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Age and growth of Indo-Pacific sailfish, *Istiophorus platypterus*, from the Arabian Gulf

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Abstract

Dorsal and anal fin spines were collected from 85 sailfish from the Gulf and used to estimate age from putative annular growth bands observed in thin transverse sections. A total of 84 (98.8%) of these were successfully read with an average percent error in precision of 4.8%. Nine year classes (0+ to 8) were estimated from spines examined. Spines lacking a pair of translucent and opaque rings were placed in the 0+ year class; however the somatic size of these individuals suggested they were between 6 and 10 months in age. Estimated age classes for females ($n = 50$) ranged from 0+ to 8 years, while males ($n = 34$) ranged from 0+ to 6 years. Age class 1, followed by 0+ and 3 were the most abundant for both sexes, comprising 75% of all samples.

Females exhibited the maximum sizes for lower jaw-fork length (LJFL) and weight within 101 sampled sailfish. The LJFL for females ($n = 65$) ranged in size from 129 to 199 cm and weight ranged from 11.5 to 47.0 kg. For males ($n = 36$), LJFL ranged from 125 to 177 cm and weight ranged from 12.5 to 38.0 kg. The von Bertalanffy growth function fitted to the observed LJFL, weight and age data indicated a rapid growth rate during the first 2 years, after which length stabilized for males and females continued growing to a greater maximum mean length and weight.

The relationships of measured morphological traits to LJFL derived from the non-linear equation $Y = a\,\mathrm{LJFL}^b$ and their regression coefficients showed a negative allometric growth for weight, head, and pelvic fin length. Most other measurements were effectively isometric, with the exception of the anal fin in males, which showed positive allometric growth. A comparison of allometric growth between females and males using a modified *t*-test against linear regressions indicated no significant differences between LJFL and other morphometric characters (P ranged 0.135–0.980).

Keywords: Sailfish; *Istiophorus platypterus*; Arabian Gulf; Age; Growth; Fin spine analysis

1. Introduction

The Indo-Pacific sailfish (*Istiophorus platypterus* Shaw and Nodder, 1792) occurs throughout coastal tropical and subtropical waters of the Pacific and Indian Ocean (Nakamura, 1983), including the Arabian Gulf (also known as Persian Gulf, hereafter referred to as Gulf). Sailfish are a member of the billfish family Istiophoridae that also includes marlins and spearfishes, and are highly regarded by recreational fishers for their spectacular gamefish characteristics. This is apparent in the Gulf nation of the United Arab Emirates (UAE) where, as the sole residing billfish species, sailfish represent an economic asset for the recreational fishing and tourism sectors.

Globally, large predatory fish species, including billfish, are reported declining at alarming rates due to overexploitation (Myers and Worm, 2003), a trend that appears to be affecting species inside the Gulf as well. Sailfish are winter residents in the UAE and undertake springtime transboundary migratory movements into Iranian territory where they are exposed to drift gillnet fishing. Conventional tagging and mitochondrial DNA studies indicate this population lives year-round within the Gulf, thus forming a separate stock from sailfish in the adjacent Gulf of Oman and Arabian Sea (Hoolihan, 2003; Hoolihan et al., 2004). A decline in Gulf

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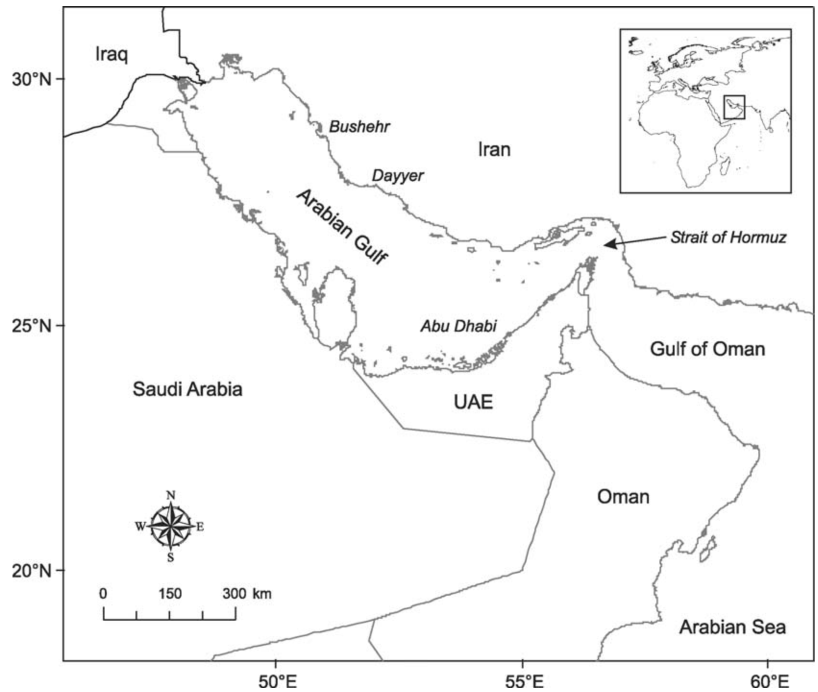

Fig. 1. Map of Gulf region.

sailfish capture rates suggests overexploitation, thus raising concerns that a unique genetic component of Gulf biodiversity may be threatened (Hoolihan, 2004). Geographically, the 239,000 km^2 area of the Gulf (Hunter, 1982) is relatively small and limits the size of this genetically isolated stock (Fig. 1), which therefore emphasizes the importance of obtaining basic sailfish biology and life history information that will enable development of sound conservation management strategies.

