

# Preliminary Age and Growth Estimates of the Rabbitfish, *Chimaera monstrosa*, with Implications for Future Resource Management

**E. Calis**

Zoology Department, Trinity College, Dublin 2, Ireland

**E. H. Jackson**

An Bord Iascaigh Mhara (Irish Sea Fisheries Board), Crofton Road  
Dun Laoghaire, Co. Dublin, Ireland

**C.P. Nolan**

An Bord Iascaigh Mhara (Irish Sea Fisheries Board), Crofton Road  
Dun Laoghaire, Co. Dublin, Ireland

and

**F. Jeal**

Zoology Department, Trinity College, Dublin 2, Ireland

CALIS, E., E. H. JACKSON, C. P. NOLAN, and F. JEAL. 2005. Preliminary Age and Growth Estimates of the Rabbitfish, *Chimaera monstrosa*, with Implications for Future Resource Management. *J. Northw. Atl. Fish. Sci.*, 35: 15-26. doi:10.2960/J.v36.m501

## Abstract

The holocephalan, *Chimaera monstrosa*, constitutes 13–15% of the discards in deepwater trawlers operating off the West Coast of Ireland. Given the increased interest in the production of dietary supplements for human consumption derived from the liver oil of this species, a directed fishery has the potential to develop in areas of occurrence. In common with the majority of shelf slope and deep-water species, there is a paucity of biological and life history information available on this species. No information is available on the growth and maturation rates, with the closest comparative material being from commercially retained *Callorhinchus* species from New Zealand. A total of 62 specimens (10 male, 52 female) were collected non-randomly, by at-sea observers in the Rockall Trough and Faroe-Shetland Channel (ICES areas; 27 IVa, VIIb and VIIc) in August and October 2001 from the hauls of commercial fishing vessels. Specimens ranged in size from 26 cm to 74 cm pre-supra caudal fin length. The range of maturity was from juvenile to mature for both sexes. Dorsal fin spines were removed and serial cross-sections were used to establish the optimum position of section. Growth increments were counted in ground and polished transverse sections, and four readers conducted 3 independent readings of each section. The estimated ages ranged from 3 to 30 years and 4 to 26 years, for males and females, respectively. The von Bertalanffy growth parameters of *Chimaera monstrosa* were:  $L_{\infty} = 78.87$  (cm),  $K = 0.0673$  per year and  $t_0 = -2.513$  (yr). These parameters, together with the estimated ages, indicate that *Chimaera monstrosa* is a long lived, late maturing species. A significant relationship between the corrected total spine length and the estimated age was determined. As the removal of the dorsal fin spine is a simple technique, which does not decrease the commercial value of the fish, this method could provide a useful tool for the interim determination of age prior to confirmation by more detailed techniques.

*Key words:* age, chimaera, deepwater, growth, histology, maturation, rabbitfish

## Introduction

The holocephalan, *Chimaera monstrosa* is benthic to benthopelagic in habit generally occurring between 300 m and 1 250 m along the continental slope of the north Atlantic from Morocco to Iceland, and including Scandinavia, the North Sea, North of Scotland, the north and west of Ireland, Portugal and the Cape of Good Hope (Day, 1880; Farrell, 1859; Bigelow and Schroeder, 1953; Went, 1963, 1968; Stehmann and Bürkel, 1984; Haedrich

and Merrett, 1988; Merrett *et al.*, 1991; Gordon and Bergstad, 1992; Gordon *et al.*, 1996).

*Chimaera monstrosa* is oviparous, and migrates inshore during spring and summer to lay slender egg capsules at depths often below 100 m (Wheeler, 1969; Stehmann and Bürkel, 1984). The diet is taxonomically diverse (Legendre, 1944; MacPhearson, 1980; Wik, 1994; Bergstad *et al.*, 2001) and changes with season and with increasing body length (Wik, 1994). The species,

in common with other deep-sea, benthic-pelagic fishes, maintains neutral buoyancy through mobile pectoral fins and a large, oily liver (Garman, 1904; Marshall, 1971).

Recent interest in the exploitation of chimaerids along with a number of co-habitant deepwater, squaloid sharks for their meat and liver oil (Brennan and Gormley, 1999; Hardy and Mackie, 1971; Ngwenya and Foster, 1991), has focussed attention on the paucity of information available on the life history of these species upon which to base fisheries management advice.

Chondrichthyan fisheries, in general, urgently require biological and life history information on target species in order to determine levels of total mortality and estimate natural and fishing mortality components, in order to avoid the classic "Boom and Bust" pattern of exploitation historically experienced in other fisheries (Holden, 1974; Ketchen, 1986; Camhi *et al.*, 1998; Roberts, 2002). This is particularly true for deepwater species where slow rates of growth, longevity, low reproductive output and a high age at first maturity are significant factors in the maintenance of viable and sustainable populations (Holden, 1974; Wourms, 1977; Ketchen, 1986; Haedrich, 1996; Camhi *et al.*, 1998; Clarke *et al.*, 2002a, 2002b; Roberts 2002). In addition, the mechanism of the precautionary approach advocates the collection of biological data in tandem with the development and expansion of new fisheries, particularly when the target species are considered to be threatened and about which little is known.

In the absence of area specific biomass estimates, the determination of growth rates and population age profiling can provide valuable information on the population dynamics of exploited species (e.g. Weber and Fordham, 1997).

The use of the dorsal fin spine, possessed by holocephalans, as an ageing structure has followed the successful use of this structure in teleosts (Conand *et al.*, 1995; Megalofonou and De Metrio; 2000; Sun *et al.*, 2001) and both shallow and deepwater elasmobranchs (Kaganovskaia, 1933; Holden and Meadows, 1962; Beamish and McFarlane, 1985; Ketchen, 1975; Soldat, 1982; Tucker, 1985; Caillet, 1990; Saunders and McFarlane, 1993; Polat and Gumus, 1995; Tanaka, 1990; Wilson and Seki, 1994; Machado and Figueiredo, 2000; Avsar, 2001).

Of the holocephalans, the dorsal fin spines of *Callorhynchus milii* (Sullivan, 1977; Francis, 1997), *Callorhynchus capensis* (Freer and Griffiths, 1993) and the dorsal spines, vertebrae, fin rays and dental plates of *Hydrolagus colliei* (Halstead and Bunker, 1952; Johnson and

Horton, 1972) have been examined as ageing structures with varying success and degrees of confidence.

The dorsal spine of *Chimaera monstrosa* is positioned anterior to the first dorsal fin. The spine is believed to function as a defensive device, particularly in juveniles and sub-adults (Patterson, 1965; Maisey, 1979; Reis, 1895) when it is capable of inflicting a painful and venomous wound (Evans, 1923; Halstead and Bunker, 1952; Magerøy and Baerheim, 1991). The spine is inserted into the dorsal midline over the vertebral column, more shallowly than that of the squalid or heterodontid sharks.

