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Research Article

Biological aspects of the pickhandle barracuda, *Sphyraena jello* from Dhofar coastal waters of Oman (Arabian Sea)

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Abstract

The pickhandle barracuda, *Sphyraena jello* Cuvier, 1829, is the most common species of Barracuda in Oman Waters but its basic biological information is still absent, hence this study was conducted. A total of 662 individuals were sampled in the Dhofar region along the southwest coast of Oman in the Arabian Sea from June 2021 to May 2022. The length-weight relationship for combined sexes was $W=0.0151\ TL^{2.7221}$. The average monthly values of the gonado-somatic index and the percentage of different maturity stages of gonads for males and females indicated that *S. jello* spawns throughout the year, with spawning peaking from June to August. The length at first maturity was estimated at 71.9 cm TL for males and 74.0 cm TL for females and the age at first maturity was 4.1 and 4.3 years, respectively. The determination of age derived from the sectioned otolith reading revealed that the age of the studied fish varied from one to 24 years with the dominant age of 3 years old. The longevity of *S. jello* was calculated at 27 years old. The values of growth parameters in von Bertalanffy growth function for combined sexes were estimated as: $L\infty=161.18$ cm, $K=0.119\ yr^{-1}$ and $to= -0.88$. The present study indicates that *S. jello* is a long-lived species with slow growth rate, so it is vulnerable to overfishing. Further monitoring studies of *S. jello* are needed to develop scientifically sound and effective management measures for their fishery.

Keywords: Pickhandle barracuda, *Sphyraena jello,* Reproduction, Age and growth, Oman, Arabian Sea

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Introduction

There are eight species of barracudas (family Sphyraenidae) reported from the waters of Oman by Randall (1995). These active marine predator fishes are important commercial resources of Oman, accounting for about 7–11% of the total landing of large pelagic fishes. In recent years, catches of barracudas have increased from about 3000 t in 2011 to almost 11000 t in 2018 and 2019. The most common species, contributing to approximately 60% of barracudas catches in Oman, is the Pickhandle barracuda, *Sphyraena jello* Cuvier, 1829 (MOAFW, 2020). The *S. jello* is a large barracuda that can reach 150-152.5 cm in total length (Fischer and Bianchi, 1984; Kasim, 2000), and its maximum published weight is 11.5 kg (Froese and Pauly, 2023). The *S. jello* is widely distributed in the Indo-West Pacific from the Red Sea south to the southeastern coast of South Africa and east to New Caledonia and Vanuatu (De Sylva and Williams, 1986). In the waters of Oman, *S. jello* is found along the entire coastline of the Arabian Sea and the Sea of Oman (Al-Abdessalaam, 1995). The species is subject of artisanal commercial fishery and a popular target for recreational fishing.

Despite its fisheries and ecological importance, basic biological information on the *S. jello* in Omani waters is absent and limited for other areas. Okera (1982) studied maturation condition of *S. jello* from Australian waters. Length-weight relationships of *S. jello* were presented in several studies, as in the waters of South Africa (Van der Elst, 1981; Harrison, 2001), Yemen (Edwards and Shaher, 1991; Al Sakaff and Esseen, 1999; Al-Kamel *et al*., 2020), Pakistan (Hosseini *et al*., 2009b), India (Abdurahiman *et al*., 2004) and Philippines (Kulbicki *et al*., 1993). Several studies on fishery, length-weight relationships, growth, and population parameters of *S. jello* was conducted in India (Premolatha and Manojkumar, 1990; Krishnadas and Nair, 1994; Kasim, 2000). Hosseini *et al.* (2009a,b) reported data on feeding and spawning of *S. jello* in Iran's waters of the Persian Gulf. Food and feeding habits of *S. jello* were studied in the coastal waters of Malaysia (Bachok *et al*., 2004), Sri Lanka (Dananjanie *et al*., 2009), the east coast of India (Bharathi and Ponni, 2019), Pakistan (Manzoor *et al*., 2019), and Indian Chabahar coastal waters in the Sea of Oman (Raeisi *et al*., 2021). Some studies were devoted to gillnet selectivity on the fishery of *S. jello* (Dananjanie *et al*., 2009; Priya *et al.*, 2018). There are published data about the fatty acid profile (Taheri *et al*., 2017), physicochemical characteristics of muscle proteins (Ramachandran *et al*., 2006) and cases of leiomyosarcoma tumour for *S. jello* (Vijayapoopathi *et al*., 2016). Recently, it was shown that *S. jello* skin can be a source of collagen (Harianti *et al*., 2021).

Hence, the aims of the present study were to ascertain information on the biology of *S. jello* as the size-age composition, length and age at first maturity, feeding, reproduction and spawning season, age and growth that are essential in managing barracuda fishery in the waters of Oman.

Material and methods

Sample collection and processing

A total of 662 specimens of *Sphyraena jello* were collected from fish markets and directly from traditional fishermen in the Dhofar region of Oman situated along the southwest coast of Oman in the Arabian Sea from June 2021 to May 2022. Sampling was not possible during the December and January months when specimens of *S. jello*

were not available in fishermen in Dhofar. The fishes were caught using handlines and occasionally gillnets. At least 40-60 specimens were randomly collected per month. The samples were transferred in ice boxes to the laboratory of the Fisheries Research Center-Dhofar in Salalah City for further biological analysis.

In the laboratory, the total (TL), fork length (FL), and body depth (BD) of each fish were measured and weighed to the nearest 1 g. Fish sex was determined by visual examination of gonads which were dissected out and subsequently weighed to 0.01 g (GW). The stage of gonad maturity was assessed using a scale developed for Sphyraenidae by De Sylva (1963) and modified by Allam *et al*. (2004) (I - immature, II - maturing, III - nearly ripe, IV - ripe, V - spawning and VI - spent). The stomach with gut was removed and dissected, and the food content was weighed to 0.01 g. Stomach content was analyzed visually and general food items were identified up to generic or group level. A pair of sagittal otoliths were extracted from each fish, cleaned in water, dried, and placed in a small labeled plastic bag for further age determination.

