# A Comparative Analysis of Growth Zones in Four Calcified Structures of Pacific Blue Marlin, *Makaira nigricans*

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**ABSTRACT: Sagittae, vertebrae, and anal and dorsal fin spines collected from Pacific blue marlin in Kona, Hawaii were evaluated for legibility and interpretability of growth patterns, ease of collection and processing, and the precision of the resultant annulus counts for use in estimating age. Sagittae, and anal and dorsal fin spine sections contained growth zones assumed to be annual events and there was a linear relationship between age estimates of corresponding samples. Vertebrae had numerous minute growth increments, but contained no marks which could be interpreted as annual. While nonparametric tests revealed no significant difference between age estimates from different hardparts of the same fish, dorsal and anal spine counts had the best agreement. Anal and dorsal fin spines were more practical in terms of ease of collection, processing, legibility, and interpretation; however, age estimates of spine samples from larger fish required a statistical replacement of inner growth zones that were destroyed by matrix expansion. Although more difficult to collect and interpret, sagittae provide more detailed age information. Mean length-at-estimated age data based on anal spine band counts are also presented.**

Increased knowledge of billfish age and growth is essential for sensible management of these fisheries. Although there is a paucity of such information for most billfish species, the Western Pacific Fisheries Management Council was forced to draft a management plan for the Pacific blue marlin, *Makaira nigricans*, with only cursory data (WPFMC 1985). This lack of information is due to the many difficulties involved with studies of large pelagic fish species (Prince and Pulos 1983), compounded by lack of routine sampling programs by research agencies in the Pacific region.

Various calcified structures have been utilized for age estimation of the Istiophoridae. Dorsal spine sections have provided age estimate data for Atlantic sailfish, *Istiophorus platypterus* (Jolley 1974, 1977; Hedgepeth and Jolley 1983), Atlantic white marlin, *Tetrapterus albidus*, and Atlantic blue marlin, *Makaira nigricans* (Prince et al. 1984). Sagittal otoliths have been described as potentially useful structures for ageing most billfish species (Radtke 1981, 1983; Radtke and Dean 1981; Radtke et al. 1982; Prince et al. 1984; Wilson 1984; Cyr 1987). Jolley (1974) described numerous circuli in the vertebrae of sailfish; however, both scales and vertebrae have now been dismissed as structures for age estimation in billfish (Prince et al. 1984).

Age estimation of Pacific blue marlin is still in the developmental stages, and most data have focused on sagittae (Radtke 1981; Wilson 1984), with little effort on other skeletal structures. The objective of the present study was to examine, interpret, and quantitatively compare growth patterns in the sagitta, vertebrae, and dorsal and anal fin spines of blue marlin from Kona, HI. Each structure was evaluated in terms of ease of collection and processing, legibility of growth patterns, and the relative precision of the resulting age estimates.

## MATERIALS AND METHODS

Pacific blue marlin were sampled at the Hawaiian International Billfishing Tournaments in Augusts 1982 ($n$ = 48), 1983 ($n$ = 113), and 1984 ($n$ = 98), and at the Kona Gold Jackpot tournament in May 1983 ($n$ = 20), Kailua-Kona, HI. Additional spine samples were obtained from the Pacific Gamefish Research Foundation ($n$ = 32), the Hawaii Fishing Agency ($n$ = 2), and the National Marine Fisheries Service, Southeast Fisheries Center (a specimen from Kona which was shipped to Miami for taxidermy). Meristic data collected for each fish included lower jaw-fork length (LJFL to 0.1 cm),

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roundweight (W to 0.5 lb converted to kg), sex, and date of capture (Hill 1986).

## Anal and Dorsal Fin Spine Analyses

Anal and dorsal fin spines were collected and prepared for analysis following modified methods of Prince et al. (1984) (Hill 1986). The second anal spine and sixth dorsal spine were selected for age analysis. These were chosen because they were the thickest of the spine complex, and sections taken from spines anterior to these had more prominent core matrices.

Spine length, defined as the distance from the hole at the center of the condyle base to the spine tip, was measured to the nearest millimeter. Thin cross sections from anal and dorsal fin spines were taken at positions marked at 10% and 5% (respectively) of the spine length from the condyle hole. Spine sections were examined using a compound stereoscope at 63× and 120× magnification using either transmitted light or reflected light with a black background. The focus of the spine was defined as the midpoint of the distance between the anterior and posterior portions of the spine along the midsagittal plane. All growth bands were counted and their radii measured with an ocular micrometer along the plane from the focus of the spine to the widest radius of the spine section. Spine radius (anal spine radius = AR; dorsal spine radius = DR) was defined as the distance from the focus to the outside edge of the spine along the same plane.

Statistical replacement of early missing anal and dorsal spine growth bands in larger fish was accomplished by summarizing band radii statistics from smaller, younger specimens in which these early bands were visible. Compiled band radius statistics included spine samples which had at least the first or second band visible. Unpaired *t*-tests were applied to compare corresponding radii between those specimens containing the first and second band and to compare corresponding band radii between sexes.

Final corrected age estimates were assigned to spine samples missing early bands by comparing the radii of the first four visible bands to the means and 95% confidence limits of the compiled data. When the radii of at least three successive bands of the first four visible bands fitted well within the 95% confidence limits of three or four bands of the compiled data, corresponding ages were assigned. The use of this technique to provide final age estimates was based upon the assumption that there was a predictable number of growth bands per millimeter of radius in the core matrix, and that the first several visible bands were analogous in age to matching bands of the compiled radius data.

## Sagitta Analyses

Sagitta were cleaned, prepared, and examined following the methods of Radtke (1983) and Hill (1986). Terminology for sagitta orientations is based on Prince et al. (1986). Sagittal otolith weight (SW) was measured to the nearest 0.005 mg. Age assignments were based on combined counts of external growth features present on the sagittae, which included ridges along the anterior rostrum edge on the ventral plane of growth and ridges along the ventral surface of the medioventral and medial planes of growth.

Previous studies of Istiophorid sagitta have supplemented age estimates based on external features with examination of internal growth features using thin transverse sections and light microscopy (Wilson 1984; Prince et al. 1986). However, Hill (1986) statistically compared age estimates using external and internal growth features and found no significant difference between the two methods. Therefore, age estimates reported in this study were based only upon examination of external features.

## Vertebrae Analyses

Caudal vertebrae numbers 22 and 23 were removed from the area between the posterior portion of the second dorsal fin and the base of the caudal fin. These were the only vertebrae which could be removed without lowering the market value of the fish. Vertebrae were simmered for several hours in hot water to remove extraneous tissues and then air dried for at least 72 hours. Vertebral spines and arches were removed, anterior and posterior centra separated, cut longitudinally along the dorsoventral plane, and stored in 95% isopropyl alcohol.

Vertebral cone depth (CD) (as defined by Johnson 1983), referred to in this paper as centrum cone depth was measured to the nearest 0.05 mm. Growth rings were observed after carefully peeling away the thin layer of cartilaginous tissue which covers the bony face of the centra. Centrum length, from focus to outside edge, was divided into approximately 5 mm sections and the average number of rings per millimeter was calculated for each section by counting three 1 mm portions in each section. Total increment number was extrapolated from these data.

## Assessment of Ageing Techniques

The usefulness of each hardpart for estimating age in blue marlin was assessed by considering ease of collection, hardpart growth, precision of age estimates, and the legibility of each hardpart.