Understanding age and growth characteristics ranks among the most important components of fishery population analysis required for accurate stock assessment and management (Campana, 2001), however this information has not been previously documented for sailfish from inside the Gulf. Standard aging techniques that rely on counting incremental growth patterns in hard structures such as otoliths, fin spines, and vertebrae have been investigated in billfish, although specimen scarcity and expense have restricted the number of these studies. deSylva (1957) estimated age and growth of western Atlantic sailfish based on length frequency analysis, and suggested rapid growth and short (4 year) life expectancy. Jolley (1974, 1977) and Hedgepeth and Jolley (1983) reported age classes (without validation) up to 8 years by enumerating incremental circuli (bands) in dorsal fin spines, but indicated that enlargement of the spine's vascular spongy core eroded the early growth bands in older individuals.

The small size of billfish otoliths makes them difficult to analyze by the usual transverse sectioning methods. As an alternative, Radtke and Dean (1981) used scanning electron microscopy (SEM) to examine the external morphology of sailfish otoliths and reported the presence of ridges that were assumed to form annually; thus, allowing more accurate age estimation of older individuals by avoiding the problems associated with vascular core enlargement observed in fin spines. Prince et al. (1986) reported an increase in life expectancy (13–15+ years), from a tag-recaptured western Atlantic sailfish at liberty for nearly 11 years, by validating these ridge structures in sagittal otoliths with SEM; also corroborated earlier reports suggesting early year growth bands in fin spines are eroded by vascular core enlargement. Although SEM presents advantages in aging older billfish, the cost and availability prohibit its general use for most fish aging studies. Another consideration is that removal of otoliths causes more invasive damage than fin spine removal and may not be allowed for market-bound fish.

Validation of band formation periodicity in dorsal spines using marginal increment ratio (MIR) analysis has been reported for sailfish from the Gulf of California (Alvarado-Castillo and Félix-Uraga, 1996) and Taiwan (Chiang et al., 2004). Both studies reported a 1-year cycle to form a pair of opaque and translucent growth bands in the fourth dorsal fin spine.

Age, growth and corresponding length–weight relationships from other studies indicate that sailfish grow rapidly in early years and exhibit sexual dimorphism, with females growing to larger maximum size than males (deSylva, 1957; Merrett, 1968; Skillman and Yong, 1974; Prager et al., 1995). Obtaining knowledge of similar relationships for Gulf sailfish is an important component for understanding the stock structure and recruitment traits of this isolated population. This study evaluates the utility of using structural growth

Table 1
Sampling frequency for 101 sailfish

	January	February	March	April	May	June	July	August	September	October	November	December	Total
2000	–	–	–	–	–	–	–	–	–	–	2	1	3
2001	3	3	2	1	–	–	–	–	–	–		2	11
2002	1	2	2	–	–	39	–	–	–	–	–	–	44
2003	3	13	7	19	–	–	–	–	–	–	–	1	43
Total	7	18	11	19	0	39	0	0	0	0	2	4	101

increments in dorsal and anal fin spine sections, along with examining somatic growth patterns, for establishing key demographic characteristics of Gulf sailfish that could benefit future conservation management strategies.

2. Materials and methods

2.1. Allometry

Sailfish ($n = 101$) were sampled between November 2000 and December 2003 (Table 1) and measured for various morphometric characters, sexed macroscopically, and fin spines collected ($n = 85$) for age estimation. In total, 60% of females and 44% of males were collected from UAE waters using rod and reel with trolled live and dead baits, while the remainder consisted of commercial gillnet landings at the Iranian ports of Bushehr and Dayyer further north in the Gulf (Fig. 1). Weight was measured to the nearest 0.5 kg and lengths to the nearest 1.0 cm with a flexible steel tape rule (curved body measurement), as per the 14 traits illustrated in Fig. 2.

Bill and caudal ray damage was common, leaving LJFL as the most reliable measurement for comparison with other traits in this study (Rivas, 1956). Growth relationships between LJFL and other morphometric traits were estimated by non-linear regression for males, females and pooled sexes with the allometric growth equation:

$$Y = aX^b \tag{1}$$

where Y is the trait to be compared to LJFL (X).

Linear regression slopes comparing LJFL to other morphometric traits were subjected to analysis of covariance and a modified t-test (Sokal and Rohlf, 1995) to determine if allometric growth varied between sexes.

