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Age and growth of sailfish *Istiophorus platypterus* (Shaw in Shaw and Nodder, 1792) from Mazatlan, Sinaloa, Mexico

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Abstract Age and growth of the sailfish *Istiophorus platypterus* were determined for the area off Mazatlan coast, Sinaloa, in the Gulf of California, between September 2002 and August 2003. The lower jaw-fork length and total weight of 572 specimens were measured, and the fourth dorsal spine was collected to determine age. The monthly variation of the sample size displayed a well-defined seasonal pattern, which peaked during the warm period (May–November) and declined during the rest of the year (temperate period). Significant differences were detected in the size structure by sex during the temperate period, with females displaying larger sizes and greater abundance (Female: Male = 3.35:1). In the warm period the size structure was similar, with the sex ratio reaching F:M = 0.73:1. This suggests a different sex-related recruitment in the fishing zone, with males moving more actively than females. While female size remained relatively unchanged over the year, male size increased during the warm period. Age was estimated using the number of growth rings on the cross-sectioned fourth dorsal spine, after the number of absorbed growth rings in the vascularized zone had been estimated. Nine age groups were identified; group-5 was the most abundant, representing 31% of the catch. The trend of the monthly change in the percentage of opaque-edge spines and the average of the marginal increase rate indicated that the formation of growth rings displayed an annual pattern. The von Bertalanffy growth model was adequately fitted to age and back-calculated length data. Significant differences were detected when growth was compared between sexes; females grew faster than males.

Keywords Age · Growth · Sailfish · *Istiophorus platypterus* · Gulf of California

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Introduction

Sailfish (*Istiophorus platypterus*) are highly migratory pelagic fish that occur throughout coastal tropical and subtropical waters of the Pacific and Indian Oceans, having a tendency to be found close to the coast and near islands (Nakamura 1985). In the eastern North Pacific Ocean, sailfish are distributed between Ecuador and the Baja California Peninsula. In winter, their center of abundance is located off the Acapulco coast, from where they migrate northwards to reach the Baja

California Peninsula, coinciding with the warm water movement of summer and fall (Kume and Joseph 1969). In Mexico, this species is reserved for the recreational fishery in the first 50 km from the coastline (DOF 1995). Between 1990 and 2002 the average catch in the Gulf of California was ~6400 specimens. Over 50% were caught off Mazatlan coast, Sinaloa, where sailfish are available throughout the year (Macías-Zamora et al. 2000; DOF 2004).

Age and growth determination in fish are vital components in decision-taking for fisheries management (Lai et al. 1996). Some reports of age and growth of sailfish caught in the Pacific Ocean are: Koto and Kodama (1962) estimated sailfish growth through the size frequency of specimens caught by longline vessels in the eastern China Sea from 1952 to 1955. Alvarado-Castillo and Félix-Uraga (1996, 1998) and Chiang et al. (2004) used the fourth spine of the dorsal fin to determine age and describe growth of fish caught in the southern part of the Gulf of California and along the Taiwan coast, respectively. Some investigations of sailfish age and growth in the Atlantic Ocean are: De Sylva (1957) analyzed size-frequency distribution; Jolley (1974, 1977) and Hedgepeth and Jolley (1983) used spines; Radtke and Dean (1981) and Prince et al. (1986) analyzed otoliths; Hoolihan (2006) used spines to estimate age and describe growth of sailfish caught in the Gulf of Arabia.

Fin spine ageing is the most common technique used to estimate age and growth parameters of large pelagic billfishes. Kopf et al. (2010) provide a critical overview of the methods used in previous fin spine ageing studies on billfishes, as well as recommendations towards the development of a standardized protocol for estimating the age of striped marlin, *Kajikia audax* and white marlin, *Kajikia albida*.

The objective of this study was to estimate age through the use of growth rings on the cross sections of the fourth dorsal spine, and to describe the growth pattern of sailfish caught off Mazatlan coast, Sinaloa, in the Gulf of California.

Materials and methods

Sailfish specimens caught by the recreational fleet off Mazatlan coast (Fig. 1) from September 2002 to August 2003 were sampled. For each specimen, the lower jaw fork length (*LJFL*) and total weight (*TW*) were measured, the sex and maturity stage were recorded, and the fourth spine of the dorsal fin was collected for age determination. This hard structure was selected based on its easy extraction. It has proved to be useful in age estimation and its growth is proportional to somatic growth (Jolley 1974; Hill et al. 1989; Kopf et al. 2010). Spines were air-dried to remove remaining tissue.