To test the hypothesis that hardpart growth was proportional to somatic growth of the animals, both LJFL and W were modeled with AR, DR, SW, and CD, categorized by sex. The significance (two-tailed test) of $r^2$ values was tested (Schefler 1979). A paradigm of the ageing theory is that the number of increments in or on a hardpart increases with the growth of the structure. To test this assumption, AR, DR, SW, and CD were modeled against increment counts for each structure and the significance of the $r^2$ values was tested.

Relative precision of age estimates and hardpart legibility were determined by comparing the variability of estimated ages between hardparts from the same fish. Direct comparisons of age estimates from corresponding hardparts (anal spines, dorsal spines, and sagittae) were modeled with linear regression, and the slopes of these regressions were tested to see if they varied significantly from parity (Ho: beta = 1; Zar 1984). The significance of correlation coefficients ($r$) of the comparisons was tested using methods outlined by Schefler (1979). These relationships were also tested using a Wilcoxon Signed Ranks test (Sokal and Rohlf 1981). Owing to the difference in increment types, vertebrae were not considered in these comparisons.

To test the consistency of age estimates within and between readers, a subsample of 20 of each hardpart was read three times each by two readers. Age estimates were compared using the Average Percent Error (APE) method of Beamish and Fournier (1981). Mean age estimates of each of these comparisons were compared using the Wilcoxon Signed Ranks test. Uncorrected anal and dorsal spine band counts were utilized for all reader comparisons.

## RESULTS

Hardparts and morphometric data were taken from a total of 211 male and 105 female blue marlin. Males ranged in size from 114.8 cm LJFL (19.1 kg) to 263.1 cm LJFL (170.3 kg) and females from 147.0 cm LJFL (20.9 kg) to 445.8 cm LJFL (748.0 kg). The 263.1 cm LJFL male and the 445.8 cm LJFL female are the largest specimens of blue marlin from which biological data have been reported in the literature. The mean length of females (264.9 cm LJFL) was significantly greater than that of males (205.1 cm

TABLE 1.—Summary of numbers and size ranges of Pacific *Makaira nigricans* from which skeletal hardparts and measurements were collected. LJFL = lower jaw-fork length, AR = anal spine radius, DR = dorsal spine radius, SW = sagittal otolith weight, CD = centrum cone depth.

| | | LJFL (cm) | | | Weight (kg) | | | Hardpart size | |
|---|---|---|---|---|---|---|---|---|---|
| Hardpart | N | Min. | Max. | Mean | Min. | Max. | Mean | Min. | Max. |
| Anal spines | | | | | | | | AR (mm): | |
| Males | 150 | 114.8 | 263.1 | 205.3 | 19.1 | 170.3 | 75.0 | 3.98 | 10.10 |
| Females | 49 | 163.8 | 363.4 | 260.4 | 35.2 | 555.2 | 180.8 | 5.66 | 18.11 |
| Dorsal spines | | | | | | | | DR (mm): | |
| Males | 66 | 177.0 | 263.1 | 208.7 | 46.3 | 170.3 | 78.5 | 7.65 | 12.46 |
| Females | 30 | 163.8 | 445.8 | 275.7 | 35.2 | 748.0 | 227.4 | 6.58 | 21.00 |
| Otoliths | | | | | | | | SW (mm): | |
| Males | 54 | 169.5 | 251.5 | 206.4 | 38.6 | 138.8 | 75.9 | 0.415 | 4.985 |
| Females | 45 | 163.8 | 445.8 | 265.9 | 35.2 | 748.0 | 197.4 | 0.800 | 10.400 |
| Vertebrae | | | | | | | | CD (mm): | |
| Males | 122 | 169.5 | 251.5 | 206.3 | 38.6 | 138.8 | 74.8 | 17.45 | 40.48 |
| Females | 77 | 147.0 | 337.7 | 261.1 | 20.9 | 447.7 | 176.5 | 18.30 | 45.99 |
| Total | | | | | | | | | |
| Males | | 114.8 | 263.1 | 205.1 | 19.1 | 170.3 | 74.2 | | |
| Females | | 147.0 | 445.8 | 264.9 | 20.9 | 747.9 | 190.9 | | |

LJFL) (Student's $t$-test; $P < 0.05$). Not all hardparts were collected from all fish. For a breakdown of fish size ranges and hardparts collected, the reader is referred to Table 1.

## Hardpart Growth

The relationships between AR, DR, and CD, and LJFL were best described by significant ($P < 0.001$) positive linear equations (Table 2). Coefficient of determination values ranged from $r^2 = 0.19$ for male vertebrae to $r^2 = 0.72$ for female anal spines (Fig. 1). The relationships between SW and LJFL were exponential, with $r^2 = 0.41$ for males and $r^2 = 0.35$ for females (Table 2, Fig. 2). Logarithmic equations best described the relationships between AR, DR, CD, and W for both sexes (Table 2). Coefficient of determination values were significant ($P < 0.001$), ranging from $r^2 = 0.30$ for male vertebrae to $r^2 = 0.87$ for female dorsal spines. Sagitta weight had a linear relationship with W, with $r^2 = 0.32$ for males and $r^2 = 0.46$ for females.

Overall, there were generally higher coefficients of determination between AR, DR, CD, and W compared with those with LJFL. In addition, females generally had stronger relationships between hardpart size and body size (LJFL and W) when compared to males, the exception to this being the relationship between female SW and LJFL.

## Growth Increments

Thin cross sections of dorsal and anal fin spines revealed a vascularized core matrix and a cortical region containing major growth bands (Fig. 3). A growth band was composed of alternations of translucent and opaque rings. Many growth bands were comprised of smaller rings that were most obvious at the widest lateral portion of the spine section (Fig. 4). Since band radii were measured from the focus outward along the widest portion of the spine, excessive numbers of smaller rings along the counting path made delineation of the outside edge of the translucent zone difficult at times, especially in exceptionally large spine samples. In such cases, it was necessary to refer to the dorsal and ven-

TABLE 2—Modeled relationships between fish growth (in length and weight) and hardpart growth for male and female Pacific *Makaira nigricans*. LJFL = lower jaw-fork length, W = roundweight, AR = anal spine radius, DR = dorsal spine radius, SW = sagitta weight, CD = centrum cone depth.

| Comparison | Equation | $r^2$ value |
|---|---|---|
| Anal spine radius vs. LJFL | | |
| Males | $AR = -0.5207 + 0.0394(LJFL)$ | 0.52 |
| Females | $AR = -2.5879 + 0.0528(LJFL)$ | 0.72 |
| Anal spine radius vs. W | | |
| Males | $AR = 1.3061 * W^{0.4079}$ | 0.62 |
| Females | $AR = 1.5300 * W^{0.3885}$ | 0.81 |
| Dorsal spine radius vs. LJFL | | |
| Males | $DR = -0.2700 + 0.0474(LJFL)$ | 0.49 |
| Females | $DR = 0.2440 + 0.0526(LJFL)$ | 0.71 |
| Dorsal spine radius vs. W | | |
| Males | $DR = 2.0850 * W^{0.3513}$ | 0.53 |
| Females | $DR = 2.3157 * W^{0.3499}$ | 0.87 |
| Sagittal weight vs. LJFL | | |
| Males | $SW = 0.0152 * 10^{(0.0103 * LJFL)}$ | 0.41 |
| Females | $SW = 0.3250 * 10^{(0.0038 * LJFL)}$ | 0.35 |
| Sagittal weight vs. W | | |
| Males | $SW = -0.642 + 0.0412(W)$ | 0.32 |
| Females | $SW = 1.1625 + 0.0144(W)$ | 0.46 |
| Vertebral cone depth vs. LJFL | | |
| Males | $CD = 2.5616 + 0.1226(LJFL)$ | 0.19 |
| Females | $CD = 5.2871 + 0.1106(LJFL)$ | 0.45 |
| Vetebral cone depth vs. W | | |
| Males | $CD = 7.509 * W^{0.3031}$ | 0.30 |
| Females | $CD = 10.101 * W^{0.2377}$ | 0.50 |