Where least-squares linear regression was used in analyses of allometric growth trait relationships, the assumption of linearity was tested using graphical methods. Scatter plots were used to check the assumption that the residuals were normally distributed. Plots of the standardized predicted values against the standardized residuals were used to verify the assumption that residuals are not correlated with the size of the predicted values. Variables were $\log_e$ transformed to satisfy the assumptions of regression where necessary. The additional assumption of homogeneity of slopes for the analyses of covariance were tested using a modified t-test (Sokal and Rohlf, 1995).

2.2. Aging

Fin spines collected from 85 sailfish (51 females, 34 males) were evaluated for age estimation. Spines from the first dorsal (no. 4) and anal fins (nos. 2 and 3) were collected along with measurements of LJFL, TW and girth. The sampling technique and variety of spines varied between individuals depending on what collection was allowed by fishermen at particular landing sites. In many instances, excision of the complete spine was not permitted for market consigned fish, thus requiring partial removal by severing close to the body with side cutting pliers. Spines were placed in polyethylene bags and stored frozen at $-18\,^{\circ}\mathrm{C}$ prior to further processing. After thawing, soft tissue was manually removed with a knife. Residual tissue was removed by soaking spines in dilute household bleach (sodium hypochlorite) for 3–10 min and then gently cleaned under tap water with a non-scratching plastic scrubbing pad. Spines were then stored in paper envelopes for drying and later embedded in epoxy resin (West Systems, USA). Transverse sections (~0.5 mm

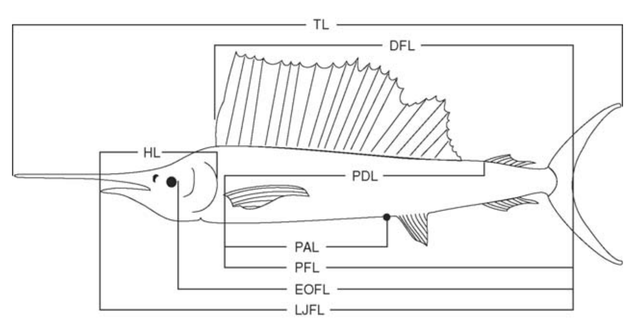

Fig. 2. Length (cm) and weight (kg) parameters used for analysis of Gulf sailfish: Round weight (W), weight of the whole intact carcass; total length (TL), from tip of bill to a straight line formed between the distal rays of the caudal fin (*Note*: bills were removed from most gillnet captures before landing; consequently this dataset was reduced); girth (GR), trunk circumference measured posterior of pectoral fin insertion; head length (HL), from tip of mandible to posterior point of operculum; lower jaw-fork length (LJFL), from tip of mandible to distal point of middle caudal rays; eye orbit-fork length (EOFL), from posterior edge of orbit perimeter todistal point of middle caudal rays; dorsal-fork length (DFL), from anterior insertion of first dorsal fin to distal point of middle caudal rays; pectoral-fork length (PFL), from anterior insertion of pectoral fin to distal point of middle caudal rays; pectoral–dorsal length (PDL), from anterior insertion of pectoral fin to anterior insertion of second dorsal fin; pectoral–anus length (PAL), from anterior insertion of pectoral fin to anterior perimeter of anus; anal-1 length (Anl-1), from anterior insertion to distal point of longest ray; pectoral length (Pec-L, Pec-R), from anterior insertion to distal point of longest ray; pelvic length (Pelv), from insertion to distal end of longest pelvic fin.

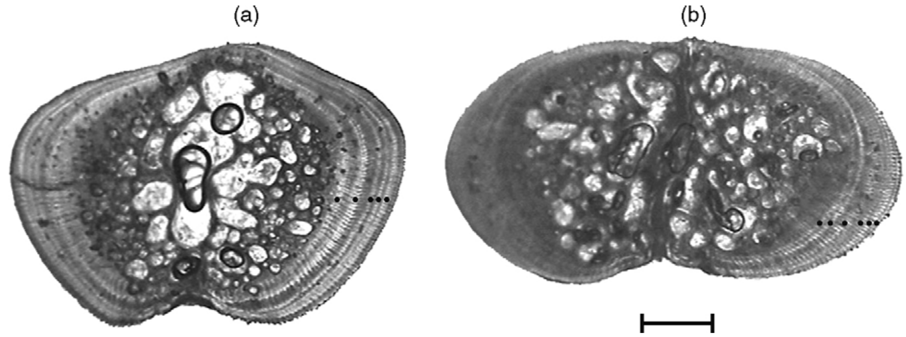

Fig. 3. Photomicrographs of transverse sections through the second (a) and third (b) anal spines. Black dots show circuli (bands). Scale bar = 1 mm.

thickness) were cut on a low speed lapidary saw with diamond wafering blades, then viewed using transmitted light under a stereoscope at 10–20× magnification along with direct digital image capturing to a PC with a microscope mounted camera.

