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Age and growth of juvenile swordfish, *Xiphias gladius linnaeus,* from the Mediterranean Sea

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Abstract

Age estimates were made on otoliths of 21 juvenile swordfish, *Xiphias gladius* Linnaeus, captured in the Mediterranean Sea. Increments were observed in swordfish sagittae sectioned in a transverse plane and viewed with light and scanning electron microscopy. Increment counts, presumed to be daily, were made for age estimation. Estimated ages ranged from 87 to 147 days of fish ranging in size from 51 to 74 cm lower jaw fork length (LJFL). A growth rate of 2.3 $cm \cdot day^{-1}$ for the range of size of the fish was estimated. Spawning dates were estimated to occur from June 27 to August 25, which is consistent with reported times of gonad maturation and occurrence of swordfish larvae in the plankton.

Keywords: Age; Growth; Mediterranean; Otolith; Pelagic; Swordfish

1. Introduction

The swordfish *Xiphias gladius* Linnaeus, occurring in warm and temperate zone waters of the Indo-Pacific and Atlantic Oceans and the Mediterranean Sea, supports important commercial and recreational fisheries. A large commercial fishery has developed in the Mediterranean in recent years, even though the existence of swordfish was known in ancient times, and the fishery is closely tied to history and the traditions of the people. In 1983, landings from the Mediterranean numbered 6896 MT which was

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26% of the world catch, increased to 20339 MT in 1988 and decreased to 13508 MT in 1992, 36% of the world catch (ICCAT, 1993).

Recent research on swordfish stocks in the Atlantic and Mediterranean shows that this species is currently being fished at near maximum levels (Miyake & Rey, 1989; ICCAT, 1993). However, a lack of biological data, particularly on age and growth rates, prevents definitive assessment of the status of the resource (Berkeley, 1989; Sakagawa, 1989).

The ability to accurately determine the age and growth rate of fish is an essential feature of population dynamics and stock assessment models for fisheries, and provides a better understanding of the life-history of a species (Wilson et al., 1991). Such knowledge is crucial for analyzing the reproductive strategy of the fish and development of resource management plans.

Age estimation of swordfish has been attempted using size-frequency analysis (Yabe et al., 1959; Kume & Joseph, 1969; Beckett, 1974; Ovchinikov et al., 1980; De Metrio & Megalofonou, 1987) and structural features of hard parts, such as spines and otoliths, (Berkeley & Houde, 1983; Radtke & Hurley, 1983; Wilson & Dean, 1983), but remains indeterminate.

Swordfish otoliths have not been widely used for age estimation because of their minute size. Li Greci (1981) described swordfish otolithios in detail and Wilson & Dean (1983) demonstrated that the microstructural morphology of the swordfish otolith is consistent with that of other pelagic teleosts aged by daily increment analysis (Radtke & Dean, 1981; Radtke & Hurley, 1983; Wilson & Dean, 1983; Prince et al., 1986).

Knowledge of the early life-history of swordfish is extremely limited. Analysis of growth increments in otoliths from juvenile specimens can provide valuable information about the early growth stages of this fish. However, otoliths from juvenile swordfish are seldom available and it is extremely difficult to verify or validate the growth zones. In fact, considering the difficulty associated with the capture or keeping juvenile billfishes alive, little experimentation can be done to measure their growth.

The goal of this study was to estimate age and growth of young swordfish from information recorded in the otoliths by determining (1) whether the observed internal increments in swordfish sagittae are possible daily growth increments by examination of morphology of the microstructure and comparison with othe pelagic fish; (2) whether the spawning dates estimated from increment counts are consistent with the timing of gonadal development of sexually mature fish and; (3) to test if estimated spawning (and hatching) dates are consistent with the observed occurrence of larvae and juveniles collected from the Mediterranean Sea.

2. Materials and methods

Twenty-six Mediterranean swordfish were collected during commercial albacore operations in the Gulf of Taranto (40 N, 17,30′E) in the autumn of 1987. Total and eviscerated weight in kg, lower jaw fork length (LJFL) in cm, and date of capture were recorded for each fish. The heads were frozen for later extraction of the otoliths.