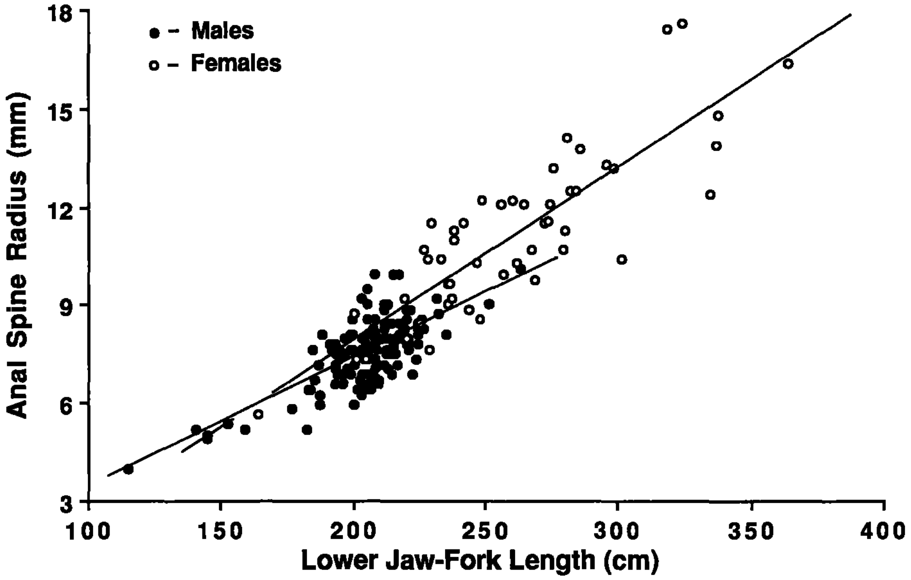


FIGURE 1.—Relationships between lower jaw-fork length (LJFL) and anal spine radius (AR) for male ($n$ = 150) and female ($n$ = 49) Pacific *Makaira nigricans*. Males: AR = −0.5207 + 0.0394 (LJFL) $r^2 = 0.52$; Females: AR = −2.5879 + 0.0528 (LJFL) $r^2 = 0.72$.

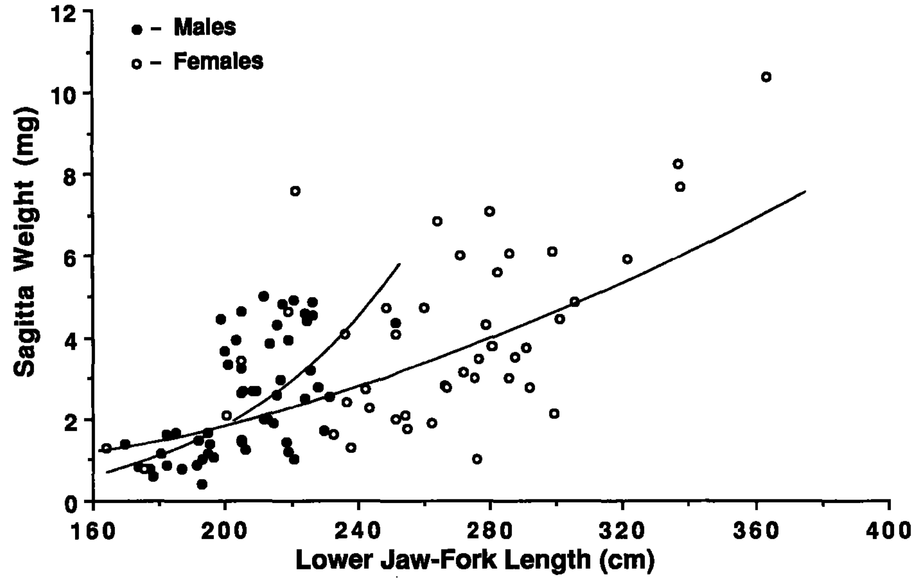


FIGURE 2.—Relationships between lower jaw-fork length (LJFL) and sagitta weight (SW) for male ($n$ = 54) and female ($n$ = 45) Pacific *Makaira nigricans*. Males: SW = 0.0152 * $10^{(0.0103* \text{LJFL})}$ $r^2 = 0.41$; Females: SW = 0.3250 * $10^{(0.0038 * \text{LJFL})}$ $r^2 = 0.35$.

tral areas of the section where the bands were more compressed and clearly delineated. Anal spines were less compressed dorsoventrally than dorsal spines and this may have increased clarity of growth bands (Fig. 3).

Sagittae contained external features that suggested changes in structural growth rate over time. Growth of the rostrum was along two planes. Early growth occurred ventrally to the fish and increments were mainly comprised of

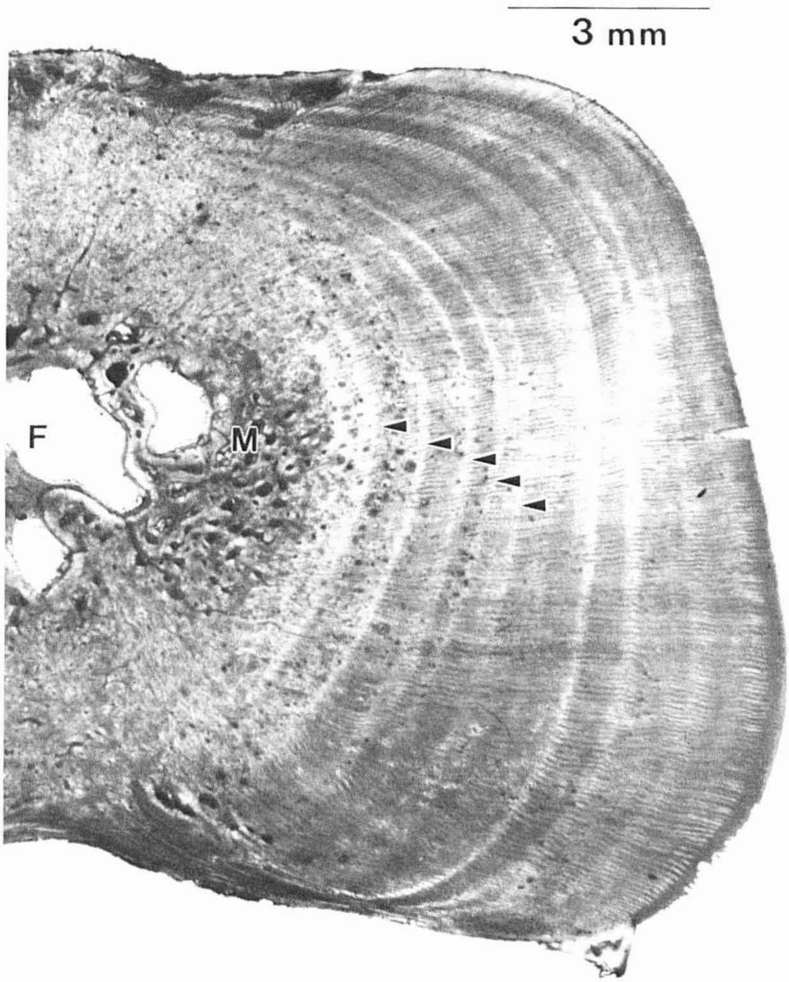


FIGURE 3.—Thin tranverse cross section of the 2nd anal spine from a 138.3 kg female Pacific *Makaira nigricans* as viewed by a binocular dissecting microscope at 63× magnification with transmitted light. Arrows indicate translucent edges of growth bands. F = focus; M = core matrix.

