

# Age and growth of the shortfin mako shark, *Isurus oxyrinchus*, from the western coast of Baja California Sur, Mexico

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## Abstract

Age and growth of the shortfin mako shark, *Isurus oxyrinchus*, were estimated using the number of growth marks on whole vertebrae from 109 individuals caught during 2000–2003 off the western coast of Baja California Sur, Mexico. A further 110 individuals were measured to obtain data on the age distribution of the population being fished. Sharks ranged from 77 to 290 cm in total length (TL). A significant linear relationship ( $r^2 = 0.91$ ) was found between the vertebrae radius and total length, suggesting isometric growth of vertebrae with total length. Distinct bands of heavier calcification were visualized with silver nitrate staining. The periodicity of these growth marks was determined by the frequency of clear and dark margins of the vertebrae in each month of the year. We found that one growth mark is deposited annually. Estimated ages ranged from 0 to 18 years, with the majority of fish being 1–5 years old. Age and TL were used to describe the shortfin mako growth. Estimates of the von Bertalanffy curve parameters for the combined sexes were:  $L_\infty = 411$  cm TL,  $k = 0.05 \text{ year}^{-1}$ ,  $t_0 = -4.7$  years. Our results suggest that shortfin makos are relatively slow growing sharks, which combined with other life-history traits such as a low fecundity and delayed reproduction, makes this species highly susceptible to overfishing.

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## 1. Introduction

There is considerable concern about shark fisheries around the world as declining catches are attributed to overfishing (Baum et al., 2003). Mexico is a major shark fishing nation in the America (Bonfil, 1994) and

is seventh worldwide in landings with 4.6% of the global production (Mendizábal y Oriza et al., 2000). Shark fishing has traditionally been a very important activity in communities along Mexico's Pacific and Gulf of Mexico coasts. Mexican shark fisheries have been gaining importance and are one of the five most important fishery resources in the country (Castillo-Geniz, 1992). In Mexico the shark catches represent 2.4% of the fisheries (Villavicencio, 1996) with an average of 33 000 metric tons (mt) per year (Mendizábal y Oriza et al., 2000). Baja California Sur

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is the most important state in shark catch in the Mexican Pacific contributing with 24.5% of the coast production (Mendizábal y Oriza et al., 2000). Reported landings of sharks for this state average 4450 mt per year (SEMARNAP, 1996–2000). However there is little information on the size of the catch by species and status of the affected stocks (Holts et al., 1998).

Shark fishery in Mexico is basically an artisanal multi-species fishery which operates with small boats ranging as far as 40 km from shore. This small boat fleet uses both gill nets and longlines (Holts et al., 1998). However in the northern states many sharks are caught by sport fishing (Castillo-Geniz, 1992). Moreover there are at least two commercial fisheries where shark bycatch occurs, the drift net fishery directed at swordfish, *Xiphias gladius*, and the purse-seine fishery of yellow fin tuna, *Thunnus albacares* (Mendizábal y Oriza et al., 2000). Sharks are caught in all coastal artisanal fisheries and there are no fishery regulations in place other than the limit on new permits (Márquez-Farías and Castillo-Geniz, 1998).

The shortfin mako shark is an important species in the commercial and recreational fisheries (Holts et al., 1998), and is also caught as bycatch mainly in the swordfish fishery (Mendizábal y Oriza et al., 2000). In spite of the fact that shortfin mako shark is important for the fisheries industry little is known about the basic biology of this species or the specific life history parameters of the animals caught in the Baja California Peninsula.

Shark management and conservation is hindered by our lack of knowledge at the population level (Baum et al., 2003), as well as the lack of basic biological information (Hoff and Musick, 1990). Biological information has been used to better understand the effects of excessive anthropogenic mortalities on specific groups and to predict population recovery trajectories (Musick, 1999). Understanding the age structure of a population forms the basis for calculations of growth rate, mortality rate and productivity, ranking it among the most influential of biological variables (Campana, 2001).

