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Biometry, length-weight relation and condition factor of Indian squid, *Uroteuthis duvaucelii* (Cephalopoda: Loliginidae), in the trawling grounds of the southeastern coast of India

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Original Article

Abstract

This study evaluated the length-weight relationship, linear morphometric traits, and condition factors (Kn) of 1,206 individuals of the Indian squid *Uroteuthis duvaucelii,* collected during a Fishery Survey of India exploratory fishery resources survey along the southeastern coast of India. Regression analysis revealed negative allometric growth between dorsal mantle length (DML) and total weight (TWt), with b values of 1.86 in males, 2.606 in females, and 2.003 for pooled sexes. For DML and mantle weight (MWt), the b values were 2.061 males, 2.41 females, and 2.102 pooled sexes. ANCOVA results indicated significant variations in sex-based differences ($P < 0.01$) in regression slopes. Linear morphometric relationships showed negative allometric growth for most of the morphometric characters, except DML-TL and MCA-MCF, which exhibited positive allometric growth. Sex wise analysis revealed that females grow faster at smaller sizes, while males attain larger maximum sizes. Condition factor (Kn) analysis revealed values ranging from 0.702 to 1.369 in males and 0.681 to 1.447 in females. The higher variability observed in females was likely due to energy allocation for reproduction. Peak Kn values were recorded at 51-70 mm DML for males and 71-90 mm DML for females, indicating optimal phases for somatic growth. In contrast, lower Kn values at larger sizes reflected the depletion of energy reserves due to reproductive activities.

Keywords: *Size variations, allometric, condition factor, Uroteuthis duvaucelii, Bay of Bengal*

Introduction

The Indian squid, *Uroteuthis duvaucelii,* is a commercially important species commonly caught in trawl catches along the east and west coasts of India (Meiyappan *et al.,* 2000). It is distributed across tropical and sub-tropical waters, extending eastwards from Mozambique to the South China Sea and the Philippines, inhabiting depths of 30-170 m (Jereb *et al.,* 2010). This species contributes approximately 1.18% of the total cephalopod production, which stands at 48.14 lakh tons along Indian waters (DoF, 2023).

The length-weight relationship allows for the estimation of one variable (*eg*. length) when the other (*eg*. weight) is known, and *vice versa*. The relative condition factor (Kn) is a measure used to assess the condition or well-being of a fish, particularly by evaluating deviations in weight at a given length asymptote (L_∞), as defined by the Von Bertalanffy growth equation. Additionally, morphometric and meristic studies often play a crucial role in identifying fish stocks, as they provide valuable insights into the structural and numerical characteristics of fish populations (Marr, 1955).

Several studies have explored various morphological parameters for species identification. For example, Pineda *et al.* (2002) used morphometric characters, such as the fin width/mantle length (FW/ML) ratio and gladius width/mantle length (GW/ML) ratio, to differentiate between two southwest Atlantic loliginid squids, *Loligo gahi* and *Loligo sanpaulensis*. Sin *et al.* (2009) analysed 23 morphometric characters to examine the morphological differentiation between two loliginid squids, *Uroteuthis (Photololigo)* chinensis and *Uroteuthis (Photololigo) edulis*, from Asia. Chembian and

Mathew (2014) identified two forms of the oceanic squid *Sthenoteuthis oualaniensis* (medium and dwarf forms) off the southwest coast of India. Himabindu *et al.* (2017) employed image processing techniques to classify squids based on morphometric measurements. Recently, Jin *et al.* (2022) utilized arm sucker ring tooth shape to identify cryptic species within the *Loliginidae* family, specifically *Uroteuthis chinensis* and *Uroteuthis edulis* in the Chinese seas, where both species are morphologically similar and commercially important for Indo-Pacific fisheries.