Length Frequency and Length Weight analysis

The size composition of *S. jello* was studied for combined sexes and separately for males and females as on minimum, maximum, and average length (TL, FL, BD) and total weight together with standard deviations, as well as on size frequency distribution for grouped 5 cm size classes. Statistical *t*-test and Kolmogorov-Smirnov (K-S) test were used to determine statistical differences in the mean values and length-frequency distribution between sexes (Zar, 1999).

The length-length relations (LLR) between the studied lengths (TL, FL, BL) were determined by the method of least squares to fit a simple linear regression equation (Sparre and Venema, 1998),

$L' = a + bL$ (1)

Where, L' and L - various body lengths, a - proportionality constant and b - regression coefficient.

Length-weight relationships were estimated for males, females and combined sexes using the allometric formula (Le Cren, 1951),

$W = a\,L^b$ (2)

Where, W is the total wet fish weight (g), L is total length (cm), a and b are the constants.

The values of constants a and b were calculated by the least-square linear regression from the log-transformed values of length and weight (Zar, 1999). The regression analysis was conducted using Regression Analysis Tool in Microsoft Excel. The 95% confidence limits (Cl) of parameters a and b, and coefficient of determination (r^2) were estimated. The obtained regressions were compared using ANCOVA test (Snedecor and Cochran, 1967). The data on length and weight were log transformed in PAST 4.03 and one-way ANCOVA test calculated the *p*-value.

Reproductive aspects

The sex ratio (SR) was determined as the number of males (M) to the number of females (F), SR=M: F. The sex ratio in different length classes and the monthly sex-ratio were tested for significant deviations from the expected 1:1 ratio with Pearson's chi-square (χ^2) goodness-of-fit test (Snedecor and Cochran, 1967) using the formula:

$\chi^2 = \sum(O - E)^2/E$ (3)

Where *O* is observed numbers and *E* is expected numbers. The *p*-value was calculated using the function CHISQ.TEST in Excel.

The length at first maturity (L_{m50}), at which 50% of females and males reach sexual maturity, was estimated by fitting the logistic function to the proportion of mature fish in 5-cm length classes. Females with ovaries and males with testis in stages III, IV, and V were considered as mature. The following logistic function was used (King, 1995),

$$P = 1/(1+e^{(-a(L - L_{m50})}) \quad (4)$$

Where *P* is the proportion of mature females or males in 5-cm length classes, *L* is the mid-class length, L_{m50} is the length at first maturity and *a* is a constant. A cumulative percent of mature fish against length classes was plotted and non-linear least-squares fitting with Microsoft Excel Solver problem was used to obtain the best fit of L_{m50} and *a*. The age at first maturity at which fish of a given population mature for the first time was calculated from the length at first maturity using the inverse of the von Bertalanffy growth function.

The reproduction activity was assessed using data on monthly changes of the mean gonado-somatic index (GSI) for males and females of *S. jello*, as well as the percentage occurrence of different maturity gonad stages of males and females during various months. GSI was calculated as expressing the gonad weight (GW) to the body weight (TW) by the formula of Wydoski and Cooper (1966),

$$GSI = GW/TW \times 100 \quad (5)$$

Age and growth analysis

A total of 176 barracudas ranging from 33.4 to 161.2 cm TL were used for otolith-based aging, including 66 males and 110 females. To ensure a homogeneous distribution of the age study across the entire size range, otoliths were selected from at least 10 fish in each 5 cm size class from minimum to maximum fish lengths. The study of fish age was based on otolith sectioning following methods described by VanderKooy and Guindon-Tisdel (2003). One otolith from each pair was embedded in epoxy resin, dried for 24 hours at ambient temperature and then one or two transverse sections with thickness ~200–300 µm were taken through the core using Isomet low-speed diamond saw. The otolith section was grinded and polished and then mounted on a glass slide with immersion oil to improve the clarity of the rings. The otolith section was photographed and examined under a stereomicroscope using both reflected and transmitted lights. The age of fish was determined based on the count number of annulus, consisting of opaque and translucent rings, along the sulcal ridge between the otolith core and otolith edge. The otoliths were examined independently by two readers, using 'blind method' without reference to the date of capture or length of the fish.

The length-at-age data was used to estimate growth parameters in the non-seasonal von Bertalanffy growth function (von Bertalanffy, 1938),

$$L_t = L_\infty (1 - e^{-K(t - to)}) \quad (6)$$

Where, L_t is the length at time *t*, L_∞ is the asymptotic length, *K* is the instantaneous growth coefficient and t_o is the hypothetical time at which length is equal to 0.

Growth curves were plotted for males, females, and both sexes combined. The parameters L_∞, *K* and t_o were calculated using the GRG nonlinear least squares technique in Solver program incorporated as add-in in Excel.

Differences in the mean length at age between sexes were determined using

analysis of covariance (one-way ANCOVA) with logarithm age as the covariate, logarithm length the dependent variable and sex as the fixed factor.

Growth performance index (*Ø*) was computed to compare the growth of this species with those of other Sphyraenidae according to the formula of Munro and Pauly (1983),

$$Ø = log\ K + 2\ log\ L_\infty \quad (7)$$

The potential longevity (maximum age, life span) of *S. jello* was calculated using the formula of Weatherly and Gill (1987) based on the estimated parameters of the von Bertalanffy growth function:

$$t\text{max} = t_o + 3/K \quad (8)$$

Where, t_o is the hypothetical age and K is instantaneous growth coefficient in the von Bertalanffy Growth Function (VBGF).

To estimate the age structure of *S. jello* in the samples from commercial catches, the data on the length frequency distribution was converted to the age frequency distribution by the age slice method incorporated in LFDA software (Kirkwood *et al*., 2003).

Results

Size composition

The total length of the Pickhandle barracuda, *Sphyraena jello* in the studied samples (n=662) ranged between 33.4 and 161.2 cm (mean 84.4±25.9 cm TL), weight was from 173.7 g to 14902 g (mean 3281.7±2927.3 g). Males (n=268) ranged from 37.2 to 151.0 cm TL (mean 87.1±28.5 cm TL), and weighed 230.5–14902 g (mean 3690 g). Females (n=394) were smaller than males in minimum and mean lengths, but larger in the maximum length, ranging from 33.4–161.2 cm TL (mean 82.6±cm TL), and their weight was 173.7–14203 g (mean 3004 g). The mean length of males was significantly greater than that of females (*t*-test, df=1, $p<0.01$).