There are few age and growth studies for the shortfin mako. Pratt and Casey (1983) studied Atlantic mako shark and suggested that two pairs of bands are deposited annually in the vertebra. They estimated 4.5 years to the older male at 225 cm fork length (FL) and 11.5 years to the older female at 328 cm FL. Whereas,

in the same year, Cailliet et al. (1983), worked with Pacific mako shark and proposed that only one pair of bands is deposited in the structure per year. The oldest fish was a female estimated to have 17 years and was the largest individual (321 cm TL) of their sample. Recently, Campana et al. (2002) estimated 21 years to a 328 cm FL Atlantic mako female and confirmed that only one pair of bands is deposited annually. The objective of this study was to gather information about the age and growth of that portion of the shortfin mako shark being landed in the waters of Baja California Sur, Mexico. These data will be useful in designing an effective management strategy for the fishery.

## 2. Materials and methods

Samples of mako shark vertebrae were collected from the cervical region of 109 fish from August 2000 to March 2003 at three localities, Punta Lobos, Punta Belcher and Las Barrancas, on the western coast of Baja California Sur, Mexico (Fig. 1). The fleets at these localities use longlines to catch sharks. Once fishermen landed the sharks on the beach, total length (TL), sex and maturity information were recorded and cervical vertebrae extracted. TL was always measured as a straight line distance from the tip of the rostrum to the end of the caudal fin.

In the laboratory, all connective tissue was removed from the vertebrae using a stereoscope. Occasionally

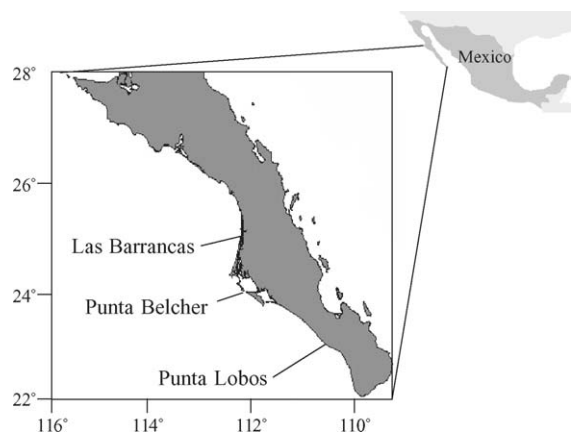


Fig. 1. Study area showing sampling locations.

it was necessary to use fine sandpaper to eliminate any trace of tissue that could interfere with staining. Cleaned vertebrae were soaked in a 1% silver nitrate solution for about 5 min, until the centra were yellowish. Vertebrae were then illuminated with an ultraviolet light source for 3–15 min until growth bands were evident. The vertebrae were then rinsed in distilled water and soaked in a 5% sodium thiosulfate solution for 2 min to remove any excess silver salts and to fix the chemical substitution. Finally, samples were stored in 70% ethyl alcohol. This process is a modification of the Von Kossa technique (Stevens, 1975) where calcium salts are replaced with silver, providing distinct, dark colored, silver-impregnated bands.

Images of vertebrae were captured with a video system, and Sigma Scan Pro 4.0 software was used to measure vertebral radius. Age estimates were made using a stereoscope (16 $\times$ ) without knowing the length of the individual. A growth mark was defined as a pair of one light and one dark band. Age was estimated independently three times and the age was recorded as the most frequent estimate. The periodicity of growth mark formation was determined by analyzing the frequency of light and dark edges on the vertebrae by month. Edge interpretations were made randomly without knowledge of the month of collection. Edge frequencies were correlated with the monthly average sea surface temperature for Punta Belcher obtained from the Reynolds sea surface temperature 2000–2001 database (Reynolds and Smith, 1994) to determine whether growth mark formation coincides with environmental variations.

Finally age and total length data were used to describe the shortfin mako growth using the von Bertalanffy model. Parameter estimations were made through the Marquardt algorithm included in Curve Expert 3.1 software.