The morphometrics and length-weight relationship of the Indian squid, *U. duvaucelii,* from Indian waters were previously studied by various authors (Mishra *et al.,* 2012; Harishchandra *et al.,* 2016; Tehseen *et al.,* 2019; Chhandaprajnadarsini *et al.,* 2020). Building on these previous studies, this present research aims to validate existing findings by analysing newly collected data from an exploratory fishery resources survey conducted along the southeast coast of India (10°-16°N/ 80°-86°E). Despite the availability of some information on this resource, further studies on morphometry, length-weight relationship is critical for advancing fishery biology and stock assessment efforts. Consequently, this study focuses on the length-weight relationship, morphometric analysis and condition factor of *U. duvaucelii* in the Southeastern coastal waters of India.

Material and methods

Study area and sample collection

The present study was conducted as an exploratory fishery resources survey by the departmental survey vessel MFV Samudrika (OAL: 28.8 m), attached to the Chennai Base of Fishery Survey of India, Govt. of India, Ministry of Fisheries, Animal Husbandry and Dairying, Dept. of Fisheries. The survey was conducted from November 2018 to October 2020, covering the area between lat 10° to 16° N and long 80° to 82° E off the southeastern coast of India within a depth range of 30-50 m and 50-100 m (Fig. 1) (Table 1). During the study period, a total of 1,206 specimens of *U. duvaucelii* were examined, comprising 650 females and 556 males. Morphometric measurements were taken following the methodology outlined by Cohen (1976). The specimens were measured for the following parameters: dorsal mantle length (DML), fin length (FL), fin width (FW) (Fig. 2), arm lengths (Arm-1: AL1, Arm-2: AL2, Arm-3: AL3, Arm-4: AL4) (Fig. 3), tentacle length (TL), tentacular club length (TCL) (Fig. 4), and mantle circumferences-anterior (MCA) and at fin insertion (MCF). All measurements were recorded to the nearest 1.0 mm using a metric ruler. Additionally, total body weight (TWt) and mantle weight (MWt) were measured to the nearest 0.1 gram using an electronic weighing balance (Table 2).

Table 1. Coordinates for sampling station of *Uroteuthis (photololigo) duvaucelii* (d'Orbigny, 1835) in the Southeastern Coast of India

Latitude	Longitude
10°30.0'N	80°16.0'E
10°32.1'N	80°12.0'E
10°48.4'N	80°02.6'E
10°52.8'N	80°01.6'E
10°54.0'N	80°00.9'E
10°58.5'N	80°00.1'E
11°00.7'N	79°58.9'E
11°14.7'N	79°56.9'E
11°20.5'N	79°53.8'E
12°22.3'N	80°12.0'E
12°44.0'N	80°18.4'E
12°48.0'N	80°19.5'E
12°52.4'N	80°20.8'E
12°54.7'N	80°21.0'E
12°54.7'N	80°21.2'E
12°56.0'N	80°21.9'E
12°56.0'N	80°21.4'E
12°56.0'N	80°21.7'E
12°56.1'N	80°21.9'E
12°58.2'N	80°22.7'E
13°09.5'N	80°24.9'E
13°14.1'N	80°24.7'E
13°17.0'N	80°25.6'E
13°17.1'N	80°24.9'E
13°17.1'N	80°25.6'E
13°17.2'N	80°25.4'E
13°17.3'N	80°25.0'E
13°18.0'N	80°25.6'E
13°18.2'N	80°24.6'E
13°18.5'N	80°25.2'E
13°24.6'N	80°25.7'E
13°42.7'N	80°23.7'E
13°52.3'N	80°21.3'E
14°05.1'N	80°20.8'E
14°25.4'N	80°17.8'E
14°41.2'N	80°14.1'E
15°05.5'N	80°15.6'E
15°10.1'N	80°20.0'E
15°11.8'N	80°18.0'E
15°12.0'N	80°24.7'E
15°12.4'N	80°21.4'E
15°17.6'N	80°24.0'E

