Acta Aquatica Turcica

Home Page: https://dergipark.org.tr/actaquatr
E-ISSN: 2651-5474
22(1): 220105, 2026
DOI: 10.22392/actaquatr.1717322

Research Article | Araştırma Makalesi

Interspecific Variation in Body and Otolith Morphometrics of Three *Sphyraena* Species (Perciformes: Sphyraenidae) from the Eastern Coast of Libya

Eman S. Alfergani[1,]*, Mohammad El-Mabrok[2], Zidan Walid Boshah[1], Abdull Abdelfatth Boshah[1]

[1]Department of Marine biology, Faculty of Science, Omar Al-Mukhtar University-LIBYA
[2] Department of zoology, Faculty of Science, Omar Al-Mukhtar University-LIBYA

*Corresponding Author: eman.salem@omu.edu.ly

Received: 12.06.2025 **Accepted:** 24.11.2025 **Published:** 01.03.2026

How to Cite: Alfergani, E. S., El-Mabrok, M., Boshah, Z. W. & Boshah, A. A. (2026). Interspecific Variation in Body and Otolith Morphometrics of Three *Sphyraena* Species (Perciformes: Sphyraenidae) from the Eastern Coast of Libya. *Acta Aquatica Turcica, 22*(1), 220105. https://doi.org/10.22392/actaquatr.1717322

Abstract: This study investigated the morphological characteristics of the body and otoliths of three Sphyraenidae species (*Sphyraena flavicauda*, *S. sphyraena*, and *S. viridensis*) collected from the Benghazi coast, eastern Libya, during winter 2023. Morphometric measurements were recorded from the left side of each specimen, including total length, standard length, head length, eye diameter, snout length, eye height, maximum body height and width, caudal peduncle dimensions, head width, and total weight. Eight morphometric ratios were calculated to evaluate proportional differences among species. The length–weight relationship indicated isometric growth, with b values ranging from 2.39 to 2.68 and condition factors from 0.375 ± 0.00 to 0.531 ± 0.013. Otolith length, height, area, and sulcus features were measured, and indices such as rectangularity, circularity, SAL/OL, OSL/SAL, CUL/SAL, OH/OL%, S index, and relative otolith size were calculated. Significant differences in body and otolith morphometrics were detected among the species, providing reliable markers for identification and supporting Sphyraenidae management in Libyan waters.

Keywords
- Sphyraenidae
- Morphometrics
- Otoliths
- Isometric growth
- Species discrimination

1. INTRODUCTION

The family Sphyraenidae comprises a single genus, *Sphyraena*, which includes about 20 species, five of which occur in the Mediterranean Sea. Among them, three species are invasive: *Sphyraena chrysotaenia* (Kunzinger, 1884), *S. flavicauda* (Rüppell, 1838), and *S. obtusata* (Cuvier, 1829). These species entered the Mediterranean Sea from the Red Sea through the Suez Canal (Golani et al., 2006; Bourhail et al., 2015). In addition, two Atlanto-Mediterranean species (*S. sphyraena* (Linnaeus, 1758) and *S. viridensis* (Cuvier, 1829)) are native to the region. Another species, *S. intermedia* (Pastore, 2009), was recently described from Taranto Bay in the central Mediterranean.

Sphyraena flavicauda, commonly known as the yellowtail barracuda, is widely distributed throughout the Indo-Pacific region. It was first recorded off the Libyan coast in 2003 (Ben Abdallah et al., 2003). The species is characterized by two longitudinal yellow-brown stripes along the body, and the tips of the pectoral fins do not reach the origin of the first dorsal fin. Its diet consists mainly of anchovies (*Engraulis encrasicolus*), followed by crustaceans and molluscs (Osman et al., 2019). The spawning season extends from May to September (Allam et al., 2004).

Sphyraena sphyraena, known as the great barracuda, is a commercially important species frequently caught in fisheries. It inhabits the eastern Atlantic Ocean, from the Bay of Biscay to Angola, including the Mediterranean and Black Seas, the Canary Islands, and the western Atlantic from Bermuda to Brazil (Golani et al., 2006). Its diet is dominated by fish, including *E. encrasicolus*, *Spicara smaris*, *Sardina pilchardus*, and *Sardinella aurita*, while crustaceans constitute a minor component (Allam, 1999). The spawning season occurs between April and August (Allam et al., 2004).

Sphyraena viridensis, or the yellowmouth barracuda, is distributed mainly in the

Mediterranean Sea and the eastern Atlantic Ocean, from Iceland in the north to Morocco and the Cape Verde Islands in the south (Golani et al., 2006). Its diet consists exclusively of fish, with Trachurus picturatus (Carangidae) being the predominant prey species. It also consumes other fish belonging to the families Sparidae (such as *Boops boops* and *Pagellus acarne*) and Labridae, including *Thalassoma pavo* (Barreiros et al., 2002). The gonad maturation period extends from April to July (Bourehail et al., 2010).

Some reports have noted potential confusion between *S. viridensis* and *S. sphyraena* due to their close evolutionary relationship (De Sylva, 1990). However, distinct morphological differences exist between the two species. In terms of coloration, *S. viridensis* displays dark vertical bars on the dorsal part of the body, whereas *S. sphyraena* exhibits a pale yellowish dorsum without visible bars (Merciai et al., 2020). Moreover, *S. viridensis* lacks a scale on the preoperculum, which is present in *S. sphyraena* (Relini & Orsi-Relini, 1997).

Otoliths are calcified structures composed mainly of calcium carbonate, located in the inner ear of fish, where they play an essential role in hearing and balance (Popper et al., 2005). Because of their continuous growth and species-specific morphology, otoliths are considered valuable taxonomic and biological archives that reflect the life history and development of fish (Zorica et al., 2010). Therefore, they are widely used in studies on age and growth estimation, identification of predator–prey relationships from stomach contents, and stock discrimination (Mohamed et al., 2019; Çiçek et al., 2021; Mirhadi et al., 2023; Mohamed et al., 2023; Nikiforidou et al., 2024).

Most published studies on Sphyraeidae have focused on age and growth (Allam et al., 2004; El-Ganainy et al., 2017; Bourehail & Hichem Kara, 2021; Ferri & Brzica, 2022), feeding habits (Barreiros et al., 2002; Kalogirou et al., 2012; Osman et al., 2019), and reproductive biology (Allam et al., 2004), with relatively little attention given to otolith morphology and its application in species differentiation (Bourehail et al., 2015; Yedier, 2021). The present study aims to examine selected body morphometric traits and to describe and compare the morphological and ecomorphological features of otoliths in Sphyraeidae species collected from the eastern coast of Libya (Benghazi area).