### 3. Results

During the 3 years of this study 219 sharks were measured. The specimens ranged from 77 to 290 cm TL, with 70% of the fish being between 90 and 160 cm TL. The largest male registered in this study was 242 cm TL and the largest female was 290 cm TL, whereas the smallest specimen registered was 77 cm TL for both sexes. Because no statistical difference was found between males and females length frequencies (Kolmogorov–Smirnov,  $p > 0.05$ ), the length frequency distributions for both sexes were combined (Fig. 2). Based on external features males become mature over 180 cm TL, whereas there were not mature females in this study.

The relationship between vertebral radius and TL was linear ( $r^2 = 0.91$ ) indicating isometric growth between the vertebral centrum and body length (Fig. 3). This relationship was compared between males and females and no statistical differences were found (ANCOVA,  $p > 0.05$ ).

In order to count growth marks it was necessary to identify the birth mark. This mark was located by using the vertebrae from individuals close to the birth length (70 cm TL) as reported by Mollet et al. (2000).

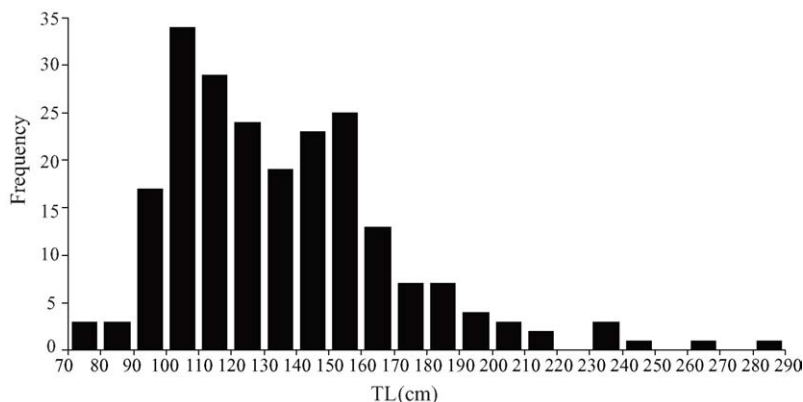


Fig. 2. Length frequency histogram of 219 mako sharks caught during 2000–2003 at the western coast of Baja California Sur.

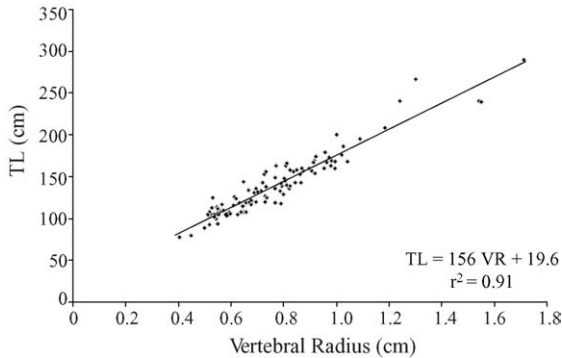


Fig. 3. Relationship between vertebral radius and total length for shortfin mako shark ( $n = 109$ ).

The birth mark was found at a radius between 3.5 and 4 mm and the following growth marks were consecutively enumerated. Three repeated readings of each vertebra had a mean coefficient of variation of 8.9%, which is within the precision values reported in other shark studies (Campana, 2001). In addition, a pre-birth mark was located near the origin of the vertebra (Fig. 4); however, this prenatal mark was not considered in age estimation.