The length frequency distributions for males and females of *S. jello* in 5 cm size classes are shown in Figure 1. Higher abundance of females was observed in length classes 65–80, 85–95, and 120–135 cm TL. The largest number of males was registered in the size class 55-70 cm, 85-95 cm, 115-125 cm TL. Thus, the distribution peaks of females were slightly larger than those of males, but the number of males in larger size classes (TL 105-155 cm TL) exceeded the number of females, therefore, in average sizes, males turned out to be larger than females. Overall, individuals less than 50 cm TL represented only 2.0%, while fish measuring larger than 100 cm TL comprised 23.1% of the total number of the studied fish.

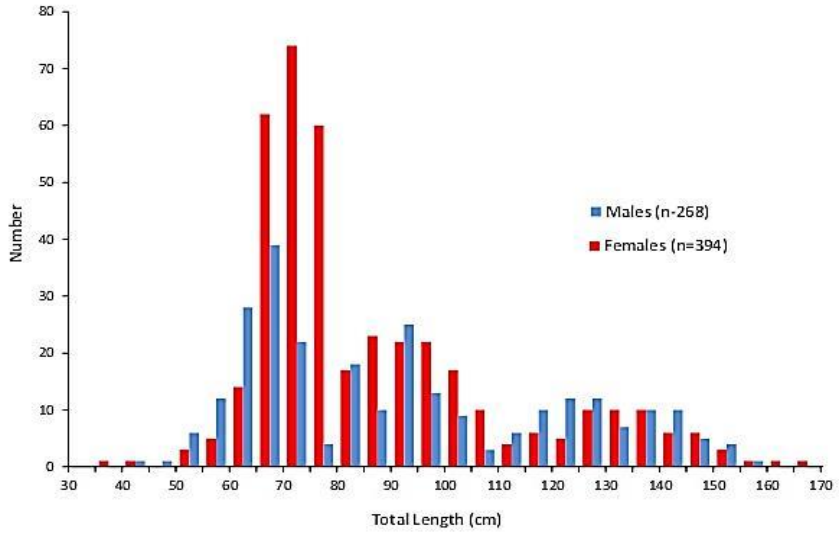

Figure 1: Length frequency distribution of females and males of *Sphyraena jello* sampled in Dhofar during 2021–2022.

The Shapiro-Wilk test indicated that the length of females (W=0.870, p<0.01) and males (W=0.923, p<0.01) in the samples were not normally distributed. Therefore, a nonparametric test () was used to compare these samples distribution. The Kolmogorov–Smirnov two-sample test showed a significant difference between the engths frequency distributions of females and males (p=0.0016).).

Larger average sizes both males and females (more than 80 cm TL) were observed from June to October, while in other months mean sizes of the studied specimens were between 65 and 80 cm TL (Fig. 2).

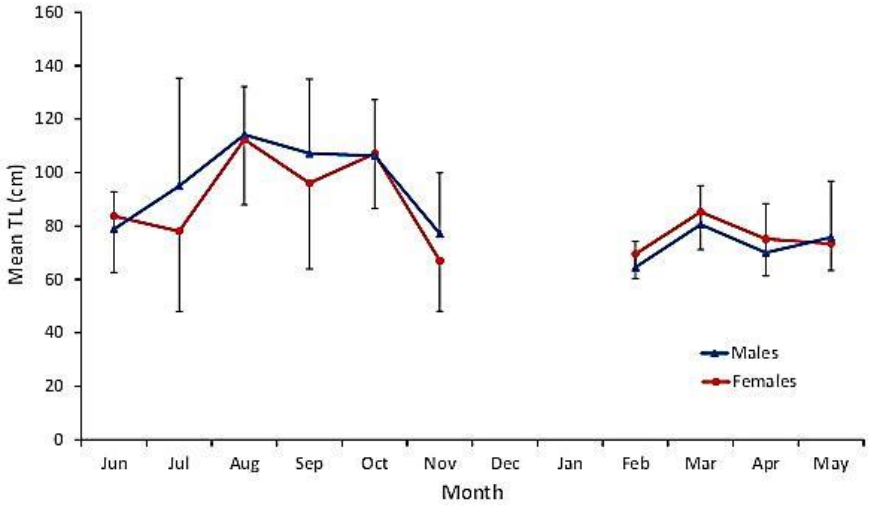

Figure 2: Mean total length of males (TL + SD) and females (TL – SD) of *Sphyraena jello* in different months in the Dhofar region from June 2021 to May 2022.

Length-length and length-weight relationships

Relationships between total, fork lengths and body depth measurements of *S. jello* were highly significant and directly proportional, so it was described by linear equation (formula 1) with a coefficient of determination (R^2) ranging between 0.89 and 0.99 (Fig. 3).