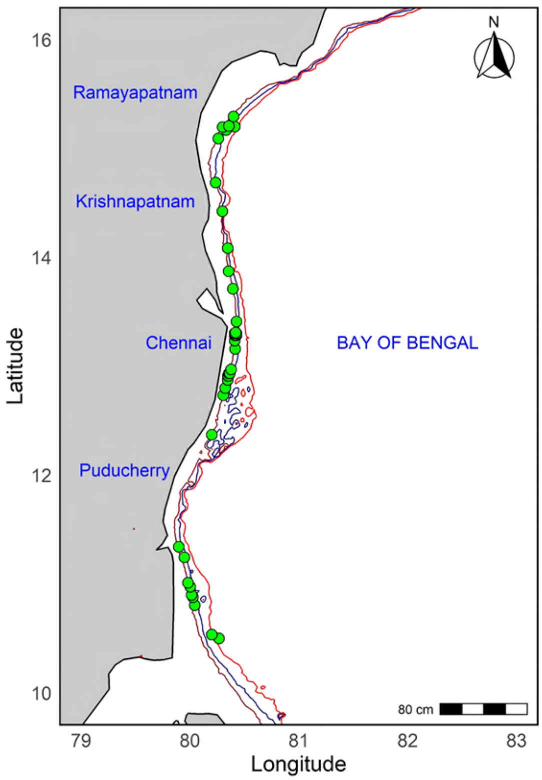


Fig. 1. Sampling stations showing the *U. duvaucelii* in the trawling grounds of the southeastern coast of India

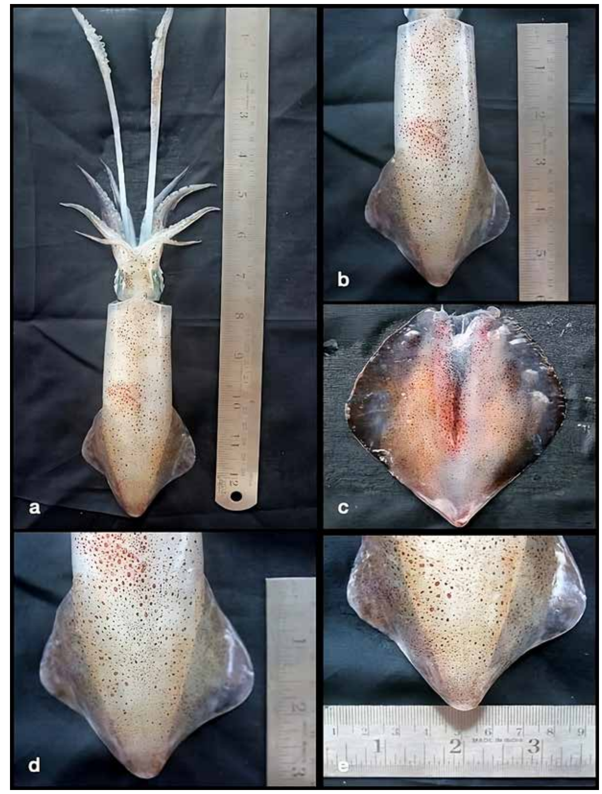


Fig. 2. Morphometric measurement of *U. duvaucelii,* a) dorsal view, b) measure of mantle length, c) Dorsal side of fin, d) measure of fin length, e) measure of fin width