2. MATERIALS AND METHODS

A total of 67 specimens of *Sphyraena* species were collected during the winter of 2023, including *Sphyraena flavicauda* (n = 17), *S. sphyraena* (n = 25), and *S. viridensis* (n = 25). Specimens were obtained from local fishermen using gill nets in the coastal waters of Benghazi, eastern Libya (32° 8'46.48"N, 20° 3'23.12"E). Immediately after capture, all specimens were preserved in ice and transported to the laboratory for morphometric and otolith analyses.

Species identification was performed in the laboratory according to Golani (1992) and Golani et al. (2006). The following morphometric measurements were recorded: total length (TL, mm), standard length (SL, mm), head length (HDL, mm), eye diameter (ED, mm), snout length (LS, mm), eye height (EH, mm), maximum body height (MBH, mm), maximum body width (MBW, mm), caudal peduncle length (CPdL, mm), caudal peduncle height (CPdH, mm), caudal peduncle width (CPdW, mm), and head width (HDW, mm) (Figure 1). All measurements were taken from the left side of each specimen following standardized ichthyological procedures. The total weight (TW, g) was measured to the nearest 0.01 g using an analytical balance (Sartorius Mod. BP2100S, Germany).

Eight morphometric ratios were calculated to evaluate proportional differences among species: ED/HDL%, HDL/SL%, LS/SL, CPdL/SL, MBH/MBW, CPdH/MBH, CPdW/MBW, and HDW/MBW (Watson & Balon, 1984; Winemiller, 1991; Willis et al., 2005).

The length–weight relationship was estimated according to Ricker (1975) using the equation $TW = aTL^b$, where a is the intercept and b is the slope of the regression line. The 95% confidence interval ($CI_{95}\%$) was calculated as b ± (1.96 × Sb), and Student's t-test was applied to determine whether b significantly differed from 3 (Sokal & Rohlf, 1987). Fulton's condition factor (K_F) was calculated as $K_F = 100 \times TW / TL^3$ (Fulton, 1904).

Otoliths were extracted through the nostril opening by making a cut anterior to the first branchial arch into the otic capsule. After extraction, otoliths were thoroughly cleaned of blood and tissue residues with distilled water, dried, and stored in labeled plastic boxes. Each otolith was examined and photographed under a stereomicroscope (OPTECH Mod. SZ, Germany) equipped with a digital camera (Olympus Mod.NO-7070, Japan). Otolith length (OL), height (OH), perimeter (OP), area (OA), sulcus length (SAL), sulcus area (SA), ostium length (OSL), and cauda length (CUL) were measured to the nearest 0.1 mm using Digimizer software (version 4). Morphological terminology followed Tuset et al. (2008).

Only the left otolith was used for analysis. The following otolith ratios were calculated: OL/TL%, OH/OL%, SAL/OL%, OSL/SAL%, and CUL/SAL%. Three shape indices were also derived: rectangularity (R = OA / (OL × OH)), circularity ($C = OP^2 / OA$), and S-index (SI = SA / OA%) (Assis, 2020; Tuset et al., 2003). The relative otolith size (OR) was determined according to Lombarte & Cruz (2007) using the equation $OR = 1000 \times OA \times TL^{-2}$.

All morphometric data and ratios were processed in Microsoft Excel 2013. Descriptive statistics (mean ± standard error) were calculated for each parameter. Differences among the three *Sphyraena* species were analyzed using one-way analysis of variance (ANOVA). When significant differences were detected ($P < 0.05$), Duncan's multiple range test was applied to identify homogeneous groups. All statistical analyses were performed using SPSS Statistics version 21.

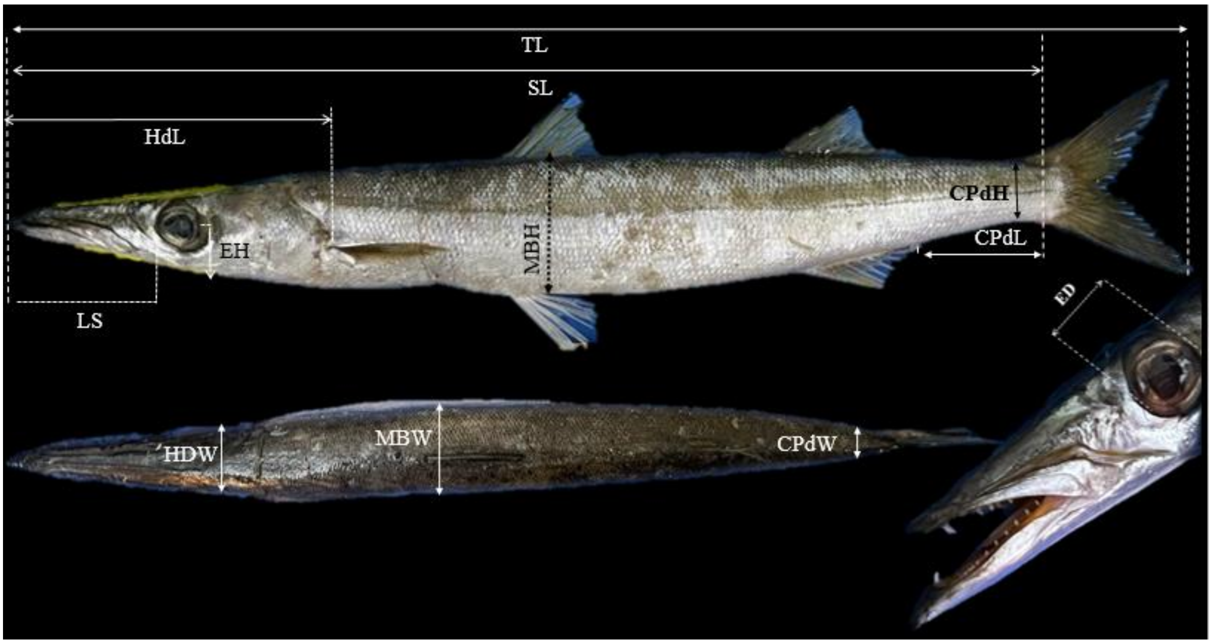

Figure 1. Morphometric measurements used in the present study for *Sphyraena* species. TL = total length, SL: standard length, HD: head length, LS: length of snout, EH: eye height, ED: eye dimantion, MBH: maximum body height, MBW: maximum body width, CPdL: caudal peduncle length, CPdH: caudal peduncle height, CPdW: caudal peduncle width, and HDW: head width.