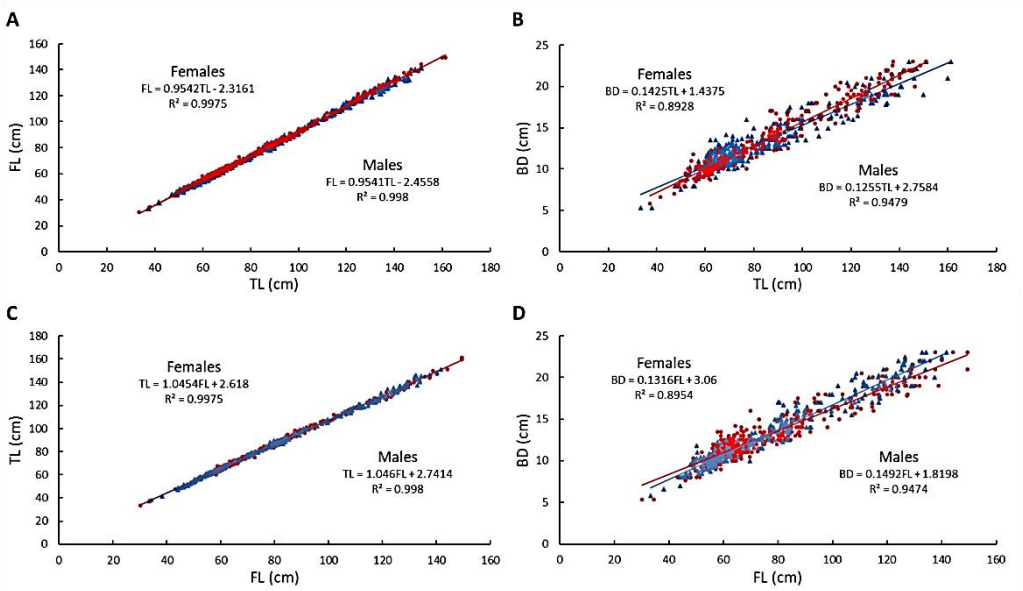

Figure 3: Length-length relationships for males (blue dots) and females (red dots) of *Sphyraena jello* between: A - total and fork lengths; B – total length and body depth; C - fork length and total length; D – fork length and body depth.

The relationships between the total length and somatic weight of the fish (2), calculated separately for males, females, and combined sexes, showed that coefficient *b* ranged from 2.6599 for females to 2.7851 for males, indicating a negative allometric growth in weight in the *S. jello* (Table 1). The a coefficient of determination (r^2) for all length-weight relationships was highly correlated (0.976-0.988).

Table 1: Length-weight relationships for males, females and pooled sexes of *Sphyraena jello*.

Sex	n	TL range (cm)	*a*	95% CI *a*	*b*	95% CI *b*	r^2
Males	268	37.2–151.0	0.0114	0.097–0.01350	2.7851	2.7578–2.8227	0.9877
Females	394	33.4–161.2	0.0199	0.0165–0.0239	2.6599	2.6178–2.7021	0.9752
Combined	662	33.4–161.2	0.0151	0.0133–0.0171	2.7223	2.6935–2.7511	0.9813

Females were slightly heavier than the males measuring the same length up to 90 cm TL, however, above these size males were heavier than females. The LWR regression equations for males and females compared for equality with the ANCOVA test showed that their slopes did not differ significantly between the sexes (p =0.825).

Sex ratio

Of the 662 specimens studied, females constituted 60.0% (n=394) and males 40.0% (n=268) with an overall sex ratio (Male: Female) of 0.68: 1, which was significantly different from the hypothetical 1: 1 according to chi-square (χ^2) test (χ^2=24.0; df=11; p<0.05)(3) (Fig. 4).

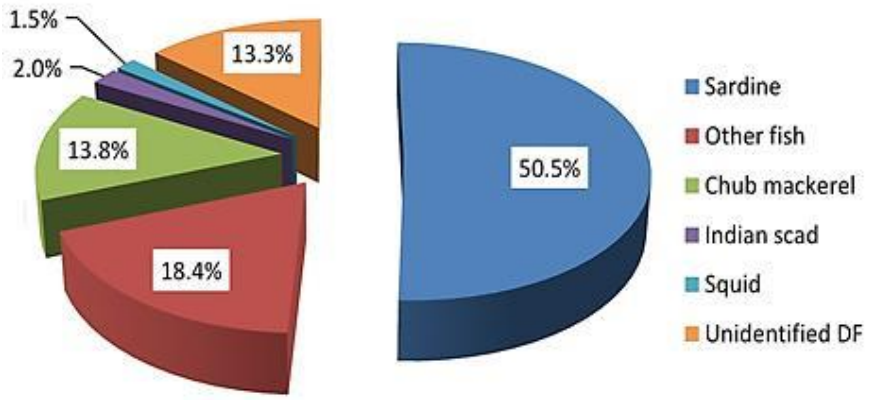

Figure 4: Food composition (%) of *Sphyraena jello* in the Dhofar region of Oman.

The monthly sex ratio indicated that females dominated in all studied months (except October), especially from February to July (Fig. 5), while in other months the sex ratio was close to 1: 1. Overall, the monthly difference in the sex ratio was significant (χ^2 test=24.62, p=0.01).

Length and age at first maturity

Maturing testis (Stage III and above) and maturing ovaries (Stage III and above) was considered mature and was used for the determination of mean length at first sexual maturity. The logistic function (4) revealed that the mean size at the first maturity (L_{m50}) in *S. jello* was 71.9 cm TL for males and 74.0 cm TL for females (Fig. 6) indicating that males of *S. jello* mature at a slightly earlier length than females. The age at first maturity, calculated based on data of the length at first maturity and inversed von Bertalanffy growth function, was 4.1 years for males and 4.3 years for females.

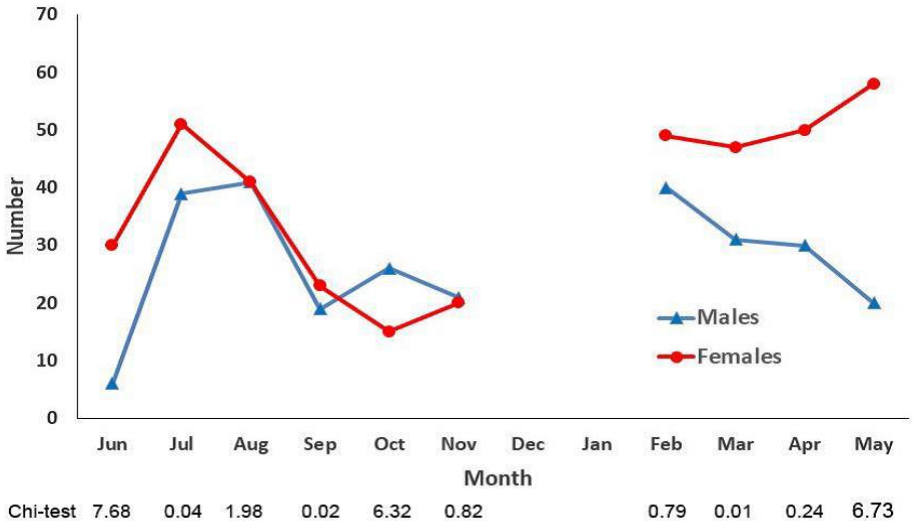

Figure 5: Monthly changes in the abundance of males and females of *Sphyraena jello* in the samples from June 2021 to May 2022 and values of Chi-test in the sex ratio.

