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Young-of-the-Year Yellowmouth Barracuda *Sphyraena viridensis* (Cuvier, 1829) Growth in Eastern Algeria Based on Otolith Microstructure Analysis

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Abstract

Age estimates were made on otoliths of 32 young-of-the-year (YOY) Barracuda, *Sphyraena viridensis* Cuvier (1829), captured in the south-western Mediterranean Sea. Increments were observed in Barracuda sagittae sectioned in a transverse plane and viewed with light microscopy. Increment counts were made for age estimation. Estimated ages ranged from 27 to 299 days of fish ranging in size from 15.9 to 38.9 cm total length (TL). The observed mean growth rate is 3.487 mm.day^{-1}. Decreasing growth performance is evidenced according to age: 3.822 mm.day^{-1} between 159 and 302 mm (27–139 days), 1.596 mm.day^{-1} between 352 and 389 mm (172–299 days).

Keywords Daily growth rate · Sagittae · *Sphyraena viridensis* · Eastern Algeria

Introduction

Otoliths naturally log data that record and store information in their microstructure and chemistry at different spatio-temporal scales related to growth and habitat use by fish (Kalish 1989; Campana 1999; Yamashita et al. 2000; Berg et al. 2005). Because of the information they contain, otoliths are unique and the single most important biological structure in the teleost fish body (Berg et al. 2005). The discovery of daily increments has made the interpretation of otolith microstructure a major tool for investigating the early life history of fishes (Pannela 1971). The presence of daily increments has now been verified for a wide variety of species (Jones 1986).

Family Sphyraenidae (Barracudas) contains one genus Sphyraena which includes twenty-one species (Nelson 2006). They are pelagic to demersal fishes, single or in schools. Four Sphyraenidae species occur in the Mediterranean Sea, two of which, *Sphyraena chrysotaenia* (Klunzinqer, 1884) and *S. flavicauda* (Ruppell, 1838) are of Red Sea origin (Golani et al. 2006). *Sphyraena viridensis* (Cuvier, 1829) is an Atlanto-Mediterranean species found from Iceland to Morocco and Cape Verde, Madeira Island, the Canaries and the Azores (Ben-Tuvia 1986; Froese and Pauly 2014). However, its exact distribution and abundance is unknown (Kara and Bourehail 2003). Golani et al. (2006) noted that it occurs mainly in the southern Mediterranean. Milana et al. (2014) reported that *S. viridensis* is a native Mediterranean species, with an occurrence no longer rare and suggested as having a north ward distributional expansion. In many reports, *S. sphyraena* (**Linnaeus, 1758**) and *S. viridensis* are considered as the juvenile and adult of the same species *S. sphyraena* (Relini and Orsi-Relini 1997; Vacchi et al. 1999; Golani et al. 2006). Pastore (2009) describe a new species *S. intermedia* and believe that it is not hybrid between *S. sphyraena* and *S. viridensis*. Considering otolith shape, Bourehail et al. (2015) distinguish the two species *S. sphyraena* and *S. viridensis*.

In Mediterranean, Sphyraenidae, all species combined, have an average annual production of 1000 T in 2014 (FAO 2016). In western Mediterranean, *S. viridensis* is becoming more and more present in fisheries (Azzurro et al. 2011) and has become very common on the Algerian coasts since the early 1990s where it is highly appreciated by consumers.

Despite its ecological interest as indicator of Mediterranean warming (http://www.ciesm.org/marine/programs/tropicalization.htm) and its economic importance, information on the biology and dynamics of *S. viridensis* is extremely limited. Only Allam et al. (2004) studied its growth in Egyptian waters. Villegas-Hernandez et al. (2014) compared its reproduction with those of *S. sphyraena* in the

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north-west Mediterranean; Barreiros et al. (2002) analysed its diet in the Atlantic.

