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Size, age and sexual maturity of the blue shark, *Prionace glauca*, in the Mediterranean Sea

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Blue sharks, ranged from 70 to 349 cm in total length (TL), were sampled from the swordfish and tuna fishery in the Mediterranean Sea during the four-year period 1998-2002. Males were predominant (64.3% male, 35.7% female) and sex ratio showed an increase of the males as size progresses. Gonad observation revealed that females smaller than 120 cm TL had immature ovaries with invisible oocytes while ovaries with visible yolked oocytes were present in specimens larger than 180 cm TL. Ovary weight varied from 4 to 137 g and maximum oocyte diameter was 21.1 mm in mature females. All males smaller than 125 cm TL were immature presenting not calcified claspers that did not reach the posterior end of the pelvic fins. Males larger than 187 cm were all mature presenting heavy calcified claspers, which extended much more than the posterior end of the pelvic fins. Total length at first maturity ranged from 205 to 215 cm in females and from 185 to 195 cm in males. Caudal vertebrae were collected from specimens between 84 and 315 cm TL and vertebral ring counts were used to estimate age. Age estimates ranged from 0^+ to 12 yr and age at first maturity was estimated to about 4 yr.

Keywords: blue shark, size distribution, age, sexual maturity, Mediterranean Sea

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INTRODUCTION

The blue shark, *Prionace glauca* (Linnaeus, 1758) is a large pelagic carcharhinid that is widely distributed in the world's oceans and the adjacent seas in temperate and tropical waters. Males and females are known to segregate in different areas by size (Nakano, 1994; Castro *et al.*, 1999) and make seasonal reproductive migrations, travelling considerable distances each year (Nakano, 1994). While blue sharks are among the most abundant, widespread, fecund and faster growing of the elasmobranches, they are also the most heavily fished sharks in the world. The impact of annual fisheries mortality (mainly of by-catch), estimated at 10 to 20 million individuals, is likely to have an effect on the world population, but monitoring data are inadequate to assess the scale of any population decline (Froese and Pauly, 2005). In the Atlantic, the blue shark is distributed from Newfoudland to Argentina in the west and Norway to South Africa, including the Mediterranean, in the east (Compagno, 1984). Although stock structure in this species remains uncertain, there is evidence to support a single North Atlantic stock. In the Mediterranean Sea, blue sharks are primarily captured as by-catches in the large pelagic fisheries, targeting swordfish or tuna (Megalofonou *et al.*, 2005a; 2005b). The biological aspects of the species in the area are poorly studied to date (Megalofonou *et al.*, 2005b), so that the questions whether they comprise a single Mediterranean stock or what is their stock structure remain unanswered. Determining their age and maturity and moreover describing their reproductive cycle are necessary elements for understanding their biology, applying reasonable assessment techniques and enforcing management measures. This paper analyses biological data from blue sharks caught by the Italian and Greek swordfish and albacore long line fleet through a five-year period. Our aim was to estimate age at size using vertebrae ageing techniques and size at maturity.

MATERIALS AND METHODS

During the period 1998-2002, blue sharks were sampled by observers stationed both at main fishing ports and on board commercial fishing vessels targeting swordfish (*Xiphias gladius*) or albacore (*Thunnus alalunga*) in the Aegean Sea, the Ionian Sea, the Adriatic Sea and the Levantine basin (Fig1). Size measurements were recorded for each specimen including total length (TL), round weight (RW) and dressed weight (DW). Total length was measured in a straight line from the snout tip to the end of the upper caudal lobe. Whenever length measurement were not possible - because fish were gutted, finned and decapitated - the following conversion formula was used to derive total length from dressed weight:

$$TL = 74.6\ DW^{0.307}$$ (Megalofonou *et al.*, 2000; $n = 555$).

Whole vertebrae were used for the purpose of age estimation. A section of the vertebral column (usually 5-6 vertebrae from the precaudal notch area) was removed and frozen in a plastic bag labelled with an ID corresponding to the data for each fish (size, sex, location and date of capture). In the lab the sectioned vertebral columns were separated in unique vertebrae parts and the centra were cleaned removing the muscular and connective tissues. Two methods were applied for age reading: (a) X-ray radiography (Cailliet *et al.*, 1983; Cailliet, 1990), which is a method commonly used to enhance the clarity of bands on vertebrae of sharks. The method yields better clarity of bands when combined with a video image analysis system. (b) Digital enhanced images of whole vertebrae. Whole vertebral face images were obtained under reflected light using a SONY Exwave HAD digital camera at a resolution of 768*576 pixels and Image Analysis Pro Plus 3.1 video capturing software. The images were subsequently digitally enhanced.

