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Growth and maturity of *Carcharhinus dussumieri* (Muller and Hellen, 1839) in the Persian Gulf and Oman Sea

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Abstract

This study aimed to estimate the growth pattern and to determine age at maturity (Lm_{50}) and longevity of white cheek shark, *Carcharhinus dussumieri* (Muller and Hellen, 1839) during 2014 and 2015. This species is being severely exploited in the Persian Gulf and Oman Sea, so growth, maturity and diet will be critical for stock assessments and management advice. Longevity estimates based on vertebral ageing were 8 and 13 years for male and female of *C. dussumieri*. Results indicated a Gompertz growth model and a logistic growth model for females and males, respectively. The obtained curve revealed a sigmoid relation between clasper length and total length of the shark. Females matured from 60 to 68 cm and their mean maturity size was 64.17 cm. Male *C. dussumieri* matured within a similar size range (61-68 cm) with mean maturity size of 63.14 cm.

Keywords: white cheek shark, maturity size, Gompertz, logistic, Persian Gulf, Oman Sea

Introduction

The family Carcharhinidae with 12 genera and 48 species is the third richest shark family in species diversity. Additionally, this family has the highest biomass and species richness in tropical areas (Fischer and Bianchi, 1984). The genus *Carcharhinus* with 29 species is dominantly distributed in temperate and warmer zones (Fischer and Bianchi, 1984). In the west part of the Indian Ocean, 21 species of the genus *Carcharhinus* live of which 13 species are also reported in the Persian Gulf and the Oman Sea (Carpenter et al., 1997).

More than 10 species of *Carcharhinus* inhabits in Iranian waters of the Persian Gulf (Hormozgan Province), amongst which white cheek shark, *Carcharhinus dussumieri* (Muller and Hellen, 1839) is also found throughout the Persian Gulf (Carpenter et al., 1997). Sharks are slow-growing organisms with a few newborns in every pregnancy and play an important role in the inhabiting ecosystem (Cortes, 1999؛ Gelsleichter et al, 1999؛Stevens et al., 2000).

Understanding the life cycle and biology of these Condrichthyans is integral to their conservation and successful fisheries management which could be applied in quantitative assessment of the population size. For instance, if the

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relations amongst length, age, body mass, fecundity and sexual maturity are accurately recognised, length-and age-structured models can be used in population dynamics modelling (Punt et al., 2000; Aires-da-Silva and Gallucci 2007). Effective management of Chondrichthyans is particularly important, as many species often have biological characteristics (e.g. slow growth, low fecundity), implicating that only a relatively small proportion of the population can be sustainably harvested annually (Walker et al., 1998).

Studies are already indicating that regional elimination of sharks from the ecosystem can cause disastrous effects such as a considerably increased abundance of some crustacean, fish and sea mammals which would led to other species to be constrained, trophic cascade effect and finally the collapses of the whole ecosystem (Ward and Myers 2005, Myers et al. 2007). One pound of dried shark fins is commonly retailed at US$ 300. As a one-milliard dollar industry, this vast market is not managed or monitored properly (http://Sharkresearchcommittee.com).

During a few recent years, the annual shark catch has been increasing rapidly along the Iranian waters of the Persian Gulf and the Oman Sea. Stocks of white cheek shark seem to be plentiful, but there are some concerns about its overexploitation. Like most of fish stocks in the Persian Gulf, there is a lack of information about white cheek shark stocks. Therefore, identifying the growth patterns of *Carcharhinus* in order to assess their impacts in marine ecosystems in the Persian Gulf is necessary.

Despite the commercial and ecological importance of the white cheek shark, our current knowledge on its life history in the Persian Gulf and the Oman Sea is limited to a single study on its reproductive biology (Asadi, 2001). Hence, due to the lack of information on growth and Lm_{50} of the white cheek shark in the Persian Gulf and Oman Sea, it is significant to achieve a better understanding of the species´ status in the local marine ecosystem, especially in terms of its fishing condition in this area. In the present study, we investigated the growth rate and Lm_{50} the white cheek shark in order to determine the feeding preferences of this species in the Persian Gulf.