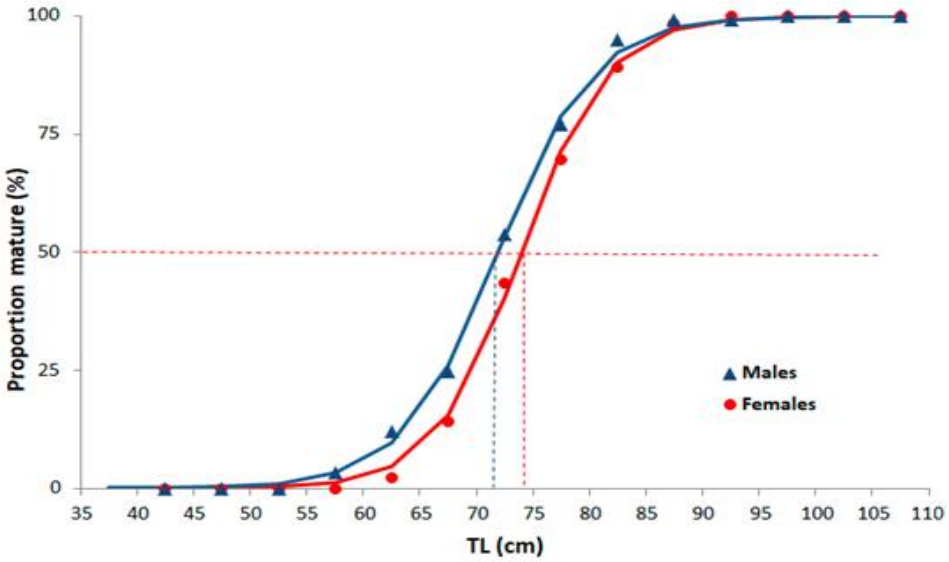

Figure 6: Length at first maturity for males and females of *Sphyraena jello*.

Spawning season

The monthly changes of the mean gonadosomatic index (5) of *S. jello* showed that the females always recorded higher values of GSI than males (Fig. 7). The higher GSI values were observed in females from March to July (2.95-3.38) and in October (3.15). The GSI values of males were found higher from March to July (2.13-3.02) and during September and October (2.39-2.63). The lower GSI values were found both in males and females in August, November, and February determining the end of active reproduction phase and the release of oocytes and sperms.

The monthly analysis of gonadal developmental stages of *S. jello* revealed that immature and developing fish (Stage I–II) were abundant in October, November, February and March (Fig. 8). Females and males with ripening gonads (Stage III) were more numerous from February to May.

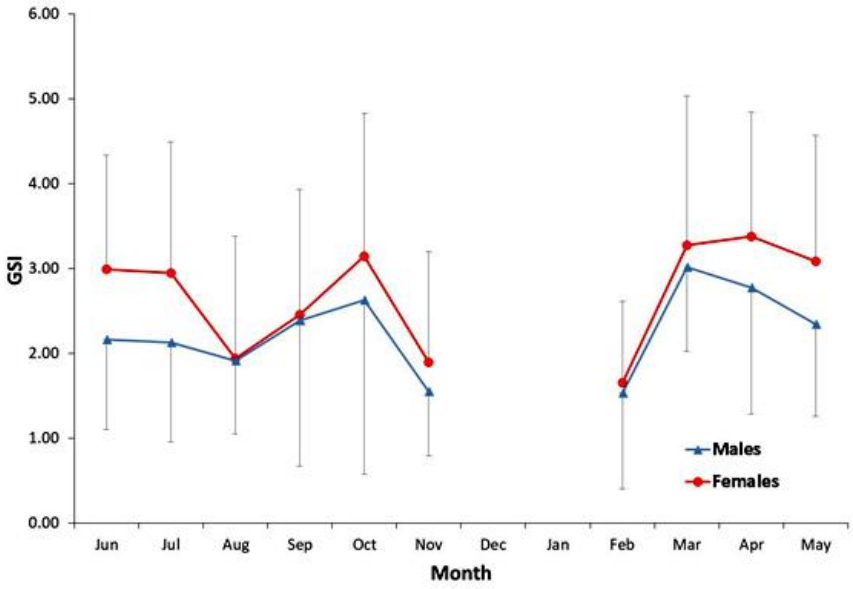

Figure 7: Monthly variation of average gonadosomatic index (GSI ± SD) in males and females of *Sphyraena jello* in the Dhofar region from June 2021 to May 2022.