In the laboratory, the condyle width of each spine was measured with a vernier caliper. Two cross sections approximately 0.6 mm thick were removed with a low-speed saw, at between ¼ and ½ of the condyle width,

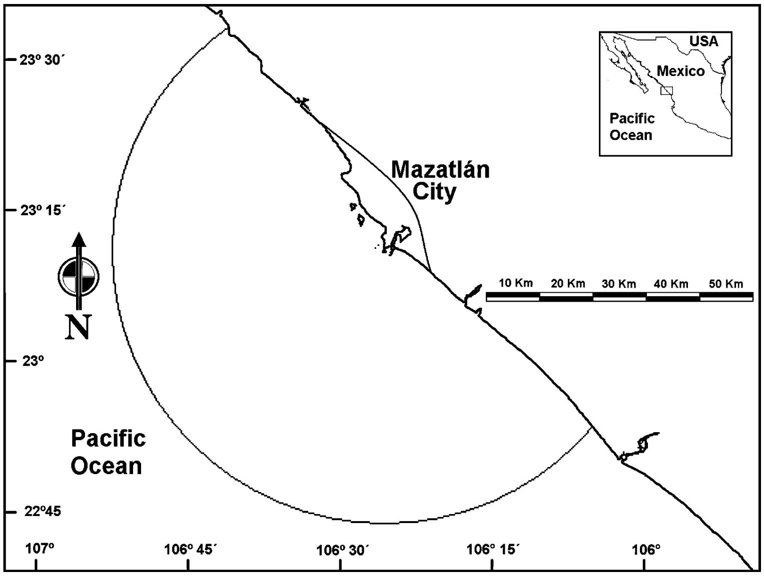

Fig. 1 Location of the study area. The *line* defines the recreational fishing zone, which is 50 km from the Mazatlan coastline, Sinaloa

measured above the base of the spine (Fig. 2). The sections were immersed in ethanol for 2 weeks to remove fat (Prince et al. 1984), then air-dried at room temperature and mounted on slides with synthetic resin.

To estimate age of the specimens, growth rings in the spine sections were read independently by two readers using an image digitizing system consisting of a computer and a stereoscope connected to a video camera. A growth ring was defined as the set of one opaque and one adjacent hyaline band. The images were magnified using a high-resolution display and were captured in 12x magnification using transmitted light. The reading precision was evaluated by using average percent error (APE) (Beamish and Fournier 1981) and coefficient of variation (CV) (Campana 2001) statistics.

The first several growth rings of larger specimens may be obscured due to the large size of the vascularized core of the spine. The number of early but missing growth rings was therefore estimated by the replacement method of Hill et al. (1989), applied to sailfish by Chiang et al. (2004). This method involved first compiling ring radii statistics from younger specimens that had the first ring visible. Radii of the first four visible rings from specimens that had missing early rings were then compared with the radii of these younger specimens. When the radii of at least two successive rings of the first four visible rings each fitted well within one standard deviation from the mean radii of each of two rings from the data compiled from the younger specimens, the number of missing rings was computed as the difference between the ring counts for the matched radii compiled from younger specimens and those from the specimen of interest.

Additionally, the spine edge type (opaque or hyaline), the total spine radius (R), and the radius of each growth ring (r_i, hyaline band outer edge) were recorded using Sigma Scan Pro 5 (Systat Software Inc., San Jose, California).

Two methods were used for determining the periodicity of growth rings. A qualitative method that analyzes the monthly change in the percent of opaque-edge spines (OES), and a quantitative method that analyzes the monthly average of the marginal increment rate in spines (MIR):

$$MIR = [(R - r_n)/(r_n - r_{n-1})]100$$

where R is the spine radius, r_n is the radius to the last complete growth ring, and r_{n-1} is the radius to the

