

Morphology and morphometric relationships of the sagitta of *Diapterus auratus* (Perciformes: Gerreidae) from Veracruz, Mexico

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Abstract: *Sagittae* otoliths are the most studied because of their morphological variability and size; the *sagittae* may also have valuable taxonomic use and for *D. auratus* has not yet been described. In the present study we present a morphological description of the *sagitta* otolith and an analysis of its correlation with various morphometric parameters. The biological material was captured with a beach seine in the coasts of Alvarado and Port of Veracruz, from November 2009 to June 2010. *Sagittae* were extracted, cleaned, photographed (SEM and optical), and measured. The analysis included the correlations between *sagitta*'s length and width, versus the fish standard length, height and weight, for a total of 449 fishes. The comparison between left and right *sagitta* showed no significant difference in both otolith length and width (t-tests, $p < 0.05$) for each sex. The right otolith was used for the correlations for both males and females and the Fisher test (d.f. 161 and 143, $p < 0.001$) showed no significant differences in the slopes and intersections between them. The otolith length vs. fish weight correlation showed a positive allometric growth in males ($b = 3.9754$, $p < 0.05$) and females ($b = 4.3168$, $p < 0.05$). Rev. Biol. Trop. 61 (1): 139-147. Epub 2013 March 01.

Key words: otolith, sagitta, morphometry, correlations, Veracruz, Gerreidae, *Diapterus auratus*, mojarra guacha, Irish Pompano.

Teleost fish have three pairs of otoliths located in the membranous labyrinth (Smale *et al.* 1995) at the rear of the neurocranium (Morales-Nin 2000). The labyrinth includes three semicircular canals and three compartments: sacculus, utriculus and lagena; each sac contains one otolith, the *lapillus*, the *sagitta* and the *asteriscus*, respectively (Morales-Nin 2000, Berra & Aday 2004, Popper *et al.* 2005). Otoliths are calcareous concretions in the form of aragonite (Jawad 2007, Parmentier *et al.* 2007), their taxonomic utility was recognized by Cuvier and their value in paleontology was first acknowledged by Koken (1884) (Tuset

et al. 2008). In most teleost, the *sagitta* is the largest otolith and the *lapillus* is the smallest among the three (Paxton 2000). *Sagittae* also exhibit variable morphology and topography among the species (Torres *et al.* 2000, Jawad 2007, Battaglia *et al.* 2010). As a result, their use as a taxonomic character has proliferated in recent years.

Because of their chemical composition, they can withstand some degree of dissolution and often species can be recognized by distinctive morphology of the *sagitta* (Longenecker 2008, Tombari *et al.* 2010). Moreover, the resistance of otolith to deterioration made it

possible to use them in paleontological studies (Girone *et al.* 2006, Battaglia *et al.* 2010) or in the identification of prey in stomach contents of fishes, birds or mammals (Silva *et al.* 2000, Palma *et al.* 2002, Polo & Grijalba 2008, Biffi & Iannacone 2010). Also, oceanographers have determined species of fishes from otoliths in sediments (Battaglia *et al.* 2010). The first's researchers that demonstrated a positive relationship between otolith length and fish length were Trout (1954) and Templemann & Squires (1956). Also, studies of relationships between otolith length and fish weight have been done (Waessle *et al.* 2003, Baker 2006, Longenecker 2008).

One of the characteristic groups of fishes of coastal zones in the Gulf of Mexico and in the South Atlantic of the American continent belongs to the Family Gerreidae. These organisms can be found in both estuaries and coastal lagoons; generally, juveniles occur in estuaries and adults in the coastal zones (Abarca *et al.* 2004, Abarca *et al.* 2007). The morphologic characteristic that distinguish the members of this family is the extremely protusible jaws. A member of this family is *Diapterus auratus*, the Irish Pompano or Mojarra Guacha. In Mexico, this species, is one of the most abundant species of the Southern part of the Gulf of Mexico and is an important part of the commercial fisheries (Castillo-Rivera *et al.* 2005). However, in spite of their abundance, studies of their biology and anatomy are scarce (Kobelkowsky 2004). Therefore, the aim of this study was to obtain data of the correlations of otolith size (length and width) with the fish length, height and total weight, and a description of the otolith morphology of *Diapterus auratus*.

