish size to back-calculate the length and weight of eleven gerreid species along the Mexican coast. We found strong relationships between otolith length and

**Table 3**. Regression statistics for linear and non-linear functions relating measurements (mm) of sagittae length (OL) to standard length (SL) and total weight (Wt) for Gerreidae fish caught in Mexican Pacific and Atlantic coasts. *a* and *b*, parameters of the regressions; 95% CI, confidence limits of *b*; $r^2$, coefficient of determination; SE *b*, standard errors of *b* ($P$ < 0.05); *mPPE*%, mean percent prediction errors; D–W, the Durbin–Watson test statistic (P<0.01); *values autocorrelated. **See text for these species.

| Species | SL = *a* + *b*×OL | | | | | (95%) CI | D-W | Wt = *a*×OL$^b$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *a* | *b* | SE *b* | $r^2$ | *mPPE*% | | | *a* | *b* | SE *b* | $r^2$ | *mPPE* % |
| *Deckertichthys aureolus* | 77.49 | 40.11 | 3.39 | 0.74 | 7.9 | 33.3–46.9 | 1.82 | 95.22 | 2.23 | 0.17 | 0.76 | 7.9 |
| *Diapterus auratus* | 15.94 | 15.81 | 0.94 | 0.90 | 2.03 | 13.9–17.7 | 1.77 | 110.7 | 2.15 | 0.28 | 0.67 | 10.5 |
| *D. brevirostris* | -2.52 | 22.68 | 1.11 | 0.91 | 3.4 | 20.4–24.9 | 2.10 | 418.1 | 3.44 | 0.23 | 0.92 | 11.6 |
| *D. rhombeus* | -3.34 | 18.79 | 0.33 | 0.98 | 3.01 | 18.1–19.4 | 2.12 | 356.8 | 3.77 | 0.22 | 0.99 | 15.9 |
| *Eucinostomus argenteus* | 1.22 | 21.68 | 1.11 | 0.92 | 4.3 | 19.4–23.9 | 2.38 | 356.5 | 3.32 | 0.16 | 0.94 | 13.5 |
| *E. currani* | 1.30 | 24.76 | 1.50 | 0.91 | 3.4 | 21.6–27.8 | 2.30 | 920.2 | 3.95 | 0.26 | 0.91 | 12.3 |
| *E. dowii* | 1.68 | 23.32 | 1.30 | 0.83 | 2.8 | 20.7–25.9 | 1.87 | 452.1 | 3.30 | 0.14 | 0.85 | 8.6 |
| *E. entomelas* | -24.04 | 30.07 | 1.48 | 0.88 | 6.1 | 27.1–33.1 | 1.68 | 431 | 3.20 | 0.25 | 0.87 | 19.3 |
| *E. gula* | -20.27 | 26.41 | 0.76 | 0.95 | 3.7 | 24.8–27.9 | 2.14 | 1144 | 4.6 | 0.21 | 0.96 | 16.1 |
| *E. melanopterus* | -24.27 | 29.82 | 0.87 | 0.96 | 3.7 | 28.1–31.6 | 2.13 | 1132 | 4.37 | 0.28 | 0.97 | 11.8 |
| *Eugerres lineatus* | -43.39 | 28.68 | 2.03 | 0.85 | 11.6 | 24.5–32.8 | 0.96* | 322.6 | 1.5 | 0.12 | 0.96 | 8.5 |
| *E. plumieri* | -17.23 | 25.74 | 2.23 | 0.83 | 8.1 | 21.1–30.3 | 1.67 | 459.9 | 3.42 | 0.33 | 0.94 | 25.5 |
| *Gerres cinereus* (Pac.)** | -191.2 | 57.55 | 3.64 | 0.85 | 13.2 | 50.2–64.8 | 1.32 | 319.1 | 1.1 | 0.13 | 0.74 | 8.6 |
| *G. cinereus* (Atl.)** | 5.82 | 23.84 | 4.41 | 0.60 | 5.2 | 14.6–33.1 | 1.96 | 879.3 | 4.21 | 0.42 | 0.90 | 10.5 |

fish size in the 14 neotropical Gerreidae species. The differences in length between the left and right sagittae were not significant, consistent with previous results (*i.e.* Škeljo and Ferri 2012; Rivera-Felix *et al*. 2013).