Growth rings on vertebrae were defined as band pairs, opaque ones (calcified) and translucent ones (less-calcified). We identified as birthmark the angle change on the centrum face. Each sample was aged in an independent manner by two readers (for both methods). For samples that readings did not coincide, the procedure was repeated until an agreement was achieved or otherwise it was left out of the analysis. Ageing was applied by determining the obvious banding patterns (growth bands or growth rings) on vertebrae.

The reproductive system (claspers and testis in males and ovaries in females) was inspected visually to determine the sex and state of sexual maturity. Sexual maturity stage was evaluated on the basis of: a) the morphology and rigidity of claspers (Aasen, 1966) and comparing clasper length to pelvic fin length (Holden and Raitt, 1974) in males; b) both macroscopic observations of ovaries and oocyte diameters (Holden and Raitt, 1974; Pratt, 1979) in females. Oocyte diameters were measured using Quantimet 500/W (Leica, UK) image analyser.

The percentages of mature individuals per length class were estimated for males and females separately. A logistic curve was fitted to the data and the total length where 50% of the individuals are mature gave the length of first maturity (King, 1995): $P=1/(1+\exp[-r(L-L_m)])$ where r is the slope of the curve and L_m is the mean length at sexual maturity or the length which corresponds to a proportion of 0.5 (or 50 per cent) in reproductive condition.

RESULTS

A total of 502 blue sharks were measured and sexed during the five-year period 1998-2002, of which 323 (64.3%) were males and 179 (35.7%) were females (Fig. 2). Overall males outnumbered females by a sex ratio females/males almost 1:1.8 which was significantly different from a 1:1 sex ratio (χ^2 test, $P < 0.05$). Males ranged in total length from 74 to 330 cm (mean= 162.8 cm) and females from 70 to 349 cm(mean= 156.3 cm). There was a statistically significant difference between the two length frequency distributions (males-females) (*Kolmogorov-Smirnov* test, $P < 0.05$) and sex ratio showed an increase of the males as size progresses (Fig 3.).

Vertebrae from a total of 46 blue sharks, ranging from 81 to 315 cm in TL, were examined. Growth band reading was easier examining whole vertebrae face images than the x-radiograph images (Fig. 4) and therefore this method was selected for age estimation. Age estimates for the blue shark ranged from young of the year to twelve years. The oldest fish in our sample was a 315 cm TL specimen that had twelve bands, while the youngest was one 81.7 cm TL juvenile that had one band. Most of the blue shark sampled was four to seven years old. Mean observed lengths at number of growth rings are shown in figure 5.

Gonad observation revealed that females smaller than 120 cm TL had immature ovaries with invisible oocytes while ovaries with visible yolked oocytes were present in specimens larger than 180 cm TL. Ovary weight varied from 4 to 137 g and maximum oocyte diameter was 21.1 mm in mature females. All males smaller than 125 cm TL were immature presenting not calcified claspers that did not reach the posterior end of the pelvic fins. Males larger than 187 cm were all mature presenting heavy calcified claspers, which extended much more than the posterior end of the pelvic fins. Males mature at a slightly smaller length than females. Total length at first maturity ranged from 205 to 215 cm in females and from 185 to 195 cm in males. The mean length at first maturity L50 was estimated to 202.9 for males and 214.7 for females (Fig.6). The age at first maturity was estimated to 4 years (185 cm TL) for males and 5 years (200 cm TL) for females. Full maturity is attained by year 5 in

males and 6 in females, since all specimens above these sizes were reproductively active.