Some sections exhibited vague bands that were difficult to enumerate. Heating sections darkened the opaque bands, enhancing the contrast with translucent bands. Sections were placed on a glass microscope slide and heated rapidly (1–2 s) on a laboratory hot plate with a surface temperature around 100 °C. This procedure was repeated two to three times when necessary. In all cases, heating was found to improve band visibility, although overheating the sections would cause the opposite effect and reduce contrast. Digital computer enhancement of brightness and contrast, as well as image inverting, provided alternative perspectives that aided scoring of ambiguous sections. The presence of one opaque and one translucent band was assumed to represent 1 year of growth based on findings of sailfish from the Gulf of California (Alvarado-Castillo and Félix-Uraga, 1996) and Taiwan (Chiang et al., 2004), but has yet to be validated for Gulf sailfish. Partial formation of a translucent band on the perimeter edge was counted as 1 year.

Theoretical growth parameters were estimated by fitting the von Bertalanffy (1938) growth function (VBGF), using standard non-linear least squares regression, to the back-calculated lengths (LJFL) at age:

$$L_t = L_\infty(1 - \exp^{-k(t-t_0)}) \qquad (2)$$

where L_t is the LJFL at age t, L_∞ the theoretical asymptotic LJFL, k the rate at which L_∞ is approached, and t_0 is the theoretical age when fish length = 0.

All statistical inferences are based on the $\alpha = 0.05$ significance level.

3. Results

3.1. Aging

Alternating opaque and translucent growth increments (bands) were observed in transverse sections of fin spines from Gulf sailfish when viewed with transmitted light under low power magnification (Fig. 3). Nine year classes (0+ to 8) were estimated from 85 sampled sailfish. Individuals lacking a pair of opaque and translucent bands were assigned to the 0+ year class, although somatic size suggested these individuals were probably 6–10 months of age. Overall, 84 out of 85 fin spines were readable. Estimated age for females ($n = 50$) ranged from 0+ to 8 years, while males ($n = 34$) ranged from 0+ to 6 years (Table 2). Year class 1, followed by 0+ and 3 were the most abundant for both sexes, comprising 75% of the total (Fig. 4).

3.2. Growth

For pooled males and females, LJFL ranged from 125 to 198 cm (Fig. 5a) and weight ranged from 11.4 to 47.0 kg (Fig. 5b). The VBGF curves for LJFL and weight suggested a rapid initial growth rate (Fig. 6). The initial growth is not illustrated in Fig. 6 curves, but is clearly reflected in the mean LJFL reached by 0+ year class females (139.7 cm, S.E. 3.50) and males (143.3 cm, S.E. 2.43); also in the mean weight attained for 0+ year class females (14.4 kg, S.E. 0.89) and males (16.9 kg, S.E. 1.05). Both sexes exhibited similar sizes for LJFL during the initial 2 years of growth, after which males stabilized and females continued growing to reach a

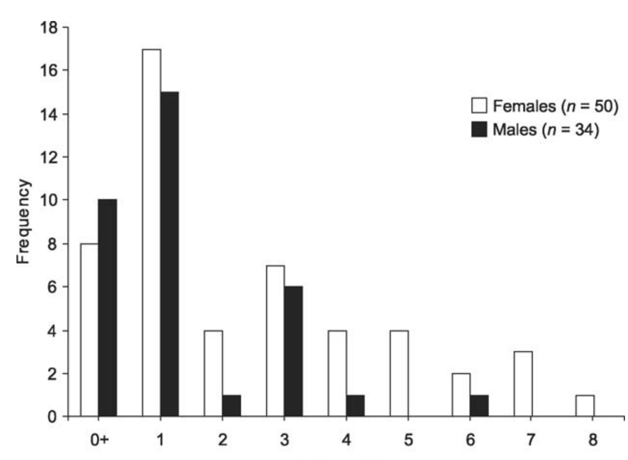

Fig. 4. Frequency distribution of estimated age classes for male (shaded) and female (unshaded) sailfish.

Table 2
Range and mean (in parentheses) of LJFL, weight and girth for sailfish in estimated age groups

Age group	*n*	LJFL range (mean) (cm)	Weight range (mean) (kg)	Girth range (mean) (cm)
Females				
0+	7	131–158 (139)	11.4–18.5 (14.4)	50–59 (53.3)
1	18	129–161 (148)	14.5–26.0 (20.8)	53–65 (58.9)
2	4	156–175 (168)	22.5–32.0 (28.0)	63–73 (68.3)
3	6	164–177 (170)	22.8–30.0 (27.0)	66–72 (69.5)
4	4	148–190 (172)	21.5–32.5 (30.1)	62–73 (69.5)
5	5	162–182 (172)	24.5–32.5 (27.3)	65–72 (68.4)
6	2	197–199 (198)	32.5–47.0 (39.8)	72–79 (75.5)
7	3	174–190 (180)	25.0–32.0 (28.7)	66–73 (68.3)
8	1	198 (198)	46.5 (46.5)	80 (80.0)
Males				
0+	10	125–149 (141)	13.6–21.5 (16.9)	50–62 (55.7)
1	15	132–162 (144)	15.8–24.5 (18.4)	55–62 (57.3)
2	1	143 (143)	18.0 (18.0)	59 (59.0)
3	6	143–168 (157)	22.0–26.0 (23.0)	62–69 (65.0)
4	1	177 (177)	24.1 (24.1)	72 (72.0)
5	0	–	–	–
6	1	160 (160)	30.5 (30.5)	67 (67.0)