3. RESULTS

Significant morphometric variations ($p < 0.05$) were observed among the three *Sphyaena* species (*S. flavicauda, S. sphyaena, and S. viridensis*), as shown in Table 1. The overall body dimensions showed that *S. viridensis* attained the greatest measurements in most parameters, followed by *S. sphyaena* and *S. flavicauda*. The *S. viridensis* had a total length (TL) of 406.97 ± 6.01 mm (TW: 255.85 ± 11.89 g) and a standard length (SL) of 347.29 ± 6.43 mm. These measurements were much longer and heavier than those of *S. sphyaena* (TL: 371.36 ± 5.33 mm, SL: 317.22 ± 4.70 mm, and TW: 204.95 ± 10.49 g) and *S. flavicauda* (356.71 ± 6.54 mm and 304.57 ± 5.58 mm, TW: 243.95 ± 15.55 g). Similarly, head length (HDL) reached its maximum in *S. viridensis* (110.10 ± 1.52 mm), followed by *S. sphyaena* (99.89 ± 1.43 mm) and *S. flavicauda* (94.62 ± 1.34 mm); this measurement was a difference in the three species. Maximum body height (MBH) varied significantly among species, with the highest value recorded in *S. viridensis* (41.73 ± 1.23 mm), whereas *S. sphyaena* exhibited the lowest (37.16 ± 0.68 mm). The maximum body width (MBW) did not differ significantly among species. The caudal peduncle length (CPdL) and the caudal peduncle height (CPdH) were greatest in *S. viridensis* (CPdL: 57.65 ± 1.23 mm, CPdH: 20.08 ± 0.39 mm), respectively, showing significant differences from both *S. flavicauda* (CPdL: 49.58 ± 1.15 mm, CPdH: 19.22 ± 0.42 mm) and *S. sphyaena* (CPdL: 49.92 ± 0.75 mm, CPdH: 18.03 ± 0.40 mm). In terms of head size, the head width (HdW) ranged from 24.29 ± 0.46 mm in *S. sphyaena* to 25.71 ± 0.40 mm in *S. viridensis*, with no significant differences between species. Eye diameter (ED) showed marked variation, being largest in *S. flavicauda* (16.60 ± 0.20 mm) and smallest in *S. sphyaena* (14.41 ± 0.20 mm). Similarly, the length of the snout (LS) increased significantly from *S. flavicauda* (45.43 ± 0.81 mm) to *S. viridensis* (54.55 ± 0.76 mm) and showed a significant difference among three species of *Sphyaena*.

Among the morphometric ratios, the highest CPDL/SL was found in *S. viridensis* (0.166 ± 0.03), and the lowest value was shown in *S. flavicauda* (0.149 ± 0.00). In contrast, the ratio ED/HDL was greater in *S. flavicauda* (17.56 ± 0.27) and lowest in *S. viridensis* (13.49 ± 0.29), and these ratios (CPDL/SL and ED/HDL) show significant differences in the three species. The ratio of snout length to standard length (LS/SL) did not show a significant difference between *S. sphyaena* (0.157 ± 0.001) and *S. viridensis* (0.157 ± 0.007), but they differ from *S. flavicauda* (0.149 ± 0.001) ($p < 0.05$). Other ratios, such as HDL/SL, CPdH/MBH, CPdW/MBW, MBH/MBW, and HdW/MBW, did not show significant differences among species (Table 1).

Fulton condition factors for *S. flavicauda*, *S. sphyraena*, and *S. viridensis* were 0.531±0.013, 0.406±0.006, and 0.375±0.006, respectively, which means they were all less than one. We calculated the length-weight relationship for the three species as shown: $TW=0.047TL^{2.39}$ $R^2=0.88$ ($CI_{95\%}$ for b: 1.63-3.14) for *S.flavicauda*, $TW=0.012TL^{2.68}$ $R^2= 0.90$ ($CI_{95\%}$ for b: 2.31-3.06) for *S.sphyraena*, $TW=0.020TL^{2.55}$ $R^2=0.88$ ($CI_{95\%}$for b: 2.08-3.02) for *S.viridensis*, and they were isometric growth (b=3, P > 0.05) (Table 2).

Table 1. Morphometric parameters and morphometric ratios (Mean±SE.) of three *Sphyraena* species.

	Species	***S. flavicauda* (17)**	***S. sphyraena* (25)**	***S. viridensis*(25)**
Morphometric Parameters	Total Length, TL	356. 71±6.549	371.36±5.337	406.97±6.012
	Total weight, TW	243.950±15.551	204.958±10.493	255.853±11.899
	Standard length, SL	304.57±5.588	317.22±4.709	347.29±6.437
	Eye diameter, ED	16.608±0.207[a]	14.416±0.206[b]	14.840±0.390[b]
	Head length, HDL	94.622±1.347[a]	99.889±1.433[b]	110.102±1.529[c]
	Maximum body height, MBH	39.037±1.374[ab]	37.162±0.686[a]	41.733±1.230[b]
	Maximum body width, MBW	30.742±0.542[a]	28.882±0.584[a]	30.784±0.888[a]
	Caudal peduncle length, CPdL	49.588±1.153[a]	49.928±0.752[a]	57.645±1.233[b]
	Caudal peduncle height, CPdH	19.220±0.420[a]	18.031±0.404[a]	20.080±0.392[b]
	Caudal peduncle width, CPdW	12.837±0.890[a]	14.683±0.321[b]	15.356±0.275[b]
	Head width, HdW	25.220±0.370[a]	24.295±0.466[a]	25.719±0.407[a]
	Length of snout, LS	45.432±0.815[a]	49.789±0.799[b]	54.558±0.765[c]
	Eye height, EH	17.442±0.569[a]	16.700±0.243[a]	17.567±0.299[a]
Morphometric Ratio	ED/HDL%	17.56±0.272[a]	14.44±0.210[b]	13.49±0.294[c]
	HDL/SL%	31.101±0.455[a]	31.499±0.135[a]	31.707±0.300[a]
	LS/SL	0.149±0.001[a]	0.157±0.001[b]	0.157±0.007[b]
	CPdL/SL	0.149±0.001[a]	0.157±0.001[b]	0.166±0.031[c]
	MBH/MBW	1.268±0.029[a]	1.294±0.028[a]	1.370±0.051[a]
	CPdH/MBH	0.495±0.018[a]	0.486±0.009[a]	0.487±0.014[a]
	CPdW/MBW	0.416±0.023[a]	0.510±0.010[a]	0.505±0.016[a]
	HdW/MBW	0.821±0.013[a]	0.843±0.012[a]	0.844±0.022[a]

Different superscript letters within the same row indicate significant differences among species (p<0.05)

Table 2. Parameters of Length-Weight relationship (a,b) with confidence intervals(CI95%),coefficient of determination(R2), significance level (P value) and mean Condition Factor (KF) ±standard error of three Sphyraena species.