The dorsal spine is also considered to reduce turbulence and aid the hydrodynamics of the first dorsal fin. In addition it is equipped with a smooth anterior keel, which runs longitudinally along the centre of the anterior margin of the spine, and is considered to reduce spine erosion. (Maisey, 1979).

The structure of the dorsal spine in holocephalans differs from that of elasmobranchs by having two rather than three distinct structural layers of dentine. The dorsal spine of *Chimaera monstrosa* is composed of an outer and an inner layer of dentine, which collectively form the trunk dentine (Maisey, 1979). A distinct boundary termed the trunk primordium is present between the two concentric dentine layers. This consists of collagen fibres that run longitudinally through the spine. A single layer of odontoblasts, to the external side of the trunk primordium centrifugally deposits the outer dentine and a similar layer occurring between the inner dentine and the spine lumen centripetally deposits the inner dentine. The odontoblasts produce an intracellular matrix into which they secrete amorphous cement material through their dendritic processes. These processes leave anastomosing dendritic odontoblast canaliculi in their wake as the dentine increases in density.

The thickness of the inner dentine layer increases towards the tip of the spine whereas the thickness of the outer dentine layer increases towards the base, as successive concentric layers of dentine are deposited over time. As a result, the tip of the spine contains the maximum number of growth increments and the optimal point of section, present in this region, is determined through the compensation for erosion, the position of the internal apex of the pulp cavity and information gathered through serial sectioning (Sullivan, 1977).

Temporal interpretation of similar mechanisms of accretion in the dorsal spines of the squalid shark, *Squalis acanthias*, suggest that growth increments, apparent as

rings generally within the inner dentine layer, are the consequence of variability in the growth rate between summer and winter associated with metabolic variability, which is effected by fluctuating water temperatures and food availability (Stevens, 1975; Tucker, 1985; Holden and Meadows, 1962). Slow winter growth leads to the accumulation of continually deposited dentine in the inner dentine, visible as dark or opaque zones of deposition, whereas fast summer growth is manifested by light, translucent zones. The deposition of an opaque and translucent zone pair forms a periodic increment, which is similar in form to that reported and validated from the dorsal spine of the squalid shark *Squalus acanthias* (Tucker, 1985; McFarlane and Beamish, 1987).

Indirect verification of the annual nature of dentinal increments in the holocephalan *Callorhinchus milii* and *Callorhinchus capensis* have been attempted using size-frequency analysis (Sullivan, 1977) and incremental addition to the spine (Freer and Griffiths, 1993). Subsequent debate has questioned the use of length frequency techniques in the determination of age-classes (Francis, 1997) and highlighted the difficulties in interpretation of the internal spine structure.

Despite the difficulties encountered in the development of ageing techniques (Gallagher and Nolan, 1999), the interpretation of periodic increments and the verification of age estimates when using the dorsal spine of deep-water holocephalans, the structure continues to have the potential to be used as an ageing tool.

Of the commercially retained holocephalan species only two members of the Callorhinchidae have been the focus of limited, directed research (DiGiacomo and Perier, 1994). Current interest in the utilization of the liver oils of chimaerids and rhinochimaerids for cosmetic purposes and human consumption, coupled with an increase in the commercial retention and market development of these species, suggests a developing industry demand for the liver oil of these species. Whereas there is an immediate requirement for a responsible assessment of the fisheries status and potential of these species there is also a fundamental need for basic biological information on the life history of target species. This study addresses this precondition for the commercially retained chimaerid, *Chimaera monstrosa*, a species, about which, relatively little is known.

## Materials and Methods

During September 2000 and August and October 2001, 62 specimens of *Chimaera monstrosa* were collected by scientific observers aboard commercial fishing

vessels fishing at depths ranging from 471 m to 740 m in the Rockall Trough and the Faroe-Shetland Channel (ICES Fishing areas: 27 IVa, 27 VIIb and 27 VIIc).

Specimens were collected in an opportunistic and non-random manner and pre-supra caudal fin length (PSCFL) (to the nearest 0.5 cm below), sex and maturity stage (assigned after Stehmann 1987) recorded. The sample consisted of 10 males, ranging from 26 cm to 71 cm PSCFL and 52 females, which ranged from 28 cm to 74 cm PSCFL.

Dorsal fin spines were removed from each individual by sliding a blade between the fin and spine, cutting through the basal cartilage and exiting through the flesh anterior to the spine. The spines were cleaned in boiling water and the cartilaginous core was removed using fine forceps. Processed spines were allowed to air dry and were stored in individually labelled paper envelopes.

A suite of morphometric measurements were taken from the air-dried spines using digital callipers (Fig. 1). In addition, the extent of the internal apex of the pulp cavity, as it approaches the spine tip, was measured from the spine base using a wire seeker, and the thickness of the dentine between the tip of the internal pulp cavity and the spine tip calculated.

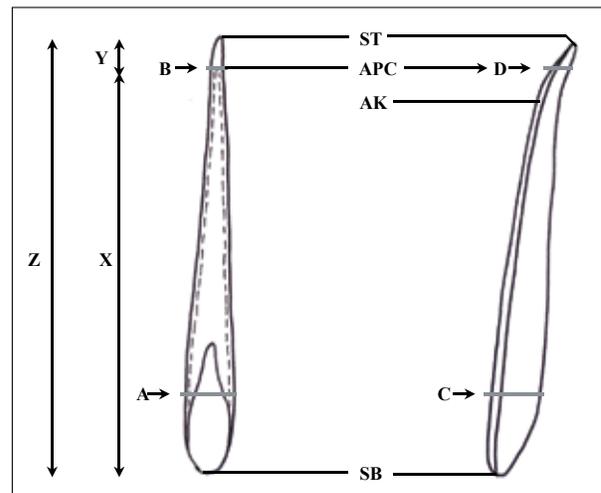


Fig. 1. Standard dorsal spine measurements of *Chimaera monstrosa* in posterior (left) and lateral (right) aspects. A, Widest diameter of spine base; B, Lateral diameter at apex of the pulp cavity (APC); C, Widest diameter of spine base (SB) in an anterior to posterior direction; D, Diameter at the apex of the pulp cavity in an anterior to posterior direction; X, Distance from the apex of the pulp cavity to the spine base; Y, Distance from the apex of the pulp cavity to the spine tip (ST); Z, Distance from the spine tip to the spine base; AK, Anterior keel.

Spine lengths were standardised by applying a correction for tip wear (Sullivan, 1977). The lateral spine width was measured microscopically at distances of 5 mm, 10 mm, 15 mm and 20 mm from the tips of spines showing the least wear and the relationship between spine width and the distance from the spine tip determined. Unworn, spine length was subsequently back-calculated for all spines using this relationship.

Serial and longitudinal cross-sections were prepared to establish the optimum position of transverse section and to investigate the structure of the dorsal spine. Sections of 500 µm were cut using a BUEHLER-ISOMET low speed saw (Model No. 11-1280-250) fitted with a BUEHLER diamond impregnated blade.