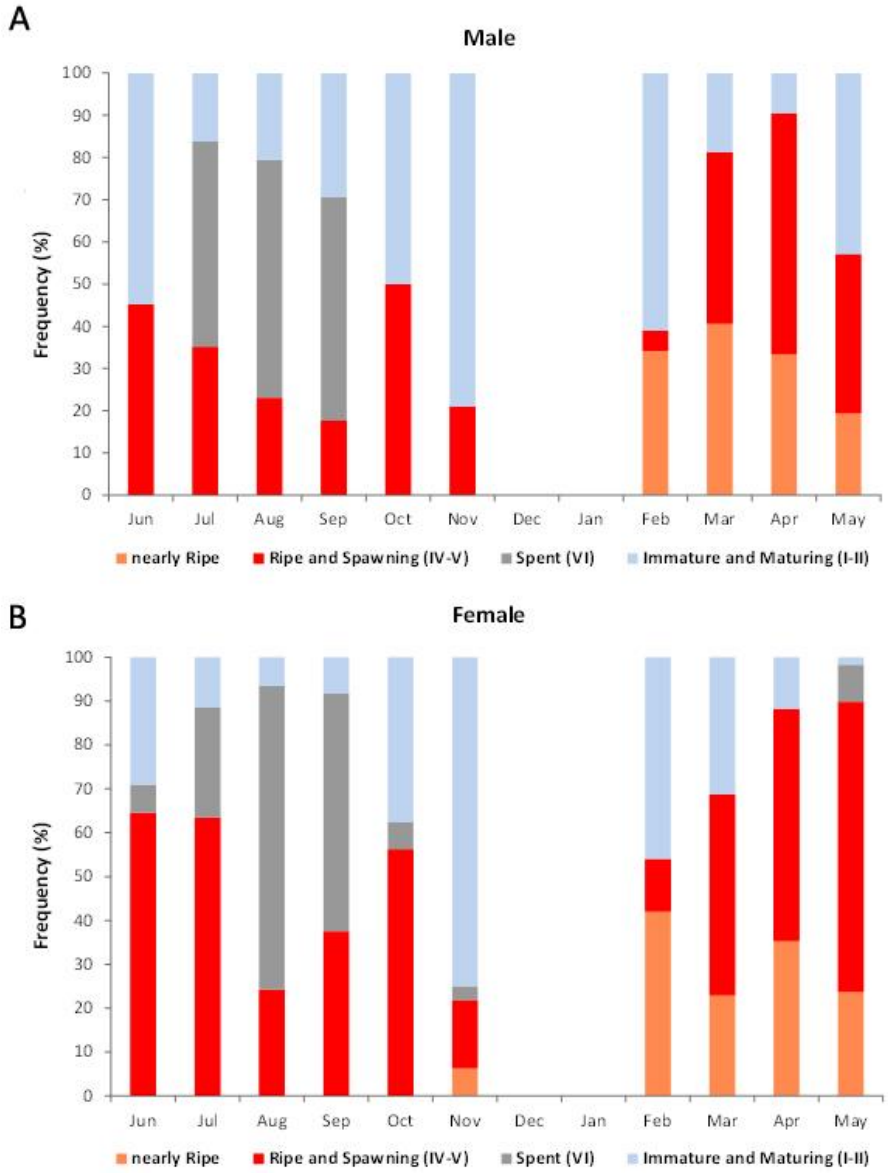

Figure 8: Monthly changes of relative frequency of different gonad developmental stages for males (A) and females (B) of *Sphyraena jello* in the waters of Dhofar from June 2021 to May 2022.

Fish with full ripe and running gonads (Stages IV–V) were found during all studied months, but maximum numbers of the 'spawning capable' females were observed from May to July (63.5-66.1%), and maximum numbers of spawning males from March to June (37.7-57.1%). Many fish with running gonads also occurred in October. Females with spent empty gonads (Stage VI) occurred from May to October, while spent males were found from July to September.

Age and growth

According to the aging study, *S. jello* reached to 33.4–38.1 cm TL during the first year of life, 47.3-57.5 cm TL in the second year, and 54.2–74.9 cm TL at the age of 3 years. The age of the largest measured female at 161.2 cm TL was estimated at 21 years. The maximum recorded age was 24 years for three males of 142.1, 144.0, and 146.0 cm TL. Most individuals were aged between 3 and 9 years, and the average age was 6 years.

The age-length relationships and growth curves for males, females, and combined sexes are shown in Figure 9 and the estimation of growth parameters are presented in Table 2. The males grew faster than females during first 10 years of life, because coefficient *K* was higher, however, L_∞ value was higher in females and older females can attain larger sizes than males. No significant difference was found between the male and female growth models (p>0.05) using ANCOVA test (p=0.972).

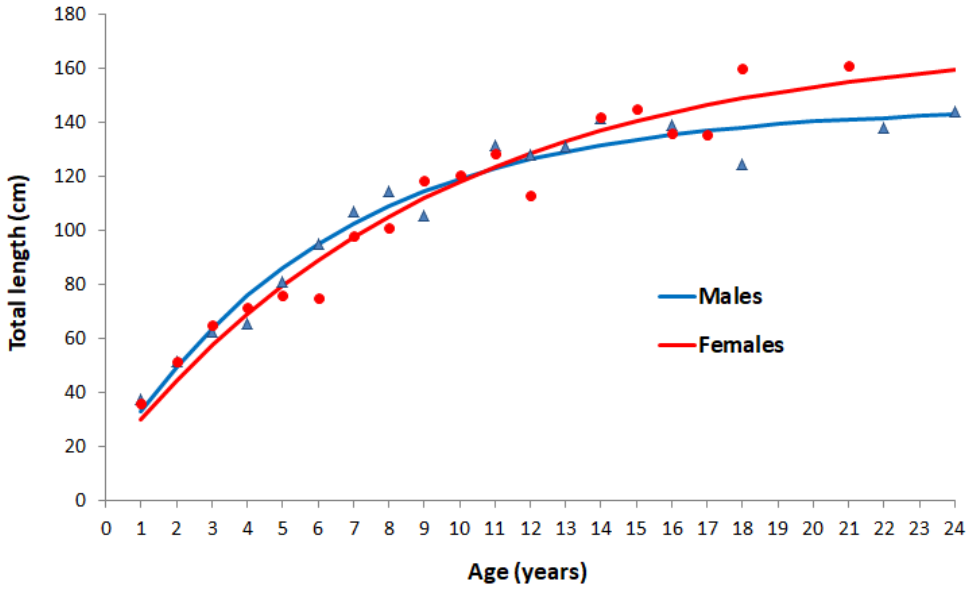

Figure 9: The mean length at age and VBGF curves for males and females of *Sphyraena jello* from the waters of the Dhofar region of Oman.

Table 2: Parameters of von Bertalanffy growth function for males, females and sex combined of *Sphyraena jello*.

Sex	*n*	L_∞ (cm)	K (yr^{-1})	t_o (yr)	r^2
Male	66	146.03	0.145	–0.96	0.89
Female	110	170.99	0.109	–0.75	0.93
Combined	176	161.18	0.119	–0.88	0.92

n is a number, L_∞ is the asymptotic length, *K* is the instantaneous growth coefficient and t_o is the hypothetical time at 0 length.

Values of the growth performance index (7) were calculated 3.49 for males and 3.50 for females of *S. jello*, indicating that their growth rate is very close and not significantly different. The potential longevity of *S. jello* was estimated using the formula of Pauly and Munro (1984) that based on t_o and *K* values (8) was 20 years for males and 27 years for females.