Species	**a**	**b**	**CI 95%**	**R^2**	**P value**	**K_F**
S. flavicauda	0.047	2.39	1.63-3.14	0.88	0.137	0.531±0.013[a]
S. sphyraena	0.012	2.68	2.31-3.06	0.90	0.918	0.406±0.006[b]
S. viridensis	0.020	2.55	2.08-3.02	0.88	0.076	0.375±0.006[c]

Different superscript letters indicate significant differences among species (P<0.05)

The otolith of *S. flavicauda* was oblong, constituting 1.673±0.132% of the total length of the fish. The ratio of the height of the otolith to the length of the otolith was 42.455±0.396. The sulcus (SAL: 5.544±0.117 mm) were heterosulcoid and constituted 84.970±0.762% of the length of the otolith. The area of the sulcus in relation to the surface area of the otolith (S index) was 32.1065±0.143. The ostium (OSL: 2.408±0.118 mm) was funnel-like, its length relative to the length of the sulcus being 45.946±0.549%, while the cauda (CUL: 2.809±0.120mm) was tubular, strongly curved, and formed about 52.834±0.457% of the length of the sulcus, Circularity=30.709±1.959, Rectangularity=0.537±0.064, Otolith relative size (O_R)= 0.110±0.009.

As for *S. sphyraena,* the otolith was spindle-shaped, and it constituted about 2.532±0.061% of the total length of the body. The ratio of the height of the otolith to the length of the otolith was 33.152±0.794%, and the length of the sulcus varied in relation to the length of the otolith: 84.133±2.809%, and its area relative to the surface area of the otolith was 32.305±0.866. The ostium was funnel-like, with an average length of 3.695±0.118mm, and was 46.528±0.597% of the length of the sulcus. The cauda was tubular and slightly curved, with an average length of 4.229±0.120mm, which was 53.296±0.527 % of the length of the sulcus Circularity=32.185±0.964, Rectangularity=0.699±0.024, Otolith relative size (O_R)= 0.146±0.005.

In *S.viridensis,* the otolith was spindle-shaped and constituted about 2.236±0.027% of the total length; the OH/OL was 34.366±0.406%. Sulcus also had a variable average length of 7.448 ± 0.108 mm and formed the lowest percentage compared to the two species, about 81.944 ± 0.858% of the length of the otolith. As for its area in relation to the surface area of the otolith, it was 30.153±1.223. The ostium was funnel-like, with an average length of 3.599±0.0948mm (OSL/SAL: 48.287±0.793%). The cauda was tubular and straight, with an average length of 3.826±0.065 mm, and constituted 51.423±0.791% of the sulcus length Circularity=34.160±1.2910, Rectangularity=0.637±0.059, Otolith relative size (O_R)= 0.126±0.003 (Table 3, Figure 2).

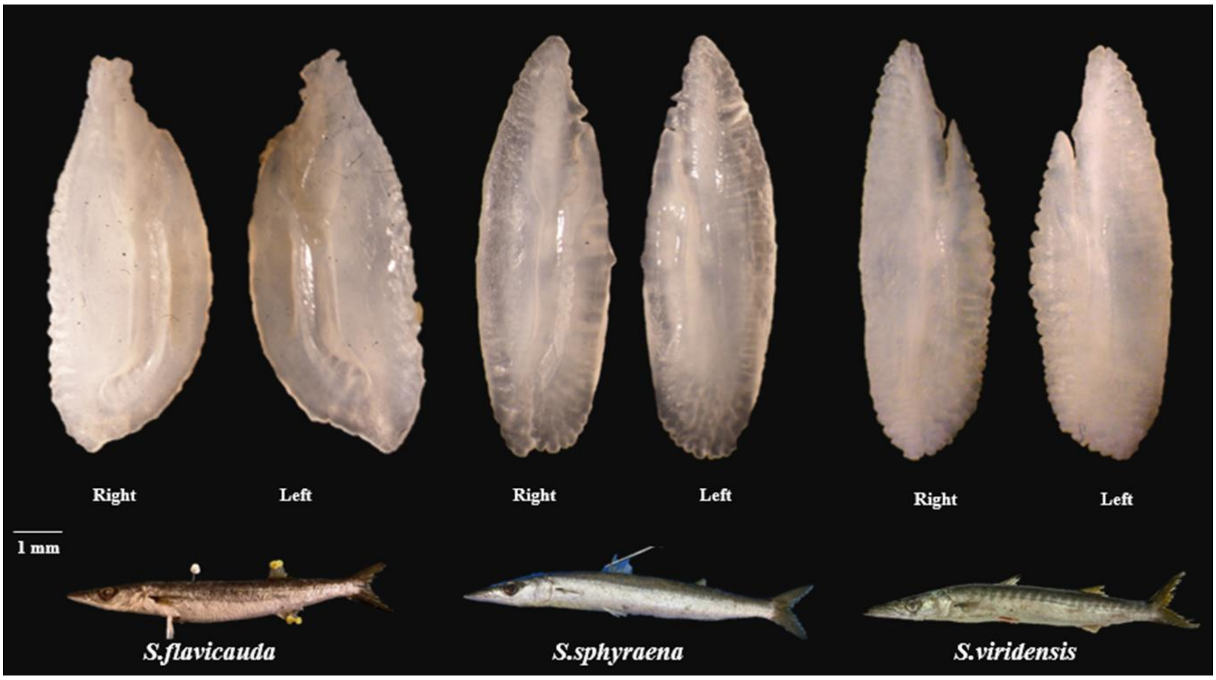

Figure 2. Otolith shape in three *Sphyraena* species in this study.