To estimate the optimum position of section containing the full complement of growth increments (Sullivan, 1977), serial cross-sections were taken from three of the longest spines. Sections were taken at distances of 0.5 cm, 1.0 cm and at each subsequent centimetre from the spine tip towards the spine base.

Prior to sectioning, the position of section was clearly marked on each spine in pencil. A transverse section, perpendicular to the vertical growth axis of the spine was then taken approximately 250 µm distally, from this position. The blade was then advanced by 500 µm from this point ensuring that the optimal section of the spine was contained within the section cut from each spine.

A single section was taken at 0.5 cm, five sections at 1.0 cm (one at 1.0 cm and two distal and proximal to this point) and three sections at each subsequent 1.0 cm (one at the each 1.0 cm and one distal, one proximal to this point). Each section was cleaned in xylene, allowed to dry in the fume cupboard and mounted in the same manner as the longitudinal sections.

Three spines from the modal PSCFL size class were selected for longitudinal section and incubated in a 5% Trypsin solution (Trypsin from hog pancreas, Activity 101 units/mg, Fluka Chemie GmbH. Chemical abstract registry No. 9002-07-7) at 37°C for 9 hours to remove adherent tissue. Following this procedure, the spines were rinsed thoroughly in distilled water and allowed to air dry. Each spine was transversely sectioned into three equal lengths and embedded in resin ("Resin C", Scott Bader Company Ltd., [www.scottbader.com](http://www.scottbader.com)).

Sections of 500 µm thickness were longitudinally sectioned along the axis of the central keel of the spine from each resin block. Sections were subsequently rinsed

in distilled water, allowed to air dry and then mounted onto clean glass slides using an ethyl cyanoacrylate adhesive (CAS No. 7085-85-0; Proprietary name; "Superglue").

Mounted sections were initially ground down to a thickness at which the resolution of the internal structure of the spine became most distinct, using fine grade (P1200) aluminium oxide abrasive paper (1913 siawat plain, SIA Abrasives, [www.sia-abrasives.ch](http://www.sia-abrasives.ch)), lubricated with distilled water. A final polish using the commercial metal polish, BRASSO was applied directly to the sectioned material using a cotton swab (Proprietary name; "Cotton bud"), to remove scratch marks.

Sections were illuminated using a low intensity fibre optic transmitted light and viewed under  $\times 100$  magnification. The clarity of the internal structure of the spine was enhanced by the application of a drop of white mineral oil (CAS No. 8042-47-5; Proprietary name; "Baby oil").

Remaining spines were sectioned transversely at the lateral spine width determined to be the optimum point of section.

Three readers estimated the number of increments per section (Fig. 2) on three independent occasions using criteria developed for this purpose (Table 1). Estimates were conducted in the absence of any information on the size, weight or sex of the specimen in order to avoid the introduction of bias and to permit an analysis of the percentage agreement and coefficient of variation between readers (Eltink, 2000; Eltink *et al.*, 2000; Beamish and Fournier, 1981).

## Results

The sample of 62 *Chimaera monstrosa* was composed of 10 males (16.1%) and 52 females (83.9%). The range of pre-supra caudal fin length (PSCFL) was similar for both sexes (Table 2). The PSCFL frequency (Fig. 3) was positively skewed, due to the under-representation of hatchlings and fish up to 25 cm.

### Optimal position of section

The optimal position of section occurred at a lateral spine diameter of 1.80 mm. The number of internal growth increments followed a pattern in which the frequency increased from the spine base to a maximum at the optimum position of section, after which it decreased towards the tip. Along the length of the spine, the thickness of the inner dentine increased towards the tip whereas the outer dentine increased in thickness towards the spine base.

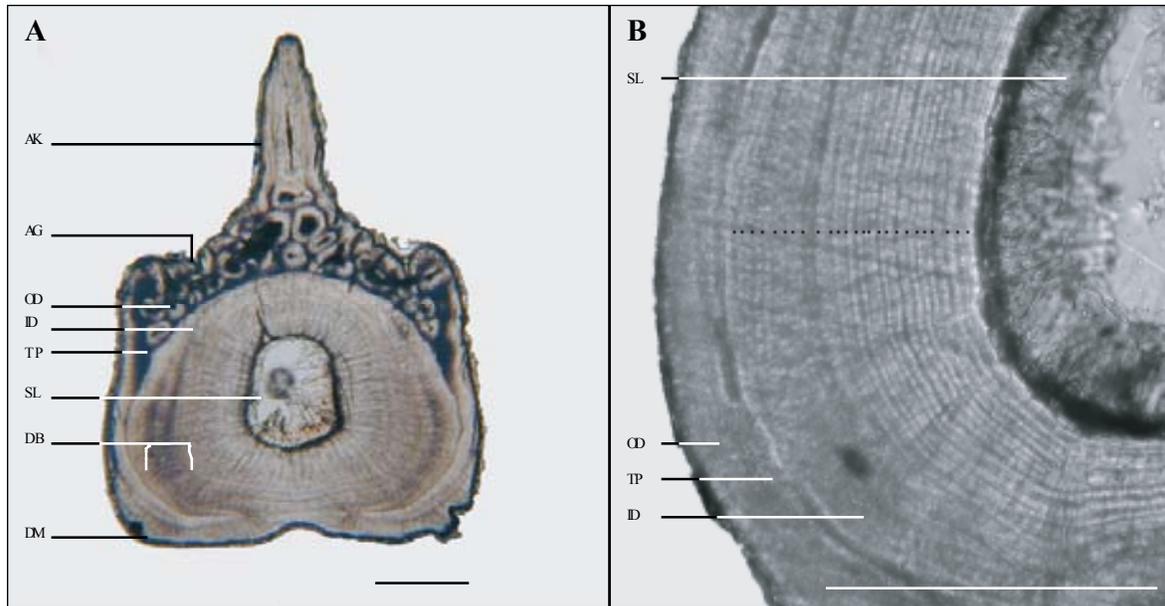


Fig. 2. (A) Transverse sections of the dorsal spine of *Chimaera monstrosa* in general transverse section, and (B) illustrating the zone of maximum inner dentine expansion. AK, Anterior keel; AG, Antero-lateral groove; OD, Outer dentine; ID, Inner dentine; TP, Trunk primordium; SL, Spine Lumen; DB, Discontinuity band; DM, Dentate margin; (...) Growth increments; Scale bars = 0.5 mm.

TABLE 1. Reading criteria for the identification and counting of periodic growth increments in the dorsal spine of *Chimaera monstrosa*.

1. Increments consisting of a dark, opaque and pale translucent band pair within the inner dentine layer are counted.
2. Counting is initiated at the trunk primordium and continues inward to the spine lumen. The trunk primordium is not counted as an increment.
3. Increments should be counted in the plane of maximum expansion of the inner dentine; i.e. along the postero-lateral axis of the spine rather than in an anterior to posterior direction.
4. Each increment should be traced along its length to ensure that no increment is present between it and the next.
5. The innermost increment should be traced along its length to ensure that no increment is present between it and the spine lumen.
6. Where an increment is expected, but not apparent, it cannot be counted.