Materials and Methods

Sampling was conducted in the Persian Gulf waters during two years from December 2012 to June 2014 (Fig. 1). For growth calculation and gonad description, 605 shark samples including 289 females and 316 males which were caught by mid water trawl and gillnet were analyzed.

Vertebral Processing and Growth Analysis

From the anterior part of the vertebral column, somewhere between the gills and the first dorsal fin, a section of five vertebrates was removed and kept frozen. Using a scalpel, neural and hemal arches together with soft tissue were removed and only the vertebral centra left behind. Then, centra were soaked in a solution of % 5 sodium hypochlorite (bleach) for ~30 min to remove the remaining soft tissues. Thereafter, they were rinsed thoroughly under tap water and placed in an oven at 60°C for 24 h.

The sectioned centera were examined under a dissecting microscope using transmitted light (Fig. 2). Determination of the shark´s age was conducted by counting the pairs of transparent and translucent growth bands which was deposited

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on the corpus calcareum (Cailliet and Goldman, 2004). The birth mark was recognizable by an angle shift on the corpus calcareum.

Prior to aging all centra, a random subsample of the vertebrae was read by two experts to ensure that an agreement in interpreting the banding pattern was achieved. Then, one of the readers examined the whole centers twice. The precision between and within readers was evaluated by the method of Chang (1982), as the coefficient of variation (CV) and percentage of agreement was checked by the method of Goldman and Musick (2006). The bias between and within readers was statistically calculated using a test of symmetry based on Bowker's test (Evans and Hoenig, 1998). An information-theoretic, multi-model inference (MM) approach was applied for growth modeling (Burnham and Anderson, 2001; Katsanevakis and Maravelias, 2008). Models included a three-parameter version of the von Bertalanffy growth equation (VB), a three-parameter version of the Gompertz function (GOM) and logistic growth curve (LOG). Each model suggests an alternative hypothesis for growth and, in each case, an asymptotic growth was assumed. The three applied models were as the following. Length-weight relationship was estimated for males and females of white cheek shark (Table 1).

(1) Von Bertalanffy (VB): $L_t = \beta_2 + (\beta_1 - \beta_2)(1 - \exp(-\beta_3 t))$

Where L_t is length as function of time, β_1: L_∞ (cm), β_2: L_0 (cm) and β_3: k (years^{-1}).

(2) Gompertz (GOM): $L_t = \beta_2 exp\left(ln\frac{\beta_2}{\beta_1}\right)(1 - \exp(-\beta_3 t))$

Where L_t is length as function of time, β_1: L_∞ (cm), β_2: L_0 (cm) and β_3: k (years^{-1}).

(3) Logistic (LOG): $L_t = \frac{\beta_1 \beta_2 \exp(\beta_3)}{\beta_1 + \beta_2(\exp(\beta_3 t) - 1)}$

Where L_t is length as function of time, β_1: L_∞ (cm), β_2: inflection of point; and β_3: k (years^{-1}).

Models were fitted by the method of Maximum Likelihood in statistical package Excel (Ver. 2013) with VBA programming language (Haddon, 2011).

Models performance relative to each other was checked using Akaike's Information Criteria (AIC). The model with the least AIC (AIC_{min}) was chosen as the best model, AIC_{min}. AIC differences was calculated as $\Delta_{AICi} = AIC_i - AIC_{min}$ and ranked relative to the best model in order to support the remaining models (i=1-3). Models with Δ_{AIC} of 0 and 2 had a substantial support, whereas those with Δ_{AIC} of 4 to 7 showed considerably less support. Models with Δ_{AIC} of > 10 essentially revealed no support (Burnham and Anderson, 2001).

Akaike weights (w) were calculated as the evident weight in favor of the model which is selected as the best mode in a set of candidate models (Burnham and Anderson, 2001).

Approximately 95% confidence interval and the precision in parameter estimation of the best fit and population estimates were derived from 10 000 resampled dataset.

