

USE OF MARGINAL INCREMENT ANALYSIS TO VALIDATE THE ANAL SPINE METHOD
FOR AGEING ATLANTIC SWORDFISH AND OTHER ALTERNATIVES FOR AGE DETERMINATION

*E. D. Prince, D. W. Lee, S. A. Berkeley**

Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida, U.S.A.

**South Atlantic Fishery Management Council, 1 Southpark Circle, Charleston, South Carolina, U.S.A.*

SUMMARY

Anal spines for 508 Atlantic swordfish, *Xiphias gladius*, were examined using marginal increment analysis in an attempt to validate the accuracy of the anal spine method for estimating age and growth. Two sources of data were used--413 anal spines were sampled from swordfish from the Florida Straits between 1979-1980, while 95 spine samples were obtained from fish caught in the central Caribbean Sea during the winter of 1986. These data sets were combined and the analysis indicated that the data were so highly variable that differences in mean monthly marginal increments or mean monthly marginal increment ratios could not be detected.

Although marginal increment analysis did not provide evidence for validating the anal spine method of aging swordfish, we present preliminary data which indicate that other approaches to age determination might prove more productive. The daily increment method using otoliths from five juvenile swordfish (17.9 to 40.0 cm lower jaw fork length) resulted in a range of estimated ages of 32 to 50 days and shows promise for estimating early growth. Directed efforts for sampling skeletal structures from long-term tag-recaptured swordfish will prove helpful in validating older age groups.

RESUME

Les épines anales de 508 espadons atlantiques, *Xiphias gladius*, ont été examinées au moyen de l'analyse de la croissance marginale pour tenter de vérifier le degré de précision de la méthode qui utilise les épines anales pour estimer l'âge et la croissance. Deux sources de données ont été employées: 413 épines anales prélevées sur des espadons en provenance des détroits de Floride en 1979-80, et 95 sur des poissons capturés dans la région centrale de la mer des Antilles pendant l'hiver 1986. Ces jeux de données ont été combinés; leur analyse indique que les données étaient tellement variables qu'il était impossible de détecter les différences de la croissance marginale moyenne par mois, ou le taux correspondant.

Bien que l'analyse de la croissance marginale n'ait pas apporté de preuves permettant de vérifier la méthode qui utilise les épines anales pour la détermination de l'âge de l'espadon, nous présentons des données préliminaires qui signalent que d'autres méthodes de détermination de l'âge pourraient s'avérer plus efficaces. La méthode qui étudie la croissance journalière, appliquée aux otolithes de 5 espadons juvéniles (de 17,9 à 40,0 cm de longueur maxillaire-fourche), a donné une gamme d'âges estimés qui va de 32 à 50 jours et semble prometteuse pour estimer la croissance des premiers stades. Les efforts visant à échantillonner les pièces osseuses de poissons repris porteurs de marques longtemps après le marquage s'avèrera utile pour évaluer les groupes plus âgés.

RESUMEN

Se examinaron las espinas anales de 508 peces espada (Xiphias gladius) del Atlántico, por análisis del incremento marginal, en un intento de convalidar la exactitud de este método, usado para estimar la edad y el crecimiento. Se emplearon dos fuentes de datos: muestreo de 413 espinas anales de peces espada procedentes del Estrecho de Florida en el periodo 1979-1980 y 95 muestras de espinas de peces capturados en la zona central del Caribe durante el invierno de 1986. Estos conjuntos de datos fueron combinados y los análisis indican que los datos eran tan variables que las diferencias en la media de los incrementos marginales mensuales o tasa media de incrementos marginales mensuales, no pudo ser detectada.

Si bien el análisis del incremento marginal no facilitó la evidencia para validar el método de espinas anales para determinar la edad del pez espada, presentamos datos preliminares que indican que otros enfoques podrían resultar más productivos para los estudios de determinación de la edad. El método del incremento diario empleado en otolitos de cinco peces espada juveniles (17.9 a 40.0 cm de mandíbula inferior a horquilla) dió un rango de edades estimadas entre 32 y 50 días y parece prometedor para la estimación del primer crecimiento. El muestreo de estructuras óseas de peces espada recapturados bastante tiempo después de serles colocada la marca, puede resultar útil para determinar la edad de peces más viejos.