The total spine length (TSL) of each spine was corrected for wear using the relationship between the distance from the spine tip and the lateral spine diameter for the least worn spine in the sample (Fig. 4). The distance from the optimum position of section to the spine tip was extrapolated to be 18.5 mm for the unworn spine.

The longitudinal sections prepared were not used to pinpoint the optimal position of section, as the growth increments were too difficult to discern in this plane of section.

#### Age relationships

From the 62 dorsal spines processed 1 was discarded due to reading difficulties encountered and 3 spines were used in the preparation of longitudinal sections. The remaining 58 dorsal spine sectioned consisted of 48 females and 10 males. Age estimates ranged from 3 to 30 years for males and 4 to 26 years for females. The modal and mean ages were calculated for each fish. The modal age was accepted as the estimated age where it was not biased by a readers repeated over or under-estimation. In cases where there was bias (difference between modal and mean age  $\geq 1$ ) the mean age was taken to be the estimated age.

The correlation between the PSCFL and corrected TSL ( $r^2 = 0.9125$ ) (Fig. 5) was stronger than that of PSCFL and the uncorrected TSL ( $r^2 = 0.7795$ ). The relationship between estimated age and corrected TSL revealed a linear relationship ( $r^2 = 0.8279$ ) (Fig. 6). This result provides a degree of confidence for the use of dorsal spines as an ageing tool for *Chimaera monstrosa*.

The relative bias was calculated among readers, readings, and the modal age to investigate any systematic

TABLE 2. The range, mean and standard deviation of the pre-supra caudal fin length (PSCFL) of male and female *Chimaera monstrosa*.

PSCFL	Males (cm)	Females (cm)
Minimum	26.00	28.00
Maximum	71.00	74.00
Mean	45.11	52.42
Standard deviation	16.35	11.33

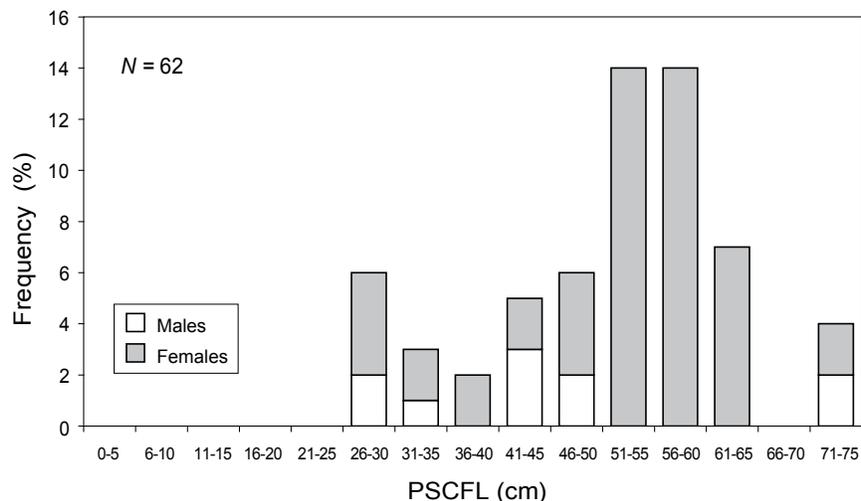


Fig. 3. The pre-supra caudal fin length (PSCFL) (cm) frequency for male and female *Chimaera monstrosa*.

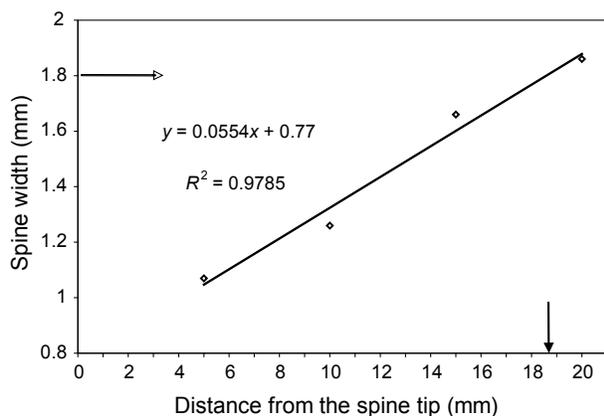


Fig. 4. The relationship between the distance from the spine tip (mm) and spine width (mm) for the least worn *Chimaera monstrosa* spine.

differences in the estimated number of growth increments. Reader 3 underestimated consistently relative to the other readers and to the modal age (Table 3).

The Index of Average Percent Error (IAPE) provided a measure of intra-reader and inter-reader variability. The

individual IAPE estimates indicate that Reader 2 had the highest precision and Reader 3 had the lowest precision between readings (Table 4). The overall IAPE value of 4.33% is acceptable and indicates a high level of reading precision, considering the problems encountered with readability of sections. The overall agreement for all spine readings was 49.4% while the coefficient of variation was 8.3%.

#### von Bertalanffy Parameters

The von Bertalanffy parameters were determined for combined sexes, using the fisheries programme FISH-PARM (Prager *et al.*, 1987). The following growth curve was derived:

$$L_t = 78.87 \text{ cm} \left[ 1 - e^{-0.0673(t+2.513)} \right]$$

$L_\infty$  was 78.87 cm, the von Bertalanffy growth coefficient,  $K$  was 0.0673 per year,  $t_0$  was  $-2.513$  yr and  $L_0$  was 12.28 cm. The von Bertalanffy curve was constructed for the combined sexes and fitted with the length-at-age data (Fig. 7).

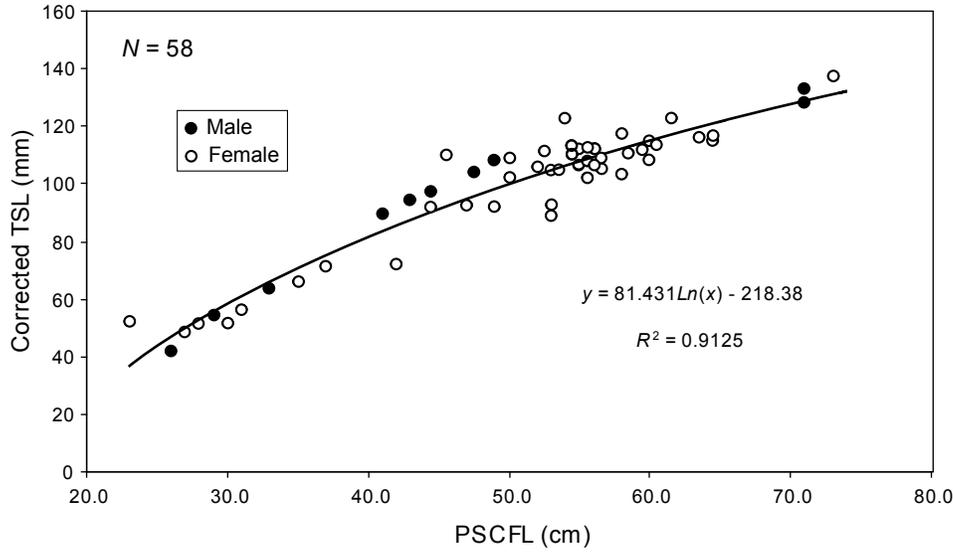


Fig. 5. The relationship between the pre-supra caudal fin length (PSCFL) (cm) and the corrected total spine length (TSL) (mm) for male and female *Chimaera monstrosa*.