MATERIALS AND METHODS

The biological material was captured every month with a beach seine in the coasts of Anton-Lizardo (19°03'47.40" N - 95°59'30.23" W), Alvarado (18°46'3.5" N - 95°45'47.2" W), and Port of Veracruz (19°11'47.55" N - 96°07'43.40" W), from November 2009-June 2010. The taxonomic identification was based

on Carpenter 2002. The fishes were measured (standard length ST, cephalic length CL and fish height FH) with a caliper with ± 0.1 mm precision, weighted, with a semi-analytic balance with ± 0.001 g precision and photographed.

Sagittae were removed, cleaned and photographed (SEM and optical). Otoliths were examined and described using the terminology of Tuset *et al.* 2008. The length, greatest distance measured from the anterior tip to the posterior edge parallel to the sulcus and width, the greatest distance from the dorsal otolith edge to the ventral one, perpendicular to the sulcus, of each *sagitta* were measured (Harvey *et al.* 2000) with the software DIGIMIZER 3.7 program. The otoliths were deposited at the Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México (UNAM).

The nule hypothesis was that no difference existed between left and right sagitta and it was tested with a paired *t*-test (Echeverria 1987, Volpedo & Thompson 1996). Linear regressions were obtained for each sex to investigate possible sexual differences. The relationships between otolith and fish sizes were determined using a least-squares linear regression for the following parameters: otolith length (OL) vs fish height (FH), otolith length (OL) vs cephalic length (CL), otolith length (OL) vs standard length (SL), and otolith width (OW) vs fish height (FH) (Echeverria 1987, Gamboa 1991, Harvey *et al.* 2000, Jawad 2007, Battaglia *et al.* 2010). Also the relationships between otolith length (OL) and fish weight (FW) were determined using a least-squares regression of the log of otolith length and weight (Volpedo & Thompson 1996, Waessle *et al.* 2003) for each sex (males and females) by using Le Cren equation (Le Cren 1951, Bagenal & Tesch 1978), that is mathematically expressed as a potential function of the weight (g), versus otolith length (mm), according the equation ($W=a L^b$).

The species growth types were determined by means of the *t*-Student test, considering the constant b value or allometry coefficient (Yañez 1986), in order to verify if growth type

matched the isometric type ($b=3$, $p<0.05$), the following equation was used $t=(b-3)/Sb$ (Sokal & Rolf 1996), where $t=t$ -student value, b =slope, Sb =slope standard error.

A Fisher test was applied F (d.f. 161 and 143, $p<0.001$), for comparing the slopes of the estimated relations for males and females of *D. auratus* (Sokal & Rolf 1996).

RESULTS

Otolith morphology: The sagitta of *D. auratus* is ovate; the posterior margin is rounded in contrast with the anterior margin that is angled. The dorsal margin is irregular, the ventral margin is sinuated. The sulcus acusticus is heterosulcoid, ostial and has a suprmedian position; it is divided into an anterior ostium and posterior cauda by a constriction (the colum). The ostium is funnel-like, it has a cistura; the rostrum is broad and the antirostrum is small and angled. The cauda is tubular; the posterior part has slightly curved part. The crista superior in the anterior part is well developed. There is a broad dorsal depression (Fig. 1).