INTRODUCTION

Accurate age and growth information are a critical need for rigorous assessment of the status of fish populations (Prince and Pulos 1983). Although three approaches were recently presented for estimating the age and growth rate of Atlantic swordfish, Xiphias gladius (Prince and Pulos 1983), the accuracy of age determination methods has not been firmly established. Farber and Prince (1985) reviewed these papers in order to evaluate the most promising source of age and growth data for use in stock assessment. They reported that the data from Berkeley and Houde (1983) was the most complete of the three studies examined but were less than ideal for stock assessment since validation of the accuracy of the anal spine method was not accomplished.

Berkeley and Houde (1983) speculated that most bands on swordfish anal spines were probably formed in the winter, based on their findings that the lowest marginal increment measurements occurred during the winter season. However, the authors felt that small sample sizes during the winter months contributed to their inability to detect statistically significant differences in seasonal growth and firmly establish the time of annulus formation. Farber (1986) and Turner (1986) conducted additional analyses of the marginal increments from the original data of Berkeley and Houde (1983) and again reported that these analyses did not validate the anal spine method of ageing swordfish.

The acquisition of anal spines from winter caught swordfish from the central Caribbean Sea in 1986 made it possible to examine seasonal growth during a period that was not included in other studies. Therefore, the objective of this analysis was to re-examine the validity of the anal spine method of ageing swordfish by applying marginal increment analysis (MIA) to a combined data set, consisting of winter caught swordfish (1986) and the original data of Berkeley and Houde (1983). In addition, other alternatives to estimating the age of swordfish are examined.

Methods

The methods of sample collection, spine preparation and analysis of the original data (N = 413) are well described in Berkeley and Houde (1983). Collections of anal spines from January and February, 1986, were made through a contract lent by the National Marine Fisheries Service to the Corporation for the Development and Administration of the Marine Resources (CODREMAR) in Puerto Rico. Observers hired by CODREMAR were placed aboard U.S. longline vessels fishing in the central Caribbean Sea but used Puerto Rico as their home port. A total of 111 swordfish were sampled for anal spines during the winter of 1986. Of these,

95 were judged suitable for marginal increment analysis; 42 were males, 36 were females, and 17 had no sex information. Sixteen samples could not be used in the analysis because spine zonations were either abnormal, vague, or indistinct. The data for each fish consisted of capture date, lower jaw fork length (LJFL), sex, and information on anal spine measurements. Spine preparation and sectioning procedures of the original study (Berkeley and Houde 1983) were applied to the 1986 winter samples. Briefly, these procedures consisted of making two or three cross sections (less than 1 mm thick) with a slow speed saw in an area just above the condyle base of the second anal spine. Sections were stored in vials containing 5% Formalin and sections were viewed under a dissecting scope or on a video monitor (6 to 25X magnification) using transmitted light.

Zonations and marginal increments on the 1986 winter spine sections were measured and counted using a visual analysis system developed by McGowan et al. (1987) and recently modified by upgrading the microscope with a Zeiss (model SV-8) stereoscope. Computations of all measurements for each sample were made using the visual analysis system software, which measures the distance between sets of XY coordinates at a specific magnification on the video monitor in millimeters. Because the system has a high level of resolution in both the digitizer board (256 times 256 pixel units) and the video monitor, we feel that the potential problems associated with different magnifications and recording measurements in integers identified by Turner (1986) did not apply to 1986 data analyzed on the visual analysis system.

Two variables were examined for the marginal increment analysis: marginal increment measurement (MI) and marginal increment ratio (MIR). The MI is defined as the measurement, in millimeters, from the proximal edge of the last perceived translucent zone to the edge of the structure. The MIR used followed the original method of Hayashi (1976) and recently employed by Harris and Grossman (1985) as follows:

$$MIR = \frac{(R - r_n)}{r_n - r_{n-1}} \quad (1)$$

where R = spine radius, the distance from the focus to the edge of the section; and

r_n = radius at the most recent complete zone n.