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The length-weight relationship was estimated by total length (cm) and total weight (g) according to the following equation (Froese, 2006):

$W = aL^b$

Lm50

As described by Walker (2005), a single index was used for staging maturity in each sex. Determination of maturity was based on clasper condition (C=1-3) in males and uterus condition in females (U=1-7). For statistical analysis, data obtained from maturity-stage was converted to binary format (immature=0, mature= 1). Population estimates of length at maturity were established separately for males and females, using a logistic regression model (Roa et al 1999) which was reformulated by Walker (2005) to be biologically meaningful as the following:

$$P(I) = P_{MAX}\left(1 + e^{-\ln(19)\left[\frac{1-\beta_1}{\beta_2-\beta_1}\right]}\right)^{-1}$$

Where $P(I)$ is the proportion of population mature in STL, I; β_1 and β_2 are fitted parameters corresponding to l_{50} and l_{95}, respectively; and P_{MAX} is the asymptote. A generalized linear model with binormal error structure and logit-link function was applied to estimate parameters β_1 and β_2. The overall significance of fitted models was tested by comparing the amount of explained deviance relative to null model using Chi-squares tests.

t_0 where calculated by Pauly equation (1980):

$\log -(t_0) = -0.3922 - 0.2752 logL_\infty - 1.038 logK$

The weight-age relationship was fitted using the following equation (Haddon, 2011).

$\hat{w}_t = w_\infty\left[1 - e^{-k[t-t_0]}\right]^b$

Where W_∞ is the asymptotic weight and b: the slope in length-weight relationship. The following formula was applied to estimate W_∞.

$W_\infty = aL_\infty^b$

Growth performance index was measured by the following equation (Gayanilo and Pauly, 1997):

$$\phi = \log K + 2logL_\infty$$

The likelihood ratio test was used to compare growth curve between male and female by the following equation (Haddon, 2011):

$$X_K^2 = -N \times Ln\left[\frac{\sum RSS_i}{RSS_P}\right] = -N \times Ln\left(\frac{RSS_\Omega}{RSS_\omega}\right)$$

Where k is the degrees of freedom, N: total number of observations from both curves combined, RSS_Ω: total sum of squared residuals derived from fitting both curves separately and $RSS\omega$: total sum of squared residuals derived from fitting the curves with one of the hypothesized constraints.

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ISSN 1303-2712
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Results

Totally, 605 samples of white cheek shark were studied for biometric measurements and description of gonadal maturation stages. . Mean length for males and females of *C. dussumieri* were 67.278±0.889 and 71.4±1.13, respectively **.**Results of the present study demonstrated that length-frequency distribution had a significant difference between males and females (N=605, $D_{k.s}$=1.22)(Fig. 3).

Growth

Mean inter-reader percentage agreement (PA) and PA^{-1} year between the first and second read pooled into 50mm length groupings was 56% and 71% for *C. dussumeiri*, whereas Chang's coefficient of variation (CV) was 26.40%. Precision was low though no significant difference was observed between the readers (Bowker's test of symmetry: X^2=14, *P*, 0.13).

Vertebrae centra from 260 specimens of *C. dussumeiri* were obtained and read. Total length ranged between 41–106 cm for males (n=140) and 40.6–121 cm for females (n=120). The youngest male and female were zero year and were 29.5 cm. The oldest male was 8 years old with total length of 106 cm while the oldest female was 13 years old with total length of 121 cm.

A strongly asymptotic growth curve was recognized for both sexes of *C. dussumeiri*, with fast growth rates during the five few years of life which rapidly decreases thereafter (Fig. 4, Table 2). The most parsimonious model for males in the multi-model analysis of growth was logistic model (Table 2, Δ_{AIC}=0).

The von Bertalanffy model was also supported by the data to a lesser extent (Table 2, Δ_{AIC}=6.89), whereas the Gompertz model showed little support. The Gompertz model was by far the best, given the data (**Table 2**, Δ_{AIC}=0), and The von Bertalanffy model was also supported by the data to a lesser extent (Table 2, Δ_{AIC}=6.91).

The best growth curves were acquired by the test of Akaike information test in males and females of white cheek shark. A diagram is represented to compare growth curves estimated in males and females. Comparison of the growth curve between males and females revealed a significant difference (P<0.05) (Fig. 4).

As shown in **Fig. 5**, confidence interval for parameters of L_∞, K and L_0 was estimated by Maximum Likelihood method. In addition, the weight-age relationship was estimated in the fish sampled in the present study (Fig. 6).