We used analysis of variance to compare between species (ANOVA, Duncan test), as there were significant differences between *S. flavicauda* on the one hand and *S. sphyraena* and *S. viridensis* in relation to otolith measurements such as otolith length, height, area, perimeter, ostium length, and sulcus length. In addition to the indicators represented in OH/OL%, we found significant differences ($P < 0.05$) between the three species with regard to sulcus length, cauda length, and OL/TL%. *S. flavicauda* shared with *S. viridensis* that there were no significant differences (P >0.05) in the relative size index of otoliths and CUL/SAL, in contrast to *S. sphyraena* differed from *S. viridensis* in CUL/SAL%. The *S. flavicauda* differs from the *S. viridensis* in the OSL/SAL%.

Table 3. Mean and Standard error values of various parameters of otolith for fish study.

Parameter	*S. flavicauda*	*S. sphyraena*	*S. viridensis*
Otolith Length, OL (mm)	6.553±0.120[a]	9.468±0.241[b]	9.095±0.157[b]
Otolith Height, OH(mm)	2.633±0.130[a]	3.150±0.140[b]	3.119±0.056[b]
Otolith Area, OA(mm^2)	13.791±0.173[a]	20.475±0.858 [b]	20.655±0.728[b]
Otolith Perimeter, OP(mm)	22.055±0.697[a]	25.592±0.727[b]	27.068±0.727[b]
Sulcus Area, SA(mm^2)	4.270±0.119[a]	6.618±0.336[b]	6.185±0.237[b]
Sulcus length, SAL(mm)	5.544±0.117[a]	7.938±0.219[b]	7.448±0.108[c]
Ostium Length, OSL(mm)	2.408±0.118[a]	3.695±0.118[b]	3.599±0.094[b]
Cauda length, CUL(mm)	2.809±0.120[a]	4.229±0.120[b]	3.826±0.065[c]
Sulcus length /otolith length, SAL/OL%	84.970±0.762[a]	84.133±2.809[a]	81.944±0.858[a]
Ostium Length/ Sulcus length, OSL/SAL%	45.946±0.549[a]	46.528±0.597[ab]	48.287±0.793[b]
Cauda length/ Sulcus length, CUL/SAL%	52.834±0.457[ab]	53.296±0.527[b]	51.423±0.791[a]
Otolith Length /Total length, OL/TL%	1.673±0.132[a]	2.532±0.061[b]	2.236±0.027[c]
Otolith Height/Otolith Length, OH/OL%	42.455±0.396[a]	33.152±0.794[b]	34.366±0.406[b]
S index	32.106±0.143[a]	32.305±0.866[a]	30.153±1.223[a]
Circularity	30.709±1.959[a]	32.185±0.964[a]	34.160±1.291[a]
Rectangularity	0.537±0.064[a]	0.699±0.024[a]	0.637±0.059[a]
Otolith relative size	0.110±0.009[a]	0.146±0.005[b]	0.126±0.003[ab]

Different lowercase letters (a, b, c) indicate statistically significant differences between three species at the 0.05 level ($p<0.005$),based one-way ANOVA.

4. DISCUSSION

This study aims to examine some of the external morphological features of the body and otoliths of three species of Sphyraenidae collected from the eastern coast of Libya. Fish of this family are characterized by their elongated bodies and large heads with a pointed snout, prominent lower jaw, and fang-like teeth, in addition to their wide eyes (Golani et al., 2006). Shaila Prasad et al. (2021) mentioned that during their study of *S. obtusata* collected from the Vizhinjam coast in India, the HDL/SL value was 0.35 (35%), which is greater than what we found in the fish of the current study. We recorded significant differences in ED/HDL% and CPDL/SL in the three species. *S. viridensis* differs from the other two species in having broad dark lines along the upper half of the body, extending down the lateral line in the front of the body. *S. flavicauda* differs in the location of its first dorsal and pelvic fins. Additionally, its pectoral fin tip does not reach the origin of the first dorsal fin. Its pointed snout and silver coloration may reduce visibility to prey, while its caudal and posterior fin positioning facilitates rapid movement (Golani et al., 2006; Moyle and Cech, 2014).

Fulton's condition factors for *S. flavicauda*, *S. sphyraena*, and *S. viridensis* were 0.531 ± 0.013, 0.406 ± 0.006, and 0.375 ± 0.006, respectively, all being less than one. Statistical analysis indicated significant interspecific differences in condition factor values among the three species. The obtained K_F values were higher than those reported by Allam et al. (2004) from Egyptian waters, which were 0.482 ± 0.029 (*S. flavicauda*), 0.352 ± 0.030 (*S. sphyraena*), and 0.331 ± 0.0168 (*S. viridensis*). Moreover, Ragheb (2023) emphasized the influence of body shape on the condition factor, noting that elongated species such as *S. chrysotaenia* exhibit K_F values lower than one (0.617 ± 0.037), whereas deep-bodied, laterally compressed species such as *Sparus aurata* (Sparidae) typically present values exceeding one (1.272 ± 0.070). In this study, the length-weight relationship was isometric growth, according to the student t-test. In comparison to the study on the Alexandria coast, the highest regression coefficient was found for *S. flavicauda* at b = 3.27, followed by *S. viridensis* at b = 2.93 and *S. sphyraena* at b = 2.92 (Allam et al., 2004). And on the other hand, El-Ganainy et al. (2017) reported that the growth pattern exhibited negative allometric growth. The difference in the condition factor and the value of the regression coefficient (b) in the length-weight relationship with previous studies is due to several factors, including the size and time of sample collection, gonad maturity, status of stomach content (empty or full), gender, and environmental factors (Kuriakose, 2014).

The shape of the otolith ranged from oblong in *S. flavicauda* to spindle-shaped in *S. sphyraena* and *S. viridensis*. We also noted differences in the otolith's margins. The dorsal margin was entire in *S. flavicauda*, crenate in *S. sphyraena*, and lobed in *S. viridensis*. As for the ventral margin, it was crenate in *S. flavicauda*, lobed in *S. viridensis*, and entire in *S. sphyraena*. The anterior edge was irregular in *S. flavicauda* and peaked in the other two species, while the posterior edge was round and lobed in *S. sphyraena* and *S. viridensis* and oblique in *S. flavicauda*. Similarly, Yedier's (2021) study on the shape of otoliths and their relationship to total length indicated that they have a spindle-shape and highlighted differences in the shapes of the margins (dorsal and ventral) and regions (anterior and posterior) between pairs of otoliths as well as among different length groups in *S. sphyraena*. In contrast to what we found in *S. flavicauda*, Lin and Chang (2012) explained that the dorsal and ventral margins were almost entire, and the general shape of the otolith ranged from oval to elongate.