The high coefficients of determination ($r^2$>0.85, on average) for both regression equation models, the low standard errors of the regression coefficients, and the low mean percent prediction errors indicated very strong bivariate relationships, and accordingly, the equations derived in this study are highly applicable for size predictions (Table 3). Therefore, the application of the regression equations to predict the body length and weight of selected Gerreidae species based on otolith length appears to be statistically appropriate (*i.e.* the length variable is a good indicator of original fish length and weight).

For the yellowfin mojarra *G.cinereus*, the regression equations, and descriptions are separated by ocean basin because there is molecular and morphometric evidence for two distinct species (F.J. García-Rodríguez, pers. comm.[1]).

Similar studies have examined the relationship between gerreid fish weight and sagittal length. For example, Rivera-Félix *et al*. (2013) found a positive allometric relationship between otolith length and fish weight for the Irish mojarra *D.auratus*, in contrast to the negative allometric relationship observed in the present study. However, in the previous study, the linear relationship between fish length and the length of otoliths was not evaluated, but their approach considered the otolith length a depended variable (Rivera-Felix et al. 2013: Figure 2A, 2B, 2C, 2D, 2E). Gallardo-Cabello et al. (2014) and Espino-Barr et al. (2015) used the relationship between fish length and otolith length in the short-nosed mojarra *D. brevirostris* and the yellowfin mojarra *G. cinereus* to determine the age and growth, respectively. However, their data on length–length relationships are not comparable with the results of the present work because the otoliths were estimated in mm and fish length in cm.

The results of this study will be helpful for future ecological studies aimed at determining the prey size and biomass of gerreid fish based on the length of recovered otoliths in the stomach contents of piscivorous predators. Although these regression models may be used to study the feeding habits of piscivores, food-web interactions, and diet analyses inter alia, it is necessary to consider the limitations of this technique when estimating the original body size and weight of gerreid fish from recovered otolith lengths (*e.g.* the results may be influenced by abrasions in the digestive tract of predators, age, ontogenic stage, growth rate, or gender (Jobling and Breiby 1986)). Consequently, the lengths and weights of fish calculated from digested otoliths will markedly underestimate the original prey size (Škeljo and Ferri 2012).

Moreover, the nature of the sampling in the present study (*i.e.* the variation in the number of specimens and species length ranges among localities) did not allow comparisons of model regressions for any sizes, areas, and seasons among the gerreid species. Because these factors were not taken into account, the regression equations should not be applied to fish and otoliths outside of the size ranges used in this study, and they should be applied with caution to otolith samples from other geographic areas.

Although the effects of preservatives on otolith size need to be considered when gut contents are stored in a chemical stabilizer (Hansel *et al*. 1988), this was not considered for samples obtained in the present study because we did not use preservatives. Instead, measurements were obtained immediately after the removal of the otolith from fresh or thawed specimens.

Knowledge of individual lengths and weights of prey items in the gut contents of piscivorous is of great importance not only to estimate ingested biomass but also to establish the average prey size (Gosztonyi *et al*. 2007). However, accurate diet analyses require the identification and quantification of intact prey items as well as prey items that are partially or almost completely digested.

In this regard, the present study enhances our knowledge of otolith length with respect to fish length and weight. Otoliths can be used to identify fish to the genus and species levels in the gerreids (De La Cruz-Agüero *et al*. 2012); accordingly, the otoliths found in piscivorous gastric contents and scat could be used to improve the assessment of the diet of marine piscivores. We found that prediction of the length and weight of Gerreidae species based on sagittal length may be performed with an acceptable prediction error. Additionally, these models in combination with published length/mass relationships for mojarras (De La Cruz-Agüero *et al*. 2011) can be used to estimate both the length and mass of ingested gerreids. Furthermore, these data improve our understanding of the potential role of gerreid fish in the trophic ecology of piscivorous species in the coastal areas of Mexico.

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