The sample size was 449 fishes and comprised 144 females with range of 29-191mm, and 305 males with range of 28-180mm SL. The analysis of the morphometric parameters showed no significant differences between the right and left *sagittae* in both females ($t=-0.259$, $p<0.05$) and males ($t=0.442$, $p<0.05$). Therefore

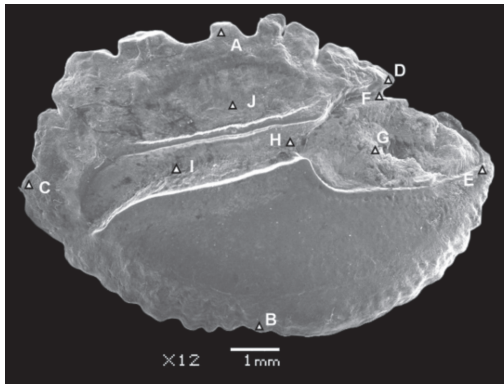


Fig. 1. SEM photography of the inner face of the left *sagitta* of *Diapterus auratus*.

the right otolith was used in the regression analysis. For the OL-SL relation (Fig. 2C and 3C) the best fit was recorded for males ($r^2=0.660$) while the lowest value of the coefficient of correlation was for the females ($r^2=0.644$). The regression analysis of the OL-FH, for each sex is shown in figure 2 (A) and 3 (A); the student t -test did not found significant differences between this relation in males and females. The OL-W relationship shown in figure 2 (E) and 3 (E), recorded the highest values of the coefficient of correlation with $r^2=0.986$ for males and $r^2=0.822$ for females. In all the cases, the models of regression used for describing the relation between otoliths and the parameters of the different measures of the fishes were appropriate, reflected on the high coefficients of correlation that oscillated between 0.71-0.98 marking a significant correlation for the slopes and intersection. The equations and coefficient of correlation obtained by the linear regression of the different measures of the otolith and the standard length and weight of *D. auratus* are shown in figure 2.

In terms of growth type, *D. auratus* shows a positive allometric growth of otolith length relative to fish weight in both males and females since the coefficient b , differed significantly from the theoretical value of 3. The coefficients of determination (R^2) were similar.

The regression slopes for the measures of the *sagitta* in males and females showed no significant differences between sexes when comparing them with the fisher test ($F_{(161, 143, p<0.001)}$) (Table 1).

TABLE 1
Slope comparison (Fisher test) of males and females of the different regressions of *D. auratus*

Relation	F calc	F teo _(161, 143, p<0.001)
OL-W	1.163433884	n.s.
OL-SL	0.98960953	n.s.
OL-CL	0.968476642	n.s.
OL-FH	0.989393786	n.s.