This study is the first attempt to estimate age and growth of young *S. viridensis.* In this purpose, we used the information recorded in the otoliths. Analysis of daily growth increments in otoliths from juvenile specimens can provide valuable information about the early growth stages. The ability to accurately determine the age and growth rate is an essential feature of population dynamics and stock assessment models for fisheries.

Materials and Methods

Study Area and Sampling

Sagittal otoliths used in this study were obtained from samples of 32 specimens, caught in the Gulf of Annaba in the south-western Mediterranean Sea (36°54'N, 7°45′E) (Fig. 1), where temperature ranged from 14 to 25.5 C° and salinity from 35.1 to 37.5 (Frehi et al. 2007). The juvenile Barracuda *Sphyraena viridensis*, ranging from 159 to 389 mm in total length (17.06 to 228.44 g) were collected between July and October 2009 from commercial trawlers and from the artisanal fishery.

Laboratory Procedures

Total weight (TW) in g, total length (TL) in mm, and date of capture were recorded for each fish. Sagittal otoliths (left and right) were removed, cleaned of adhering tissue, dried and stored in clean Eppendorf tube. The following measures of each otolith were taken with a calliper to the nearest mm: length (Lo), width (lo) and the thickness (To). Their weight (Wo) is committed to 0.001 g. From each pair, one otolith was randomly selected and mounted on a glass slide with thermoplastic Crystalbond resin. Each otolith was sectioned and ground with a series of abrasive papers of decreasing roughness from 12 to 9 to 3 mm and polished with 0.3 mm alumina paste on a polishing cloth until daily rings were discernible from the centre to the edge (Miller and Storck 1982; Secor et al. 1991; Jones 1992; Hayes 1995). The process was checked frequently under a light microscope adapted for video viewing to avoid over-polishing the centre. Counts of rings in each otolith were blind-read; the information about fish length and date of capture was withheld from the reader. All otoliths were read twice by two readers and final age estimates achieved when the differences, obtained from the two readings, were less than 5 days. A system microscope with objective lenses with nominal magnifications of 20×, 40× and 100× was used for the daily ring counts. The daily rings were counted from the nucleus to the dorso-posterior axis, however the readings were not always countable in a linear axis. Age was determined by counting the number of increments from the nucleus to the outer edge of the otolith.

The spawning season was determined by analysing the temporal evolution in the relative frequency of maturity stages and the gonado-somatic index GSI = (GW/TW) × 100. Based on juvenile frequency distribution and the GSI, the date of spawning was determined. Hatch date distributions were back-calculated by subtracting the estimated age (days) from the date of capture.

Data Analysis

The relationship between different otolith measures (length Lo, width lo, thickness To and weight Wo) and somatic parameters (TL, TW) was investigated by linear regression. Paired t-tests were used to determine if there were different daily age counts between left and right otoliths. No significant differences in increment counts were found between left and right otoliths (paired t-test, $N = 32$, $P > 0.05$), so for further daily age estimations only one otolith was randomly selected. The precision of the daily ring counts was calculated using the average percentage error (APE) of Beamish and Fournier

Fig. 1 Location of studied area in the South-Western Mediterranean Sea

(1981) and coefficient of variation (CV) (Chang 1982; Campana 2001). An age–length key was generated to convert larger length samples from the population into ages. Observed daily growth rate was calculated by dividing the fish length by its age in days. Individual growth rate differences were researched by K-means analysis (MacQueen 1967). Theoretical daily growth rate ($mm.d^{-1}$) was determined from the slopes of a linear regression based on the following equation:

$$TL = a + b \times age\ (d)$$

where, TL is the total fish length (mm); *a* is the fish size at age 0; *b* is the somatic growth rate. Statistical analyses were performed with Minitab 18 software package.