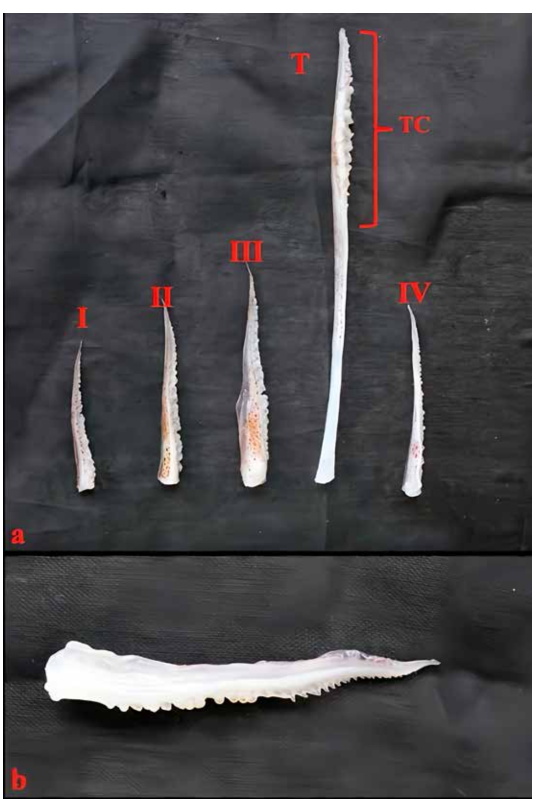


Fig. 3. a) Position of arms (I to IV) and tentacle (T) in head region. b) fourth left arm of male showing hectocotylized arm (TC- Tentacular club) of *U. duvaucelii*

Fig. 4. a) measure of tentacular length, b) measure of tentacular club length, c) position of different size sucker rings (A-anterior to P- posterior) of *U. duvaucelii*

Table 2. Morphometric measurements of *Uroteuthis (photololigo) duvaucelii* (d'Orbigny, 1835) in the Southeastern Coast of India

	Males				Females			
Parameters	n	Range	Mean	SD	n	Range	Mean	SD
Dorsal Mantle Length (mm)	556	49-222	102.6	29.2	650	40-184	100	24.1
Total Weight (g)	556	5.1-201	40	25.3	650	6-184	41	26.7
Mantle Weight (g)	414	2.8-135	23.1	16.7	483	3.1-94.4	22.7	13.2
Fin Width (mm)	318	24-119	54	15.8	330	21-99	54.5	14
Fin Length (mm)	330	18-123	50.8	16	343	23-86	48.9	12
Tentacle Length (mm)	314	75-247	148	27	339	62-227	152.7	30
Tentacle club Length (mm)	314	21-65	39	7.9	339	18-75	42.9	12.6
Arm Length-I (mm)	324	19-77	41.6	10	332	16-70	37	9.7
Arm Length-II (mm)	325	21-89	49	11	337	22-85	46	11
Arm Length-III (mm)	324	28-93	55	12	337	26-99	54	13
Arm Length-IV (mm)	329	22-80	48	10.5	341	18-86	47.6	11.4
Mantle C A (mm)	330	3-102	70	9.6	342	43-100	70.4	11
Mantle C F (mm)	330	36-112	68.6	10.2	343	29-102	69.5	11

*n- Numbers, SD- standard deviation

Nonlinear relationship

The length-weight relationship of *U. duvaucelii* was analyzed using the nonlinear model described by Le Cren (1951) and the least squares method. The relationship is expressed as:

$$\text{Log } W = \log a + b * \text{Log } L \text{ (or) } W = a L^b$$

where W represents the weight (in grams), L is the total length (in millimetres), and a (the intercept) and b (the slope) are the fitted constants (Sujatha *et al.,* 2014). According to this model, if the value of b is greater than 3, the growth is considered to be positive allometric growth, meaning the species has increased in weight at a rate faster than its dorsal mantle length (DML). Conversely, if b=3, the species exhibits isometric growth, where weight and length increase proportionally. If b<3, the species shows negative allometric growth, where weight increases at a slower rate compared to the DML (Zeidberg, 2004; Chembian, 2013).

Linear morphometrics

The linear relationships between the variables DML, FL, FW, AL1, AL2, AL3, AL4, TL, TCL, MCA, and MCF were examined for both sexes. This analysis utilised the simple linear regression model as proposed by Ricker (1973).

$$y = a + b X$$

In the context of the regression analysis, where *x* and *y* represent two variables, *b* denotes the regression coefficient, and *a* is a constant specific to the dimensions under investigation (Simpson *et al.,* 1960). The regression coefficient *b* reflects the ratio of growth rates between the two variables. When b = 1, it signifies isometric growth, where both variables increase at the same rate. A value of b > 1 indicates a positively allometric relationship, suggesting that the variable *y* grows at a faster rate than *x*. Conversely, if *b < 1*, the relationship is negatively allometric, meaning that *y* grows at a slower rate than *x* (Gould, 1966). The P values of the b for the linear and nonlinear relationship of both sexes were obtained by using the Minitab-14 software, and the confidence intervals (CIs) were obtained from ANOVA and ANCOVA using MS Excel 2019.