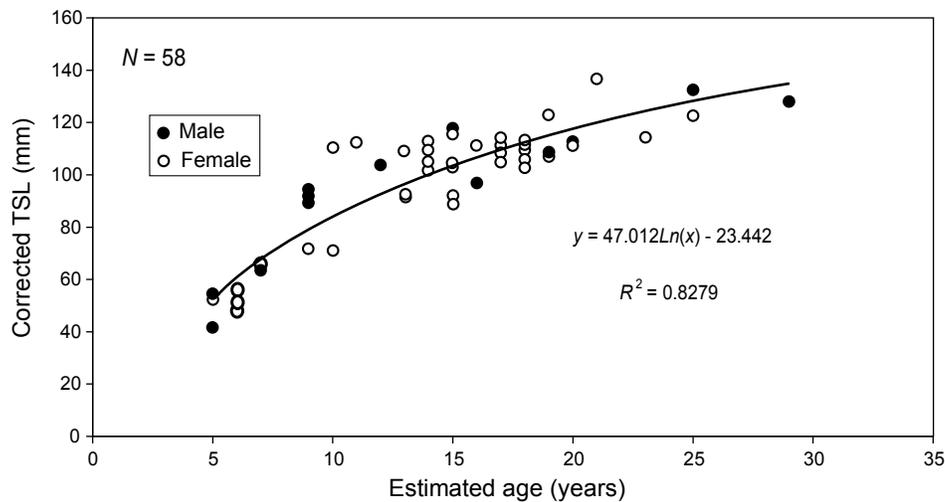


Fig. 6. The relationship between the estimated age and the corrected total spine length (TSL) (mm) for male and female *Chimaera monstrosa*.

### Discussion

The objective sampling of deepwater fish species imposes significant practical problems upon those with whom this responsibility lies. In consequence, the knowledge accumulated on the co-habitants of this environment is achieved through a variety of methods ranging from high cost, technologically advanced means to resources limited and opportunistic methods.

The limited sampling opportunities presented aboard commercial fishing vessels targeting deepwater species

within the depth range of *Chimaera monstrosa*, imposed constraints on the sampling design for this study, and as a result introduced temporal, sex, size and maturity biases.

Suggestions that *Chimaera monstrosa* may segregate by sex, size or maturity at different feeding grounds and depths, is reinforced by the dominance of females and the lack of individuals smaller than 26 cm PSCFL in the sample examined. Although these biases are acknowledged as being of significance in the determination of von Bertalanffy growth co-efficients, the age length keys determined

TABLE 3. The relative bias of readers 1, 2 and 3, over repeated readings A, B and C and between readers and the modal age. "—" indicates no significant bias ( $P > 0.05$ ); \* indicates possibility of bias ( $0.01 < P < 0.05$ ); \*\* indicates significant bias ( $P < 0.01$ ).

Reading	Inter-reader bias test and Reader against Modal age bias test								
	R 1 (A)	R 1 (B)	R 1 (C)	R 2 (A)	R 2 (B)	R 2 (C)	R 3 (A)	R 3 (B)	R 3 (C)
R 1 (A)	▨	—	—	—	—	*	—	—	*
R 1 (B)	—	▨	—	—	—	—	—	**	**
R 1 (C)	—	—	▨	—	—	—	—	**	**
R 2 (A)	—	—	—	▨	—	—	*	**	**
R 2 (B)	—	—	—	—	▨	—	**	**	**
R 2 (C)	*	—	—	—	—	▨	**	**	**
R 3 (A)	—	—	—	*	**	**	▨	—	*
R 3 (B)	—	**	**	**	**	**	—	▨	—
R 3 (C)	*	**	**	**	**	**	*	—	▨
MODAL	—	—	—	—	—	**	*	**	**

TABLE 4. The Index of Average Percent Error (IAPE) estimates for Readers 1, 2 and 3 and the number of readings conducted (N).

Reader	1	2	3
N	58	58	52
IAPE	4.28%	3.34%	5.47%

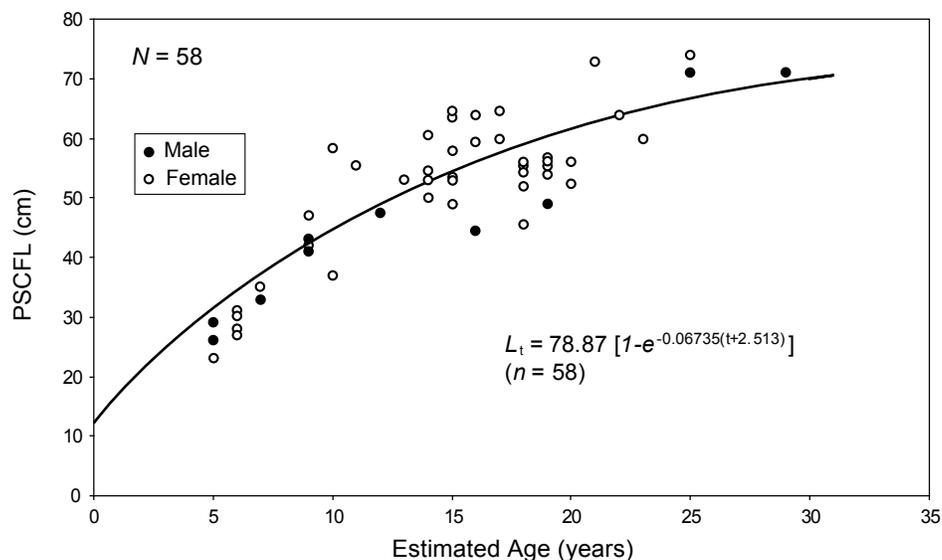


Fig. 7. The fitted von Bertalanffy growth curve and observed length-at-age for the combined sexes of *Chimaera monstrosa* (male, female).

for *Chimaera monstrosa* herein, are considered to closely describe the absolute parameters.

The dorsal spine of *Chimaera monstrosa* differs from that of squaloid sharks by containing two (inner and

outer) rather than three (inner, middle and outer) layers of dentine and no exterior covering of pigmented enamel containing growth increments. Growth increments are present within the inner dentine layer, which increases in thickness towards the spine tip.