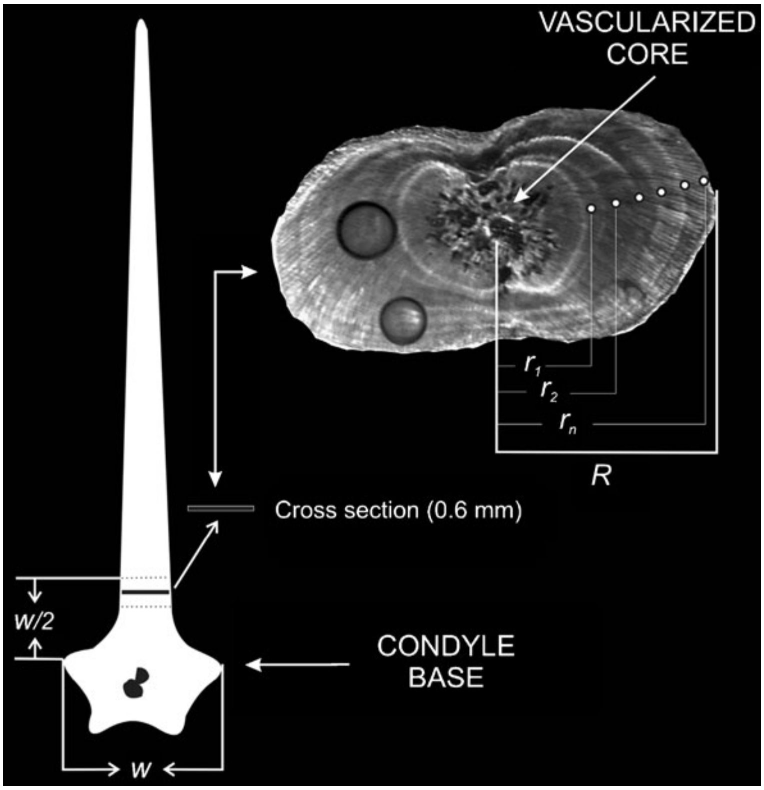

Fig. 2 Schematic diagram of the fourth dorsal spine of sailfish and the location of the cross section. Cross section showing the measurements taken for age determination. W = maximum width of condyle base, R = radius of spine, ri = radius of ring i. The vascularized core and growth rings (1, 2, 3, 4, 5, 6) are also shown

penultimate growth ring (Hayashi 1976; Campana 2001).

To evaluate the effect of SST on growth ring formation, the SST monthly averages were estimated for 1997–2003 (http://las.pfeg.noaa.gov/las6_5/servlets/dataset?catitem=115), and their relationship to the monthly changes of MIR was evaluated.

To back-calculate sailfish length at previous ages we used the relationship between LJFL and R. Spine radius data were grouped into 0.3-mm intervals and the mean LJFL was calculated for each interval (Smale and Taylor 1987). We used three methods for back-calculating LJFL. The first assumed that the relationship between LJFL at time of capture ($LJFL_c$) and R was linear, using the Fraser-Lee equation (Francis 1990):

$$LJFL_i = a + (LJFL_c - a)(r_i/R)$$

where $LJFL_i$ is the length to growth ring i (r_i), and a is the intercept of the regression line $LJFL = a + b\ R$.

The second method used the algebraic method of Duncan (1980) to estimate the a constant:

$$a_i = [R_1(ln\ LJFL_2) - R_2(ln\ LJFL_1)]/(R_2 - R_1),$$

where R_1 and R_2 are the minimum and maximum spine radii in the size interval i, and $LJFL_1$ and $LJFL_2$ are the minimum and maximum lengths in the size interval i. Size intervals were chosen according to the trend in the LJFL cumulative frequency distribution, and the average of the constant for the entire length interval was estimated by averaging the a_i values.

The third method assumed that the relationship between $LJFL_c$ and R was nonlinear, and that $LJFL = c\ R^d$, using the Monastyrsky equation (Francis 1990):

$$LJFL_i = (LJFL_c(r_i/R)^d$$

The back-calculation of size at age was estimated because recreational-fishing in Mexico practices catch and release of small sized fishes as a conservation measure; therefore, the small specimens remain underrepresented in samples.

The von Bertalaffy growth model was fitted to the age-back-calculated LJFL data to describe the sailfish growth pattern:

$$LJFL_t = LJFL_\infty[1 - exp(-k(t - t_0))],$$

where $LJFL_t$ is the length at age t, $LJFL_\infty$ is the asymptotic length, k is the annual growth constant, t_0 is age at length 0 and t is age. The growth parameters and 95% confidence intervals (CI) were estimated using least-squares with the Levenberg-Marquardt algorithm, include in the nonlinear estimation option from Statistica software (Statsoft 2007). The LJFL by age was estimated for each sex using specific growth models, and differences were assessed through an analysis of the residual sum of squares (ARSS) (Haddon 2001). To estimate the age structure of sailfish catches, an age-length key was developed to estimate the age of specimens whose spines were not collected.