For age validation, the periodicity of growth mark formation was determined by the monthly frequency of light and dark edges. From late winter to late spring (February to May) the edges of the vertebrae were usually light, giving way to dark edges in summer through early winter (July–January) (Fig. 5). These two periods were significantly different (Kruskal–Wallis,  $p < 0.05$ ). This suggests that only one pair of bands is deposited annually. The color of the vertebral edge was correlated

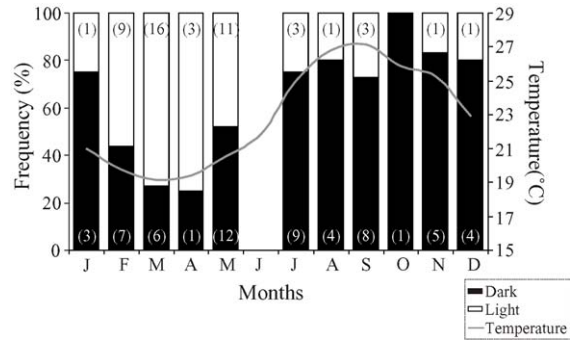


Fig. 5. Mako shark vertebra edge frequency during an average year related to monthly average sea surface temperature for the study area. Sample sizes by month are in parenthesis.

with average sea surface temperature. Light edges coincided with the lowest temperatures ( $19.2\text{--}21.0^\circ\text{C}$ ) and dark edges predominated when the temperature was highest ( $22.9\text{--}27.2^\circ\text{C}$ ).

Age frequency for sexes was combined (Fig. 6) because males and females did not show statistical differences (Kolmogorov–Smirnov,  $p > 0.05$ ). Individuals ranged from 0 to 18 years old. The oldest male was estimated to be 9 years old (209 cm TL) and the oldest female 18 years old (290 cm TL). The age structure shows that the specimens between 1 and 5 years old were most abundant, and they ranged from 90 to 160 cm TL.

The von Bertalanffy growth curve fitted the observed data closely ( $r^2 = 0.94$ ) (Fig. 7). Parameter estimates of von Bertalanffy growth model with sexes combined were:  $L_\infty = 411$  cm TL,  $k = 0.05 \text{ year}^{-1}$ ,  $t_0 = -4.7$  years.

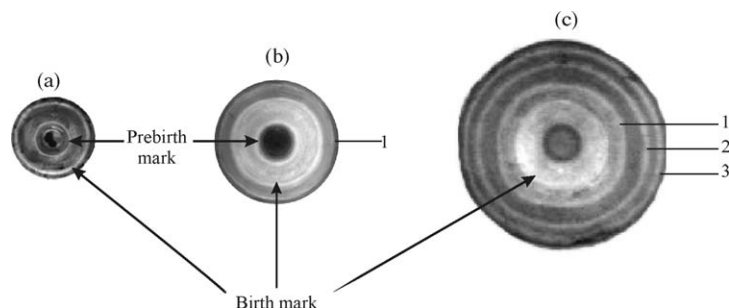


Fig. 4. Mako shark vertebrae treated with silver nitrate. (a) From a 77 cm TL male, vertebra radius 0.45 cm, estimated age 0+; (b) from a 114 cm TL male, vertebra radius 0.55 cm, estimated age 1; (c) from a 139 cm TL male, vertebra radius 0.83 cm, estimated age 3.

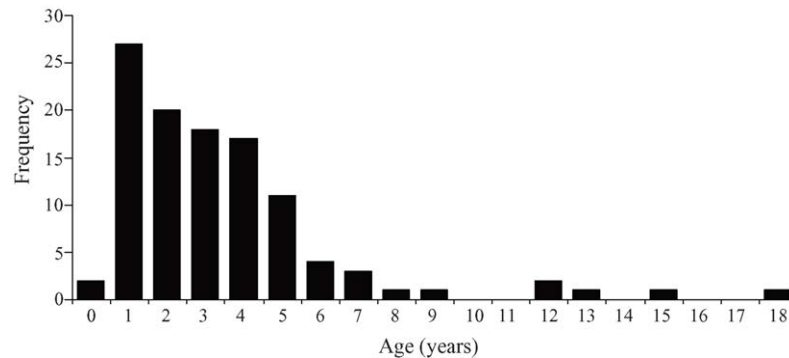


Fig. 6. Age frequency histogram of 109 shortfin mako sharks caught during 2000–2003 at the western coast of Baja California Sur.