ridges along the anterior rostrum edge (Fig. 5). Between two and four ridges were counted along the anterior edge of the rostrum. Ridges were also visible along the ventral portion of the medial plane of growth (Fig. 6). Most sagittae had an excess of calcium carbonate which hindered ridge quantification to varying degrees (Fig. 6). Several sagittae were difficult to interpret owing to the mottled appearance of the rostrum face.

Vertebrae contained numerous minute (0.05–0.1 mm) concentric growth increments which were topographical features on the centrum face (Fig. 7). There were no prominent 3-dimensional features or changes in ring density which might be indicative of annular events.

## Increment Counts and Hardpart Growth

Statistical replacement of early missing anal and dorsal spine bands in larger fish was accomplished by summarizing band radii statistics from smaller fish in which these early increments were visible (Fig. 4). Twenty-one percent of anal spines and 24% of dorsal spines had at least the first and second assumed annulus visible. There was no significant difference ($P <$

FIGURE 5.—Right sagitta from a 35.2 kg female Pacific *Makaira nigricans*. Arrows indicate prominences quantified for estimation of early lateral rostrum growth. R = rostrum; A = antirostrum; C = core region; p = posterior; a = anterior.

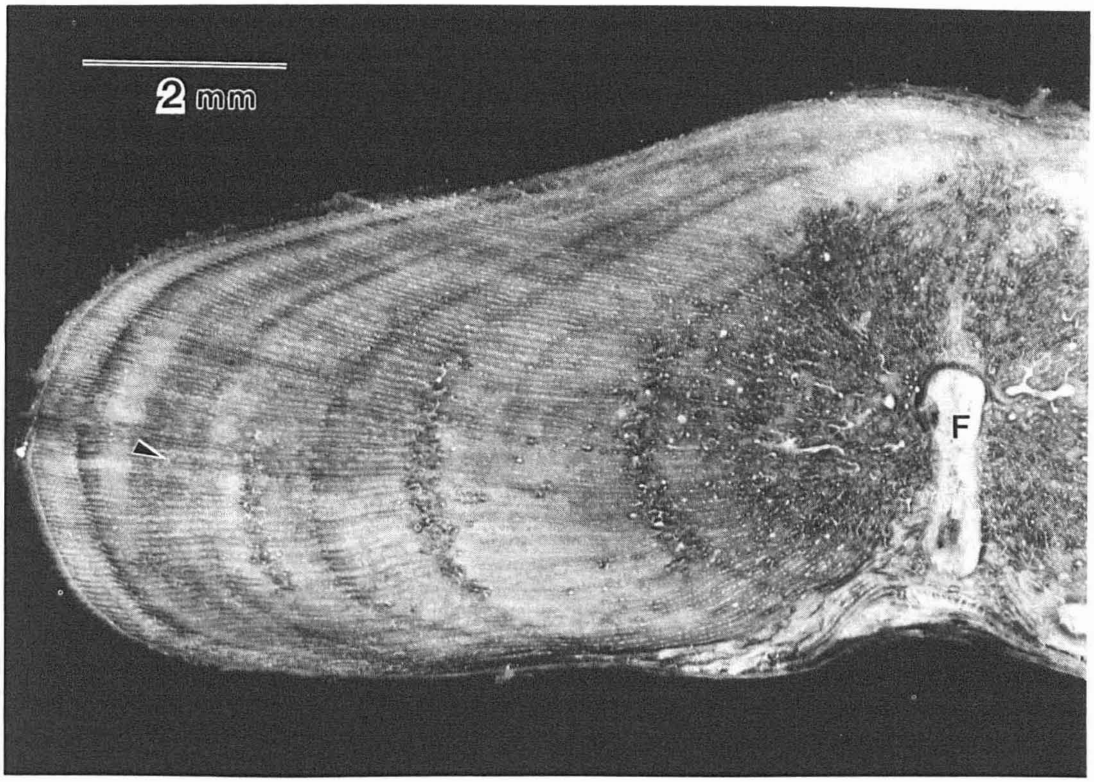
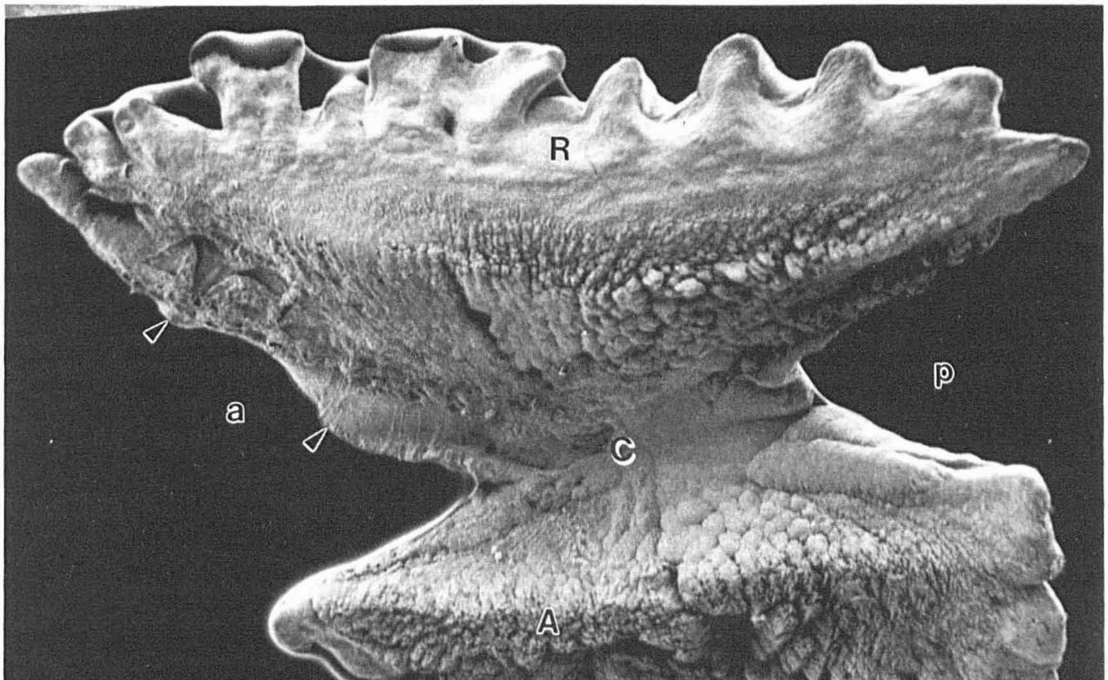


FIGURE 4.—Thin tranverse cross section of the 6th dorsal spine from a 52.4 kg male Pacific *Makaira nigricans* as viewed by a binocular dissecting microscope at 63× magnification with reflected light and a black background. F = focus. Arrow indicates area of multiple rings within a single growth band increment.