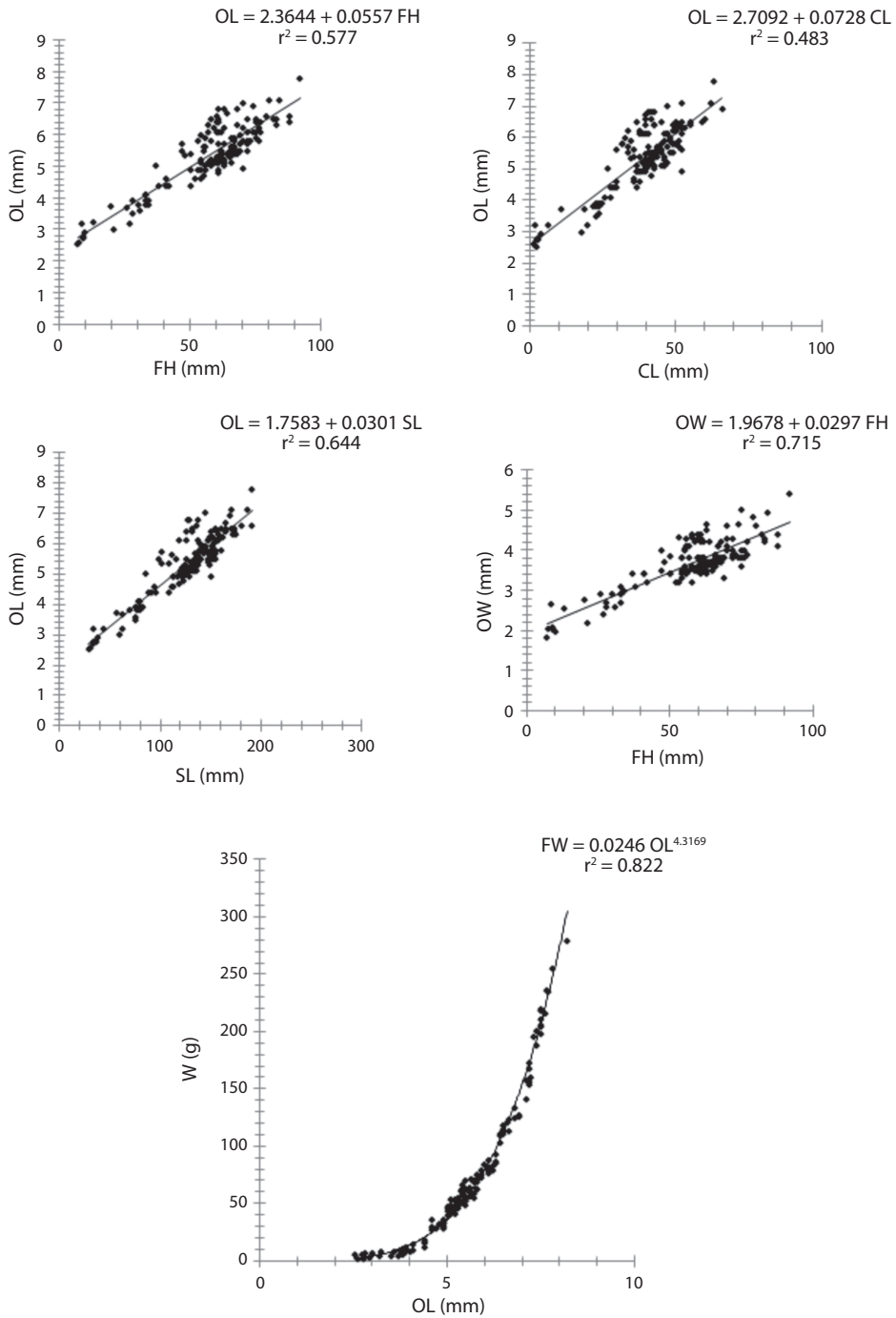


Fig. 2. (A) FH vs OL **(B)** CL vs OL **(C)** SL vs OL **(D)** FH vs OW **(E)** OL vs W for females of *D. auratus*. All regressions were significant at $p < 0.05$.

