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Length-weight relationships and size at first maturity of four commonly landed elasmobranchs in Malvan, Maharashtra

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Original Article

Abstract

Elasmobranchs are amongst the most threatened faunal groups globally, with fishing being the key contributor to their decline. Given the varied life histories of elasmobranchs, sustainable fisheries management requires detailed investigation with fishery and species-specific strategies. The present study aimed to explore the life-history traits, specifically length-weight (L-W) relationships and size at first maturity (L_{50}), of the commonly landed and commercially important sharks and rays off the coast of Malvan, western India. These included *Scoliodon laticaudus*, *Chiloscyllium griseum*, *Chiloscyllium arabicum* and *Brevitrygon walga*. The L-W relationship was estimated using linear regression and analysis of covariance (ANCOVA), while Student's t-test was carried out to test for isometry. L_{50} was determined by fitting a logistic regression to the proportion of mature individuals and the body length. ANCOVA showed no significant difference between the sexes; therefore, male and female specimens were pooled to obtain a single equation. L-W relationships for *S. laticaudus*, *C. griseum*, *C. arabicum* and *B. walga* were as follows: $0.003820L^{2.97}$, $0.00398L^{2.95}$, $0.001713L^{3.13}$ and $0.017489DW^{3.21}$. The shark species showed isometric growth, whereas *B. walga* showed positive allometric growth. L_{50} for males of *S. laticaudus*, *C. arabicum* and *B. walga* were 41.30 cm, 57.15 cm and 21.36 cm, respectively. L_{50} for females of *C. arabicum* and *B. walga* were found to be 58.32 cm and 19.00 cm, respectively. The data generated on the L-W relationship will contribute to our understanding of fish biology and physiology, while information about L_{50} of the elasmobranch landings can be utilised for tracking the health of the population and estimating minimum legal size (MLS) for developing fisheries-specific interventions in the study region.

Keywords: *Chondrichthyans, life-history traits, maturity, threats, reproductive biology*

Introduction

Elasmobranchs (sharks, rays, and skates) face a higher extinction risk than most other vertebrates, and over one-third of them are threatened according to the IUCN Red List criteria (Dulvy *et al.*, 2021). Even though this group shows immense diversity and abundance in unexploited ecosystems, a slight increase in fishing pressure can lead to significant declines in their populations (Ferretti *et al.*, 2010). Most elasmobranch species have slow growth and low fecundity, which makes them highly susceptible to anthropogenic stressors (Stevens, 2000). Globally, overfishing, along with pollution, habitat destruction, and climate change, are major threats to their population (Dulvy *et al.*, 2014). While sharks have tremendous socio-economic value through fisheries and tourism (Gallagher and Hammerschlag, 2011), the current rates of their exploitation raise concerns about the sustainability of these practices. As integral drivers of the stability of marine food webs (Myers *et al.*, 2007), the sustainable management of these animals must be prioritised.

India ranks third in shark landings, contributing to an average catch of 67,391 metric tonnes annually between 2007 and 2017 (Okes and Sant, 2019). The maximum elasmobranch landings recorded in 1998 and 2000 were 75,000 tonnes, dropping to less than 45,000 tonnes by 2019 (Kizhakudan *et al.*, 2015; FRAD and CMFRI, 2020). While fishing bans and alternative livelihoods have been suggested as solutions for reducing elasmobranch mortality, sharks and rays provide food security to millions and are often caught as incidental catch (Gupta *et al.*, 2020a). In India, one of the major reasons for retaining shark bycatch, including juveniles, is to support the domestic demand for shark meat (Karnad *et al.*, 2019). Consequently, there is a need for their fisheries to be managed sustainably. Currently, only about 9% of global shark landings are considered biologically sustainable (Simpfendorfer and Dulvy, 2017).

Planning sustainable outcomes for shark populations with varied life histories requires detailed investigation with fishery and species-specific management. Life history information, such as length-weight relationships, maturity, and reproductive strategies, can help assess population dynamics and determine the resilience of populations to exploitation (D'Alberto *et al.*, 2017). These traits may vary between populations of the same species as a consequence of population dynamics or environmental factors (D'Alberto *et al.*, 2017; Tyabji *et al.*, 2020). Additionally, fisheries exploitation can induce changes in maturity and other life history traits of fish stocks (de Roos *et al.*, 2006; Hunter *et al.*, 2015). Hence, studying these traits at a regional and fishery level is crucial to assess potential fishery impacts and design appropriate management strategies.