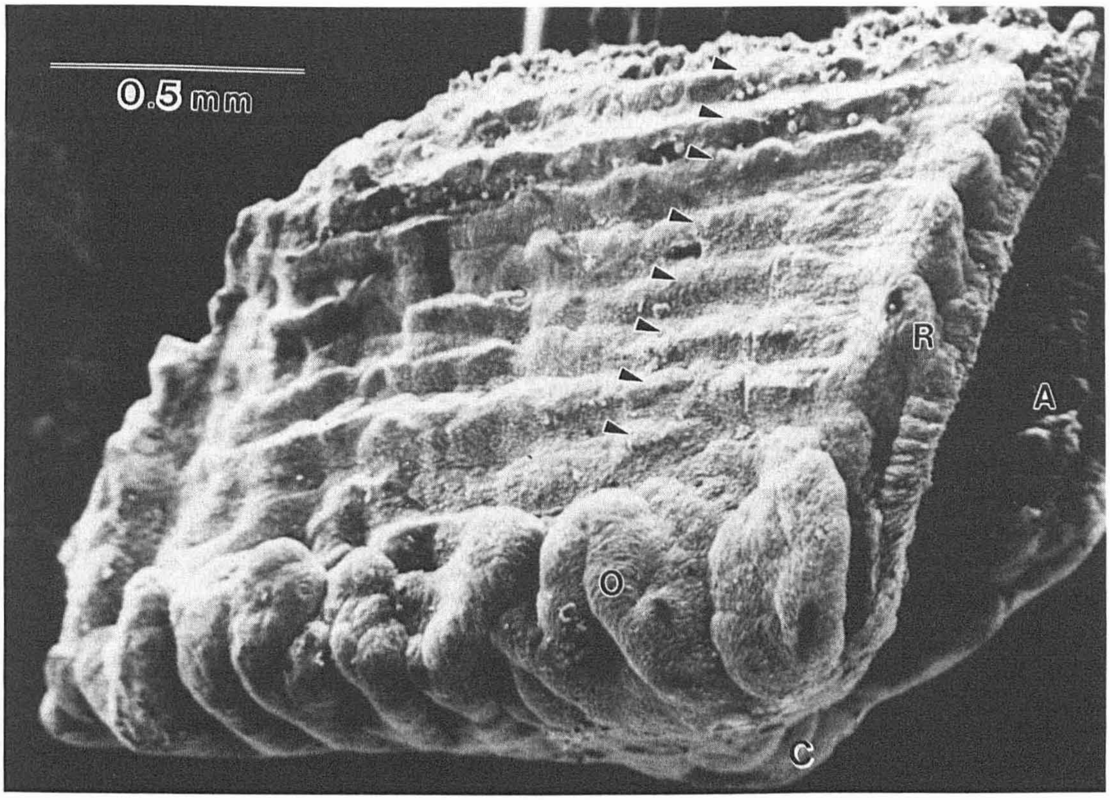


FIGURE 6.—Left sagitta from a 80.1 kg male Pacific *Makaira nigricans*. Arrows indicate rostral ridges quantified for age estimation. R = rostrum; A = antirostrum; C = core region; O = calcium carbonate overburden obscuring ridges.

0.01) between corresponding annuli for these two sets of data for either anal or dorsal spines; therefore, these two data sets were combined. There was, however, a significant difference in corresponding anal and dorsal spine band radii between males and females from the sixth band outward; therefore data were separated by sex (Fig. 8A, B).

Increment counts (sagitta ridges, corrected spine bands, and vertebral increments) increased with hardpart growth for each of the four structures considered. This relationship was logarithmic when increment counts were compared to AR, DR, and SW, and linear when compared to CD for both sexes (Table 3). Coefficients of determination were higher for females in all cases, and ranged from $r^2 = 0.39$ for male dorsal spines to $r^2 = 0.83$ for female dorsal spines.

## Hardpart Comparisons

There was a positive linear relationship between estimated counts of corrected growth in-

TABLE 3—Modeled relationships between hardpart growth and increment counts for Pacific *Makaira nigricans*. LJFL = lower jaw-fork length, W = roundweight, AR = anal spine radius, DR = dorsal spine radius, SW = sagitta weight, CD = centrum cone depth, AC = corrected anal spine band counts, DC = corrected dorsal spine band counts, SC = sagittal ridge counts, VC = vertebral increment counts.

| Comparison | Equation | $r^2$ value |
|---|---|---|
| Anal fin spines | | |
| Males | $AC = 0.4521 * AR^{1.4316}$ | 0.62 |
| Females | $AC = 0.5878 * AR^{1.2729}$ | 0.78 |
| Dorsal fin spines | | |
| Males | $DC = 0.9353 * DR^{1.0044}$ | 0.39 |
| Females | $DC = 0.5380 * DR^{1.2227}$ | 0.83 |
| Sagittal otoliths | | |
| Males | $SW = 7.7206 * SW^{0.2941}$ | 0.41 |
| Females | $SC = 7.1512 * SW^{0.4095}$ | 0.42 |
| Vertebrae | | |
| Males | $VC = 86.922 + 13.742(CD)$ | 0.56 |
| Females | $VC = 59.115 + 15.311(CD)$ | 0.69 |