Results

Otoliths of YOY. *S. viridensis* are lancelolated and thin. The inner face is convex and the outer face is flat. The dorsal margin is sinuate. The posterior margin is rounded ventrally. The *sulcus* is *ostial* and the *cauda* had a poorly defined tip. Length of YOY *S. viridensis* was strongly correlated with their otolith width ($r^2 = 0.872$), length ($r^2 = 0.898$), thickness ($r^2 = 0.742$) and weight ($r^2 = 0.894$) (Table 1). The Age-weight relationship is Wt (g) = $32.29exp^{0.007x}$ ($r^2 = 0.833$) (Fig. 2).

Sectioning and polishing of the sagittae enhanced the light microscopy images, particularly in the area near the core (Fig. 3). The primordium, thought to be the original point of growth, was clearly visible as a dark spot in the center of the core. In general, patterns of formation of micro-increments of YOY *S. viridensis* < 40 cm TL were very distinctive, showing two micro-structural zones (I and II) (Fig. 3a.). The first one formed immediately after a diffuse area surrounding a central primordium and extended to ~20 days (Fig. 3b.). The increment width in Zone I, showing a sequential increase, a regular appearance and almost a complete absence of subdaily microincrements. Zone II is characterised by the presence of wider micro-increments (Fig. 3c.) where the formation pattern is more irregular, with the presence of growth discontinuities.

The estimated age obtained from the increment counts of the otoliths ranged between 27 d (15.9 mm TL) and 299 d (389 mm TL). The daily growth increments consisted of an accretion zone and discontinuous zone and were clearly and easily distinguished along a counting path from the core to the ventral edge. Precision of daily ring counts estimates was calculated as APE 1.5% and CV 1.86%. An APE and CV values which are below 10% comprise an acceptable ageing accuracy between ageing estimates.

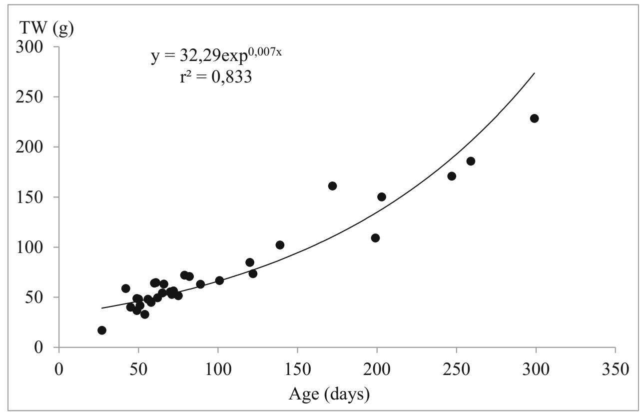

Fig. 2 Age–weight relationship estimated for young of the year *Sphyraena viridensis* from Algerian eastern coasts

Individual observed average daily growth rate varied between 1.301 ± 1.28 mm and 6.142 ± 1.28 mm (mean = 3.487 ± 1.28 mm). Two phases of different growth rate are identified: 3.822 $mm.day^{-1}$ from 159 mm (27 d) to 302 mm (299 d) and 1.596 $mm.day^{-1}$ from 352 (172 d) to 389 mm (299 d) (Fig. 4).

Estimated spawning dates, based upon the otolith analysis, were from April 11 to August 03. The half of the sampled specimens (50%) spawned in July (Fig. 5).

Discussion

Otolith morphology of YOY. *S. viridensis* is not different from those of adults (Bourehail et al. 2015). Statistically significant relationships exist between otoliths measurement and fish length. Therefore, it is possible that otoliths morphometric measurements (Lo, lo, and Eo) could provide a good alternative way to age young *S. viridensis.*

Our observations of the sagittae clearly recognized fine increments resembling those found in otoliths from some

Table 1 Summary statistics of otolith measurements (sagittae) of young-of-the-year *S. viridensis* from eastern Algeria