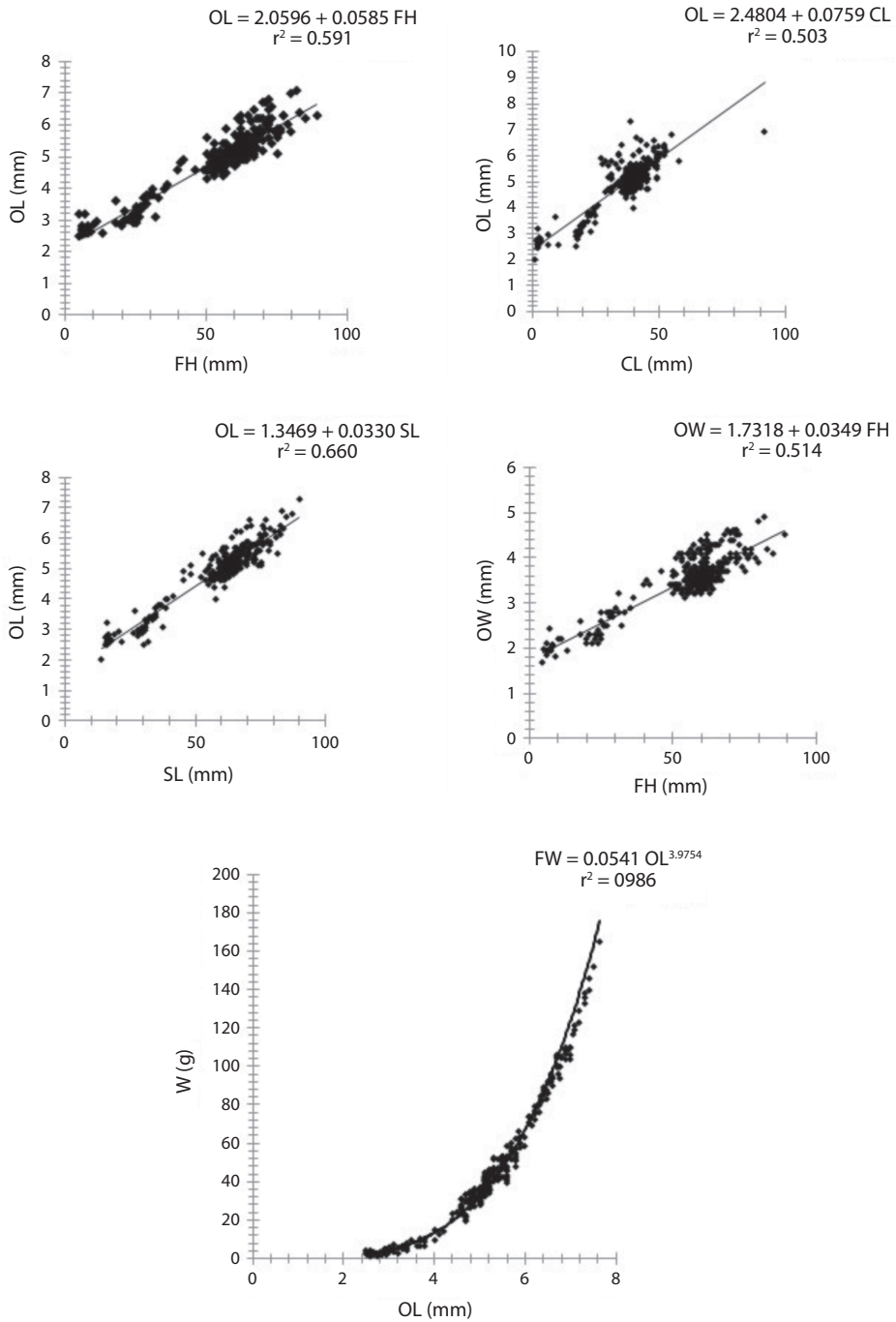


Fig. 3. (A) FH vs OL (B) CL vs OL (C) SL vs OL (D) FH vs OW (E) OL vs W for males of *D. auratus*.

DISCUSSION

Diapterus auratus, is recognized as a typical species that habit coastal waters of all warm seas, they also enter to coastal lagoons and estuaries (Allen & Robertson 1998, Arceo & Vega 2009). In estuarine systems it is an important species throughout the year because of their numerical abundance and biomass, representing a local resource, nevertheless, information about the morphology and morphometry of otoliths of this species is scarce, and only partial information is available in some species. *Sagitta* otolith has been used as a taxonomical tool for identifying fishes due their large size and degree of interspecific differences (Harvey *et al.* 2000, Battaglia *et al.* 2010). Also, specific guides covering certain geographical areas have been published (Baker 2006, Tuset *et al.* 2008). In the present study we provide a description of the sacular otolith of *D. auratus* that allow researchers the identification of this species. The morphology of the *sagitta* of *Gerres filamentosus*, given by Baker, differs from *D. auratus* because this one is ovate, the ventral margin is sinuate and the dorsal margin is irregular. Hüseyin (2008) and Stransky *et al.* (2008), mention that the development of the otolith in fishes, as an ontogenetic process, could be regulated by environmental factors; particularly the disponibility of food, or some other environmental factor, so that proportions of this structure could change for the same species developed in different conditions. However, considering the morphology, Kanak & Tachihara (2006) mention that the otoliths of *Gerres* sp. in Okinawa, Japan, are very similar to that of *Diapterus rhombeus*.

Based on the results, the otoliths of *D. auratus* showed no significant differences between right and left *sagitta*, ($p < 0.05$). The lack of significant differences between right and left *sagittae* is consistent with the observation that the pair of otoliths are specular images of each other (Hunt 1992), something similar was reported by Labropoulou & Papaconstantinou (2000) for fishes of the Mediterranean.