Life-history traits of elasmobranchs have been previously studied in India, such as in Calicut (Devadoss, 1987; Devadoss, 1989), Dakshin Kannada (Kulkarni *et al.*, 1988), Gujarat (Dash *et al.*, 2019), and Mumbai (Mathew and Devaraj, 1997). With a shallow coastline and a range of marine habitats, including estuaries, mangroves, and corals, Malvan is a hotspot for marine biodiversity. This study aimed to explore vital biological information–length-weight relationships, size at first maturity–of commonly landed and commercially important elasmobranch species from Malvan, namely, *Scoliodon laticaudus*, *Chiloscyllium griseum*, *Chiloscyllium arabicum,* and *Brevitrygon walga*. These species were selected based on field observations and previous studies (Kottillil *et al.*, 2023).

Material and methods

The study was carried out in March 2021 in Malvan (16.3492°N, 73.5594°E), in the Sindhudurg district of Maharashtra in India (Fig. 1). Trawlers, gillnets, and purse seines operate here, along with numerous artisanal fisheries, with fishing grounds extending from Ratnagiri in the North to Goa in the South (Gupta *et al.*, 2020a). Hence, specimens sampled in this study represent populations from these waters.

Landing surveys were conducted on alternate days, sampling catches from all types of fishing gear. The study species were identified as per Jabado and Ebert (2015) for sharks and Last *et al.* (2016) for rays. Biological data, including sex, total length (L), disc width (DW), weight, and the maturity stages, were recorded to calculate the length-weight (L-W) relationship and the size at first maturity (L_{50}; Tyabji *et al.*, 2020). The maturity stage in males was determined by the length and the degree of clasper calcification (Tyabji *et al.*, 2020), whereas, in females, the specimens were dissected and assessed for the development of ovaries and oviducts (Stehmann, 2002; Powter and Gladstone, 2008). Specimens of the study species were sampled randomly from the landings. Morphological data and male maturity were recorded during daily auctions. For recording the female maturity stages, specimens were purchased and then dissected at the field base.

For L-W relationships, 304 samples of *S. laticaudus*, 53 of *C. griseum*, 86 of *C. arabicum,* and 111 of *B. walga* were sampled (including gravid females). To estimate L_{50}, the sample sizes were as follows: *S. laticaudus* (M=173, F=76), *C. griseum* (M=28, F=12), *C. arabicum* (M=41, F=21) and *B. walga* (M=64, F=30), where M and F refer to male and female specimens respectively.

The L-W relationship for fish is of the form: $W=aL^b$, where *a* coefficient is dependent on the body form and *b* indicates the nature of growth, *i.e.*, isometric or allometric; (Le Cren, 1951; Froese, 2006;). These parameters were estimated using linear regression modelling by transforming the equation to natural logarithmic form, i.e., $\ln (W)= \ln (a) + b \ln (L)$ (Froese, 2006). ANCOVA was used to test for the equality of the male and female regression equations (Snedecor, 1956). In case of no statistical difference between equations, a common equation was derived after pooling both sexes. When the value of *b* is ~3, it is said to follow an isometric growth pattern, *i.e.*, 'unchanging specific gravity' (Froese, 2006); whereas, when *b* is found to be significantly different from 3, growth is considered allometric (Froese, 2006). Student's t-test was used to test for the statistical significance of *b* against 3 (Froese, 2006).

Size at first maturity (L_{50}) was determined by fitting a logistic regression between the proportion of mature individuals and length as a predictor variable (Sathianandan and Mohamed, 2017; Tyabji *et al.*, 2020). Based on the maturity scales discussed in Stehmann, 2002, the maturity stages (for both sexes) were