Structural examination of the dorsal fin spines of two species of related callorhynchid holocephalans from South African and New Zealand waters demonstrated that the maximum number of internal growth increments occurred at lateral spine diameters ranging from 1.80 mm to 2.00 mm (Sullivan, 1977; Freer and Griffiths, 1993). The position of maximum increment occurrence in *Chimaera monstrosa* agreed with these findings and was present close to the tip of the spine at a lateral spine diameter of 1.80 mm. The determination of this point was imperative in the standardisation of the sectioning procedure for spines exhibiting varying degrees of wear.

Prior to these observations the only structural comment on the dorsal fin spine of a holocephalan was that describing the rejection of the dorsal fin spine, along with other structures (vertebrae, fin rays and the tooth plates), as an ageing tool in the Chimaerid, *Hydrolagus colliei* (Johnson and Horton, 1972). In this instance, sections were taken from the spine base, an area indicated by subsequent investigations to be the position of thinnest inner dentine thickness and most recent increment deposition.

Examination of longitudinal spine sections, sectioned in an anterior posterior axis, similar to that used for squaloid sharks (Holden and Meadows, 1962) failed to confirm the location of the optimum position of section in *Chimaera monstrosa*. The resolution of growth increments was generally occluded by invasive canaliculi (tubes through which odontoblasts deposit dentine). In addition, the curvature of the spine compounded these difficulties, particularly in the identification of spine cone bases previously described from the spines of *Squalus acanthias* (Holden and Meadows, 1962). Although a lateral rather than an anterior-posterior plane of section, may improve increment and cone base resolution, this supposition is based on the greater expansion of the inner dentine in this plane of section and an associated improvement in the resolution of the internal structure, as a consequence of the greater area of inner dentine exposed. The achievement of a consistently medial section in this plane is, however, considered to have significant practical and technical difficulties related to the curvature of the spine.

In addition to the canaliculi, the readability of spine sections was decreased by the presence of scratches made by the blade during the sectioning process. These were reduced by slowing the blade speed and by subsequently polishing the spine section on both sides prior to mounting. The achievement of highly polished and unscratched sections is of particular importance in the resolution of growth increments, a factor supported by the high coefficients of variation between readers and readings associated with

sections affected by scratch marks and/or a high density of canaliculi. Although the presence of false increments also posed reading difficulties, this was redressed through the strict application of unambiguous, reading criteria for all spine sections.

The maximum age estimates observed were 30 years for male and 26 years for female *Chimaera monstrosa*. These ages probably underestimate the true maximum age of this species, owing to the limited sample size examined. This restricted sample size and the female dominance of the sample led to the estimation of von Bertalanffy parameters using individual age-length values, independent of sex. The growth rate of *Chimaera monstrosa* ( $K = 0.067$  per year) derived is within the range reported for other slow growing, holocephalan and elasmobranch species, known to range over the continental shelf slope and into deepwater (Table 5).

Difficulties in the collection of intact hatchling and juvenile specimens of this species and the propensity of historical records to report the total length of specimens inclusive of an unascertainable length of caudal filament has resulted in a lack of reliable information on the size of hatchlings of this species. During the course of the current study, the smallest reliable pre-supracaudal fin length (PSCFL) measurement recorded was 12.0 cm, for an individual, which lacked a prominent yolk sac scar (E. H. Jackson, Irish Sea Fisheries Board, Ireland, pers. comm.). The estimated length at hatching derived from the fitted von Bertalanffy growth curve of 12.28 cm PSCFL, slightly overestimates the observed smallest size but is within 3 mm of that observed for this species.

The theoretical age at zero length ( $t_0 = -2.513$ ) derived for male and female *Chimaera monstrosa* was within the range of those estimated by previous studies of other holocephalan and elasmobranch species ( $-4.880 < t_0 > +0.165$ ) (Table 5).

The theoretical asymptotic length,  $L_{\infty}$ , was estimated to be 78.87 cm. This is considered to be a reliable estimate of this parameter given the numbers of individuals present in older age-classes and the fact that this value exceeds the maximum observed length of 74.00 cm. Although the paucity of mature individuals in the sample examined prevented the construction of classical maturity ogives, the length (PSCFL) at first maturity, used in conjunction with the linear relationship between age and PSCFL, estimated the age at first maturity to be 13.4 years for male and 11.2 years for female *Chimaera monstrosa*.

Of significant relevance to future fisheries interest in this species, is the relationship discovered between

TABLE 5. The von Bertalanffy parameters  $K$  and  $t_0$  reported by sex, for Callorhynchid Holocephalans, slow growing shelf and deepwater elasmobranchs and *Chimaera monstrosa*.

Species	Sex	$K$ (per yr)	$t_0$ (yr)	Reference
<i>Callorhynchus milii</i>	M	0.089, 0.473	-0.96, -0.24	Francis (1997)
	F	0.060, 0.224	-1.06, -0.53	
<i>Callorhynchus capensis</i>	M	-0.52	-0.052	Freer and Griffiths (1993)
	F	0.171	-0.721	
<i>Squalus acanthias</i>	M	0.070	-4.700	Ketchen (1975)
	F	0.048	-4.880	
<i>Squalus acanthias</i>	M	0.210	-2.000	Holden and Meadows (1962)
	F	0.110	-3.600	
<i>Deania calceus</i>	M	0.135	+0.165	Clarke <i>et al.</i> (2002b)
	F	0.077	-0.933	
<i>Chimaera monstrosa</i>	Both	0.067	-2.513	This study

the corrected total spine length and the estimated age. As the removal of the dorsal fin spine is a simple technique, which does not decrease the commercial value of the fish, this method could provide a useful tool for the interim estimation of age prior to confirmation by more detailed techniques.

Although these findings are provisional and unvalidated, the age and growth characteristics determined, suggest that *Chimaera monstrosa* is a typical "k-selected" species characterized by a slow growth rate, a long life expectancy, low fecundity, and a high age-at-maturity. These attributes are similar to those of many exploited elasmobranchs and suggest that any unregulated, directed fishery on *Chimaera monstrosa*, for meat or liver oil, would be susceptible to the "boom and bust" pattern experienced by many elasmobranch fisheries. In consequence, the use of *Chimaera monstrosa* and other holocephalan species as resources must be approached in a responsible manner with biologically appropriate precautions. Voyages exploring the availability of *Chimaera monstrosa* resources should carry fisheries biologists and be designed to determine estimates of abundance, stratified by depth and area. Further assessment of the resource on a seasonal basis using fishery dependent and fishery independent methods should complement these data. Once confident assessments of the exploitable biomass have been determined these may be used in conjunction with the life history data available to estimate area specific harvest potentials and regulate exploitation at a level sufficient to allow the commercial and biological sustainability of the target species.

### Acknowledgements

The authors acknowledge the help and assistance of Dawn Woodroffe, Daragh Browne and Michael Gallagher,

in the collection of samples, and Peter Stafford, Helen McCormick and Maurice Clark for technical advice.