The sulcus is an important part of the otolith, with some of its characteristics being some of the most important for species identification (location, type of aperture, shape of ostium, and cauda) (Tuset et al., 2008). In this study, the sulcus was heterosulcoid, opened widely in the anterior part, and had a median location. It was deeper in the *S. flavicauda* than in the *S. sphyraena* and *S. viridensis*, with a clear dorsal depression in the *S. flavicauda* and *S. sphyraena*, the cauda is strongly curved in *S. flavicauda* and slightly curved in *S. sphyraena* and *S. viridensis*.

The excisura ostii, which represents part of the anterior edge of the otolith where the ostium opens (Tuset et al., 2008), is distinguished in *S. viridensis* as well-developed with the presence of a deep and narrow notch. The rostrum was long, and the antirostrum was short and pointed. Unlike other species, the rostrum was long, the antirostrum was poorly defined, the excisura was wide, and the notch was absent. In previous literature, Lin and Chang (2012) reported that the rostrum of *S. flavicauda* was triangular, the excisura was narrow, and the notch was deep. As for the *S. sphyraena* collected from the northeastern Mediterranean, it has a well-developed excisura with a narrow, deep notch, a long rostrum, and a short, broad antirostrum (Çiçek et al., 2021). In the study of Tuset et al. (2008), in their description of barracuda fish, they explained that in the anterior region of the rostrum in *S. viridensis*, it is rounder than in *S. sphyraena*; in addition to that, the notch is shallow. They noted that the top of the rostrum is slightly inclined to the dorsal region, and the antirostrum is inadequately defined, with the absence of a notch.

In this study, we did not record significant differences in morphological percentages and shape indices in the study fish, with the exception of the OL/TL% and OH/OL% between *S. flavicauda* and two species (*S. sphyraena* and *S. viridensis*). In contrast to that, Bourehall et al. (2015) recorded the presence of significant differences in circularity and form factor between *S. sphyraena* and *S. viridensis* (33.3, 37.74, and 0.33, 0.381, respectively). Moreover, in goatfish, morphological indices showed a significant difference between *Upeneus tragula* and *Upeneus vittatus*, and thus the ability to separate them through morphological measurements, despite the great similarity in general characteristics (Echreshavi et al., 2021). In the Sparidae fish collected from the Aegean Sea, despite the similarity between their species, only the morphological characteristics of otoliths can be relied upon to distinguish between them (Kinacigul et al., 2000).

The S index, which represents the ratio of the area of the sulcus to the area of the otolith, was 32.305%, 32.106%, and 30.153% for *S. sphyraena*, *S. flavicauda*, and *S. viridensis*, respectively. These values were lower than those of *Sphyraena guachancho* (0.36) and other species, including *Thunnus albacares* (0.540) and *Cynoscion jamaicensis* (0.51). Additionally, this indicator's value was also very low in other fish species, such as *Pomatoschistus minutus* and *P. lozanoi*, which had values of 0.084 and 0.092, respectively (Assis et al., 2020; Gauldie, 1988; Arellano et al., 1995). In this study, we did not record any significant differences. Arellano et al. (1995) assumed that the otolith within the genera in the different species have the same evolutionary structure, and the differences are attributed to environmental variation among species, in addition to their spatial niches, depth, and differences in their food (Arellano et al., 1995; Aguirre & Lombarte, 1999).

Based on the average value of the relative size of the otoliths for S. *sphyraena*, *S. flavicauda*, and *S. viridensis*, which were 0.11, 0.14, and 0.15, respectively, we classified the otoliths of the study fish as small in size (0.10–0.32). Additionally, the relative size value of *S. sphyraena* collected from the northwestern Mediterranean Sea, O_R = 0.21, is higher than the recorded value for the same species in our study (Lombart and Cruz, 2007). This finding aligns with Paxton's (2000) suggestion that otoliths of epipelagic fish are small to very small due to several factors, including high noise levels near the surface that hinder acute hearing and a reliance on visual communication in well-lit surface waters. There were some studies linking the difference in the size of the otolith to the difference in the body's growth rate (K). Secor & Dean (1989) showed that groups of fish with high growth rates had small otoliths. The *S. flavicauda* otolith was smaller (0.53) than the *S. viridensis* otolith (0.375), and these findings agreed with what Aguirre & Lombarte (1999) found in their study of the genus *Mullus.* Finally, morphology of the otolith is considered one of the most important tools for distinguishing and identifying fish stocks. Many previous studies were based on the shape and size of the otolith to determine the differences between species (Rai and Rani, 2022; Park et al., 2023).

5. CONCLUSION

This study demonstrates distinct morphometric and otolith variations among three *Sphyraena* species (*S. flavicauda, S. sphyraena, and S. viridensis*) from the eastern coast of Libya. The observed differences in body proportions and otolith morphology among the species suggest their utility in species identification and discrimination. While these morphological differences show promise for taxonomic discrimination, further genetic and ecological studies could enhance their validation. These findings establish a foundation for future research on population dynamics, species-specific adaptations, and fisheries-dependent management strategies in the region.

ACKNOWLEDGEMENTS

We would like to thank the faculty members of the department of marine biology for their valuable support in completing this research.

AUTHORSHIP CONTRIBUTIONS

All authors contributed to collecting samples performing statistical analysis, writing the manuscript, and contributing to the language review.

CONFLICT OF INTEREST

The authors declare that there are no known financial or personal conflicts that could influence their research.

ETHICS APPROVAL

No specific ethical approval was required for this study.

DATA AVAILABILITY

For questions regarding the datasets, the corresponding author should be contacted.

REFERENCES

Aguirre, H., & Lombarte, A. (1999). Ecomorphological comparisons of sagittae in *Mullus barbatus* and *M. surmuletus*. *Journal of Fish Biology*, *55*, 105-114. https://doi.org/10.1006/jfbi.1999.0974

Allam, S.M., Faltas, S.N., & Ragab, E. **(**1999). Food and feeding habits of barracudas in the Egyptian Mediterranean waters off Alexandria. *Bulletin of the National Institute of Oceanography and Fisheries*, *25*, 395-410.

Allam, S.M., Faltas, S.N., & Ragheb, E. (2004). Age And Growth Of Barracudas In The Egyptian Mediterranean Waters. *Egyptian Journal of Aquatic Research*, *30*, 255-270.