Otolith measurements	N	r^2	*a*	*b*	Mean ± S.D.	Range
Lenght (Lo) (mm)	32	0.878	0.741	−0.925	5.79 ± 1.126	5.79–11.09
Width (lo) (mm)	32	0.86	0.603	−1.033	2.71 ± 0.324	2.11–3.64
Tickness (To) (mm)	32	0.757	0.556	−1.443	0.809 ± 0.09	0.61–1.04
Weigth (Wo) (g)	32	0.903	0.593	−2.812	0.019 ± 0.007	0.009–0.047

N, number; *SD*, standard deviation

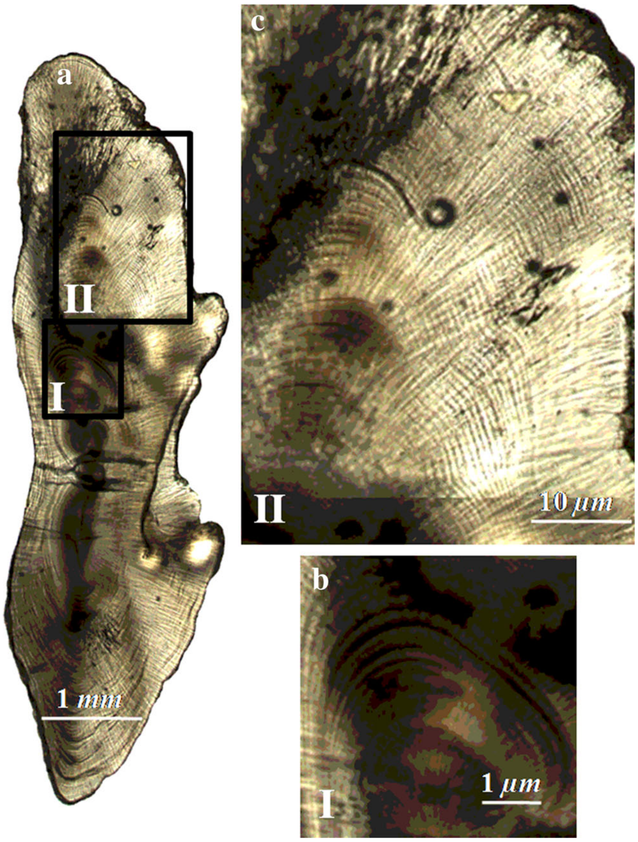

Fig. 3 Photographs showing microstructural features of sagittae from a juvenile *Sphyraena viridensis* (250 mm TL, 72 days old) from Algerian eastern coasts

adults (Bourehail et al. 2015). They were also similar to validated daily increments described for other species with similar growth pattern as the great barracuda *S. barracuda* (Kadison et al. 2010) and Swordfish *Xiphias gladius* (Megalofonou et al. 1987; Akyol and Ceyhan 2013).

A distinctive feature of this species was the occurrence of two microstructural zones in otoliths: a first zone where primary increments were more homogeneous and easy to identify, in contrast with a second zone where ring's alignment and

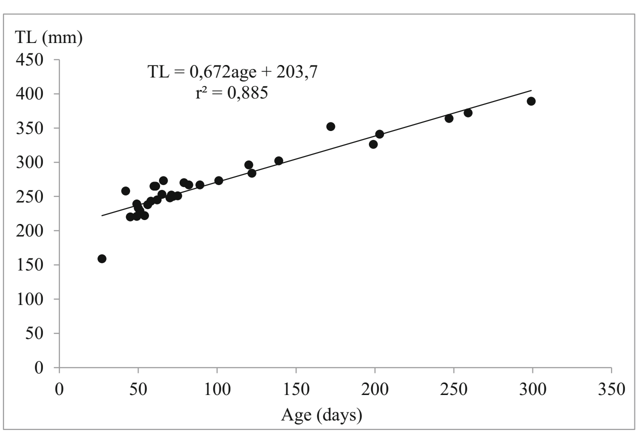

Fig. 4 Age–length relationship estimated for young of the year *Sphyraena viridensis* from Algerian eastern coasts