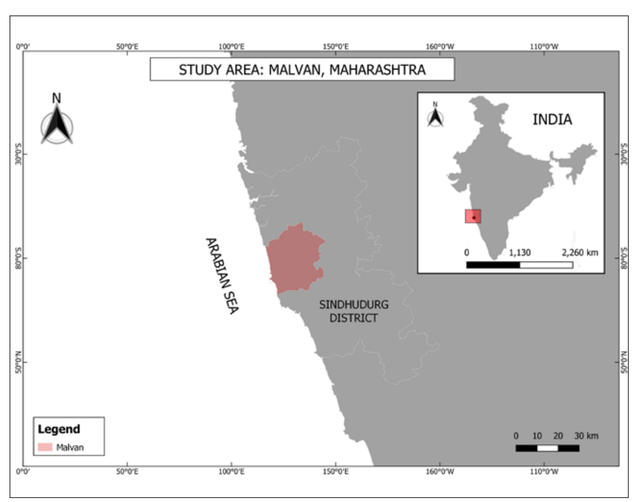

Fig. 1. Study area of Malvan, Sindhudurg district, Maharashtra

converted into a binary form: immature and mature. For both males and females: stages 1 (juvenile) and 2 (adolescent) were converted to immature, and the rest were treated as mature (Stehmann, 2002).

All analyses were conducted using R Studio (R Core Team, 2019). Packages used for the analysis include readxl (Wickam and Bryan, 2019), rlang (Henry and Wickam, 2020), dplyr (Wickam *et al.*, 2021), tibble (Müller and Wickam, 2021), ggplot2 (Wickam, 2016), lattice (Sarkar, 2008), ROCR (Sing *et al.*, 2005), car (Fox and Weisberg, 2019), caret (Kuhn, 2008) and caTools (Tuszynski, 2021).

Results and discussion

Length-weight relationships

We found that L/DW and weights were positively correlated for all the species, namely *S. laticaudus*, *C. arabicum*, *C. griseum* and *B. walga* (Fig. 2). Assumptions of ANCOVA for equality were followed by all species except for *C. arabicum* wherein robust ANCOVA (non-parametric) was used instead. No significant difference was found between male and female coefficients at a 95% confidence level; therefore, the sexes for each species were pooled to obtain a single L-W relationship equation.

The length-weight analysis is presented in Table 1, representing sample size, range of lengths and weights, parameters *a* and *b*, 95% confidence limits of *b*, coefficient of determination (R^2) and the growth pattern. The *b* values obtained for the shark species – *S. laticaudus*, *C. griseum*, and *C. arabicum* were 2.97, 2.95 and 3.13, respectively ($b<3$, t-test, $P<0.05$), indicating isometric growth. In contrast, the *b* value for *B. walga* was found to be 3.21 ($b>3$, t-test, $P<0.05$), indicating positive allometric growth, *i.e.*, the rate of increase in weight in *B. walga* is faster than that of its disc width (Froese, 2006). The productivity of the immediate environment, such as food availability, tends to influence the directionality and deviation of *b* from 3 (Prasad, 2001; Famoofo and Abdul, 2020).

Several past studies discussing the L-W relationship for the study species were reviewed, *S. laticaudus* was observed to be the

Table 1. Length-weight relationships for the four commonly landed and commercially important elasmobranchs, Malvan, Maharashtra

Species	Sex	n	Total length or Disc width (cm)		Weight (g)		Parameters of L W model				Growth pattern
			Min	Max	Min	Max	a	b	95% CL b	R^2	
S. laticaudus	M	156	21.60	50.40	30.00	441.00	0.003820	2.97	2.91-3.04	0.96	Isometric
	F	158	16.80	58.70	13.00	815.00					
C. griseum	M	29	37.90	61.00	161.00	874.00	0.00398	2.95	2.74-3.17	0.93	Isometric
	F	24	32.00	62.60	100.00	862.00					
C. arabicum	M	41	43.60	65.20	18.00	854.00	0.001713	3.13	2.99-3.26	0.96	Isometric
	F	45	20.50	66.80	20.00	860.00					
B. walga	M	58	14.00	24.20	83.00	460.00	0.017489	3.21	3.03-3.39	0.92	Positive allometric
	F	53	15.30	28.3	116.00	818.00					

Table 2. Length-weight (L-W) relationships from the previous studies for *S. laticaudus, C. griseum, C. arabicum* and *B. walga*