Results

During the study 572 sailfish specimens, but only 547 spines, were sampled. Fish availability for the recreational fishery and for sampling occurred in a distinct seasonal pattern (Fig. 3), peaking during May-November and declining to much lower numbers during the remaining temperate months. The lower catches during the temperate months reflect the lower sea surface temperature. The small catch in August did not reflect the true presence of sailfish, since we did not have access to the month's total catch. Sex was assigned to 563 individuals (306 males and 257 females) by macroscopic observation of gonads; the sex of 9 organisms could not be determined since they arrived without viscera to the landing site.

LJFL ranged from 109 to 229 cm; the average was 185 cm±13.5 cm, and 89.5% of the specimens measured between 175 and 205 cm (Fig. 4). Size differences by sex were significant (Wald-Wolfowitz Z = 9.04, $p<0.05$), with females prevailing above 200 cm. There were seasonal changes in size. During the temperate season the mean male LJFL was 172.2 cm and the mean female LJFL was 192.6 cm (Wald-Wolfowitz, Z = 2.18, $p<0.05$); the ratio of females to males was 3.6:1 (Fig. 5a). During the warm season, there were no significant differences in LJFL by sex; mean male LJFL was 182.9 cm and mean female LJFL was 186.7 cm (Wald-Wolfowitz, Z = 0.89, $p>0.05$); the ratio of females to males was 0.37:1 (Fig. 5b). The seasonal difference between sex ratios was significant (2-way contingency table, Pearson's Chi-square = 27.19, $p<0.05$). These findings suggest that during the temperate season females outnumber males by three to one, they are larger, and males move

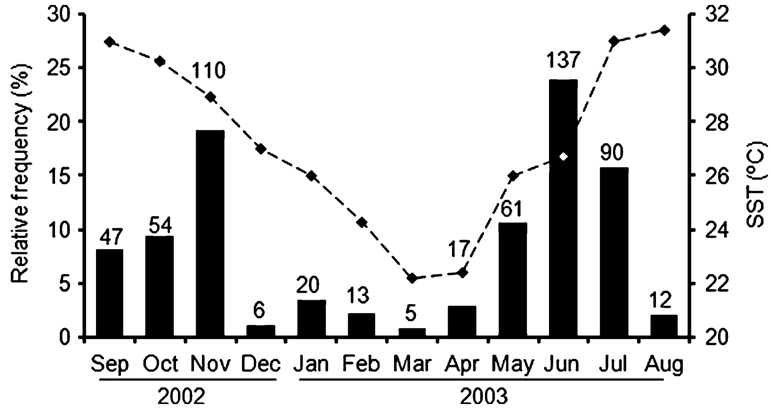

Fig. 3 Monthly sailfish sample size (*bars*) and sea surface temperature (SST) (*line*) from September 2002 to August 2003. The numbers above the bars are the sample sizes

out of this fishing area. During the warm season, the male:female relationship was dominated by males, due to a higher number of males moving into the fishing area.

Only 480 (88%) of all spines sampled for assessing age were successfully read (251 male, 229 female). The average percent error (APE) was 5.7% and the coefficient of variation (CV) was 8.1%; CV's of 10–15% are common for large pelagic fish (DeMartini et al. 2007). The first ring was visible in 34 male spines and 33 female spines. All other specimens were assigned inner rings and final age estimates were based upon these data. The maximum age of the sampled sailfish, after correction for missing early rings, was 8 years for males and 9 years for females. The maximum ages before correction were 6 years for males and 7 years for females.

The monthly percent of OES and MIR were inversely related (Pearson Coefficient $R^2 = -0.78$) (Fig. 6). The percent OES clearly indicated a decline in March, with the maximum MIR occurring 2 months later. These findings suggest that each growth ring ends its formation from May to July, with an annual periodicity, and age is assigned in years. Direct comparison of the monthly change of OES percentage and MIR versus SST was not significant (Pearson Coefficient $R^2 = -0.11$, $R^2 = 0.15$). However, this relationship was significant when SST average values were moved back 2 months (Pearson Coefficient $R^2 = -0.73$, $R^2 = 0.90$) (Fig. 6).