DISCUSSION

Our results show that an important part of the blue shark specimens caught in the Mediterranean Sea in the swordfish and tuna long line fisheries consists of juveniles. The age estimations indicated that blue shark enters the fishery in the first year of life however an important component of sub adult and adult specimens is present in the catches. Various authors have studied age and growth of the blue shark, some estimating a life span of more than 20 years for this species (Skomal *et al.*, 2003). Data from age estimations, although from a restricted sample of 48 blue sharks, showed that the population occurring in the Mediterranean is composed mainly of specimens 3 to 5 years old (140-180 cm TL) and maximum age estimated is 12 years for a specimen of 315 cm TL. Nevertheless, the maximum age and lifespan of the blue shark in the Mediterranean Sea should be higher as the larger female caught had a total length of 368 cm (Megalofonou et.al., 2005).

The sex ratio reported here was similar to this reported by Buencuerpo *et al.* (1998) in the eastern North Atlantic Ocean and the Strait of Gibraltar but inverse to those reported in the North west Atlantic (Pratt's, 1979) and North east Atlantic in British and Ireland waters (Stevens, 1976; Henderson et al., 2001). The sex ratio reported in Irish coastal waters was heavily biased in favor of females (Whelan, 1991), agreeing with Pratt's (1979) speculation that male blue sharks move inshore only upon attaining sexual maturity. Our results on size and age at first maturity, although preliminary, suggest that blue shark in the Mediterranean Sea reach sexual maturity earlier and in a smaller size than blue shark in the Atlantic Ocean. According to Pratt's (1979) estimation on minimum size at sexual maturity for blue sharks, males mature at a size of 215 cm TL while females at 257 cm.

Acknowledgements

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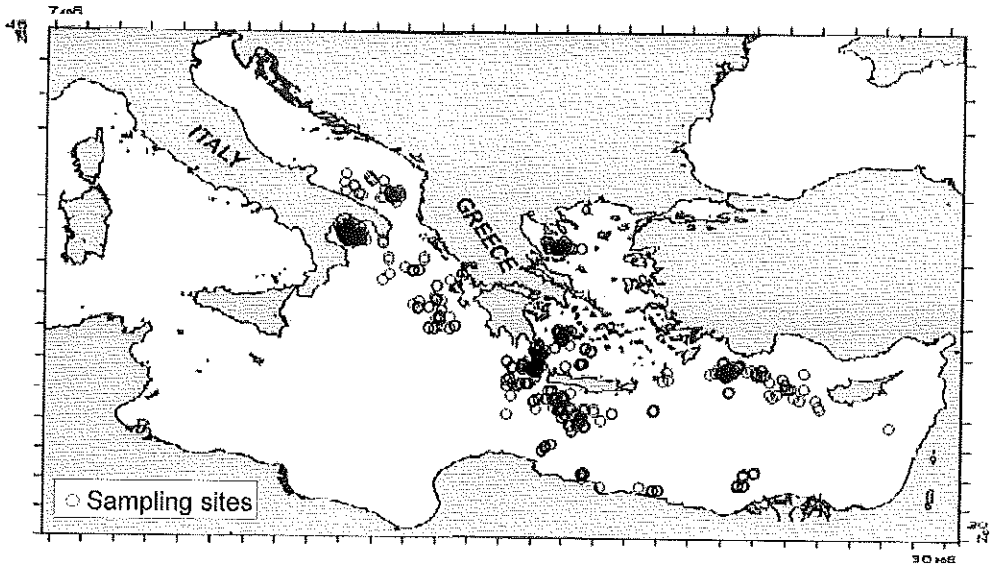


Figure 1. Map of the sampling area in the Mediterranean Sea. Long line sampling sites are indicated as open circles.