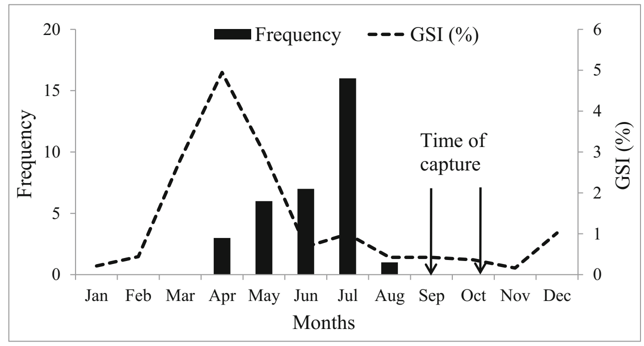

Fig. 5 Estimated date of spawning of *S. viridensis* from eastern Algeria, obtained from individual monthly length frequency, GSI and sampling time

other perturbations predominated. Microstructural zones in sagittal otoliths of YOY have been reported in several teleost fish (Wellington and Victor 1989; Beldade et al. 2007; Sponaugle et al. 2010; Garcia-Seoane et al. 2015), particularly in demersal and reef-associated fish (Victor 1986; Wilson and McCormick 1997; Sponaugle et al. 2010). These features have been linked roughly with the larval stage, the transition from larval to juvenile stages or habitat transitions, and later juvenile stages where juveniles occur in nursery areas or deeper habitats (Jenkins and May 1994; Raventos and Macpherson 2001; Plaza et al. 2001; Mansur et al. 2014). Conversely, abrupt changes in otolith microstructure seem to be less common in sagittal otoliths of YOY of pelagic fish where habitat transition is less marked (Cerna and Plaza 2016). However, subdaily rings, double microincrements, discontinuities and other perturbations have been reported in some areas of sagittal otoliths in recent studies in other pelagic fish as the great barracuda *S. barracuda* (Kadison et al. 2010) and Sword fish *Xiphias gladius* (Akyol and Ceyhan 2013) similar to the microstructural features observed in the transition zone in this study.

The succession of spawning date (May – August; Bourehail et al. 2010) and the apparition of the smaller individuals in September 15th showed by fish length frequency distribution (Bourehail, unpub. data), support the daily deposition of rings on the otoliths of 0^{+}*S. viridensis*. This is corroborated by the annual growth of this species who attains 445 mm at 1 year old (Bourehail et al. 2010).

Observed mean daily growth increment is 3.486 mm.day^{-1} during the ten first months of fish life. Two growth stages are recognized. During the first two months, the growth is better (3.822 mm.day^{-1}) than the rest of the year (1.596 mm.day^{-1}). The upward trend in the first stage suggests a period of accelerated growth, because larvae are able to feed independently. Importantly, during this period there is continuous development of morphological and sensory aspects of larvae, which increases their motility and ability to capture prey. The theoretical daily growth increment (0,67 mm.d^{-1}) is very low compared to the observed value and is equal to the calculated value in the congeneric species *S. barracuda* inhabiting the North Atlantic Ocean (D'Alessandro et al. 2013). In swordfish *Xiphias gladius*, a species with the same annual growth pattern, Arata (1954) also estimated theoretical larvae daily growth at 0.60 mm. Larvae of Sphyraenidae are known to have some of the highest rates of growth and mortality of any marine fish studied (D'Alessandro et al. 2013). This fast growth is fueled by early digestive system development and consumption of larval fishes, which are of higher energy content and nutritional value than crustaceans (reviewed in Tanaka et al. 1996; Govoni et al. 2003).

The results of this study indicate that daily growth increments can be used to estimate the age of young-of-the year *S.viridensis* and help clarify some aspects of juvenile growth of this species. Further studies on otoliths from both smaller and larger individuals, can provide the information necessary to form a better understanding of the growth of juvenile Barracudas.

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Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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