The relationship between LJFL and spine radius was analyzed assuming linear (linear regression and algebraic method) and potential relationships. For the three functions we estimated average LJFL by age (Table 1). The comparison between average lengths by age did not show significant differences (ANOVA, $F = 0.64$, $p > 0.05$). We therefore selected the linear function, estimating the proportionality constant using the algebraic method, since the LJFL back-calculation by age does not tend to overestimate age, unlike the other two functions.

To describe the growth pattern in sailfish, the von Bertalanffy model was fitted to age, and to

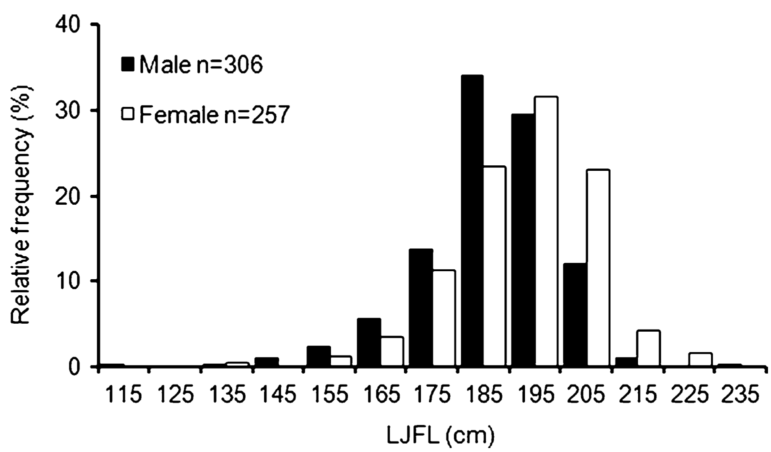

Fig. 4 Size frequency distribution for male and female sailfish caught off Mazatlan coast, Sinaloa, from September 2002 to August 2003

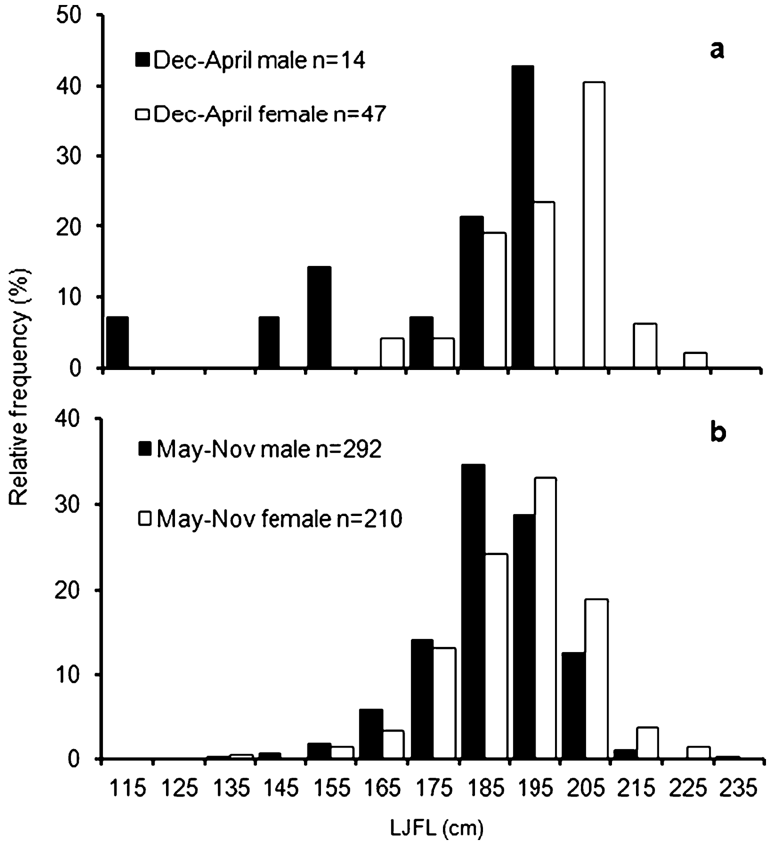

Fig. 5 Size frequency distribution for male and female sailfish caught off Mazatlan coast, Sinaloa. **a** Temperate period (December 2002–April 2003), **b** Warm period (May–November 2003)