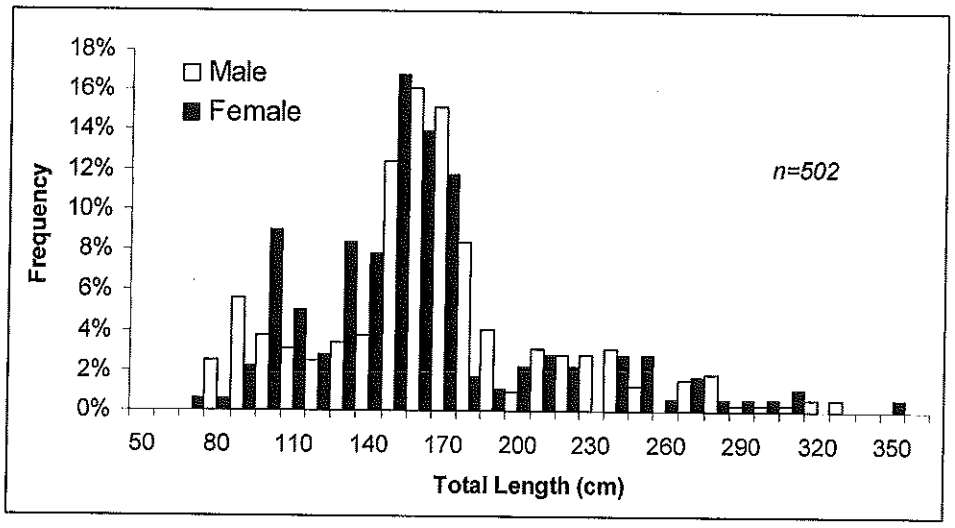


Figure 2. Length frequency distribution by sex of the blue shark specimens sampled in the Mediterranean Sea during the period 1998-2002.

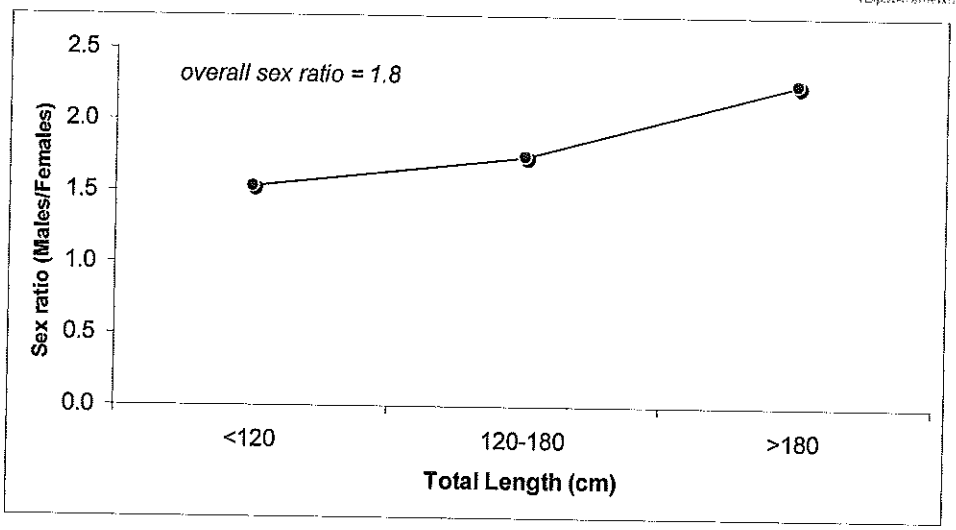


Figure 3. Trend of the sex ratio by length class for the blue shark specimens sampled in the Mediterranean Sea during the period 1998-2002.