Semicircular canals were removed (Haake et al., 1982; Wilson & Dean, 1983) and put into distilled water for 30 min. Otoliths were removed from the tissues, cleaned, dried, and attached to a glass slide with Permount. Small increments, concentric around the core region and radiating to the otolith edge, were observed with light microscopy and photographed before thin sections were prepared. Details of the methods of preparation follow the techniques of Secor et al. (1991).

The sagittae of 22 specimens, four samples were lost in processing, were removed from Permount using xylene and embedded in epoxy resin (Spurr, 1969) and ground in a transverse plane to the core using 220, 400, and 600 grit wet-dry emery paper. Sections were then polished against a piece of Microcloth containing 0.3 μm alumina polishing compound. One additional sample was lost during the polishing process.

Sections were examined at 600 to 1500 × with an Olympus BH2 compound microscope adapted for video viewing. Counts of successive increments and increment widths from the core to the ventral edge were made from the video monitor and confirmed with direct observation through the eyepieces. Counts were performed by two independent readers. Measurements were made from the core to the end of the tenth, 30th, 50th, 60th, and last presumed daily growth increment on the radius transect on 18 otoliths. Four sections were prepared by decalcification with 5% EDTA (pH 7.6), coated with gold, and examined with scanning electron microscopy (SEM) for verification of increment counts.

Counts of presumed daily growth increments were used to estimate the age and growth. An average percent error (Beamish & Fournier, 1981) of 2.1% was calculated for the two repetitive series of determinations. No difference was detected between counts of increments from the same section viewed by video projection, SEM, and compound light microscopy ($n = 4$) (Student's t-test, $p = 0.05$).

Because Yasuda et al. (1978) found that swordfish eggs hatched in 60 to 70 h after fertilization at water temperatures from 22.5 to 23.6 °C, three increments (days) were added to the count to estimate the age after fertilization.

3. Results

Swordfish (LJFL) ranged from 51 to 74 cm and weighed from 0.51 to 2.78 kg). The length-weight relationship for the 25 specimens (Fig. 1) was wt (kg) = 1.6911×10^{-8} LJFL 4.37; ($r^2 = 0.86$).

The sagittae of the juvenile swordfish are minute and the lapillus and asteriscus even smaller. Preliminary examination under the light microscope of sagittae embedded flat in Permount without any preparation revealed the optically dense core near the sulcus, surrounded by fine, apparently daily, increments. It was possible to count these to near the margin of the otolith.

Sectioning and polishing of the sagittae enhanced the light microscopy images, particularly in the area near the core. The primordium (Tanaka et al., 1981), thought to be the original point of growth, was clearly visible as a dark spot in the center of the core surrounded by two or three diffuse bipartite structural features. In some cases, the margin of this area was well defined by more optically dense material. The area of the core was surrounded by growth increments which are structurally analogous to the daily

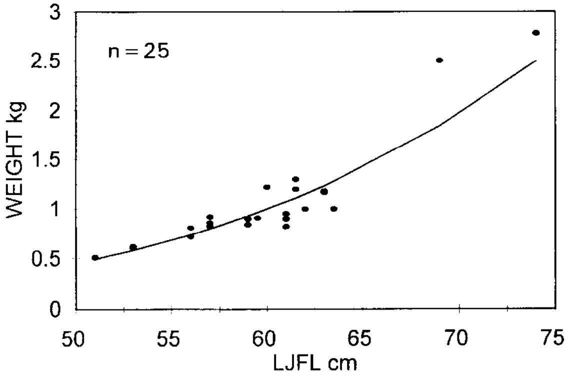

Fig. 1. Length and weight relationship for 25 juvenile swordfish from the Gulf of Taranto.