Arellano, R.V., Hamerlynck, O., Vinex, M., Mees, J., Hostens, K., & Gijselinck, W. (1995). Changes in the ratio of the sulcus acusticus area to the Sagitta area of *Pomatoschistus minutus* and *P. lozanoi* (Pisces, Gobiidae). *Marine Biology*, *122*, 355-360.

Assis, I.O., da Silva, V.E.L., Souto-Vieira, D., Lozano, A. P., Volpedo, A.V., & Fabré N.N. (2020). Ecomorphological patterns in otoliths of tropical fishes: assessing trophic groups and depth strata preference by shape. *Environmental Biology of Fishes*, *103*, 349–361 https://doi.org/10.1007/s10641-020-00961-0

Barreiros, J.P., Santos, R.S., & Borba, A.E. (2002). Food habits, schooling and predatory behaviour of the yellowmouth barracuda, *Sphyraena viridensis* (Perciformes: Sphyraenidae) in the Azores. *Cybium: International Journal of Ichthyology*, *26*, 83-88.

Ben Abdallah, A.R, Al-Turky A., & Fituri, A.A. (2003). Exotic fishes along the coast of

Libya. (Arabic with English abstract) *Libyan Journal of Marine Science*, *10*, 48-56.

Bourehail, N., & Hichem Kara, M.H. (2010). Age, croissance et reproduction du barracuda *Sphyraena viridensis* (Sphyraenidae) des côtes de l'est Algérien. *Rapp Comm Int Mer Médit*, *39*, 459.

Bourehail, N., Morat, F., Lecomte-Finiger, R., & Hichem Kara, M.H. (2015) Using otolith shape analysis to distinguish barracudas *Sphyraena sphyraena* and *Sphyraena viridensis* from the Algerian coast. *Cybium*, *39*(4), 271–278.

Bourehail, N., & Hichem Kara, M. (2021). Age, growth and mortality of the yellowmouth barracuda *Sphyraena viridensis* (Sphyraenidae) from eastern coasts of Algeria. *Journal of the Marine Biological Association of the United Kingdom*, *101*(3), 599–608. https://doi.org/10.1017/S0025315421000394

Çiçek, E., Avşar, D., Yeldan, H., & Manaşırlı, M. (2021). Otoliths atlas of 77 fish species from the Iskenderun Bay, Northeastern Mediterranean Sea. *FishTaxa*, *19*, 9-55.

De Sylva, D.P. (1990). Sphyraenidae. p. 860-864. In J.C. Quero, J.C. Hureau, C. Karrer, A. Post and L. Saldanha (eds.) Check-list of the fishes of the eastern tropical Atlantic (CLOFETA). JNICT, Lisbon; SEI, Paris; and UNESCO, Paris. Vol. 2.

Echreshavi, S., Esmaeili, H.R., Teimori, A., & Safaie, M. (2021). Otolith Morphology: A Hidden Tool in the Taxonomic Study of Goatfishes (Teleostei: Perciformes: Mullidae). *Zoological Studies* , *60*, e36. https://doi.org/10.6620/ZS.2021.60-36

El-Ganainy, A., Amin, A., Ali, A., & Osman, H. (2017). Age and growth of two barracuda species *Sphyraena chrysotaenia* and *S. flavicauda* (Family: Sphyraenidae) from the Gulf of Suez, Egypt. *The Egyptian Journal of Aquatic Research*, *43*, 75-81. https://doi.org/10.1016/j.ejar.2016.09.002

Ferri, J., & Brzica, A. (2022). Age, Growth, and Utility of Otolith Morphometrics as Predictors of Age in the European Barracuda, *Sphyraena sphyraena* (Sphyraenidae): Preliminary Data. *Fishes*, *7*, 68. https://doi.org/10.3390/fishes7020068

Fulton, T.W. (1904). The rate of growth of fishes. Twenty second Annual Report, Part III. Fisheries Board of Scotland, Edinburgh, pp. 141-241.

Gauldie, R.W. (1988). Function, form and time-keeping properties of fish otoliths. *Comparative Biochemistry and Physiology*, 91, 395-402. https://doi.org/10.1016/0300-9629(88)90436-7

Golani, D. (1992). *Rhabdosargus haffara* (Forsskål, 1775) and *Sphyraena flavicauda* Rüppell, 1833—New Red Sea immigrants in the Mediterranean. *Journal of Fish Biology*, *40*(1), 139-140. https://doi.org/10.1111/j.1095-8649.1992.tb02561.x

Golani, D., Ozturk, B., & Basusta, N. (2006). Fishes of the eastern Mediterranean. Turkish Marine Research Foundation. Istanbul. Turkey

Kalogirou, S., Mittermayer, F., Pihl, L., & Wennhage, H. (2012). Feeding ecology of indigenous and non-indigenous fish species within the family Sphyraenidae. *Journal of Fish Biology*, *80*, 2528-2548. https://doi.org/10.1111/j.1095-8649.2012.03306.x

Kinacigul, H.T., Akyol, O., Metun, G.l., & Saygi H.l. (2000). A Systematic study on the otolith characters of Sparidae (Pisces) in the Bay of Izmir (Aegean Sea). *Turkish Journal of Zoology*, *24*(4), 357-364. https://journals.tubitak.gov.tr/zoology/vol24/iss4/2

Kuriakose, S. (2014). Estimation of length weight relationship in fishes. Summer School on Advanced Methods for Fish Stock Assessment and Fisheries Management. Reprinted from the CMFRI, FRAD. Training Manual on Fish Stock Assessment and Management, p.150.