In all the cases, the model of regression used, seemed to describe adequately the relation between otoliths and the diverse measures of fishes used, showing a high correlation of the significant estimations of slopes and intersections.

The two dimensions of otoliths examined in this study (OL and OW), showed a significant relation with fish measures: standard length and weight; Tombari *et al.* 2010 pointed that the size of the otoliths depends on the species.

Researchers of feeding habitats of seabirds and marine mammals need to know the morphology of otoliths and specific equations, which are useful to calculate the size and mass of prey (Echeverria 1987, Harvey *et al.* 2000, Berra & Aday 2004). All equations relating otolith variables to fish standard length and fish weight for the specimens studied of *D. auratus* explained a very large proportion of the variance in the data (Table 1), these results are similar to those reported by Wassle *et al.* 2003, for Sciaenid species. Despite the importance of this fishes in trophic studies, their biology had not been well investigated until today.

In comparison with other similar studies on the relationship of fish and *sagitta* sizes (Gamboa 1991, Volpedo & Thompson 1996, Harvey *et al.* 2000, Waessle *et al.* 2003, Jawad 2007) we tested the differences between males and females. Echeverria 1987 and Volpedo & Thompson 1996, demonstrated that there were significant differences between males and females in some species of rockfishes and *Prionotus nudigula* respectively. The Fisher test $F_{(161, 143, p < 0.001)}$ for comparing the slopes of the distinct linear relations obtained for the morphometric estimations of otoliths and the records of males and females, confirm that this species did not show significant differences in the relationships between both sexes ($p < 0.001$).

The study and use of otoliths for the characterization of diverse aspects of the biology of fishes has been a common practice among researchers, some have used them to characterize the stages and areas where anadromous species growth (Thresher *et al.* 1994, Thorold *et al.* 1997, Secor *et al.* 1998), or for the

determination of age of commercial fish (Radtke 1987, Lecomte 1992, Secor *et al.* 1995).

Paxton (2000) give some categories of fish otolith size; Perciformes, have otoliths of small to moderate size 2-5% in SL. The otolith length of *D. auratus* is consistently of 4.4% SL in both males and females, this coincides with the percentage mentioned for the Perciformes.

It is recognized that the employment of otoliths in the ichthyological characterization, are particularly valuable because they are not submitted to calcium reabsorption (Casselman 1990, Bordino *et al.* 1999, Koen *et al.* 1999) and their morphology is characteristic of each species (Volpedo & Echeverría 2003), as recorded in the present study.

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RESUMEN

Los otolitos *sagitta* son los más estudiados debido a su variabilidad morfológica y a su tamaño, sin embargo, los otolitos de *D. auratus* no han sido estudiados hasta el momento. En el presente estudio, se muestra una descripción completa de la morfología y un análisis morfométrico de diversas medidas. El análisis incluye las relaciones entre el ancho y largo de la *sagitta* contra la longitud cefálica, longitud estándar, altura y peso de 449 peces. El material biológico fue capturado con un chinchorro playero en las costas de Alvarado y el Puerto de Veracruz de noviembre 2009 a junio 2010. Las *sagittae* fueron extraídas, limpiadas, fotografiadas (SEM y ópticas) y medidas. La comparación entre el otolito derecho e izquierdo no mostró diferencias significativas entre el ancho y largo (prueba de *t*, $p < 0.05$) para cada sexo. El otolito derecho fue utilizado para las relaciones de las distintas medidas del otolito del pez y del otolito de hembras y machos; la prueba de Fisher (d.f. 161 and 143, $p < 0.001$) no mostró diferencias significativas de las pendientes e intersecciones entre ellos. La relación longitud del otolito-peso del pez mostró un crecimiento de tipo alométrico positivo en machos ($b = 3.9754$, $p < 0.05$) y hembras ($b = 4.3168$, $p < 0.05$).

Palabras clave: otolito, *Sagitta*, *Diapterus auratus*, morfometría, correlaciones, Veracruz, Gerreidae, Mojarra Guacha, Irish Pompano.

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