### References

- AVSAR, D. 2001. Age, growth, reproduction and feeding of the spurdog (*Squalus acanthias*, Linnaeus, 1758) in the South Eastern Black Sea. *Estuar. Coast. Shelf Sci.*, **52**: 269–278.
- BEAMISH, R. J., and D. A. FOURNIER. 1981. A method for comparing the precision of a set of age determinations. *Can. J. Fish. Aquat. Sci.*, **38**: 982–983.
- BEAMISH, R. J., and G. A. M<sup>c</sup>FARLANE. 1985. Annulus development on the second dorsal spine of the spiny dogfish (*Squalus acanthias*) in British Columbia Waters. *Can. J. Fish Aquat. Sci.*, **42**: 1799–1805.
- BERGSTAD, O. A., Å. D. WIK, and Ø. HILDRE. 2001. Predator-prey relations and food sources of the Skagerrak deep-water fish assemblage. *NAFO SCR Doc.* No. 132, Serial No. N4527, 20 p.
- BIGELOW, H. B., and W. C. SCHROEDER. 1953. Fishes of the Western North Atlantic. Part 2. Sawfishes, Guitarfishes, Skates and Rays; Chimaeroids. *In*: Fishes of the western North Atlantic. Memoirs of the Sears Memorial Foundation for Marine, Yale University, New Haven, **1**: 1–514.
- BRENNAN, M. H., and T. R. GORMLEY. 1999. The quality of under-utilised deep-water fish species. Teagasc Research Report No. 22 (Project Armis No. 4560).
- CAILLET, G. M. 1990. Elasmobranch age determination and verification: an updated review. *In*: Elasmobranchs as living resources: Advances in the Biology, Ecology, Systematics and the status of the Fisheries. H. L. Pratt, S. H. Gruber and T. Taniuchi (eds.) *NOAA Tech. Rep. NMFS*, **90**: 157–165.
- CAMHI, M., S. FOWLER, J. MUSICK, A. BRAUTIGAM, and S. FORDHAM. 1998. Sharks and their relatives: Ecology and conservations. Occasional paper of the IUCN Species Survival Commission, No. 20, 39 p.
- CLARKE, M. W., P. L. CONNOLLY, and J. J. BRACKEN. 2002a. Age estimation of the exploited deepwater shark *Centrophorus squamosus* from the continental slopes of

- the Rockall Trough and the Porcupine Bank. *J. Fish Biol.*, **60**: 1–14.
- 2002b. Catch, discarding, age estimation, growth and maturity of the squalid shark *Deania calceus* west and North of Ireland. *Fish. Res.*, **1366**: 1–16.
- CONAND, F., S. B. CAMARA, and F. DOMAIN. 1995. Age and growth of three species of Ariidae (Siluriformes) in coastal waters of New Guinea. *Bull. Mar. Sci.*, **56**(1): 58–67.
- DAY, F. 1880. The fishes of Great Britain and Ireland. Volume II. London: G. Norman and Son, Printers, Hart Street, Covent Garden.
- DiGIACOMO, E. E., and M. R. PERIER. 1994. Reproductive biology of the cockfish, *Callorhynchus calorhynchus*, in Patagonian waters (Argentina). *Fish. Bull.*, **92**: 531–539.
- ELTINK, A. T. G. W. 2000. Age reading comparisons. (MS Excel workbook version 1.0 October 2000) Internet: <http://www.efan.no>.
- ELTINK, A. T. G. W., A. W. NEWTON, C. MORGADO, M. T. G. SANTAMARIA, and J. MODIN. 2000. Guidelines and tools for age reading. (PDF document version 1.0 October 2000) Internet: <http://www.efan.no>.
- EVANS, H. M. 1923. The defensive spines of fishes, living and fossil, and the glandular structures in connection therewith, with observations on the nature of fish venoms. *Phil. Trans. Roy. Soc. Lond.*, **212**: 1–33.
- FARRELL, W. C. 1859. A history of British fishes. Volume II. London: John Van Voorst, Paternoster Row.
- FRANCIS, M. P. 1997. Spatial and temporal variation in the growth rate of Elephant fish (*Callorhynchus milli*). *N.Z. J. Mar. Fresh. Res.*, **31**: 9–23.
- FREER, D. W. L., and C. L. GRIFFITHS. 1993. Estimation of age and growth in the St. Joseph *Callorhynchus capensis* (Dumeril). *S. Afr. J. Mar. Sci.*, **13**: 75–81.
- GALLAGHER, M., and C. P. NOLAN. 1999. A novel method for the estimation of age and growth in rajids using caudal thorns. *Can. J. Fish. Aquat. Sci.*, **56**: 1590–1599.
- GARMAN, S. 1904. The Chimaeroids (Chismopnea Raf., 1815; Holocephala Müll., 1834), especially Rhinchochimaera and its Allies. *Bull. Mus. Comp. Zool. Harv.*, **41**: 245–272, plates 1–15.
- GORDON, J. D. M., N. R. MERRETT, O. A. BERGSTAD, and S. C. SWAN. 1996. A comparison of the deep water demersal fish assemblage of the Rockall Trough and Porcupine Seabight, Eastern North Atlantic: Continental slope to rise. *J. Fish Biol.*, **49**(Suppl. A): 217–238.
- GORDON, J. D., and O. A. BERGSTAD. 1992. Species composition of Demersal fish in the Rockall trough, North-Eastern Atlantic, as determined by different trawls. *J. Mar. Biol. Assoc. U.K.*, **72**: 213–230.
- HAEDRICH, R. L. 1996. Deep-water fishes: evolution and adaptation in the earth's largest living spaces. *J. Fish Biol.*, **49**(Suppl. A): 40–53.
- HAEDRICH, R. L., and N. R. MERRETT. 1988. Summary atlas of deep living demersal fishes in the North Atlantic basin. *J. Natural Hist.*, **22**: 1325–1362.
- HALSTEAD, B. W., and N. C. BUNKER. 1952. The venom apparatus of the ratfish, *Hydrolagus colliei*. *Copeia*, **3**: 128–138.
- HARDY, R., and P. R. MACKIE. 1971. Observations on the chemical composition and toxicity of Ratfish (*Chimaera monstrosa*). *J. Sci. Food Agric.*, **22**: 382–388.
- HOLDEN, M. J. 1974. Problems in the rational exploitation of elasmobranch populations and some suggested solutions. In: Sea Fisheries Research. Harden-Jones F.R. (ed). Elek science, London. p. 117–137.
- HOLDEN, M. J., and P. S. MEADOWS. 1962. The structure of the spine of the spur dogfish (*Squalus acanthias* L.) and its use for age determination. *J. Mar. Biol. Assoc. U.K.*, **42**: 179–197.
- JOHNSON, A. G. and H. F. HORTON. 1972. Length-weight relationship, food habits, parasites, and sex and age determination of the ratfish, *Hydrolagus colliei* (Lay and Bennett). *Fish. Bull.*, **70**(2): 421–429.
- KAGANOVSKAIA, S. 1933. A method of determining the age and catch composition of the spiny dogfish (*Squalus acanthias*). *USSR Academy Scientific, Far Eastern Branch, Bulletin*, **1–3**: 130–141 (translated from Russian: Fisheries Research Board of Canada. Translation series 281, Ottawa, Canada).
- KETCHEN, K. S. 1975. Age and growth of Dogfish, *Squalus accanthias*, in British Columbia waters. *J. Fish Res. Board Can.*, **32**: 43–59.
1986. The spiny dogfish (*Squalus acanthias*) in the Northeast Pacific and a history of its utilisation. *Canadian Special Publish. Fish. Aquat. Sci.*, **88**: 1–78.
- LEGENDRE, R. 1944. Notes biologiques sur *Chimaera monstrosa*. *Bull. Soc. Zool. Fr.*, **69**(1): 10–18.
- MACHADO, P. B., and I. FIGUEIREDO. 2000. A technique for ageing the birdbeak dogfish (*Deania calcea*, Lowe, 1839) from dorsal spines. *Fish. Res.*, **45**: 93–98.
- MacPHEARSON, E. 1980. Food and feeding of *Chimaera monstrosa*, Linnaeus, 1758, in the Western Mediterranean. *J. Cons. Inst. Explor. Mer.*, **39**(1): 26–29.
- MAGERØY, N., and A. BAERHEIM. 1991. Ratfish (*Chimaera monstrosa*) sting. *Tidsskrift for Den Norske Laegaforening*, **111**(17): 2102–2103.
- MARSHALL, N. B. 1971. Explorations in the Life of Fishes. Harvard University Press, Cambridge, Massachusetts. 204 p.
- MAISEY, J. G. 1979. Finspine morphogenesis in squalid and heterodontid sharks. *Zool. J. Linn. Soc.*, **66**: 161–183.
- McFARLANE, G. A., and R. J. BEAMISH. 1987. Validation of the dorsal spine method for age determination for spiny dogfish. *The Iowa State University Press, Iowa*, **1987**: 287–300.
- MERRETT, N. R., R. L. HAEDRICH, J. D. M. GORDON, and M. STEHMANN. 1991. Deep demersal fish assemblage structure in the Porcupine Seabight (Eastern North Atlantic): Results of single warp trawling of lowerslope to abyssal soundings. *J. Mar. Biol. Assoc. U.K.*, **71**: 359–373.
- MEGALOFONO, P., and G. DE METRIO. 2000. Age estimation and annulus-formation in dorsal spines of juvenile bluefin tuna, *Thunnus thynnus*, from the Mediterranean Sea. *J. Mar. Biol. Ass. U.K.*, **80**: 753–754.
- NGWENYA, B. Z., and D. M. FOSTER. 1991. Enhancement of antibody-production by lysophosphatidylcholine and alkylglycerol. *Proc. Soc. Exp. Biol. Med.*, **196**(1): 69–75.