Species	Reported study	Sex	Sample Size	$W=aL^b$	Geographic region
S. laticaudus	Devadoss (1989)	M	575	$0.000006795\ L^{2.8905}$	Calicut coast
		F	578	$0.000004904\ L^{2.9574}$	
S. laticaudus	Karim *et al.* (2017)	Pooled	1520	$0.3409\ L^{2.1137}$	Bay of Bengal, Bangladesh
S. laticaudus	Kulkarni *et al.* (1988)	Pooled	458	$0.0001885\ L^{3.07489}$	Dakshina Kannada Coast
S. laticaudus	Mathew and Devaraj (1997)	Both	1900	$0.001607\ L^{3.1904}$	Mumbai
S. laticaudus	Dash *et al.* (2019)	Both	-	$0.0047\ L^{2.91}$	Gujarat (Veraval, Mangrol, Porbandar, Okha)
S. laticaudus	Fofandi *et al.* (2013)	Both	439	$0.003688\ L^{2.9465}$	Saurashtra coast
C. griseum	Devadoss (1987)	Both	-	$0.00001453\ L^{2.7314}$	Calicut
C. arabicum	Raeisi *et al.* (2016)	M	30	$0.0014\ L^{3.390}$	Iranian waters of the Persian Gulf
		F	29	$0.0071\ L^{2.935}$	
B. walga	Naderi *et al.* (2013)	Pooled	134	$0.0234\ DW^{3.08}$	Persian Gulf, Iran

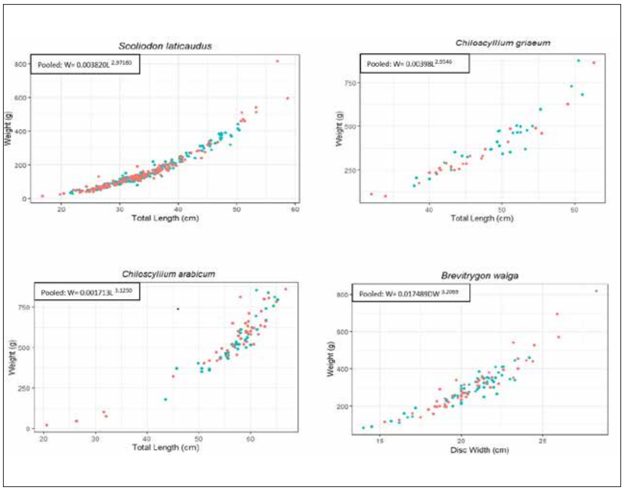

Fig. 2. Length-weight relationship for *S. laticaudus*, *C. griseum*, *C. arabicum* and disc width-weight relationship for *B. walga.* Males are represented by the blue points represent males and females by red points

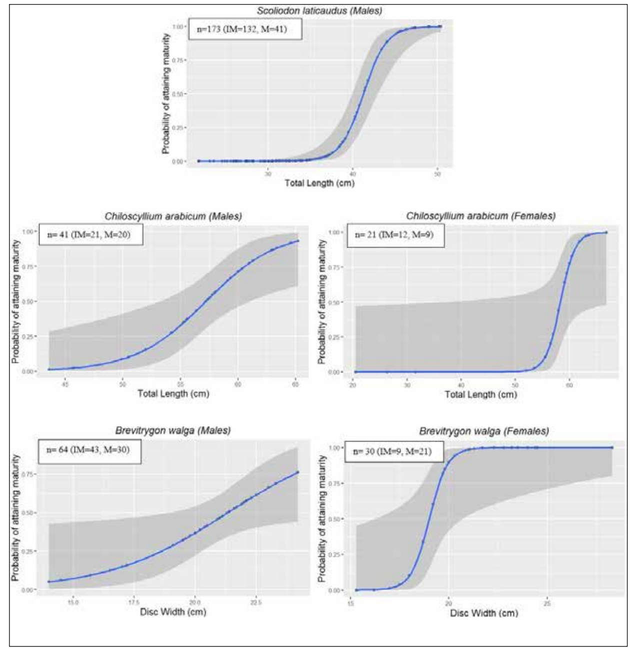

Fig. 3. Sigmoid curves fitted under logistic regression for maturity for the study species: *S. laticaudus* (males only), *C. arabicum,* and *B. walga.* (IM=immature, M=mature)

most extensively studied species for this relationship (Table 2). Similar to the present study, Kulkarni *et al.* (1988) and Fofandi *et al.* (2013) found no significant difference in the slopes of male and female regression equations for *S. laticaudus*; however, Devadoss (1979) and Dash *et al.* (2019) found otherwise. The differences in findings between the present and previous studies could be a result of factors such as environment (season, geographical region), biology (sex, population, fish condition), and artefact (number of sampled specimens, range of size) (Cruz-Aguero *et al.*, 2018).