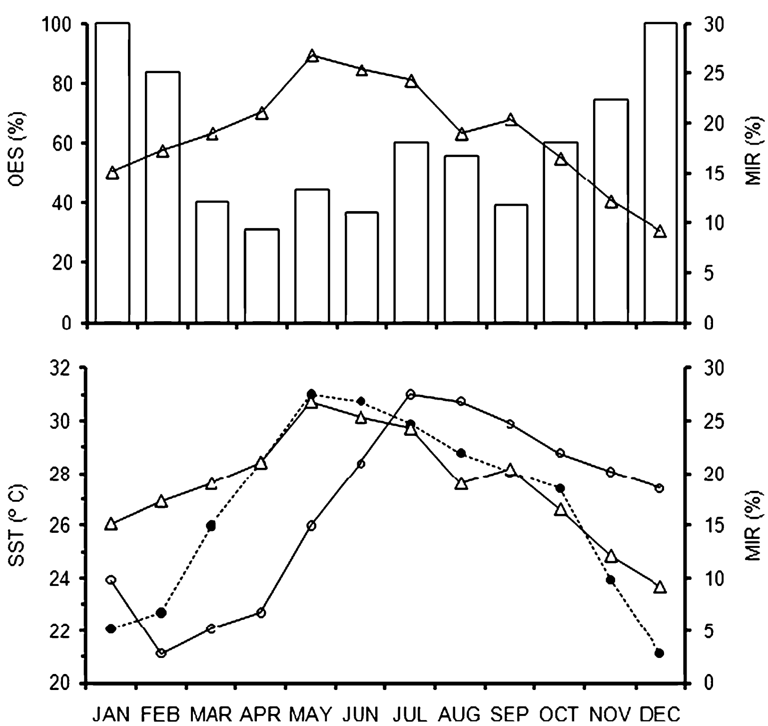

Fig. 6 Monthly average of percentage of opaque-edge spines (OES) and marginal increment rate (upper figure) and marginal increment rate and sea surface temperature (SST) for sailfish caught off Mazatlan coast, Sinaloa. Columns = OES, Triangles = MIR, Empty circles = SST, and Filled circles = SST moved back by 2 months

Table 1 Estimates of average back-calculated and observed lower jaw fork length (LJFL) by age in sailfish caught off Mazatlan coast, Sinaloa, between September 2002 and August 2003. LJFL in cm

Age	Observed	Linear model	Algebraic model	Power model
1	109.0	129.0	82.6	118.4
2	152.0	142.0	103.6	136.7
3	167.8	155.4	128.1	153.1
4	180.2	168.4	151.7	168.2
5	183.5	178.1	168.7	178.3
6	189.2	186.4	181.2	186.8
7	196.5	194.5	190.5	194.9
8	205.5	203.8	200.1	204.1
9	225.0	222.6	213.6	223.0

separately back-calculated LJFL data for each sex (Fig. 7). The growth parameters for males were $LJFL_\infty$ = 256.7 cm (CI = 208.6–304.7 cm), k = 0.16 year^{-1} (CI = 0.09–0.23 year^{-1}), $t_0 = -1.37$ years (CI = −2.09– −0.64 years), $r^2 = 0.99$; and for females $LJFL_\infty$ = 251.4 cm (CI = 222.8–279.9 cm), k = 0.18 year^{-1} (CI = 0.13–0.24 year^{-1}), $t_0 = -1.08$ years (CI = −1.64– −0.52 years), $r^2 = 0.99$. The growth curve for males differed significantly from the growth curve for females (ARSS, F = 3.80, $p<0.05$). It seems that sailfish present rapid growth during the first year of life, reaching on average 80 cm LJFL. Between the second and fourth years there is an average increase of 23 cm, and after the fourth year the growth rate stabilizes at 13 cm per year.

The length cumulative frequency was estimated, and the average $LJFL_{50\%}$ was 176 cm, corresponding to 5 years old. This size would be a mean estimate of size for fishery recruitment. When this length was calculated, based on observed data, the result was an LJFL of 185 cm, and the difference between these two values reflects the magnitude of growth overestimation for early ages using observed data to estimate growth parameters.

Age was estimated using an age-length key in the case of specimens for which a spine was not collected (n=25) or with a spine that was unsuitable for reading (n=67), and the age structure of the catch was derived from this information (Fig. 8). Fish between 1 and 9 years old were found during the study period, with ages 5 (30%), 6 (29%) and 4 (16%) years being the most abundant.