In order to calculate the MIR for each sample, it was necessary that at least one complete translucent zone be present. The original data (Berkeley and Houde 1983) was modified by converting all measurements from ocular micrometer units, adjusted by the magnification on each sample, into millimeters. Computations of the MIR for both the original data and the 1986 samples were made in this manner. Those samples that were less than one year old were identified and not used in the MIR

analysis. The original data (Berkeley and Houde (1983) and the 1986 winter samples were then merged into one data set for analysis. The average MI, MIR, and 95% confidence intervals were computed from the merged data set (Table 1) by month for each sex and for all data combined (including unknown sex).

We evaluated the daily increment otolith method of estimating the age of young swordfish as an alternative approach to using the anal spine technique. This method consisted of examining the otoliths (sagittae) from five juvenile swordfish ranging in size from 17.9 to 40.0 cm LJFL (Table 2). The five samples were collected between 1984 to 1987 by netting or from the stomachs of larger predators. The methods of otolith extraction and preparation, increment counting procedure, and reader (E. B. Brothers, Ithaca, N.Y.) used on swordfish otoliths were basically the same as those described for young blue marlin, *Makaira nigricans*, (Prince et al. 1986), except that only one count was made on each otolith. In addition, sectioning was not necessary for otoliths from these juvenile swordfish because the sagittae were sufficiently thin to allow increments to be counted easily.

RESULTS AND DISCUSSION

The average monthly MI, MIR, and associated 95% confidence intervals for each sex and all data combined were so highly variable that they did not provide evidence for validating the accuracy of the anal spine method of ageing swordfish (Figs. 1 and 2 A, B, and C, respectively). In other words, the variability associated with mean values were so extensive that differences in mean MI and MIR could not be detected. These results agree with the original conclusions of Berkeley and Houde (1983), as well as the conclusions of additional work by Farber and Prince (1985), Farber (1986), and Turner (1986) that the accuracy of interpretations of zonations on swordfish anal spines have not been established using marginal increment analysis. Such conclusions were not particularly surprising since the MIA approach for age validation, which has been successful for so many teleosts (Summerfelt and Hall 1987), has not provided evidence for oceanic pelagic species on a regular basis (Brothers 1983, Casselman 1983, Prince et al. 1986).

The optimal conditions for using MIA for age validation are reviewed by Brothers (1983) and Casselman (1983). Factors to consider in collecting data that would optimize the use of MIA for age validation and reduce the variability associated with these data include: (1) collecting hardpart samples in the same localized area for every month of the year; (2) obtaining a sample size for each month that is sufficiently large (i.e. greater than N = 50) and covers a representative size range for each sex; and (3) collecting all data during the same calendar year. Incorporating these collection procedures for sampling

oceanic pelagic species has proved difficult, if not impossible, particularly for the billfishes (Prince and Pulos 1983). For example, none of these criteria were met in the present study (Table 1, Figs 1 and 2). Therefore, we suggest that other approaches should be taken for validating the accuracy of zones on anal spines, and in addition, the use of other ageing methods (or skeletal structures) be investigated for Atlantic swordfish.

Other Approaches for Age Determination

As a general rule, it is usually much easier to estimate the age and growth rates of young fish (of any species) because zones on skeletal structures are fewer in number and are often easier to count and measure accurately compared to adults (Summerfelt and Hall 1987). The daily increment otolith method has been validated for larvae and juveniles of many species, including numerous tropical fishes, using fish of known age from grow-out studies. It is generally accepted that increment formation is linked to an endocrine-driven endogenous circadian rhythm that is influenced primarily by photoperiod (Summerfelt and Hall 1987). The daily increment otolith method is the only direct technique known for estimating growth of fish less than one year old from skeletal structures and has shown promise for estimating the age and growth of young Atlantic blue marlin (Prince et al. 1986).