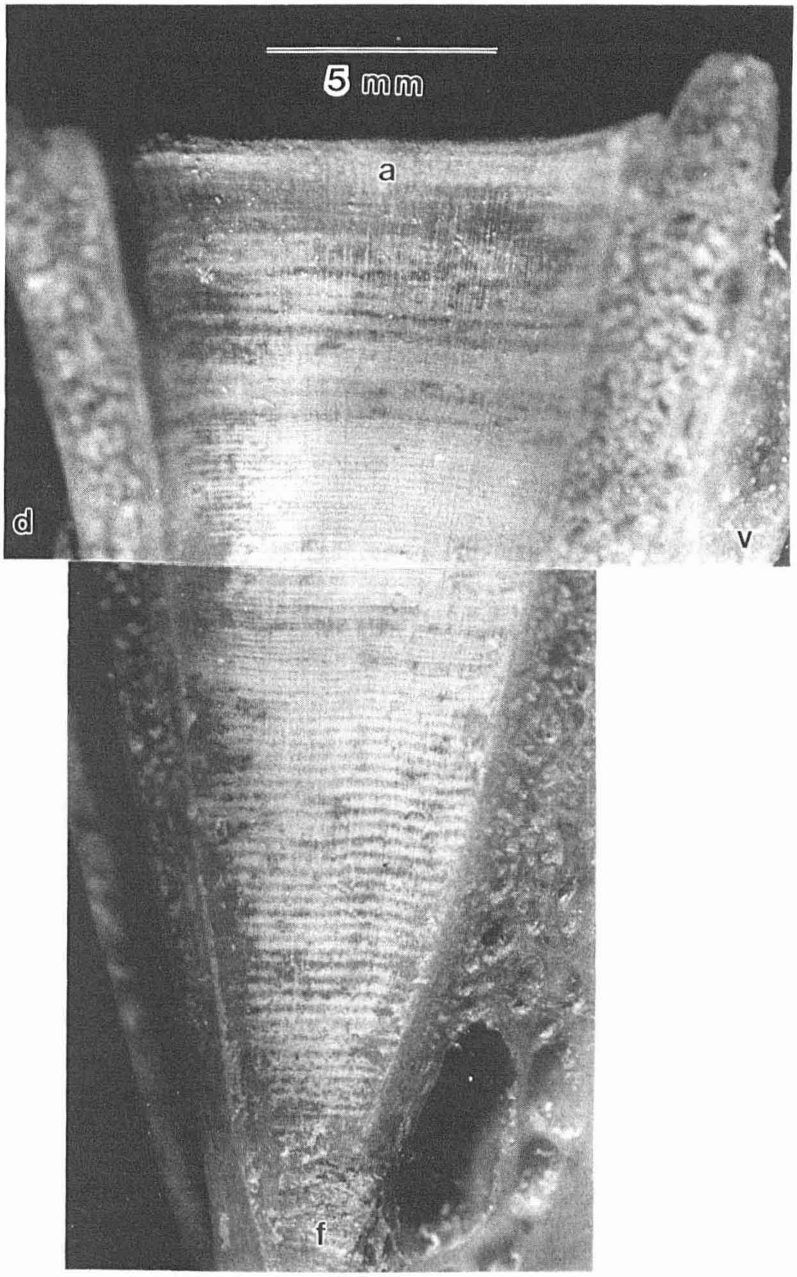


FIGURE 7.—Longitudinal cross section of the anterior centrum from the 23rd vertebrae from a 50.3 kg male Pacific *Makaira nigricans*. a = anterior end; d = dorsal; v = ventral; f = centrum focus.

crements in anal and dorsal spine sections and sagitta from the same blue marlin (Fig. 9A-C). The $y$-intercepts of these relationships were not significantly different from zero, and the slopes did not differ from parity (slope = 1; $P < 0.05$). Correlation coefficients ranged from $r = 0.84$ ($P < 0.001$) for anal spine and sagitta counts to $r = 0.95$ ($P < 0.001$) for the comparison of anal and dorsal spine counts. The greatest deviation in counts between corresponding hardparts was 9, where the anal spine count was 7 and the sagittal increment count was 16. Wilcoxon Signed Rank tests revealed no statistical difference between counts of these three structures ($P < 0.01$).

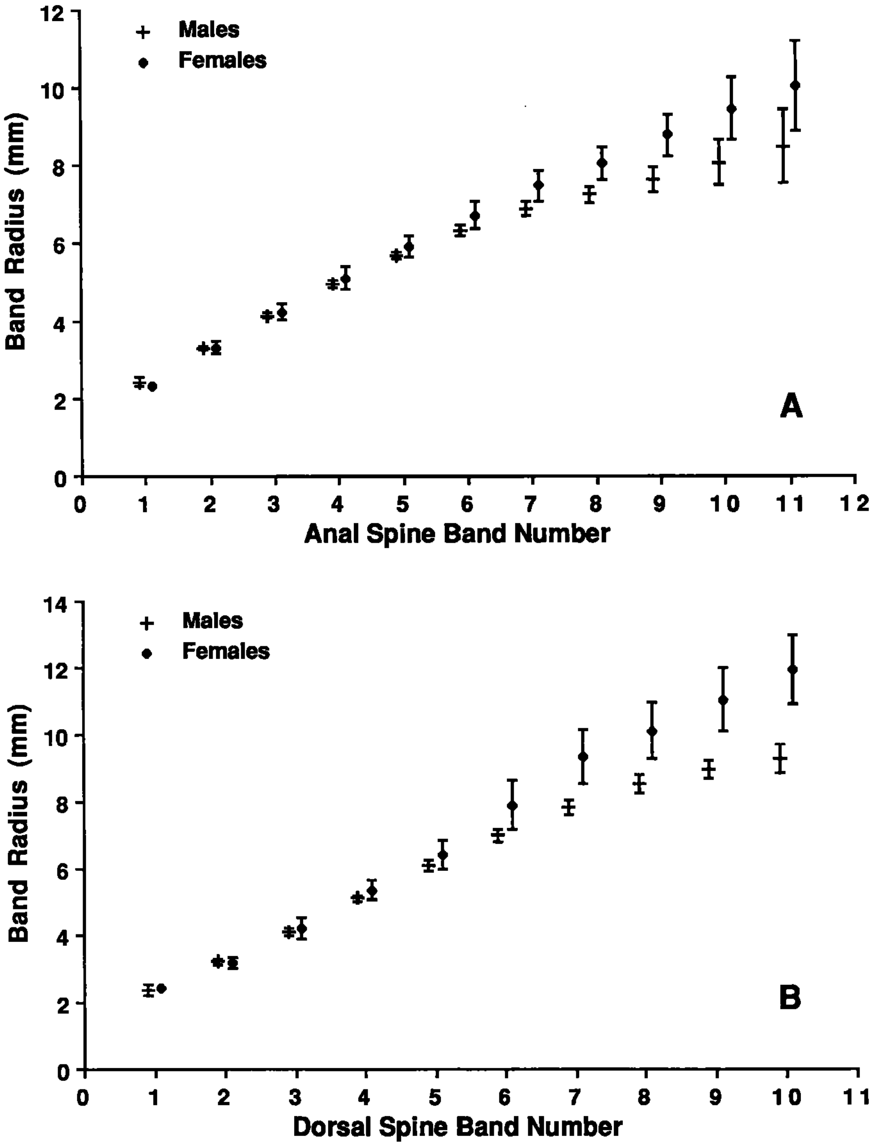


FIGURE 8.—Mean (±95% confidence limits) anal spine (A) and dorsal spine (B) band measurements for male and female Pacific *Makaira nigricans*. Data are from specimens that had at least the first or second band present. All other specimens were assigned inner rings and final age estimates based upon these data.

## Reader Comparisons

Average Percent Error (APE) values ranged from 4.88% error for anal spines counted by reader 1 to 9.68% for sagittae counted by reader 2 (Table 4). Reader 1 had lower APE values (more precise age estimations) than reader 2 for each hardpart. Both readers had lowest APE values for anal spines and highest values for sagittae (Table 4).