Lin, C.H., & Chang, C.W. (2012). Otolith atlas of Taiwan fishes. *Taiwan: National Museum of Marine Biology and Aquarium*, *12-19*, 29-35

Lombarte, A., & Cruz, A. (2007). Otolith size trends in marine com-munities from different depth strata. *Journal of Fish Biology*, *71*(1), 53-76. https://doi.org/10.1111/j.1095-8649.2007.01465.x

Merciai, R., Casadevall, M., Villegas-Hernandez. H., & Lloret, J., (2020). Twilight activity patterns and angling vulnerability of yellowmouth barracuda (*Sphyraena viridensis* Cuvier, 1829), a range expanding thermophilic fish. *Journal of Fish Biology*, *97*(2), 1-12. https://doi.org/10.1111/jfb.14375

Mirhadi, S.N., Alavi-yeganeh, M.S., & Nasri, M. (2023). Relationships between sagittal otolith and fish dimensions in silver sillago, *Sillago sihama* (Fabricius 1775) in the Persian Gulf. *Iranian Journal of Ichthyology*, *10*(3), 166-171. https://doi.org/10.22034/iji.v10i3.987

Mohamed, S.B., Mejri, M., Ben Faleh, A., Allaya, H., Jmil, I., Rebaya, M., Chalh, A., Quignard, J.P., & Trabelsi, M. (2019). Otolith shape as a valuable tool to evaluate the stock structure of Mullus barbatus from two Tunisian lagoons (Boughrara and El Biban). *Cahiers de Biologie Marin*, *60*, 507-516. https://doi.org/10.21411/CBM.A.873DBD51

Mohamed, S.B., Mejri, M., Chalh, A., Shahin, A. A. B., Quignard, J.P., Trabelsi, M., & Faleh, A. B. (2023). Distinct inter and intrapopulation variation in the otolith shape and size of *Mullus barbatus* (Actinopterygii: Mullidae) from the Bizerte and Ghar El Melh lagoons in Tunisian waters. *Marine Biology Research*, *19*(4-5), 234-248. https://doi.org/10.1080/17451000.2023.2203503

Moyle, P.B., & Cech J.J. (2004). Fishes: An Introduction to ichthyology, 5th ed. Pearson Prentice Hall. New Jersey, U.S.A.

Nikiforidou, V., Mytilineou, C., Alexandropoulos, A., & Anastasopoulou, A. (2024). Age, Growth, and Otolith Morphometrics of *Trachinus draco* (L., 1758) and *Trachinus radiatus* (Cuvier, 1829) in the Eastern Mediterranean. *Fishes*, *9*(5), 152. https://doi.org/10.3390/fishes9050152

Osman, H.M., El Ganainy, A.A., & Amin, A.M. (2019). A study on diet composition and feeding habits of Barracuda fish (*Sphyraena chrysotaenia* and *S. flavicauda*) in the Gulf of Suez. *Egyptian Journal of Aquatic Biology and Fisheries*, *23*(1), 223-232 https://doi.org/10.21608/ejabf.2019.26694

Park, J.M., Kang, M.G., Kim, J.H, Jawad, L.A & Majeed, S. (2023). Otolith morphology as a tool for stock discrimination of three rockfish species in the East Sea of Korea. *Frontiers in Marine Science*, *10*, 1301178. https://doi.org/10.3389/fmars.2023.1301178

Paxton, J.R. (2000). Fish otoliths: do sizes correlate with taxonomic group, habitat and/ or luminescence?. Philosophical Transactions of the Royal Society of London B 355, 1299-1303.

Pastore, M.A. (2009). *Sphyraena intermedia* sp. nov. (Pisces: Sphyraenidae): a potential new species of barracuda identifiedfrom the central Mediterranean Sea. *Journal of the Marine Biological Association of the UK*, *89*, 12991303. https://doi.org/10.1017/S0025315409000575

Popper, A.N, Ramcharitar, J., & Campana, S.E. (2005). Why otoliths? Insights from inner ear physiology and fisheries biology. *Marine and Freshwater Research*, *56*(5), 497-504.

Ragheb, E. (2023). Length-weight relationship and well-being factors of 33 fish species caught by gillnets from the Egyptian Mediterranean waters off Alexandria. *Egyptian Journal of Aquatic Research*, *49*(3), 361-367. https://doi.org/10.1016/j.ejar

Rai, D., & Rani, A. (2022).Comparative Otolith Morphology and Morphometry of Cyprinid Fishes from Indian Waters. *Biology Bulletin*, *49*(2), S113–S121 https://doi.org/10.1134/S1062359022140138

Relini, M., & Orsi Relini, L. (1997). The two species of barracuda (Sphyraenidae) in the Western Mediterranean. *Cybium*, *21*, 216-222.

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada*, *191*, 1-382.

Secor, D.H., & Dean, J.M. (1989). Somatic growth on the otolith–fish size relationship in young pond-reared striped bass, Morone saxatilis. *Canadian Journal of Fisheries and Aquatic Sciences*, *46*, 113-121. https://doi.org/10.1139/f89-015

Shaila Prasad, R., Santhosh, B., Abraham, K.M., Jasmine, S., Surya, Saleela K. N., & Udayakumar A. (2021). Morphometric variations associated with breeding season in obtuse barracuda, *Sphyraena obtusata*

Cuvier, 1829 observed from the commercial fish landings at Vizhinjam, Kerala, India. *Journal of the Marine Biological Association of India*, 63 (2), 36-42. https://doi.org/10.6024/jmbai.2021.63.2.2176-05

Sokal, R.R., & Rohlf, F.J. (1987). Introduction to Biostatistics. W.H. Freeman, New York, USA. 374 pp.

Tuset, V.M., Lombarte, A. González, J.A. Pertusa, J.F., & Lorente M. (2003). Comparative morphology of the sagittal otolith in *Serranus spp. Journal of Fish Biology*, *63*(6), 1491-1504. https://doi.org/10.1111/j.1095-8649.2003.00262.x

Tuset, V.M., Lombarte, A., & Assis, C.A. (2008). Otolith atlas for the western Mediterranean north and central eastern Atlantic. *Scientia Marina*, *72*(S1), 7-198. https://doi.org/10.3989/scimar.2008.72s17

Watson, D.J., & Balon, E.K. (1984). Ecomorphological analysis of fish taxocenes in rainforest streams of northern Borneo. *Journal of Fish Biology*, *25*, 371-384.

Willis, S.C., Winemiller, K.O., & Lopez-Fernandez, H. (2005). Habitat structural complexity and morphological diversity of fish assemblages in a Neotropical floodplain river. *Oecologia*, *142*, 284-295.

Winemiller, K.O. (1991). Ecomorphological diversification in lowland freshwater fish assemblages from five biotic regions. *Ecological Monographs*, *61*(4), 343-365

Yedier, S. (2021). Otolith shape analysis and relationships between total length and otolith dimensions of European barracuda, *Sphyraena sphyraena* in the Mediterranean Sea. *Iranian Journal of Fisheries Sciences*, *20*(4), 1080-1096. http://jifro.ir/article-1-4620-en.html

Zorica, B., Sinovcic, G., & Cikes Kec, V. (2010). Preliminary data on the study of otolith morphology of five pelagic fish species from the Adriatic Sea (Croatia). *Acta Adriatica*, *51* (1), 89-96.