According to the calculation of age structure using the age slices method in LFDA software, the commercial catches of *S. jello* in the Dhofar region in 2021-2022 were dominated by 3-years-old fish, which represented almost 35% the fish sampled (Fig. 10). Fish younger than 3 years and older than 12 years were poorly represented, about 11% and 9%, respectively.

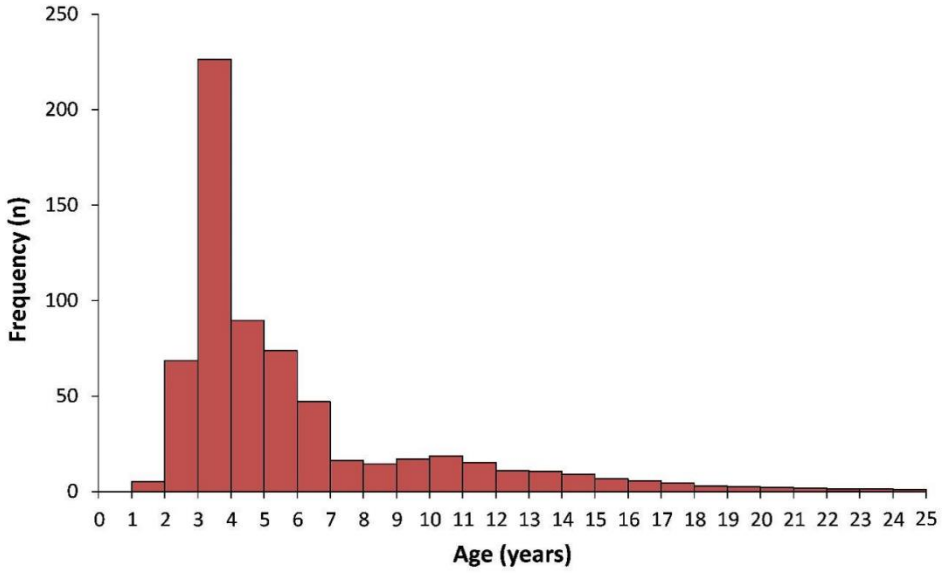

Figure 10: Age structure of *Sphyraena jello* in commercial catches in 2021–2022.

Discussion

The present study is the first attempt to evaluate the biological characteristics of pickhandle barracuda, *S. jello* in the waters of the Dhofar region of Oman in the Arabian Sea. One of the most important characteristics is the fish size which is related to a plethora of biological, demographic, ecological, fisheries, and management parameters (Pauly *et al*., 2014). The maximum published total length of *S. jello* was 150 cm (Fischer, Bianchi, 198) and 152.5 cm (Kasim, 2000), 11.5 kg body weight (Froese and Pauly, 2023). Based our data, the maximum length of *S. jello* reached 161.2 cm TL in females and 151.0 cm TL in males, while their maximum weight was 14203 g and 14902 g respectively. Thus, our results significantly exceed those previously reported both for males and females of *S. jello* and represent a new world record. According to other studies on the maximum length of *S. jello* was: from the south-west coast of India 62 cm TL (Premalatha and Manojkumar, 1990), the Cochin region of India 94.3 cm (Krishnadas and Nair, 1994), the southeast coast of India 82 cm (Priya *et al*., 2018), Persian Gulf 93.5 cm (Hosseini *et al*., 2009b), and along the coast of Pakistan in the Sea of Oman 128 cm (Manzoor *et al*., 2019). It is likely that the exceptionally large size of *S. jello* in Omani waters is a result of the very high productivity of the waters due to the upwelling system and the high availability of small pelagic fish (Bakun *et al*., 1998).

The length-length relations are important for comparative analysis because researchers used different lengths (total or fork) for their studies. From the present study, the fork length of *S. jello* is nearly about 92.4% of the total length. The barracuda has a long and elongated body and the ratio of the body depth to the total length is approximately 16.1%.

The length-weight relationship is needed to estimate growth rate, length, and age structures, the average weight of a given length group, the health status, and other components of the fish population dynamic (Beyer, 1987; Bolger and Kohler *et al*., 1995). Fish body shape and LWR relationship is affected by various factors (Li *et al*., 2023). However, *b* parameter is characteristic of the species and generally doesn't vary significantly throughout the year, unlike *a* parameter, which may vary

daily, seasonally, and or between different habitats (King, 1995). In the present study, the *b*-value in the length-weight relationship was estimated in 2.79 for males and 2.66 for females of *S. jello*. This result is consistent with most studies on the biometrics of *S. jello* (Van der Elst, 1981; Premalatha and Manojkumar, 1990; Edwards and Shaher, 1991; Al-Sakaff and Esseen, 1999; Kasim, 2000; Harrison, 2001; Hosseini *et al*., 2009b; Al-Kamel *et al*., 2020; Raeisi *et al*., 2021). The negative allometric growth ($b<3$) suggested that the accretion of length is faster than the accretion of weight with growth of *S. jello.* However, some studies reported positive allometric growth ($b>3$) of *S. jello.* Usually, these results are related to the study of young fish in small range (16.5-28.2 cm TL), as reported by Abdurahiman *et al*. (2004). However, the difference between the results can be attributed to differences in ecological conditions, swimming behavior, length ranges, and growth rates of the studied fish in different regions.

The present research provides new information about the reproduction of *S. jello* along the Dhofar coast of Oman coast in the Arabian Sea. In our study, the sex ratio of *S. jello* was in favor of females 0.68:1 (40% males and 60% females). This agrees with Premalatha and Manojkumar (1990), Bachok *et al*. (2004), and Hosseini *et al*. (2009b) who reported dominance of females with the sex ratio 0.67:1, 0.86:1 and 0.94:1, respectively. However, Okera (1982) found that the sex ratio of *S. jello* from the northern Australian waters was in favor of males. Generally, for *Sphyraena* species *S. chrysotaenia*; *S. flavicauda* and *S. sphyraena*, males dominated in smaller length groups while females were more abundant in the larger sizes (Allam *et al*., 2004). The tendency of males to decrease with the increasing fish length can be due to the shorter life span of males which is associated with the earlier attainment of sexual maturity (Hashem, 1981) and/or differential mortality rates in sex resulting in the disappearance of males from the population at an earlier time than females (Solomon *et al.,* 1984). Concerning the seasonal variation of sex ratio in the present study, it is found that females were predominated over males in all studied months except October and November. Such seasonal variation in sex ratio may be attributed to the pre-spawning migration of males (De Sylva, 1963).