We evaluated the daily increment otolith method for estimating the age of swordfish by examining otoliths from five juveniles. Photographs of several samples illustrate the clarity of zonations associated with the core, first few weeks of life, and margin of swordfish otoliths that allowed these increments to be counted easily (Fig. 3B-E). On each otolith there was an area of transition (Fig. 3B) where the axis of growth of the sagittae changed direction and this necessitated refocusing the microscope to count the zonations near the edge of the structure (Fig. 3E). The area of transition is probably associated with a change in life mode; perhaps a modification in the diet for example. In addition, the deposition pattern and zonation characteristics of these samples were similar to other tropical species where age validation of daily increments have been firmly established (E. B. Brothers, personal comm., Ithaca, N.Y.). Such observations are encouraging and suggest a certain degree of confidence in the following preliminary results.

Estimated ages based on presumed daily increments ranged from 32 to 50 days for swordfish ranging in size from 17.9 to 40.0 cm LJFL (Table 2). These data suggest that growth of swordfish within the size interval analyzed is very rapid and is similar to preliminary results of early growth of blue marlin (Prince et al. 1986). Taning (1955) speculates that a swordfish 19.20 cm long is about 2 years old but then states this growth rate seems far too slow. The preliminary results from our study confirm Taning's feelings that swordfish grow very rapidly during their juvenile stage.

Back calculated birth dates occurred during the months of March, April, May, June, and December (Table 2). These data generally agree with Arata (1954) who reported the peak of spawning for swordfish in the south Atlantic to occur from April through September. However, it is well documented that swordfish larvae have been found during every month of the year (Taning 1955), so these data by themselves do not provide strong evidence that the deposition rate of these zones occur on a daily basis. However, the characteristics and clarity of the zones suggest that the daily increment method might provide an acceptable means of evaluating the growth of swordfish less than one year old.

Another method that might provide meaningful data on the age and growth of adult swordfish would be to obtain skeletal structures from tag-recaptured fish that have been at-large for extended periods. These types of data are probably more available for swordfish compared to other billfish because of the higher tag recapture rate for swordfish (almost 6% for swordfish compared to less than 2% for other billfishes) and the commercial nature of the fishery. These considerations would also indicate that an oxytetracycline injection program, in addition to conventional tagging, might prove to be a technique that could be used on swordfish. However, an international effort would have to be made to obtain skeletal structures from tag-recaptured specimens since the structures used for ageing (i.e. heads, spines) are generally discarded at sea when the fish are processed. It might be possible to collect hardparts from tag-recaptured swordfish by providing funds for rewards through the ICCAT Enhanced Research Program for Billfish, which will have at-sea observers aboard longline vessels. We believe that, similar to Atlantic blue marlin, it will probably take more than one ageing method and/or structure to resolve the difficult age determination problem for the full size range of Atlantic swordfish.

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TABLE 1. Monthly sample sizes for MI and MIR analyses of swordfish anal spines by all sexes (males, females, and unknown sexes), females, and males, 1979-1980 and 1986.

	MI			MIR		
	all sexes	females	males	all sexes	females	males
Jan	65	28	24	61	26	23
Feb	34	10	20	32	9	20
Mar	11	5	6	10	5	5
Apr	69	25	43	60	20	39
May	46	18	28	40	15	25
Jun	64	20	44	62	19	43
Jul	40	12	27	33	11	21
Aug	40	10	28	35	10	23
Sep	59	24	35	35	13	22
Oct	52	21	31	33	14	19
Nov	24	13	11	19	11	8
Dec	4	2	2	3	1	2
TOTAL	508	188	299	423	154	250

Table 2. Count of presumed daily increments by one reader on whole otoliths from 5 juvenile Atlantic swordfish ranging in size from 17.9 to 40.0 cm LJFL. Birth dates were back-calculated based on date of capture and estimated age.

Specimen Number	LJFL (cm)	Date Caught	Estimated Age (days)	Back-calculated Birth Date
1	17.9	06/17/86	32	05/17/86
2	26.1	05/05/87	36	04/30/87
3	33.9	05/04/87	48	03/18/87
4	37.9	07/23/87	46	06/08/87
5	40.0	02/10/84	50	12/14/85