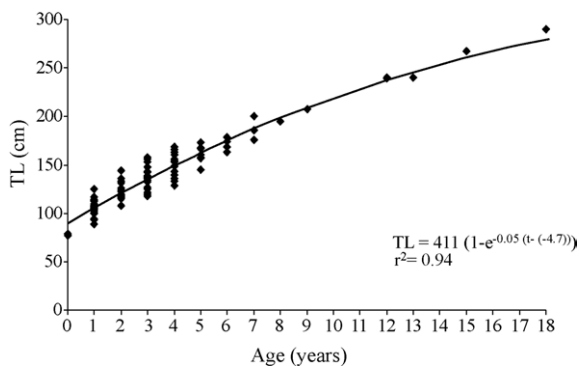


Fig. 7. The von Bertalanffy growth curve for shortfin mako shark (both sexes combined) based on age estimations by vertebrae growth marks ( $n = 109$ ).

#### 4. Discussion

The von Bertalanffy parameters estimated in this study were similar to those reported by Cailliet et al. (1983). The differences between estimates are probably due to the larger sample size in our study which covered a broader size range. Cailliet et al. (1983) studied the mako sharks from California 20 years ago, and as we probably sampled the same population it is not surprising that we obtained similar growth parameters. Our data are quite at odds with those reported by Pratt and Casey (1983); however this is certainly due to their belief that shortfin makos lay down two growth marks per year.

Our estimate of asymptotic length ( $L_{\infty}$ ) is 4% higher than the maximum size for shortfin makos (396 cm TL) reported by Bigelow and Schroeder (1948), 15% higher than the maximum size for Pacific mako sharks

(Applegate, 1977). While our estimate of asymptotic length of shortfin makos is quite close to the reported values it is important to note that our data only cover some 78% of the size range reported in the Pacific. The higher  $L_{\infty}$  is overestimated due to the absence of older sharks in the sample. The lack of large individuals may be due to any combination of several causes. Casey and Kohler (1992) and Mollet et al. (2000) suggest that larger animals, particularly females are likely to be found in deeper water and/or further offshore. Another possibility is that larger sharks prefer other food than the mackerel and herring baits offered by fishermen (Stillwell and Kohler, 1982). Pratt and Casey (1983) mentioned that the lack of mako sharks greater than 260 cm TL could be the result of fishing gear selectivity. Finally, the absence of large fish could simply be the result of overfishing (Anderson, 1985; Russ, 1991). In the case of Baja California Sur mako sharks, anecdotal information from commercial fishermen suggest that larger individuals have been present in the fishery years ago therefore we reject the fishing gear selectivity hypothesis.

Our estimate of  $k$ , a growth parameter, agrees with Cailliet et al. (1983) that this is a very slow growing species. To place this growth rate in context, the other lamnids species for which there is a good estimate of  $k$ , the great white shark (*Carcharodon carcharias*) (Wintner and Cliff, 1999) and the porbeagle shark (*Lamna nasus*) (Natanson et al., 2002) have a similar growth rate ( $k = 0.06$  and  $0.07 \text{ year}^{-1}$  respectively). Carcharhinid sharks can also have very slow growth rates, for example *Carcharhinus obscurus* ( $k = 0.045 \text{ year}^{-1}$ ) (Simpfendorfer et al., 2002), *Carcharhinus plumbeus* ( $k = 0.05 \text{ year}^{-1}$ )



(Casey et al., 1985) and *Carcharhinus leucas* ( $k = 0.07 \text{ year}^{-1}$ ) (Thorson and Lacy, 1982), however, some carcharhinid sharks have far higher  $k$  values. These include *Carcharhinus limbatus* ( $k = 0.27 \text{ year}^{-1}$ ), *Carcharhinus brevipinna* ( $k = 0.21 \text{ year}^{-1}$ ) (Branstetter, 1987b), *Rhizoprionodon terraenovae* ( $k = 0.36 \text{ year}^{-1}$ ) (Branstetter, 1987a) and another important species in the Mexican Pacific fishery, the blue shark, *Prionace glauca*. The blue shark grows much faster ( $k = 0.22 \text{ year}^{-1}$ ) than the mako and thus might respond to a different management strategy (Cailliet et al., 1983).