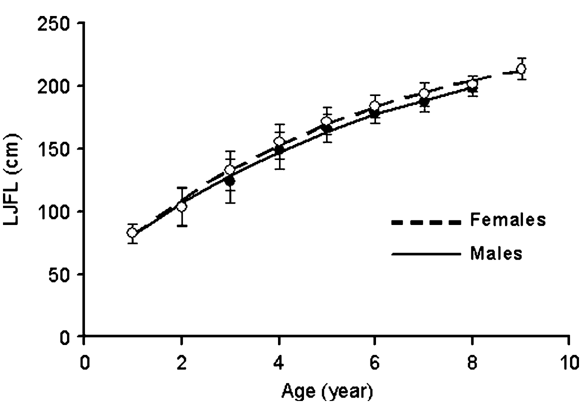

Fig. 7 von Bertalanffy growth model fitted to age and back-calculated lower jaw-fork length (LJFL) for males and females of sailfish caught off Mazatlan coast, Sinaloa. *Vertical lines* are ±1 SD

Discussion

The results indicated significant differences in the size structure by sex for sailfish caught during the temperate

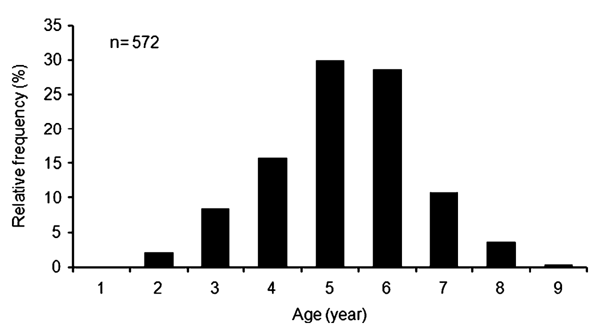

Fig. 8 Age structure of total sailfish caught off Mazatlan coast, Sinaloa

or cooler season (December–April); females were larger and more abundant than males. This difference in size between genders occurs in other regions. Jolley (1974) reported that females were larger than males and that the sex ratio changed noticeably from December to May in coastal Florida. For the same area, Hedgepeth and Jolley (1983) reported differences in size, mostly when fish were 2 years old; females grew faster than males and had greater variation in size and weight. Along the coast of Taiwan, Chiang et al. (2004) reported size differences between genders, females (80–232 cm LJFL) being significantly larger than males (78–221 cm LJFL). In the Arabian Gulf, Hoolihan (2006) reported that females were larger (129–199 cm LJFL) than males (125–177 cm LJFL). The combined evidence suggests a real difference in size between sexes.

In our study, changes in size structure and sex ratio suggest that males move more actively than females toward the coast of Mazatlan and, from there, probably move to the southern Mexican Pacific coast. Based on average catch rates from January 1990 to June 2000, Gonzalez-Armas et al. (2006) confirm that the southern Gulf of California is an important billfish fishing ground, especially for striped marlin, blue marlin and sailfish. High sailfish abundance in this area has been associated with feeding and reproductive activities (Hernández-Herrera and Ramírez-Rodríguez 1998; Rosas-Alayola et al. 2002). Gonzalez-Armas et al. (2006) confirmed some reproductive activity in the southern Gulf of California for sailfish, but this is not the principal spawning area (Hernández-Herrera and Ramírez-Rodríguez 1998). These authors found more intensive reproductive activity around Manzanillo associated with the 28°C isotherm. Larval sampling confirmed the presence of early stages of sailfish in waters off Manzanillo (Gonzalez-Armas et al. 2006). This also coincides with reports of juveniles found in the southern Gulf of California (Vidaurri-Sotelo et al. 1998).

Alvarado-Castillo and Félix-Uraga (1998) analyzed a smaller size range than our investigation, but included larger sizes (155–235 cm LJFL) and found no differences in length between sexes. They mention that the smallest sailfish are found from April to June off Mazatlan and La Paz, and Cabo San Lucas on the western side of the Gulf of California; this coincides with our results, since the smallest specimens (<165 cm LJFL) were recorded during the same period.