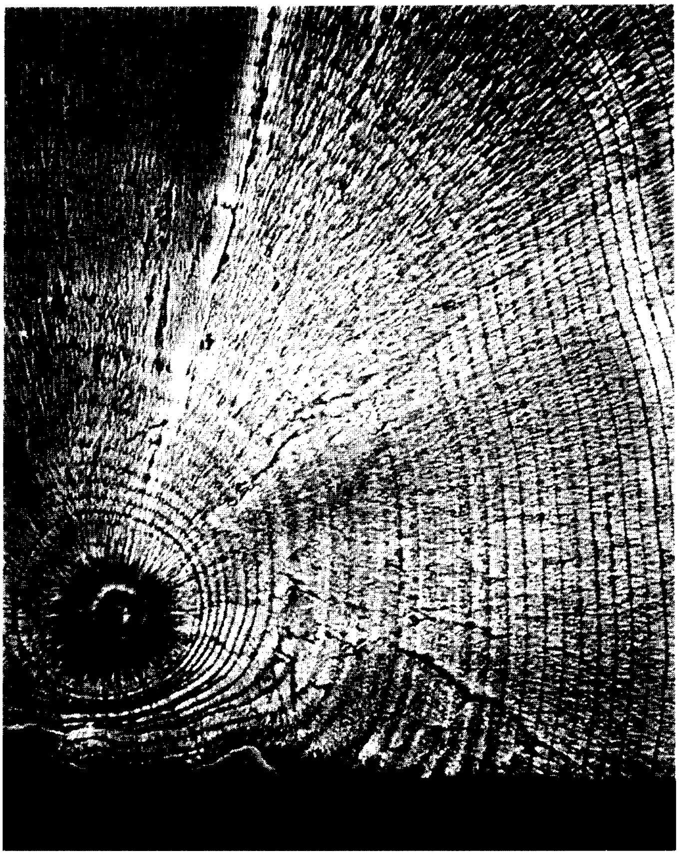

Fig. 2. Scanning electron micrograph of core region of juvenile sagittal otolith showing presumed daily increments (magnification = 710 ×).

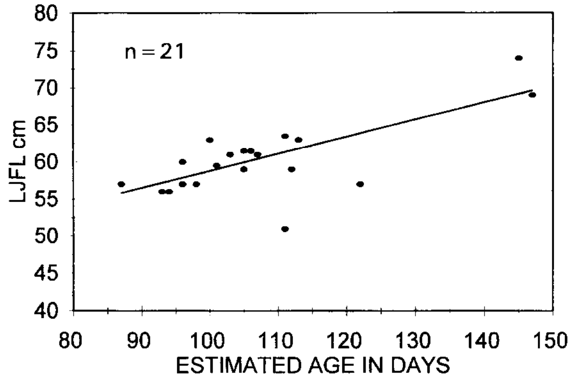

Fig. 3. A plot of LJFL versus estimated age in days.

growth units described in other species (Fig. 2) (Dean et al., 1983; Campana & Nielsen, 1985).

The presumed daily growth increments consisted of an accretion zone and discontinuous zone (Tanaka et al., 1981) and were clearly and easily distinguished along a counting path from the core to the ventral edge, and the variability in their widths was readily observable. A zone of about 10 increments just distal to the core (average width 4.8 um) was followed by another area of about 50 wider increments (average width 5.6 μm). Increment widths averaged 4.6 μm from this point to the tip of the antirostrum. The variation in increment widths from the core to the tenth, 30th, 50th, 60th, and last growth unit indicated differential otolith growth during presumably different developmental periods or growth conditions.

Estimated ages for 21 swordfish, which ranged in size from 51 cm and 0.51 kg to 74 cm and 2.78 kg, were 87 to 147 days. The average growth rate of each individual, calculated from length at estimated age, was 5.7 mm per day (range = 4.6–6.6 mm · 1 day^{-1}).

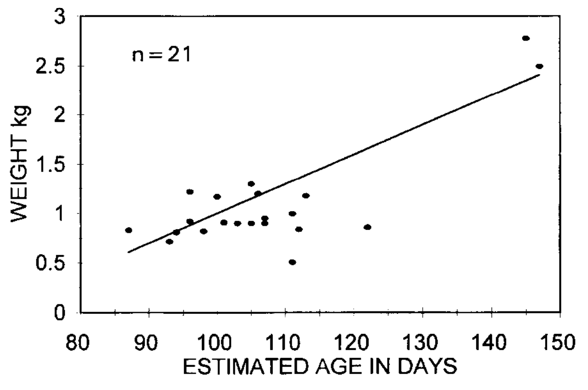

Fig. 4. A plot of fish weight (kg) versus estimated age in days.