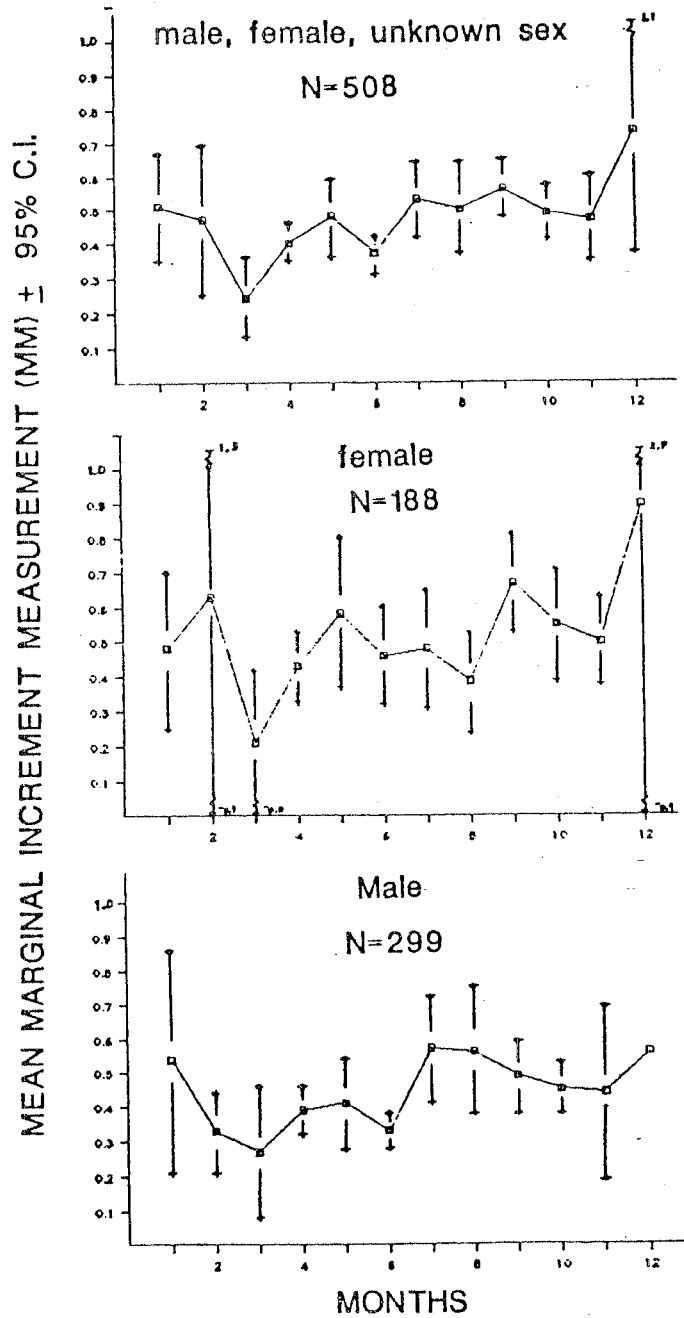


Figure 1. Mean marginal increment measurement (mm) and 95% confidence intervals from swordfish anal spines for all sexes combined (male, female, unknown sex), female, and male, 1979-80 and 1986.