The value of growth performance index ˈϕ was estimated 2.28 and 2.42 for female and male, respectively.

$\phi = \log 0.38 + 2log 121.32$ = 3.75 female

$\phi = \log 0.589 + 2log 111.05$ = 3.86 male

Lm_{50}

The mature females were found from 60 to 68 cm with maturity size of 64.17 cm length. For males, maturity occurred at length of 61-68 cm and maturity size was estimated 63.14 cm length (Fig. 7).

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When maturation began, the length of clasper and testicles weight quickly increased which made the clasper rigid. As illustrated in Figure 4, a sigmoid curve was found for the relationship between clasper length and total body length. Clasper length rapidly increased when shark reached a length of 63 to 76 cm and became stable at 73 cm length. All the sharks greater than 61 cm had rigid clasper while smaller ones had smooth clasper (Fig. 8).

Discussion

In the present study, the exponent b ranged between 2.5 and 3.5. Thus, the estimated parameters were acceptable (Froese, 2006).

We were able to obtain individuals across a full range of lengths for both sexes, although the sampled length structures of these sexes were very different This bias toward juveniles in *C. dussumieri* probably explains why a distinct asymptote was not reached in any of the growth curve models, and consequently why L_∞ exceeded the maximum length, specifically for males (males generally appear to grow to ~ 106 cm, whereas the fitted values of L_∞ reached 120 cm in several models (Table 2).

The lack of an asymptote is of typical feature in many shark growth curves (Simpfendorfer et al., 2002; Braccini et al., 2007), and computer simulation studies have shown that it might be attributed to the selectivity of the fishing gear and the effects of length-selective fishing mortality (Walker et al., 1998; Thorson and Simpfendorfer, 2009). If age underestimation has also occurred, probably this would further compound the issue.

Results of maturity stage from the current study detected that all the mature specimens had a hard and calcified clasper while immature ones showed a smooth clasper. Observations from similar studies on the reproductive biology of white cheek shark and the other species approved the results presented here (Asadi, 2001; Harry et al., 2013; Henderson et al., 2006).

A sigmoid relationship was found between clasper length and total length, indicating a slow growth rate in clasper length at earlier stages of life followed by a rapid rate during maturity stage and again a slow rate at post-maturity stage. Previous studies confirmed the sigmoid relationship between these parameters (Asadi, 2001; Harry, et al., 2013, Henderson et al., 2006, Capae, 1993).

. In a previous research on reproductive biology of white cheek shark by Asadi (2001), Lm_{50} values for males and females was reported 68.9 and 68.7 cm, respectively, which exceeded than our estimates. When fishing pressure increases maturity at an earlier age and smaller size is sometimes a natural response in fish population (Rochet, 2000). Therefore, this can be justified by the increased fishing pressure in recent years.

Despite the fact sharks are commonly caught in countries along the borderline of the Persian Gulf and the Oman Sea, there is little information on their biology and, in many cases, and stocks are not well-known. In the Persian Gulf, sharks are considered as an important component of the commercial catch while a few studies have been conducted on its biology and reproduction. The present work can be applied as a basis for future studies.

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Table 1. Descriptive statistics and length-weight relationships parameters for males and females of *C. dussumieri*, n: sample size, Min: minimum, Max: maximum, *a* and *b*: constant parameters in equation $W = aL^b$.

		Length (cm)		*WLR* parameters and statistics		
Genus	n	Min	Max	*a*	*b*	r^2
Male	316	41.0	106	0.0031	3.105	0.985
Female	289	40.6	121	0.0024	3.142	0.982

Turkish Journal of Fisheries and Aquatic Sciences
www.trjfas.org
ISSN 1303-2712
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Table 2. Comparison of three growth models fit to length-at-age data for *C. dussumeiri*. The best model represented in bold was the one with the lowest value for Akaike's information criterion (AIC). The relative support of other models can be evaluated based on Akaike differences (Δ_{AIC}). Best-fit estimates are given for parameters β1–β3 (with 95% confidence interval).