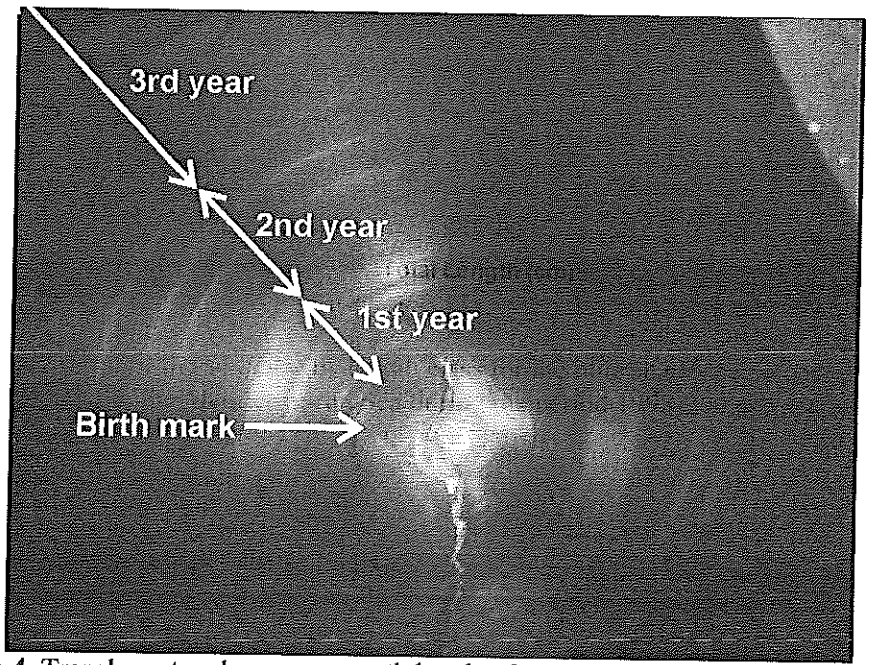


Figure 4. Translucent and opaque growth bands of a vertebra from a specimen of blue shark under transmitted light on the stereoscope.

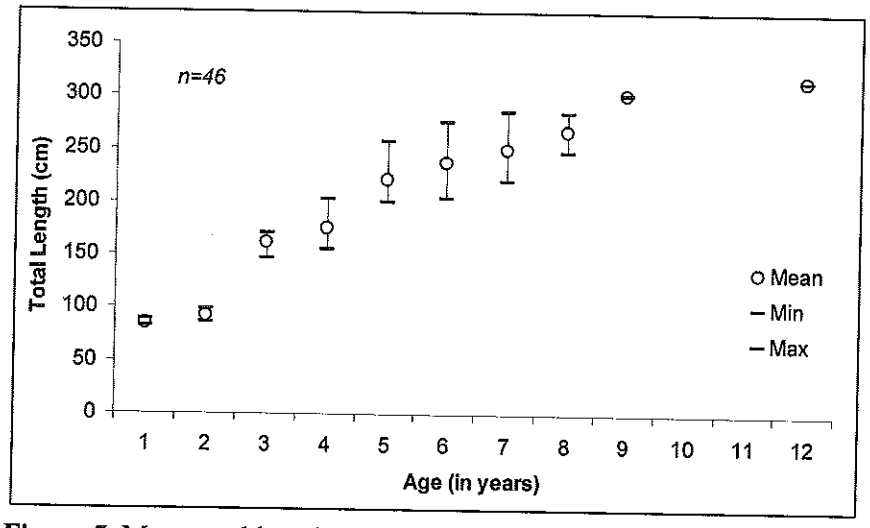
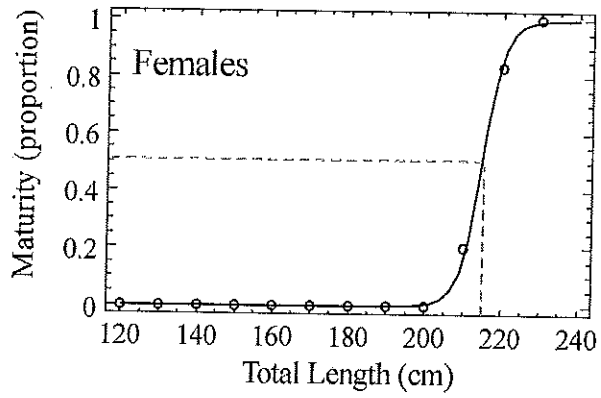


Figure 5. Mean total length at estimated ages for blue shark caught in the Mediterranean Sea during the period 1998-2002.



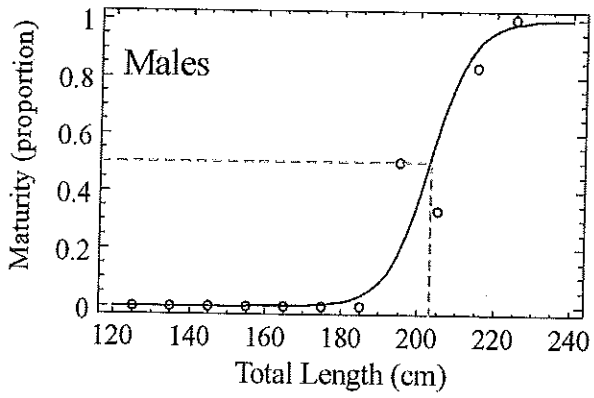


Figure 6. The logistic relathionships between the number of reproductive blue sharks (expressed as a proportion of sexually mature specimens) and total length for males and females separatelly.