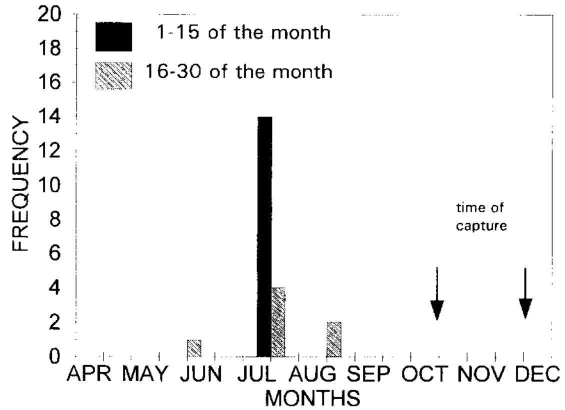

Fig. 5. Estimated date when the fish was spawned.

A linear regression model of age versus LJFL ($a = 35.8$, $b = 0.23$, $r^2 = 0.52$) and weight ($a = -2.0$, $b = 0.03$, $r^2 = 0.64$) (Figs. 3 and 4) yielded the best fit. The slope of 0.23 indicates a growth rate of 2.3 mm · 1 day^{-1} within the size interval analyzed.

Estimated spawning dates, based upon the otolith analysis, were from June 27 to August 25. Most of the specimens (85.7%) were spawned in July, especially during the first 15 days of the month (Fig. 5).

4. Discussion

In recent years, otolith microstructure examination has found an increasing number of applications in a wide range of species (Campana & Neilsen, 1985; Secor et al., 1989; Secor et al., 1995). Otolith microstructure studies, mainly of the larval and juvenile stages, have confirmed that daily increments can be used to accurately estimate age and growth rates of fishes (Brothers et al., 1976; Campana & Nielsen, 1985; Rice et al., 1985; Secor et al., 1989).

In our observations of the sagittae, with both the light microscope and with the SEM, we clearly recognized fine increments resembling those found in otoliths from adult swordfish taken in the Atlantic (Wilson & Dean, 1983). They were also similar to validated daily increments described for other species (Tanaka et al., 1981; Dean et al., 1983; Campana & Neilsen, 1985). Since otoliths from post-larvae and juvenile swordfish have all the microstructural characteristics that correspond to daily increments as observed in other species, we assume that they are daily even though the deposition rate has not been measured directly. Therefore, we used the increment counts to estimate the age and the growth rates for individual fish, as was previously done for other non-validated pelagic fish by Prince et al. (1991) for young Atlantic blue marlin and Brothers et al. (1983) for juvenile Atlantic bluefin tuna.

Daily growth increment formation can begin at a variety of points during ontogenesis, based on the species and developmental pattern (Brothers et al., 1976; Radtke &

Dean, 1981; Secor et al., 1989). Furthermore, the sagittae and probably the lapilli are known to be present at hatching in many scombrids (Sanzo, 1932; Radtke, 1983). Radtke (1983) found that in *Euthynnus pelamis* the first increment formed 1 day after hatching and ≈3 days after fertilization.

Since we have not directly determined deposition rate of the presumed daily growth increments in this study, our alternative was to verify the rate with indirect methods. A comparison of egg development in gravid female swordfish and sizes of larvae in zooplankton collections indicates that the eggs hatch quickly after spawning (3 days) and the yolk sac is relatively small. The literature on increment formation in teleosts supports the assumption that the increments probably form at hatching or very soon thereafter (Secor et al., 1989).

Two lines of evidence are used to support daily deposition: coincident distribution of estimated spawning dates and gonadal activity in adults. From our analyses, estimated spawning dates for fish we collected occurred during the months of June, July, and August, with most occurring during the first 15 days of the month (Fig. 5). These dates coincide with increased gonadal activity in adult swordfish (Megalofonou et al., 1987) and the appearance of swordfish larvae in collections from the Mediterranean, where spawning generally takes place throughout the Mediterranean Sea, and especially in the Straits of Messina, from June through August with the peak in early July (Sella, 1911; Sanzo, 1922; Cavaliere, 1963). In studies in the North Ionian Sea and the Aegean Sea, oocyte maturation in the gonads and the gonosomatic index indicate that July is the peak month for reproduction of swordfish, even though the reproductive period may be more protracted (Megalofonou et al., 1987; De Metrio et al., 1988).