Sex	Model	n*	k*	AIC	BIC	Δ_{AIC}	β_1		β_2		β_3	
Female	VB	100	3	38.8	36.14	12.22	126.69	(123.5-129.6)	27.06	(25.1-28.95)	0.245	(0.22-0.27)
	GOM	100	3	26.58	23.92	0.00	121.32	(120-122.4)	29.73	(28.45-30.7)	0.385	(0.37-0.398)
	LOG	100	3	33.50	30.84	6.91	119.51	(117.9-121.2)	34.49	(32.2-35.5)	0.497	(0.475-0.51)
Male	VB	98	3	44.40	41.26	6.89	115.32	(113.2-117.1)	28.44	(27.3-30.2)	0.29	(0.265-0.31)
	GOM	98	3	54.40	51.26	16.89	117.63	(114.1-120.6)	29.98	(26.9-32.6)	0.453	(0.423-0.473)
	LOG	98	3	37.50	34.37	0.00	111.05	(108.2-114.1)	32.64	(28.55-35.02)	0.589	(0.543-0.63)

*n= number of sample
*k = number of parameter

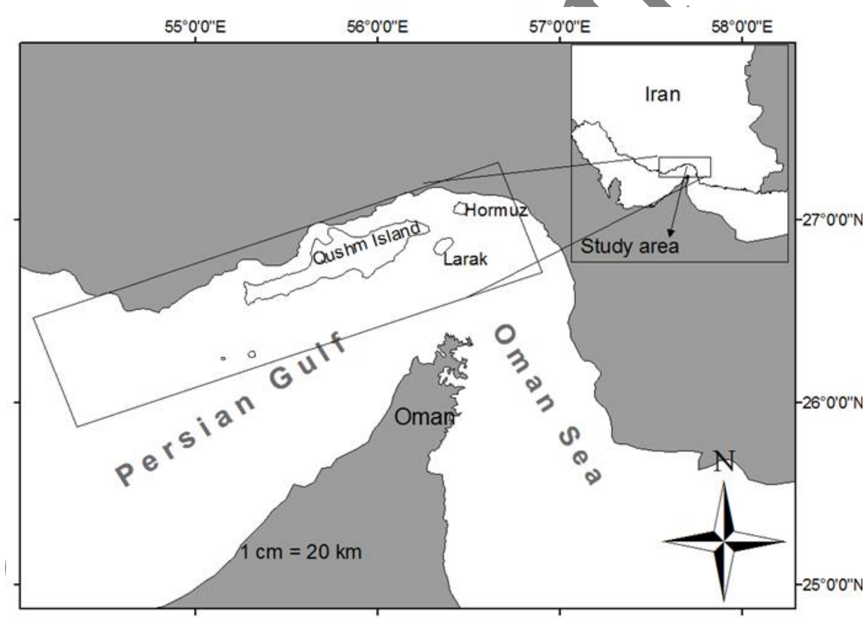

Figure 1. Study area of *C. dussumeiri* by trawl and gill net in the northern Persian Gulf

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Turkish Journal of Fisheries and Aquatic Sciences DOI: 10.4194/1303-2712-v17_2_14