Relative condition factor

The relative condition factor (Kn) was calculated to assess the health and condition of Indian squid, *Uroteuthis (Photololigo) duvaucelii* from south east coast of India, following the methodology of Le Cren (1951).

$$Kn = W/aL^b$$

where, Kn denotes the relative condition factor, W is the observed weight of the squid (grams), L is the total length (centimetres), and a & b are constants derived from the length-weight relationship ($W = aL^b$) established through regression analysis of the sampled population.

Statistical analysis

Sampling stations and other graphical representations were mapped using R statistical software (R Core Team, 2015).

Results and discussion

Length-weight relationship

The squid size ranged from 49-222 mm DML for males (mean 102.6 mm) and 5.1-201 gm weight (mean 40 gm). In females, the size varies from 40-184 mm DML (mean 100 mm) and 6 to 184 gm weight (mean 41 gm). Male squids were found to be larger than females. The regression equations describing the length-weight relationships between dorsal mantle length (DML) and total weight (TWt) of the squid were calculated for males, females, and pooled sexes (Fig. 5). The exponential formula for this relationship, $W = aL^b$, can be expressed as follows:

Male W = $0.00692DML^{1.86}$
Female W = $0.0002DML^{2.606}$
Pooled sexes = $0.00376DML^{2.003}$

These findings illustrate that females grow faster initially, but males maintain growth for a longer period, resulting in larger sizes. In all cases, the growth pattern is classified as negative allometric (*ie.*, b < 3), with females demonstrating a slightly higher growth rate than males, likely due to gonadal development and the associated weight gain during maturation. ANOVA revealed that 95% confidence intervals for the regression coefficient (b). For pooled sexes, the lower and upper limits were 1.9 and 2.1, respectively; for males, they were 1.8 and 1.9, and for females, they were 2.5 and 2.7 (Table 3). ANCOVA showed a significant difference (*P < 0.01*) between the regression curves of DML and TWt for both males and females.

Recent studies provide further support for the findings of the present study. Chandaprajnadarsini *et al.* (2020) reported similar regression coefficients for *U. duvaucelii*, with values of 1.92 for males, 2.54 for females, and 2.19 for pooled sexes from the southwestern Bay of Bengal. Similarly, Tehseen *et al.* (2019) observed *b* values of 2.11 for males and 2.42 for females in the coastal waters of Gujarat. Harishchandra *et al.* (2016) found *b* values of 2.1830 for males, 2.1375 for females, and 2.1808 for pooled sexes along the Mangalore coast. These consistent findings reinforce the concept of negative allometric growth, with males exhibiting a lower b value compared to females. Additionally, Islam *et al.* (2015) reported a regression coefficient of (b = 2.89) in the southern Gulf of Thailand, while Sabrah *et al.* (2015) found b = 1.958