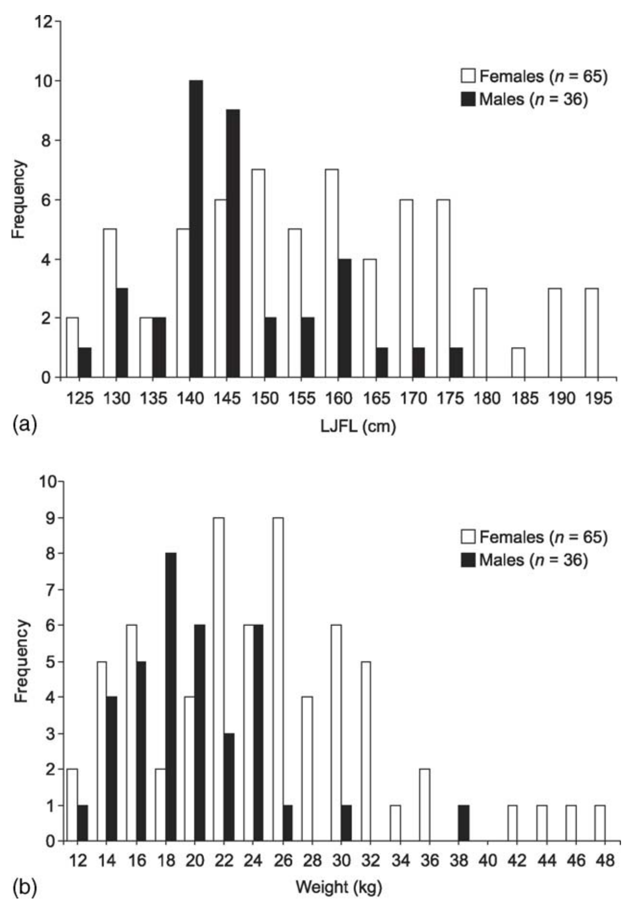

Fig. 5. Size frequency distributions for length (a) and weight (b) in 5 cm and 2 kg bins for male (shaded) and female (unshaded) sailfish.

greater L_∞ (Fig. 6). Males tended to continue gaining weight with age, but never reached the maximum sizes attained by females (Fig. 6). An ANOVA comparison of sexes was conducted using means for LJFL, weight and girth within two groups separated by year classes (Table 3). Group 1 included year classes 0+ and 1, while group 2 included year classes 2–8. There was no significant difference between sexes within group 1, however within group 2 differences were significant for weight, girth ($P < 0.01$) and highly significant for LJFL ($P < 0.001$).

The relationships of morphological traits to LJFL derived from $Y = a\,\mathrm{LJFL}^b$ and their parameters are provided in Table 4. Results showed a negative allometric growth for weight, head, and pelvic fin length. Most other measurements were effectively isometric, with the exception of the anal fin in males, which showed positive allometric growth. Variation was more apparent in fin lengths compared to body lengths.

A modified *t*-test comparing allometric growth between females and males (Sokal and Rohlf, 1995) indicated no significant differences between LJFL and other morphometric characters (*P* ranged between 0.135 and 0.980, Table 4).

Table 3
ANOVA comparison of LJFL, weight and girth between Gulf sailfish sexes within age groups 0+ to 1 and 2–8 years ($\alpha = 0.05$)

	Sample size		*F*-statistic		
	Female	Male	LJFL (cm)	Girth (cm)	Weight (kg)
Age group 1[a]	25	25	0.978 n.s.	0.417 n.s.	1.328 n.s.
Age group 2[b]	25	9	12.635***	7.424**	8.026**

Sexual dimorphism occurs in group 2, with females reaching a larger maximum size. n.s. indicates not significant.
[a] Year classes 0+ to 1.
[b] Year classes 2–8.
** $P < 0.01$.
*** $P < 0.001$.