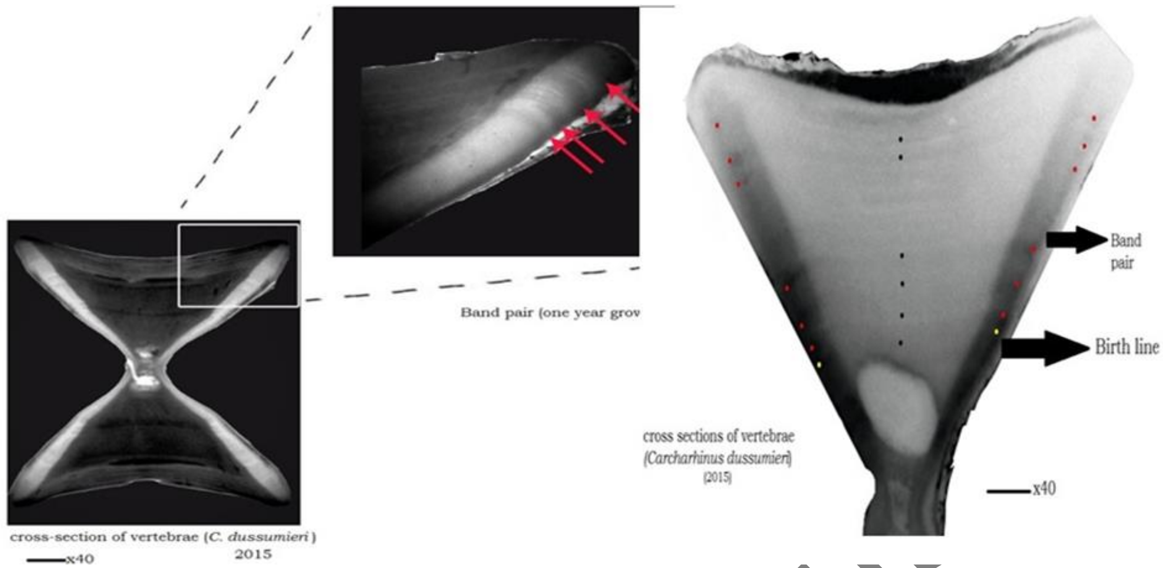

Figure 2. Cross-section of the vertebrate in a 6-year old white cheek shark.

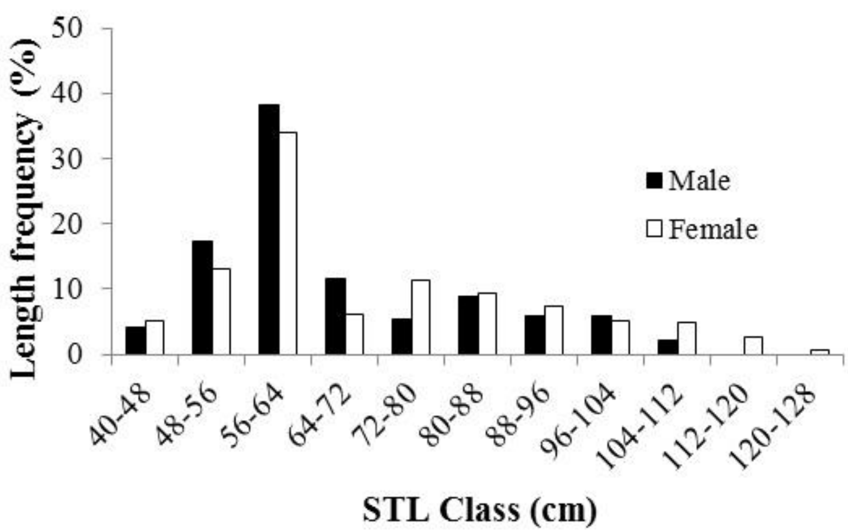

Figure 3. Distribution of length frequency in males and females of white cheek shark *Carcharhinus dussumieri*