The occurrence of sexual differences in growth is well documented in elasmobranchs, with females usually growing larger (Casey et al., 1985; Tanaka et al., 1990; Skomal and Natanson, 2003). Pratt and Casey (1983) reported different growth rates for males and females of mako sharks. Growth for both sexes is similar up to the size of male maturity, whereupon, the male growth rate is reduced (Natanson et al., 2002). Owing to the lack of large organisms in our study we could not evaluate such differences and our growth curve may be unreliable beyond and age of 7 years.

Our observation of a prebirth mark on vertebrae may be due to an embryonic change in nutrition associated with the peculiar reproductive mode of lamnoid sharks. In the sandtiger shark, *Carcharias taurus*, a prebirth mark was associated with the switch from internal yolk to embryos feeding on nutritive eggs (oophagy) (Branstetter and Musick, 1994). In the shortfin mako shark the embryos hatch at about 6 cm TL (3–4 month old) and then feed on nutritive eggs until the beginning of the last third of the gestation period (Mollet et al., 2000). We found a prebirth mark near the origin of the vertebra, suggesting that it is formed during the first months of the gestation period, perhaps corresponding with this feeding change.

Though in many sharks there is evidence that a growth mark is deposited annually (Gruber and Stout, 1983; Smith, 1984; Branstetter, 1987a; Branstetter et al., 1987; Cailliet and Radtke, 1987; Conrath et al., 2002; Natanson et al., 2002; Oshitani et al., 2003; Skomal and Natanson, 2003), there is a continuing debate over the periodicity of band pair formation in lamniforms (Natanson et al., 2002). Parker and Stott (1965) mentioned that in the basking shark (*Cetorhinus maximus*), mark formation is biennial. Branstetter and Musick (1994) suggested that the sand tiger shark forms two pairs of growth bands annually. On the other

hand, an annual periodicity has been reported for several lamniforms sharks (Cailliet and Radtke, 1987; Wintner and Cliff, 1999; Campana et al., 2002; Natanson et al., 2002). The data on makos largely support our finding of annual formation of growth marks, though Pratt and Casey (1983) suggested that in Atlantic mako sharks two pairs of bands are deposited annually. The same year, Cailliet et al. (1983) worked with Pacific mako shark and found only one pair of bands per year. Recently, Campana et al. (2002) utilizing bomb radiocarbon dating in the vertebra of a single mako from the northwest Atlantic supported annual growth mark formation, but they only examined one shark. In this study, the monthly frequency of vertebral edges showed a clear annual trend with dark edges dominant during summer-autumn and light edges dominant during winter and spring.

Conde-Moreno (2005) analyzed the maturity of the mako sharks that we sampled. He found that male mako sharks reach maturity at 180 cm TL but during a histological examination he could not find mature females. Despite this, he suggests that females reach maturity at 270 cm TL as Mollet et al. (2000) established. According to our age estimates, males will mature at 7 years and females at approximately 15 years old. Pratt and Casey (1983) suggested that growth marks in mako sharks may yield an approximation of age in immature sharks, but there is a chance that in adult organisms band formation be not an annual event. Likewise, Casey and Natanson (1992) reported the possibility that the annual periodicity in the sandbar shark, *Carcharhinus plumbeus*, does not persist throughout the lifespan of this shark, particularly among females carrying pups. Therefore it is necessary to corroborate mark periodicity on vertebrae of adult makos to be sure that the periodicity of band formation is the same during all lifespan, achieving in this way accurate maturity age estimation. We suggest that a probably late age of maturity, combined with slow growth and other life-history traits such as a low fecundity make the shortfin mako sharks highly susceptible to overfishing.

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