Comparisons of differences (D) in mean age estimates between readers revealed that reader 1 had a tendency to give higher age estimates

TABLE 4—Average percent error (APE) values calculated from triplicate uncorrected readings of 20 randomly selected anal fin spines, dorsal fin spines, and sagittae.

| | Average percent error results | |
|---|---|---|
| Hardpart | Reader 1 | Reader 2 |
| Anal fin spines | 4.88% | 8.79% |
| Dorsal fin spines | 5.50% | 9.18% |
| Sagittae | 8.15% | 9.68% |

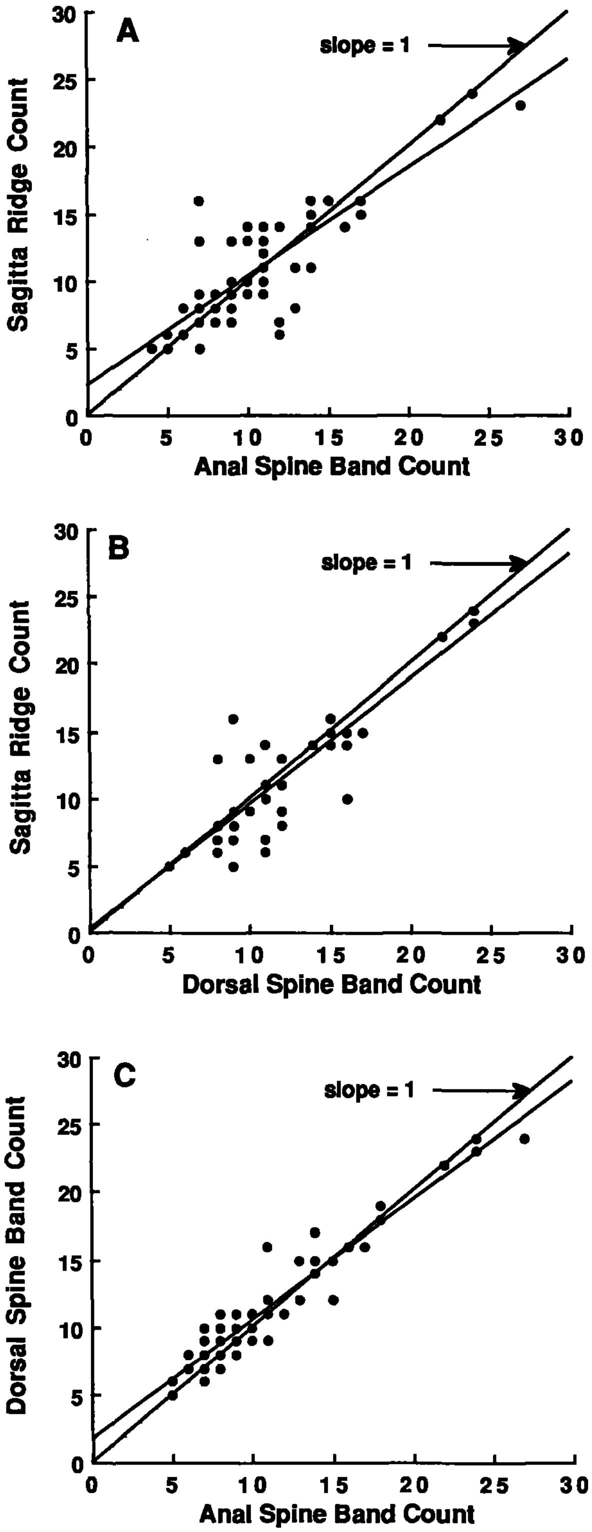


FIGURE 9.—Correlations between coresponding sagittal ridge counts (SC), corrected dorsal spine band counts (DC), and corrected anal spine band counts (AC) for male and female Pacific *Makaira nigricans*. Slopes of the regressions did not differ significantly from parity ($P < 0.05$). $SC = 2.2905 + 0.8077(AC)$ $r = 0.84$; $SC = 0.2069 + 0.9300(DC)$ $r = 0.86$; $DC = 1.7682 + 0.8779(AC)$ $r = 0.95$.

than reader 2 for both anal ($D = 0.85$) and dorsal ($D = 0.55$) counts, while reader 2 assigned higher counts to otoliths ($D = 1.5$) (Fig. 10). None of these count differences differed significantly when compared with a Wilcoxon Signed Ranks test ($P < 0.05$). The greatest difference between mean counts was 8 for otoliths. Overall, there was a greater percentage of age estimates within ±1 and ± 2 years for anal and dorsal spines than for otoliths.

## Mean Length at Estimated Age

Based on estimated ages from anal fin spines, there was a pronounced difference in growth between male and female marlin (Fig. 11). Males appear to grow to an average length of 202 cm LJFL at an estimated age of six years, after which growth is determinate. Growth of female marlin, more variable than males, is steady and does not level off as rapidly.

# DISCUSSION

Growth patterns observed in dorsal and anal fin spine sections were similar to those described by Jolley (1977) for sailfish, Prince et al. (1984) for Atlantic blue and white marlin, and Wilson (1984) for Pacific blue marlin. Sagittal otolith morphologies were also similar to those from previous studies of Pacific blue marlin (Radtke 1981; Wilson 1984), and rostral ridges were analogous to those validated in one tag-recaptured sailfish specimen (Prince et al. 1986).

Three basic assumptions of the ageing theory are that 1) the growth of a structure used is proportional to growth of the animal, 2) the number of growth increments increase with the growth of the structure, and 3) the observed increments follow a discernible time scale e.g., one year of life (Bagenal 1974). In this study, growth of each hardpart was, to some degree, proportional to growth of the animal's length or weight. Increment counts increased with size of each hardpart, providing further support for the use of these structures for age estimation studies. With the exception of the comparison between SW and LJFL, females had higher coefficients of determination for the relationships between hardpart and somatic growth. This was probably due to the fact that a greater size range of females was sampled. The variable relationship between otolith weight and body size is not surprising since otoliths are so small, relative to

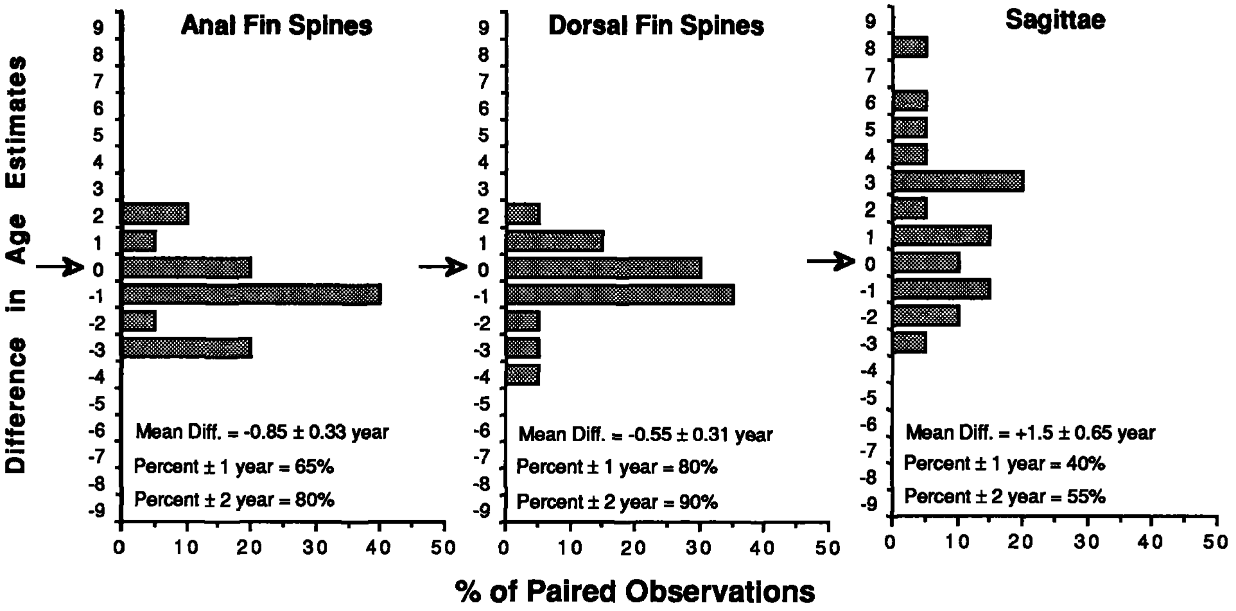


*Figure 10.—Comparison of differences of mean age estimates between readers (1 minus 2) for anal spines, dorsal spines, and sagittae.*

body size. It was expected that fin spines, much larger in size than otoliths, would have a closer relationship to body size. Prince et al. (1984) found a similar relationship between female and male size and hardpart growth for Atlantic blue marlin. The relationship between spine radius and body size may, therefore, be more useful than sagitta weight for back calculation of early growth in marlin. While the first two assumptions of ageing theory have been met, the most important assumption, that increments observed in spines and otoliths of blue marlin represent one calendar year of life, has yet to be proven.