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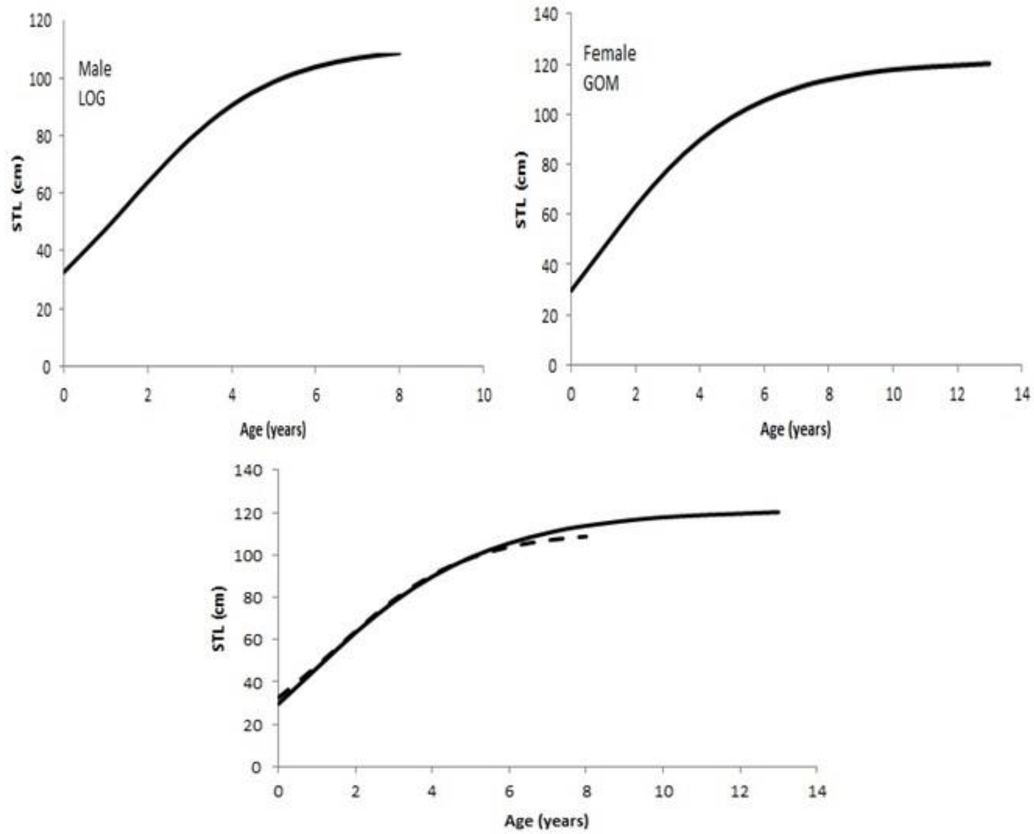

Figure4. Length and age curves obtained for white cheek shark *Carcharhinus dussumieri*

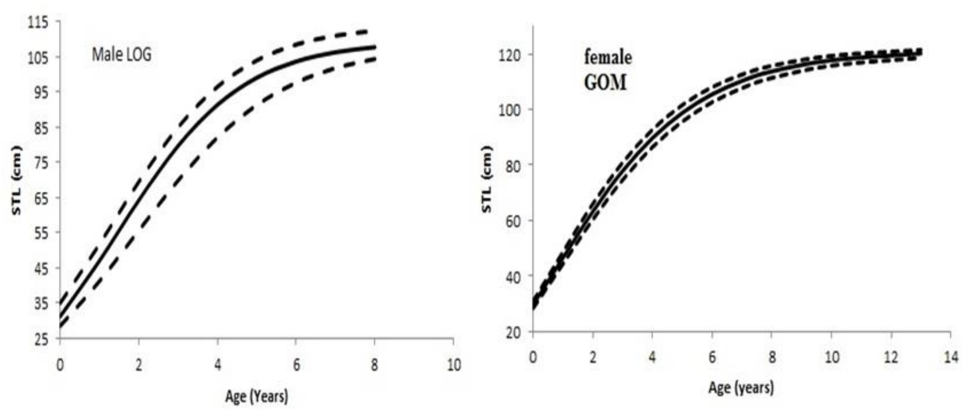

Figure 5. Length at age of *Carcharhinus dussumeiri* as determined from vertebral growth analysis.

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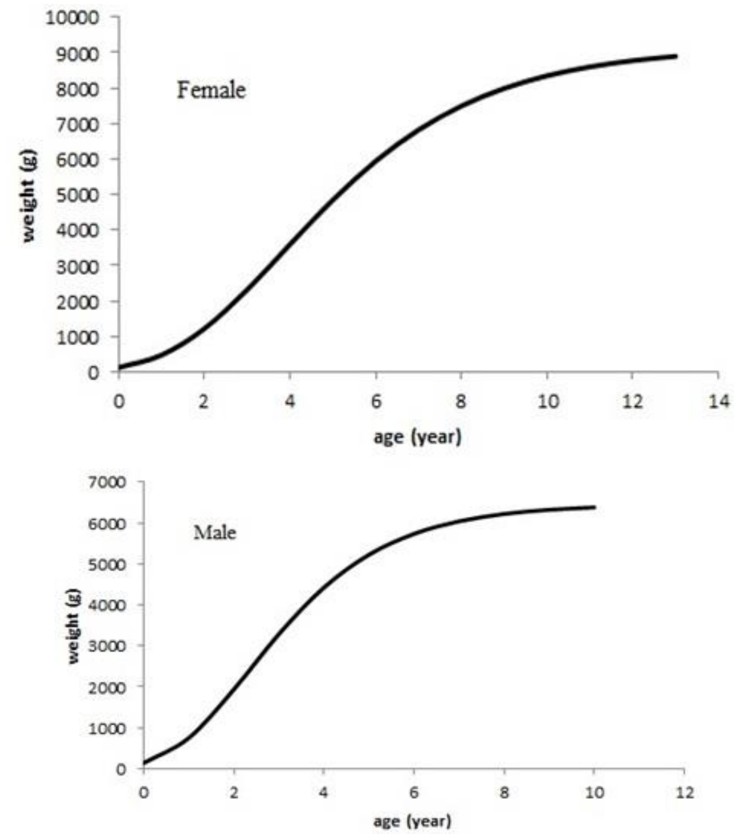