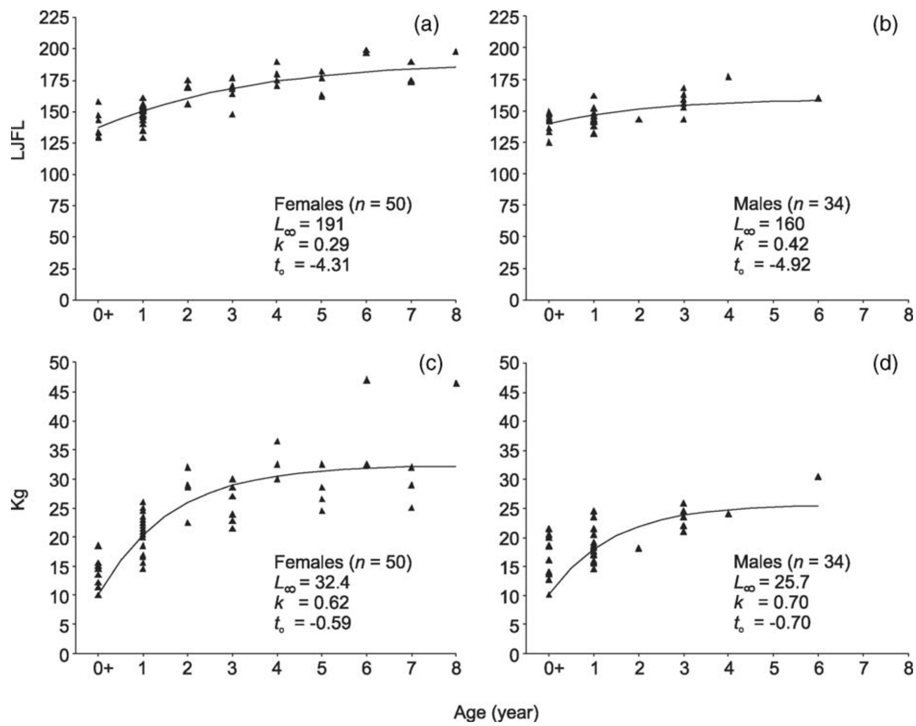

Fig. 6. Standard von Bertalanffy growth curves for observed and back-calculated length-at-age and weight-at-age for Gulf sailfish. (a) and (b) LJFL for females and males, while (c) and (d) weight for females and males.

4. Discussion

The high frequency of samples observed in the 0+ and 1 year age classes (Fig. 4) is not surprising, considering the present status of the Gulf sailfish fishery. A reduction of approximately 50% per annum for Iranian gillnet sailfish catch rates since year 2000 suggests the abundance of younger year classes may have resulted from overexploitation (Hoolihan, 2004) and, in turn, may also explain the lack of very large females from the data set. In past years, large specimens landed in the UAE have been verified to sizes reaching 226 cm LJFL and 70 kg, while tagged and released specimens have been estimated as high as 100 kg by experienced recreational charter operators (DeMaré, P.C., pers. commun.).

The maximum year classes for female (8) and male (6) sailfish in the present study are identical to what Jolley (1977) observed in Atlantic sailfish, however neither study considers back-calculation to account for band increments that may have been eroded by enlargement of the spine's vascularized core (Fig. 3). In contrast, Chiang et al. (2004) reported maximum ages for Taiwanese sailfish at 12 for females and 11 for males by back-calculating for missing bands, even though 8 was the maximum observed band count for either sex. Additionally, dorsal spine analysis of 51 Atlantic sailfish from Brazilian waters by Freire et al. (1998) showed a maximum year class of 10 for pooled sexes by back-calculating from spine diameter to account for erosion of early growth bands, contending that up to six bands were eroded in the samples. However, Freire et al. (1998) gave no indication of the actual number of observed bands, whether sexing was conducted, or what the sex ratio of the pooled samples may have been.

A comparison of estimates of size-at-age for males and females illustrated in the VBGF curves (Fig. 6) indicates a very rapid growth rate in the first 2 years. Although samples of very young (<125 cm LJFL) sailfish were lacking, the assertion of rapid growth is supported by evidence from conventional tagging data. For example, a sailfish tagged and released in the UAE during the present study (unpublished data) measured 131 cm LJFL, 52 cm girth and estimated weight of 13.6 kg. It was recaptured 412 days later in the UAE measuring 168 cm LJFL, 69 cm girth and weighing 30.0 kg, representing increases of 28% (LJFL), 25% (girth) and 121% (weight) in just over a year for a specimen between 1 and 2 years of age.

The accelerated growth of Gulf sailfish during their initial 2 years was consistent with findings reported in sailfish studies elsewhere (Jolley, 1974, 1977; Hedgepeth and Jolley, 1983; Alvarado-Castillo and Félix-Uraga, 1996; Chiang et al., 2004). Using length frequency data from 8630 Atlantic sailfish, deSylva (1957) suggested that by 1 year of age individuals reach 183 cm trunk length (measured from posterior edge of eye orbit to the anterior insertion of the caudal keels) and 9.5 kg average weight. In comparison, combined males and females ($n = 16$) from the Gulf 0+ year class (estimated at 6–10 months of age) had mean values for LJFL and weight of 140 cm and 15.6 kg, respectively. Considering LJFL represents a larger percentage of total length compared to trunk

Table 4
Regression coefficients showing relationships of morphometric variables to LJFL for female, male and pooled sexes of Gulf sailfish derived from $Y = a\,\text{LJFL}^b$