- PATTERSON, C. 1965. The phylogeny of the Chimaeroids. *Phil. Trans. Roy. Soc. London*, **249**: 101–219.
- POLAT, N., and A. K. GUMUS. 1995. Age determination of spiny dogfish (*Squalus acanthias* L. 1758) in Black Sea waters. *Israeli J. Aqua. – Bamidgeh.*, **47**(1): 17–24.
- PRAGER, M. N., S. B. SAILA, and C. W. RECSIEK. 1987. Fishparm: a computer program for parameter estimation of nonlinear models in fishery science. Dep. Oceanogr. Old Dominion University of Norfolk, U.A. *Tech. Rep.*, **87**(10): 1–37.
- REIS, O. M. 1895. On the structure of the frontal spine and the rostral cartilages of *Squaloraja* and *Chimaera*. *The Geological Magazine*. **2**(9): 385–391.
- ROBERTS, C. M. 2002. Deep impact: the rising toll of fishing in the deep sea. *Trends Ecol. Evol.*, **17**(5): 242–245.
- SAUNDERS, M. W., and G. A. McFARLANE. 1993. Age and length at maturity of the female spiny dogfish, *Squalus acanthias*, in the Strait of Georgia, British Columbia, Canada. *Environ. Biol. Fishes*, **38**: 49–57.
- SOLDAT, V. T. 1982. Age and size of Spiny Dogfish, *Squalus acanthias*, in the Northwest Atlantic. *NAFO Sci. Coun. Studies*, **3**: 47–52.
- STEHMANN, M., and D. L. BÜRKELE. 1984. Torpedinidae. p. 159–162. In: *Fishes of the North-Eastern Atlantic and Mediterranean*. P. J. P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen and E. Tortonese (eds.). UNESCO, Paris. Vol. 1, 510 p.
- STEVENS, J. D. 1975. Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.). *J. Mar. Biol. Assoc. U.K.*, **55**: 657–665.
- SULLIVAN, K. J. 1977. Age and growth of the elephant fish *Callorhynchus milii* (Elasmobranchii: Callorhynchidae). *N. Z. J. Mar. Fresh. Res.*, **11**(4): 745–753.
- SUN, C.-L., C.-L. HUANG, and S.-Z. YEH. 2001. Age and growth of the bigeye tuna, *Thunnus obesus*, in the Western Pacific Ocean. *Fish. Bull.*, **99**: 502–509.
- TANAKA, S. 1990. The structure of the dorsal spine of the deep sea squaloid shark *Centrophorus acus* and its utility for age determination. *Nippon Suisan Gakkaishi*, **56**(6): 903–909.
- TUCKER, R. 1985. Age validation studies on the spines of the Spurdog (*Squalus acanthias*) using Tetracycline. *J. Mar. Biol. Ass. U.K.*, **65**: 641–651.
- WEBER, M. L., and S. V. FORDHAM. 1997. *Managing Shark Fisheries: Opportunities for International Conservation*. TRAFFIC International, Species in Danger Series, Cambridge, United Kingdom, 61 p.
- WENT, A. E. J. 1963. Rare fish taken in Irish waters in 1962. *Ir. Nat. J.*, **14**(6): 42–43.
1968. Rare fish taken in Irish waters in 1967. *Ir. Nat. J.*, **16**: 35–39.
- WHEELER, A. 1969. The fishes of the British Isles and North-West Europe. MacMillan, 613 p.
- WIK, Å. D. 1994. Svarthå (*Etmopterus spinax*, L. 1758) og havmus (*Chimaera monstrosa*, L. 1758) i Norskerenna: Utbredelse, biologi og ernæringsøologi. Hovedfagsoppgave I marin zoology. Universitet I, Oslo, Norway, 79 p.
- WILSON, C. D., and M. P. SEKI. 1994. Biology and population characteristics of *Squalus mitsukurii* from a seamount in the Central North Pacific Ocean. *Fish. Bull.*, **92**(4): 851–864.
- WOURMS, J. P. 1977. Reproduction and development in chondrichthyan fishes. *Am. Zool.*, **17**: 379–410.
-