Figure 6. Fitted curves of weight-age relationship by the best parameters selected based on Akaike information criterion

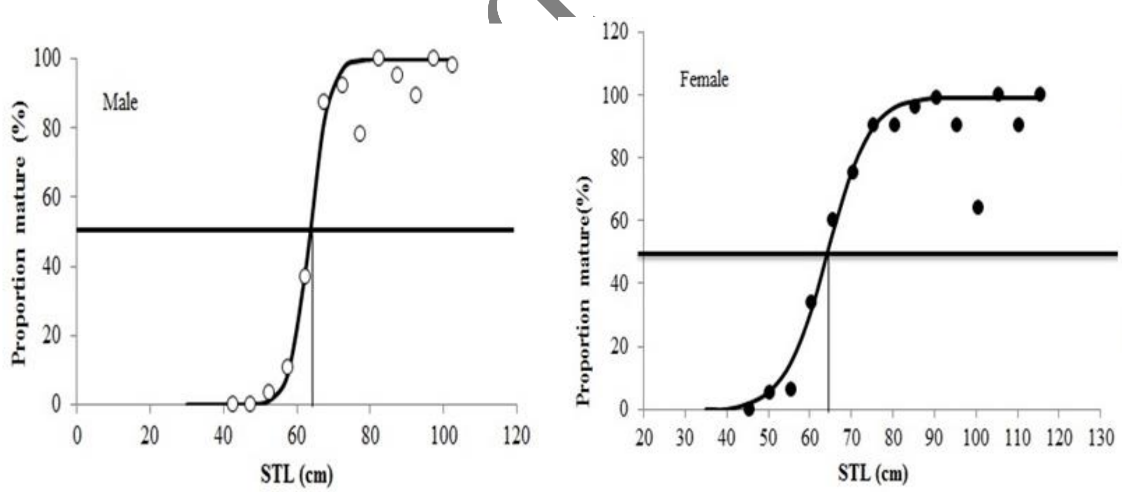

Figure 7. Mean length of male and female sharks at 50% maturity

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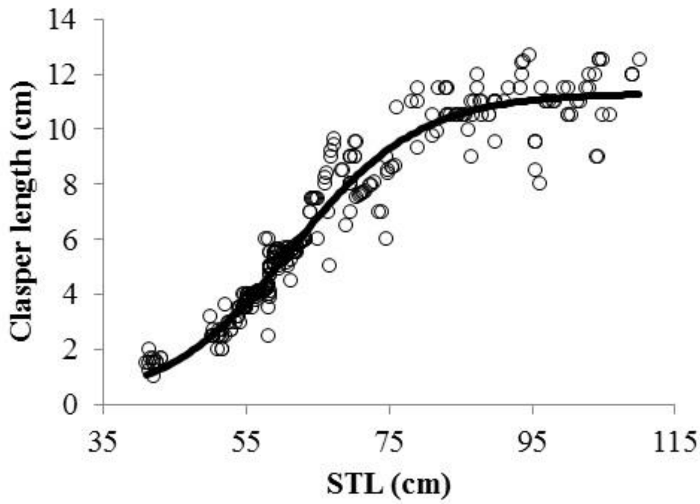

Figure 8. Relationship between clasper length and stretch total length in white cheek shark