During measurements of growth-rings, double or triple rings, or extensive vascular areas occurred in some spines, which masked the first growth rings in large specimens. These irregularities were detected in sailfish by Jolley (1974, 1977), Radtke and Dean (1981), Hedgepeth and Jolley (1983), Alvarado-Castillo and Félix-Uraga (1998), and Chiang et al. (2004).This has also been found in swordfish (Berkeley and Houde 1983; Tserpes and Tsimenides 1995; Sun et al. 2002) and in bigeye tuna (Sun et al. 2001). Observed false growth rings were overcome following the reading criteria of Hedgepeth and Jolley (1983), who established that hyaline bands that continued around the entire circumference of the spine were to be considered growth rings. Age underestimation due to the loss of the first growth rings in the vascularized zone of the spine was overcome using the statistical replacement method proposed by Hill et al. (1989), and used by Chiang et al. (2004) for sailfish captured off the Taiwanese coast. Deposition of growth rings showed an annual pattern, as demonstrated by monthly changes in the percentage of opaque-edge spines and the marginal increase rate. Earlier works on using the fourth spine of the dorsal fin of sailfish for estimating age (Jolley 1974, 1977; Hedgepeth and Jolley 1983) assumed that there was an annual formation of one opaque band followed by a hyaline band, but no assessment of this was conducted. Prince et al. (1986) stated that no direct method was available to validate age in this species, and that more precise estimates may be achieved through mark-and-recapture studies, despite the low recovery rate for large pelagic fish. Alvarado-Castillo and Félix-Uraga (1996) studied the edge (opaque-hyaline) in sailfish spines from captures from 1989 to 1991, reporting that formation of the opaque band occurred between May and November. However, their results were based on limited data, and in the best represented year that included 7 months (1991), monthly percent values were not above 40%. Chiang et al. (2004) used monthly changes in the marginal increase rate to estimate growth ring periodicity in sailfish. They found that one growth ring formed each year from September to November in males and from October to November in females, which coincided with the reproductive season. Along the Pacific coast of Mexico, the reproductive season occurs from July to November (Hernández-Herrera 2001; Gonzalez-Armas et al. 2006), coinciding with high marginal increases and formation of the hyaline band.

The use of back-calculating for length to describe growth patterns has increased, since size in younger age groups is overestimated when working with observed length. This issue is most obvious when samples come from recreational fishing, where small fish are released, if caught.

The earliest research on growth of sailfish used size frequency (De Sylva 1957; Koto and Kodama 1962), which underestimated age and overestimated growth rate; this error was shown by Hedgepeth and Jolley (1983), the first researchers to study growth using the dorsal spine for age determinations. They found that the growth rate during the first year is identical in both sexes, but that females grow faster after the second year. Alvarado-Castillo and Félix-Uraga (1998) reported no difference in growth between sexes in the southern Gulf of California; they found that three-year-old specimens had a mean LJFL of 195 cm. We observed differences in the growth between sexes and in observed lengths. Female sailfish showed a faster growth rate than males, and on average, for a 3-year-old sailfish, a LJFL of 168 cm and a back-calculated length of 129 cm were recorded. This suggests overestimation of size when using observed data without estimating the number of lost growth rings due to the vascularization of the spine nucleus. Chiang et al. (2004) found sex differences in growth and reported a growth rate about 35 cm year^{-1} during the first 3 years, which coincided with our findings.

The most abundant age groups found in this study were 5, 6, and 4, similar to reports by Chiang et al. (2004) along the coast of Taiwan, but different from Jolley (1977), Hedgepeth and Jolley (1983) in the Atlantic Ocean, and Alvarado-Castillo and Félix-Uraga (1996) in the southern Gulf of California, who reported age groups 4, 3 and 5 as the most abundant. Vascularization of the spine nucleus is common in billfish (Kopf et al. 2010). Hill et al. (1989) proposed a statistical replacement method to estimate the number of lost growth rings due to the vascularization of the dorsal spine nucleus in blue marlin. Chiang et al. (2004) used for the first time the statistical replacement method to determine age in sailfish captured off the Taiwanese coast, reporting ages of 11 years in males and 12 years in females, after correcting the number of growth rings as a function of the size of the spine vascularized zone. The maximum age for both sexes before correction was 8 years. In the present study, the maximum number of growth rings in the fourth spine of the dorsal fin of sailfish caught off Mazatlan, Mexico, was 6 for males and 7 for females. After using the replacement method, we determined 8 growth rings for males and 9 growth rings for females. Results suggest that the fourth dorsal spine of sailfish is adequate for age determination when used along with the replacement method to avoid underestimating age and overestimating growth rates.

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