While validation (or, confirmation of the temporal meaning of a growth increment) was not within the scope of this study, partial verification was achieved. Wilson et al. (1983) defined verification as "the confirmation of a numerical interpretation", usually used in reference to the precision of estimated age. Precision was determined by means of comparisons of age estimates from corresponding fin spines and sagittae as well as by means of measurement of error in age estimates within the data and between the data of both readers. In general, there was good agreement in age estimates between sagittae, anal spines, and dorsal spines from the same fish. Prince et al. (1984) described similar relationships between otoliths and dorsal spines of Atlantic blue and white marlin. While the variability of our counts between otoliths and their corresponding spines was greater than between corresponding spines, much of this variation was based on several cases in which the counts of sagittae were as much as 5–10 counts above or below those of corresponding spines. Neither the statistical tests of regression slopes nor the nonparametric tests were able to detect significant deviations from parity; these three structures may deposit increments in relation to similar environmental or growth stimuli.

Comparisons of age estimates, within the data and between the data of both readers provided information on the precision of each technique. Average percent error values of both reader estimates were lower for fin spines than for sagittae, which suggests that fin spine estimates produce a higher degree of precision than sagittae. Similarly, comparisons of differences in mean age estimates between readers revealed greater variability of age estimates resulted from sagittae compared to spines. Variability of sagittal age estimates may be due in part to problems involved with calcium overlayering, and the overlapping, successive ridges, or multiple smaller ridges on these structures. Wilson (1984) reported a similar individual variability in the general morphology and clarity of growth features of Atlantic blue marlin otoliths, and it is reasonable to assume that the interpretation of

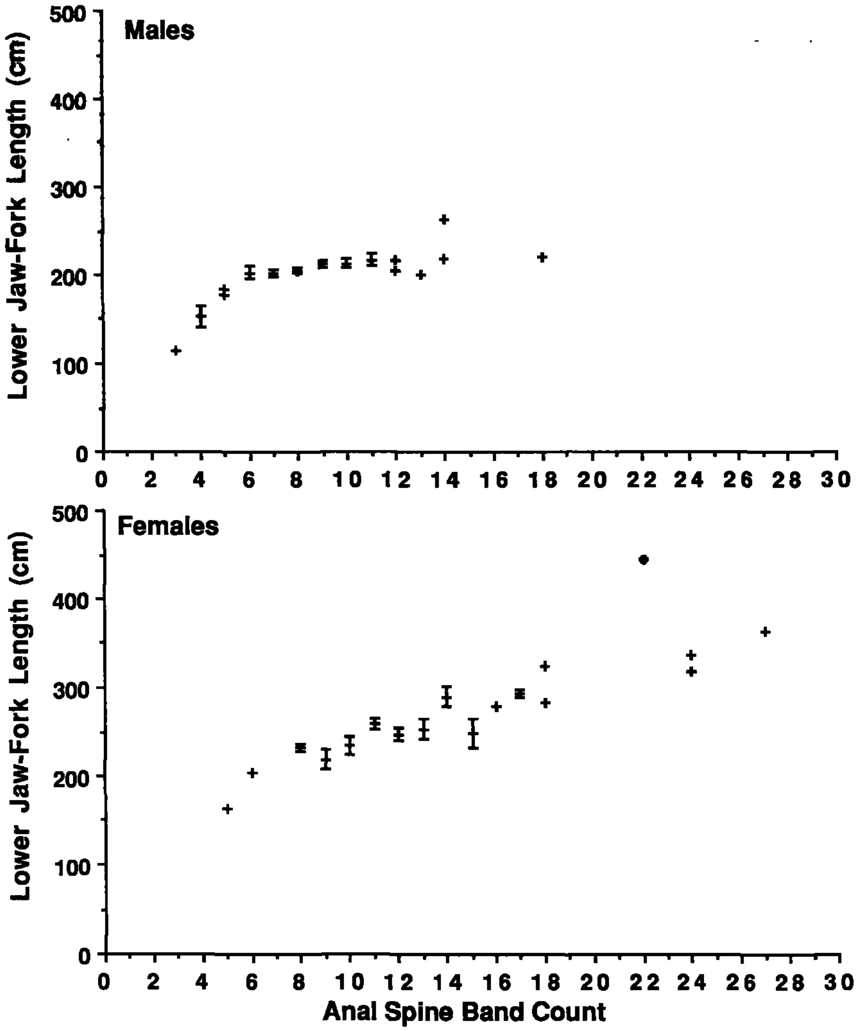


FIGURE 11.—Mean LJFL at age for male and female Pacific *Makaira nigricans* based on anal spine corrected band counts. Vertical lines terminated by narrow horizontal lines represent 95% confidence intervals (male n = 149; female n = 48). Closed diamond indicates estimated age of largest female sampled (748 kg) based upon dorsal spine and sagitta counts.

sagittal growth patterns is more subjective compared with the interpretation of spines.

Based on preliminary age estimates in this study, Pacific blue marlin males have a longevity of at least 18 years and females of at least 27 years of age. The largest female reported in this study was estimated to be 22 years of age based upon both dorsal spine and sagitta counts. The largest male sampled in this study (170.3 kg) was estimatd to be only 14 years of age and the oldest male (estimated age 18) was just above mean size. Wilson's (1984) study of Pacific blue marlin provided similar age estimates and sizes for each sex.

## CONCLUSION

1) Anal fin spines, dorsal fin spines, and sagittal otoliths contained growth information which we assumed to be annual in nature and to hold promise for age estimation of this species. Incremental patterns in caudal vertebrae, possibly related to some other environmental or growth stimuli, were not useful for age estimation at this time.

2) Anal and dorsal fin spines are simpler to collect and process than sagittae, and to provide more precise (although not necessarily more accurate) age estimates for this species. The prob-

lem of early growth increment destruction by core matrix expansion can be partially overcome through application of band radius statistics; however, this technique may introduce bias to final age estimates. With the further compilation of band radius statistics and the application of techniques such as discriminate function analysis fin spine counts may also bring final age estimates closer to "true" age.

3) Sagittal otoliths are more difficult to collect and process and have more variable growth rates and morphologies than fin spines. While age estimates based on external features of sagittae are perhaps more subjective, sagittae may provide more detailed information from internal features such as "daily" increments, valuable for age estimation of young of the year.

4) Extensive mark/tag recapture studies are needed to validate the true meaning of the periodicities assumed to be annual.

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