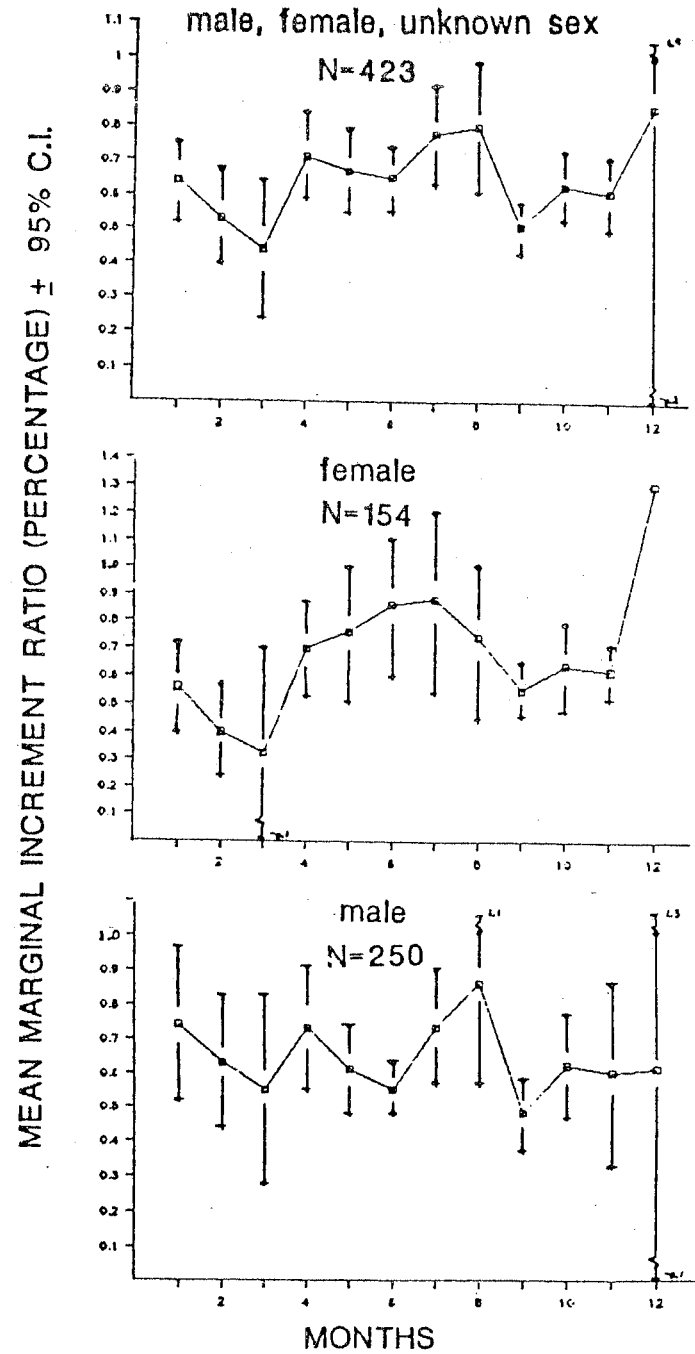


Figure 2. Mean marginal increment ratio (percentage) and 95% confidence intervals from swordfish anal spines for all sexes combined (male, female, unknown sex), female, and male, 1979-80 and 1986.