Y variable[a]	Sex	*n*	*Y* (range)	LJFL (range)	*a*	$b \pm$ S.E.	r^2	*P*
Round weight	Females	65	11.4–47.0	129–199	5.00 × 10	2.589 ± 0.132	0.86	0.421
	Males	36	12.6–37.9	125–177	6.00 × 10	2.552 ± 0.315	0.66	
	Pooled	101	11.4–47.0	125–199	5.00 × 10	2.583 ± 0.116	0.83	
Total length	Females	44	153–246	129–198	1.656	0.948 ± 0.046	0.91	0.795
	Males	17	147–213	125–170	1.152	1.019 ± 0.119	0.83	
	Pooled	61	147–246	125–198	1.506	0.966 ± 0.041	0.90	
Girth	Females	64	50–80	129–199	0.460	0.972 ± 0.051	0.85	0.608
	Males	36	50–72	125–177	0.387	1.007 ± 0.105	0.73	
	Pooled	100	50–80	125–199	0.457	0.974 ± 0.043	0.84	
Head length	Females	54	31–46	129–198	0.436	0.877 ± 0.029	0.95	0.547
	Males	27	30–42	125–177	0.357	0.915 ± 0.062	0.90	
	Pooled	81	30–46	125–198	0.404	0.891 ± 0.025	0.94	
Eye orbit-fork length	Females	54	110–171	129–198	0.724	1.034 ± 0.008	0.99	0.329
	Males	26	107–152	125–177	0.794	1.016 ± 0.018	0.99	
	Pooled	80	107–171	125–198	0.750	1.0270.007	0.99	
Dorsal-fork length	Females	54	104–161	129–198	0.728	1.021 ± 0.015	0.99	0.674
	Males	27	100–143	125–177	0.794	1.010 ± 0.030	0.98	
	Pooled	81	100–161	125–198	0.755	1.014 ± 0.012	0.99	
Pectoral-fork length	Females	54	97–151	129–198	0.659	1.028 ± 0.011	0.99	0.705
	Males	27	93–135	125–177	0.582	1.053 ± 0.027	0.98	
	Pooled	81	93–151	125–198	0.644	1.033 ± 0.010	0.99	
Pectoral–dorsal length	Females	45	73–113	129–198	0.529	1.013 ± 0.022	0.98	0.498
	Males	17	69–97	125–170	0.432	1.056 ± 0.095	0.89	
	Pooled	62	69–113	125–198	0.538	1.010 ± 0.024	0.97	
Pectoral–anus length	Females	54	42–65	129–198	0.237	1.067 ± 0.040	0.93	0.465
	Males	27	41–57	125–177	0.295	1.023 ± 0.068	0.90	
	Pooled	81	41–65	125–198	0.245	1.060 ± 0.032	0.93	
Anal-1 length	Females	54	11–21	129–198	0.501	1.139 ± 0.086	0.77	0.135
	Males	26	11–19	125–177	0.011	1.446 ± 0.206	0.67	
	Pooled	80	11–21	125–198	0.039	1.187 ± 0.078	0.75	
Pectoral (L) length	Females	53	19–35	129–198	0.088	1.119 ± 0.099	0.72	0.688
	Males	27	18–28	125–177	0.055	1.215 ± 0.181	0.64	
	Pooled	80	18–35	125–198	0.081	1.137 ± 0.081	0.72	
Pectoral (R) length	Females	54	20–34	129–198	0.116	1.063 ± 0.099	0.69	0.980
	Males	26	18–28	125–177	0.109	1.077 ± 0.192	0.57	
	Pooled	80	18–34	125–198	0.118	1.061 ± 0.082	0.68	
Pelvic length	Females	54	38–56	129–198	0.649	0.841 ± 0.044	0.87	0.951
	Males	25	35–49	125–177	0.565	0.866 ± 0.117	0.70	
	Pooled	79	35–56	125–198	0.583	0.861 ± 0.042	0.85	

P denotes probability for modified *t*-test of linear regression when comparing somatic growth between sexes.
[a] Weight in kg, lengths in cm.

length, these comparisons suggest that Gulf and Atlantic sailfish may differ in somatic proportions, with Gulf sailfish exhibiting a greater ratio of weight to length (i.e., being shorter and stockier than Atlantic specimens). Environmental factors or genetic divergence resulting from isolation may play a role in size variations (Hoolihan et al., 2004). A larger, more representative, age and growth sampling of Gulf sailfish is needed to confirm these differences. Hedgepeth and Jolley (1983) also describe exponential growth during the first 3 years for Atlantic sailfish. However, in contrast to the trunk length (183 cm) reported by deSylva (1957), Hedgepeth and Jolley's (1983) back-calculated predictions of trunk length for combined sexes ($n = 21$) was only 77.2 cm, suggesting a slower growth rate. This comparison warrants caution, as deSylva's (1957) age estimates depended on length frequency analysis instead of hard structures (i.e., otoliths, fin spines) and, as such, may be prone to errors.