Our analysis of monthly changes in GSI and the ratio of different stages of gonads in males and females revealed that *S. jello* spawns in the Dhofar region of the Arabian Sea throughout the year, with the peak of spawning from June to August. This finding is in agreement with other studies on *S. jello* that showed prolonged spawning season for the species. From Premalatha and Manojkumar (1990), the species spawns in the Arabian Sea along the southwest coast of India from March to July with a peak in April–May. Krishnadas and Nair (1994) reported the spawning season of *S. jello* in the same region near Cochin from April to September/October with increased activity during June-September. Hosseini *et al*. (2009a) found the spawning season for the barracuda in the north-west Persian Gulf along the coast of Iran from April to June with a peak in May. The spawning season of different barracuda species varies widely depending on the species and study area, but most studies also indicate a protracted spawning period. For example, according to Vinothkumar *et al*. (2022), the presence of mature females of obtuse barracuda, *S. obtusata* along the south-east coast of India throughout the year indicated year-round

spawning behavior of the species in the region.

Significant differences were found between our result on the length at first maturity of *S. jello* and its estimation by Krishnadas and Nair (1994) in the eastern Arabian Sea (Cochin region). In our study, L_{m50} was calculated to be 71.9 cm TL in males and 74.0 cm TL in females, while Krishnadas and Nair (1994) reported these values at 36.0 cm TL and 37.0 cm TL respectively. According to Premalatha and Manojkumar (1990), specimens of *S. jello* above 40 cm showed maturing gonads from March onwards. It can be assumed that according to Krishnadas and Nair (1994), *S. jello* reaches an age at first maturity during 1-2 years of life, while from our data males at the age approximately 4.1 years and females at 4.3 years. Such significant differences are difficult to explain and more research is needed to verify the results.

The present study provided new data on the age and growth of *S. jello*. Accurate fish aging is critical for the estimation of individual and population growth rates, age-at-maturity, and other related indices (Panfili *et al*., 2002). Previous aging studies of *S. jello* are scarce and based on the study of sectioned vertebrae (Edwards *et al*., 1985) or using the length-frequency method (Kasim, 2000; Hosseini *et al*., 2012). Kasim (2000) and Hosseini *et al*. (2012) indicated a maximum age for *S. jello* of only 6 years, while from our study, based on investigation of sectioned sagittal otoliths under the microscope, the fish can reach 24 years (Table 3).

Table 3: Summary on age and growth estimations for *Sphyraena jello*.

Method	Region	Maximum age	L_∞ (cm)	K (yr^{-1})	t_o (yr)	Reference
Sectioned vertebrae	Yemen	–	148.4*	0.10	+0.009	Edwards *et al*., 1985
Length frequency	India	6	168.0*	0.396	-0.0448	Kasim, 2000
Length frequency	Iran	6	109.21	0.37	–0.5	Hosseini *et al*., 2012
Sectioned otoliths	Oman All	24	161.18	0.119	–0.88	Our data
	M	24	146.03	0.145	–0.96	
	F	21	170.99	0.109	–0.75	

L_∞, K, t_o are parameters in von Bertalanffy growth function, M = males and F = females.
*Fork length.

Our results on the estimation of growth parameters in the von Bertalanffy formula (L_∞=161.18 cm TL, K= 0.119 y^{-1}) are comparable to the values estimated by Edwards *et al*. (1985), and this may be due to the fact that the study areas in the Arabian Sea were very close. However, these results differ significantly from the results of Kasim (2000) and Hosseini (2012) that reported a much faster growth rate of *S. jello* (K=0.37 y^{-1}). The value of asymptotic length (L_∞=168.0 cm FL) by Kasim (2000) is in the same range as our estimate, while Hosseini (2012) reported a much lower asymptotic length (L_∞=109.21 cm TL). So, the studies of Kasim (2000) and Hosseini *et al*. (2012) showed that *S. jello* is relatively a short-lived species, while from our study, *S. jello* is a long-lived species with a maximum age of 24 years and a life span of up to 27 years. The barracuda grows rapidly, 1-year-old fishes reach an average of 33.4–38.1 cm TL, and 2-year-olds attain 47.3–57.5 cm TL. Some fish begin to mature in their second year of life, but most

fish reach their first sexual maturity at about 4 years of age.

Some barracuda species such as *S. jello*, *S. barracuda*, *S. afra*, *S. viridensis*, and *S. novaehollandiae* grow to large sizes and live for many years, as evident from their values of asymptotic length, growth coefficient and natural mortality (Ghosh *et al*., 2021). Bourehail and Kara (2021) found a longevity of 14 years for 116.5 cm TL of *S. viridensis* in Algerian waters. The oldest individual of great barracuda, *S. barracuda* from Florida Bay in the study of Kadison *et al*. (2010) was female of 18.4-yr-old, 12 kg, 123.9 cm FL. Ayo-Olalusi and Ayoade (2018) estimated the maximum age (longevity) at 30 years and the asymptotic length in 192.68 cm TL for *S. afra* from Nigerian coastal waters. Other barracuda species viz., *S. obtusata*, *S. sphyraena*, *S. chrysotaenia* and *S. flavicauda* are small in size and live for 3-6 years (Kasim and Balasubramaniam, 1990; ElGanainy *et al*., 2017). Substantial differences in growth are observed at the individual, population, and cohort levels; which are usually genetic but are also highly dependent on physical (temperature, salinity, levels of dissolved oxygen and photoperiod), biotic (food availability and quality, competition and age and maturity) and general environmental conditions (Sparre and Venema, 1998). Long-lived species with slow growth are vulnerable to overfishing and therefore, need careful monitoring and management (Udoh *et al*., 2015).

The obtained results on basic biological parameters of *S. jello* in the waters of Oman can be useful for the assessment of some stock characteristics, however, many further studies are needed for developing stock assessment models and designing appropriate management strategies for the judicious exploitation of this commercially important barracuda species.

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