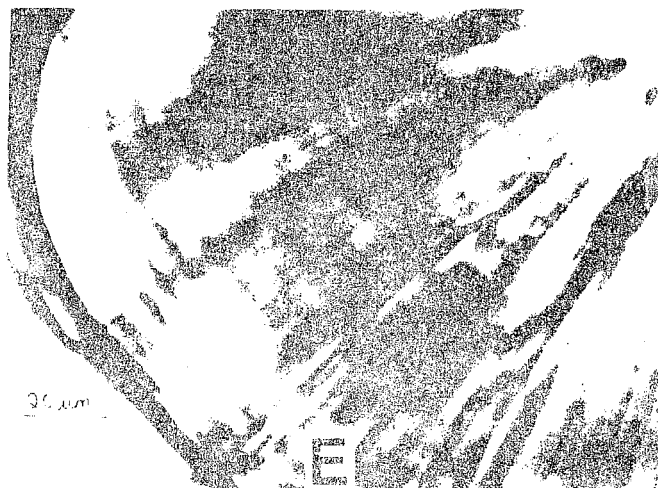
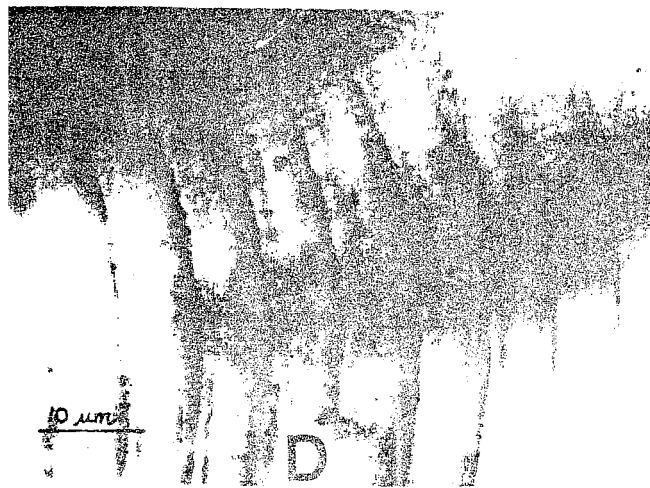
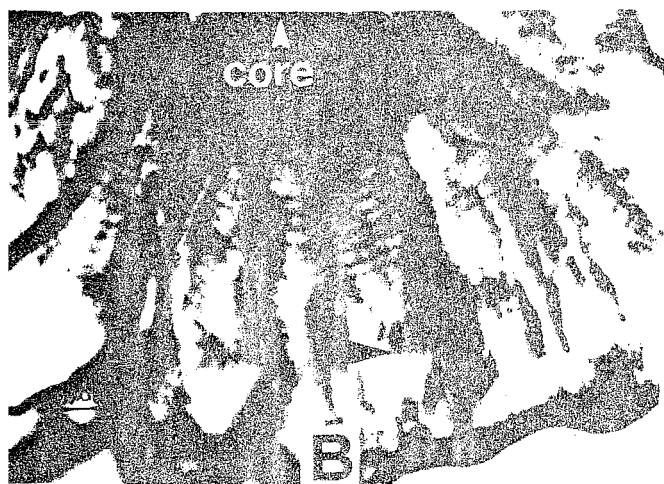
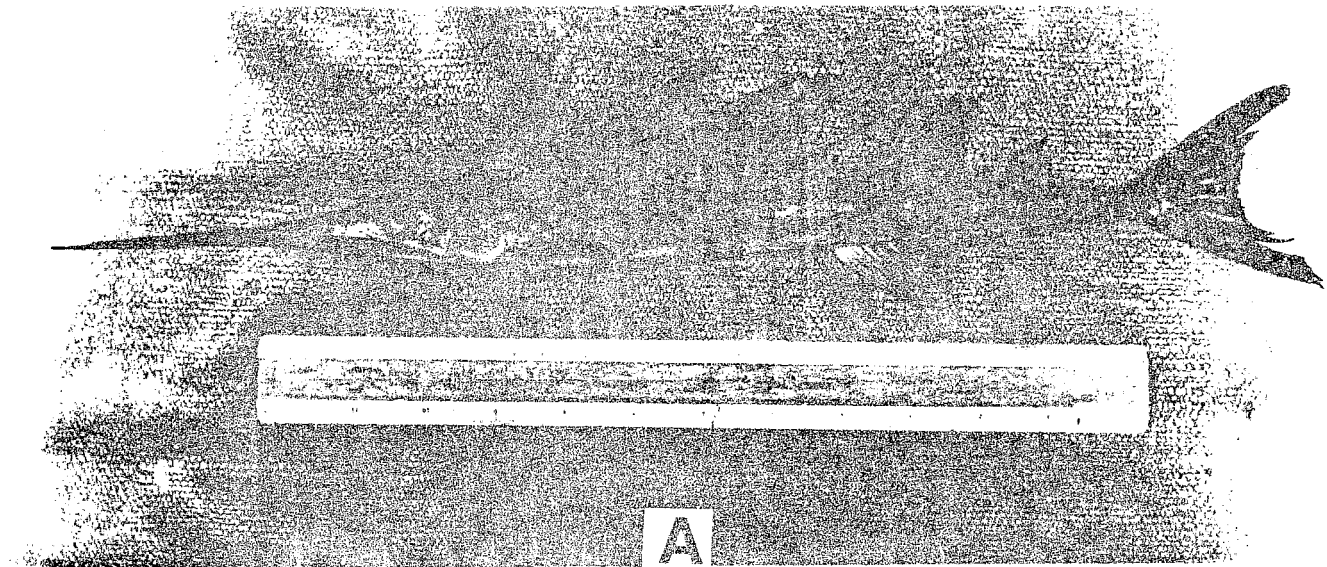


Figure 3. (A) Juvenile Atlantic swordfish (40.0 cm LJFL); (B) whole sagittae from a 37.9 cm LJFL juvenile swordfish showing origin of growth (core) and area of transition (arrow); (C) Early growth zones prior to area of transition of (B); (D) Closer-up of early growth zones of (B); and (E) Growth zones at edge of the sagittae after area of transition of (B).