Another method we used to corraborate the estimated juvenile ages was to compare this estimated spawning date with the presence of juveniles from the same population, estimated by length frequency analysis. Modal analysis of landings data from the commercial fishery suggested that swordfish between 55 and 65 cm captured in the Gulf of Taranto during autumn are less than 1 yr old (De Metrio & Megalofonou, 1987).

Considering that swordfish spawn (based upon gonadal condition and larval collections), from June to August, the individuals examined would have been spawned during the summer of the same year. Our results indicate that the swordfish which ranged in size from 51 to 74 cm, captured during autumn (October and a few in December) in the Gulf of Taranto, are juvenile individuals with estimated ages from 87 to 147 days. These results are consistent with those of De Metrio & Megalofonou (1987). Prevailing currents could act as a concentrating factor for retention of larval and juvenile swordfish in the Gulf of Taranto (Cefali et al., 1986).

Given that an individual fish, ≈60 cm long (LJFL), is estimated to be about 105 days old, the average growth, within the size interval from the theoretical dimension of zero to 60 cm, must be about 5.7 mm $\cdot$ day^{-1}. However, it is not clear whether the individual growth rate during this period is constant and linear or curvilinear. The regression analysis for swordfish within the size interval 51–74 cm showed that growth in this range was linear with a slope of 0.23 which corresponds to a growth rate of 2.3 mm per day. Thus, a slower growth during that range of length is implied. The evidence suggests that the growth rates during the early period must be more rapid than the average growth rate calculated (5.7 mm $\cdot$ day^{-1}) for the entire period. These estimates of growth rate are comparable to the estimates of post-larval and juvenile blue marlin (Prince et al., 1991) and bluefin tuna (Brothers et al., 1983).

We have not as yet examined otoliths from smaller swordfish (< 51 cm) from the Mediterranean because such samples are not available. Arata (1954) estimated that swordfish larvae may grow at a rate of 0.6 mm per day, while Tibbo & Lauzier (1983) estimated growth as about 2.0 mm per day. Berkeley & Houde (1983) estimated that the 1-yr-old individuals had a 100-cm LJFL, or a growth rate of about 3.0 mm per day, while Wilson & Dean (1983) estimated 1-yr-old fish to be 120 cm, or a growth rate estimate of a little greater than 3.0 mm per day. De Metrio & Megalofonou (1987) estimated that the average size of 1-yr-old swordfish is about 97.5 cm with a monthly growth rate of 20 to 30 cm for individuals 60 cm long (LJFL). Prince et al. (1991) estimate that a 1-yr-old blue marlin is about 175 cm and grows about 1.66 $cm \cdot day^{-1}$ during the first year.

Increment widths during the early development of the larval stages varied and were consistent between individuals at the same relative stages of development. If increment width is proportional to fish growth, wider increments are correlated with faster somatic growth (Secor et al., 1989). However, increment widths and somatic growth are not allometric over all ranges of fish growth (Secor et al., 1989). Increased increment widths were observed after the first 10 increments while there was a reduction in width after the 60th increment. Changes in increment width and growth rate could be attributed to size-dependent changes in feeding and subsequent nutrition effects and to environmental factors such as temperature and larval, and juvenile distribution in water masses. Such changes are evident in larval, post larval, and early juvenile growth of other fishes (Nishimura & Yamada, 1984; Secor et al., 1989). However, definitive evidence for differential growth rates during the different developmental stages will require larger numbers of samples of swordfish of different sizes.

The results of this study indicate that daily growth increments can be used to estimate the age of young-of-the year swordfish and help clarify some aspects of larval and juvenile swordfish growth. It is not possible at this time to draw definitive conclusions about the entire pattern of growth in larval and juvenile stages, but we believe that further studies on otoliths, from both smaller and larger individuals, can provide the information necessary to form a better understanding of the growth of larval and juvenile swordfish.

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