Size at first maturity

The L_{50} for males of *S. laticaudus, C. arabicum* and *B. walga* were 41.30 cm, 57.15 cm and 21.36 cm, respectively (Fig. 3), whereas L_{50} for females of *C. arabicum* and *B. walga* were found to be 58.32 cm and 19.00 cm, respectively (Fig. 3). Gravid females of *S. laticaudus* (n=1) and *B. walga* (n=3) were recorded, but not for the other two species. Due to the low sample size of mature individuals, logistic regression modelling was not carried out for *S. laticaudus* females and both sexes of *C. griseum*. This study is the first to estimate L_{50} for *C. arabicum* (both sexes). Females of *C. arabicum* were found to attain maturity at a greater length than males. This is in line with several studies that suggest that females prioritise larger sizes before attaining sexual maturity to support larger litter sizes (Semba, 2018).

However, L_{50} for males of *B. walga* were found to be higher than that of females in contrast with previous studies (Last *et al*., 2016). Furthermore, we found *S. laticaudus* males to mature at a small L_{50} compared to studies conducted in other locations (Devadoss, 1979; Dash *et al*., 2019; Thomas *et al*., 2020). Our results for these species may have resulted from the small sample size or may be due to biases introduced by the sampling strategy. However, these may also represent regional variations in populations of *B. walga* and *S. laticaudus*. Maturity sizes for fish can be influenced by season, availability of food, gonad development, temperature, and quality of the water (Nandikeswari, 2016; Tesfahun, 2018). Furthermore, fishing pressure can also influence fish maturity, with populations maturing earlier as a response to exploitation (de Roos *et al*., 2006), as highlighted by Barnes *et al.* (2018) for elasmobranch species caught along the Porbandar coast in Gujarat. Given the ongoing exploitation, we emphasise the need for longer-term studies to understand the potential impacts of fisheries and other pressures on the life history characteristics of regional populations of threatened elasmobranchs.

Relevance to fisheries management

In the Arabian Sea region, at least half of the elasmobranch species are reported to be threatened and are at higher extinction risk (Jabado *et al*., 2018). Three of four species in the current study are categorised as *Near Threatened,* while *C. griseum* falls in the *Vulnerable* category (IUCN Red List of Threatened Species, 2021). This study adds to the baseline information on life-history traits for these threatened and commercially important elasmobranch species in the Malvan region. Understanding the life-history patterns of elasmobranchs is crucial to assessing the risks associated with the environmental and anthropogenic impacts on this group. Length-weight relationships are vital to understanding fish biology, ecology, and physiology (Alam *et al*., 2013). For example, Barnes *et al.* (2018) suggest that the life stages may differ in their susceptibility to fishing pressures and differences in aggregation sites. Monitoring variations in the size at the first maturity (L_{50}) of the elasmobranch landings will help track the health of populations at a particular fishing location. Besides, information on L_{50} can be utilised to estimate the minimum legal size (MLS), *i.e*., the minimum size at which a particular species can be retained and legally traded, therefore discouraging the exploitation of juveniles of sharks and rays (Mohamed *et al*., 2014; Sivadas *et al*., 2017); however, the effectiveness of recommending such fisheries management tools must be evaluated in the regional context.

Malvan, one of India's biodiversity-rich areas, was declared a Wildlife (Marine) Sanctuary in 1987, although it is yet to be notified (Gupta *et al*., 2020b). Due to increasing unsustainable practices such as high-speed trawling and LED fishing in Malvan, there is a significant reduction in the catch of all species, including elasmobranchs (Kizhakudan *et al*., 2015, Karnad *et al*., 2019, Gupta *et al*., 2020a). Localised biological studies provide more accurate assessments of resilience and the extent of exploitation of the current fisheries in this ecologically important region. Life history characteristics assessed in our study can contribute to population models for elasmobranchs in this region, which are vital for effective fisheries management. Our study also serves as a baseline for long-term research in Malvan, focusing on assessing and monitoring the life-history traits of the elasmobranchs for any variations as a potential consequence of over-exploitation.

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