The curves depicted on the VBGF graphs for LJFL and weight (Fig. 6) fail to provide an accurate representation of rapid early growth, due to a lack of small-sized specimens. Instead, the curves were assigned to best fit the observed data, and in so doing, provide a more reasonable prediction of growth and the mean asymptotic sizes for LJFL and weight of older specimens in the Gulf population. In order to achieve these curves it was necessary to assign negative t_0 values for LJFL (females = −4.31, males = −4.92) and weight (females = −0.59, males = −0.70). In reality these values are untenable and fail to illustrate the exponential growth curve occurring in the initial 2 years, although it is apparent from the length and weight values attained by the 0+ year class (Table 2, Fig. 6). The estimated LJFL growth rates for females ($k = 0.29$) and males ($k = 0.42$) are undoubtedly low, and would rise accordingly if t_0 were constrained to zero. The same is true, though not as pronounced, for the estimated weight growth rates for females ($k = 0.61$) and males ($k = 0.70$).

The ANOVA comparison of group 1 (year classes 0+ and 1) with group 2 (years classes 2–8) indicated variable growth rates between sexes. No significant differences were observed between females and males in group 1, however significant differences were found in group 2 that suggested an overall faster growth rate for females. Chiang et al. (2004) reported similar findings from analysis of 1135 sailfish from Taiwan waters and Jolley (1974) found a significant difference in the length–weight relationships of 412 female and male Atlantic sailfishes. Because males appear to reach their somatic asymptote earlier, may perhaps indicate they reach sexual maturity at an earlier age. A lack of maturity data (i.e., suitable time series of gonadal indices) prevents this question from being answered for Gulf sailfish.

An important characteristic for accepting any hard part for aging analysis is that it exhibits proportionate growth throughout the life of the fish. For example, the growth of the anterior dorsal and anal spines of sailfish have been shown to have a positive correlation between increasing spine diameter and increased body length (Jolley, 1974; Alvarado-Castillo and Félix-Uraga, 1996; Chiang et al., 2004). Unfortunately, factors in the present study hindered such comparisons. Because of objections from fishermen, spine selection and full excision were not always possible. In most cases, spines were cut as near as possible to the trunk. This action effectively made it impossible to measure spine diameter at a prescribed distance from the spine condyle. Since complete fin spines were not available, testing this correlation was not possible in the present study.

The availability of spines varied with the fourth dorsal and the second and third anal spines, resulting in an overall lack of continuity for spine type. However, when multiple spines samples were available for an individual, identical band counts were observed. Jolley (1977) reported similar results when comparing dorsal and anal fin spines of Atlantic sailfish. Chiang et al. (2004) used marginal increment ratio analysis of the fourth dorsal fin of sailfish to back-calculate estimated ages of older fish, presumed to be missing early rings. Using this technique, Chiang et al. (2004) were able to increase estimated maximum ages of males from 8 to 11 years and for females, 8 to 12 years. For the present study, the combination of not having uniform spine types or complete spines prevented an analysis of marginal increment ratios.

The factor most likely to have a negative impact on this aging study would be the lack of suitable samples to produce a confident explanation of Gulf sailfish age structure. Contributing to this were the low sample number (50 females, 34 males), an incomplete time series of collections over an annual cycle and an incomplete representation of size (age) ranges. In contrast, Alvarado-Castillo and Félix-Uraga (1998) and Chiang et al. (2004) were able to sample large numbers of sailfish on a monthly basis, which enabled validation of an annual periodicity for growth ring structure. Although Gulf sailfish most likely share these annual growth increments, the lack of validation for this population is a shortcoming.

Several reasons contributed to the small sample size. The recreational catch and release fishing sector accounts for most sailfish captures in the UAE; therefore landed specimens available for research sampling are very few. Additionally, the seasonality of this species in the UAE restricts sampling activity to around 6 months of the year. After leaving UAE waters these fish are residing in Iranian Gulf waters where they are subject to capture in gillnet gears. Although considered bycatch of the tuna fishery, they are still marketed within Iran, and consequently present difficulties for the researcher needing to conduct invasive sampling procedures.

The technique used to heat sections of Gulf sailfish spines noticeably improved the visible contrast between bands. Application of heating and burning techniques do not appear in the literature from istiophorid billfish aging studies, with the exception of Jolley (1974) who reported a lack of success when attempting to burn sailfish fin spines using a technique described for otoliths by Christensen (1964).

Overall, Gulf sailfish closely resemble other sailfish populations for traits such as rapid early growth, larger maximum size for females, and length–length and length–weight growth relationships (Jolley, 1977; Hedgepeth and Jolley, 1983; Alvarado-Castillo and Félix-Uraga, 1998; Chiang et al., 2004). The overlap of size-at-age values for LJFL, weight and girth in both sexes suggests that size frequency analysis alone cannot accurately assess age classes, particularly for those older than 2 years. This may be a result of insufficient sample size, although similar observations were reported from the authors noted above. The morphometric analyses using the regression equation (1) for characters in Table 4 provide useful data (within the length ranges sampled) for comparison with other studies. Additionally, it provides a means to determine various morphometric measurements for Gulf sailfish specimens that are not wholly intact because of damage or partial processing. Considering the limited sample size and other constraints, the present study reflects merely a preliminary age and growth assessment for Gulf sailfish. Given that this population is witnessing a sharp decline, this study may represent the only available data in the foreseeable future.

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