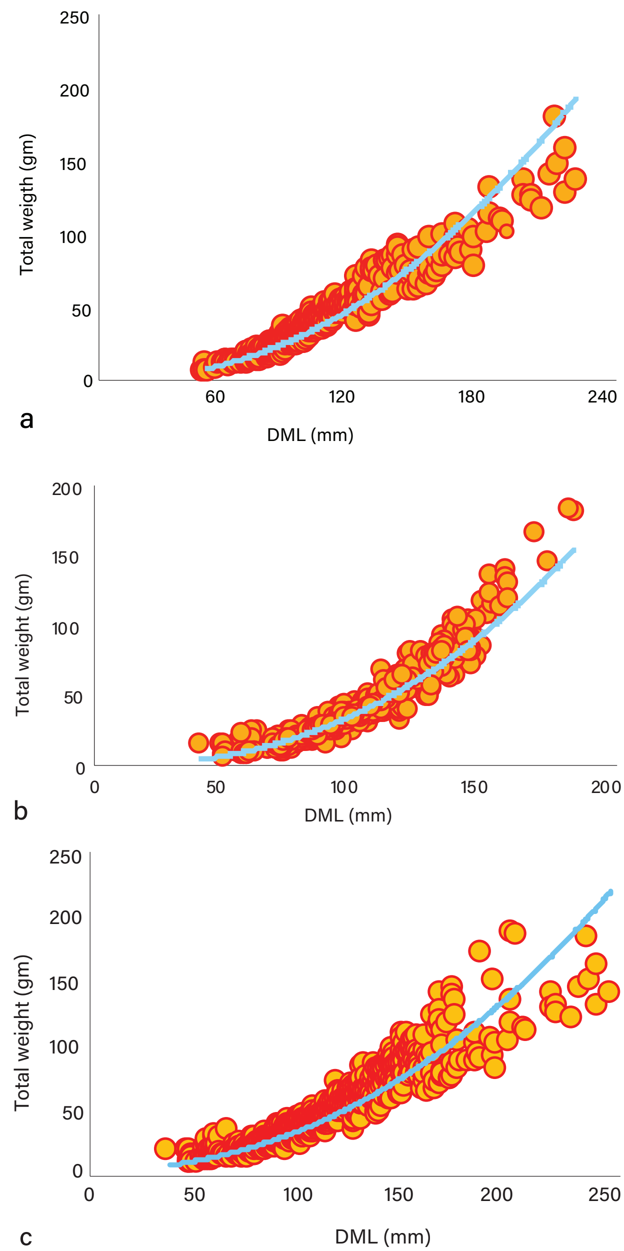


Fig. 5. The length-weight relationship of *U. duvaucelii.* a) male, b) female, c) pooled sexes in the southeastern coast of India

Table 3. Sex-wise length-weight relationship of *Uroteuthis (photololigo) duvaucelii* (d'Orbigny, 1835) in the Southeastern Coast of India

Parameters	n	R^2	a L^b	CI (b)	Growth	P (b)
Male	556	0.93	$0.00692x^{1.86}$	(1.8,1.9)	- Allometric	0.000
Female	650	0.95	$0.00023x^{2.606}$	(2.5,2.7)	- Allometric	0.000
Pooled sex	1206	0.88	$0.00376x^{2.003}$	(1.9,2.1)	- Allometric	0.000

* R^2 – Correlation coefficient. aL^b–equation, CI (b) – Confidence interval of the co efficient b (95%), b coefficient is highly significant at o level; P(b)- Hypothesis testing for slope parameter equal to 3 using the p-value approach

for males, 2.416 for females, and 2.02 for pooled sexes in the Northwest Red Sea. The present study results align with these findings, demonstrating negative allometric growth patterns with *b* values less than 3. This indicates that the length-to-weight ratio of *U. duvaucelii* is nearly proportional, further supporting the observed trends.

Linear morphometric relation in pooled sexes

Linear regression for the variables such as DML-FL, DML-FW, DML-TL, DML-TCL, DML-AL1, DML-AL2, DML-AL3, DML-AL4, DML-MCA, DML-MCF, FL-FW, TL-TCL, MCA-MCF and TWt-MWt was studied for pooled sexes (Table 4). The b value for a linear relationship of pooled sexes ranged from 0.2433 to 1.0406, with the correlation coefficient (R^2) ranging from 0.53 to 0.97. From the observation, R^2 of DML-FL (0.97), TWt-MWt (0.95) and MCA-MCF (0.94) show a high degree of correlation compared to all other parameters, and the lowest one was TL-TCL (b=0.2433) with R^2 value 0.53. Overall, most parameters exhibited negative allometric growth ($b < 1$), except for DML–TL (b = 1.0266) and MCA-MCF (b = 1.0406), which showed isometric growth. The ANOVA results revealed the 95% confidence interval (CI) for the coefficient b. For DML-TL, the lower limit of the CI was 0.96 (negative), and the upper limit was 1.08 (positive), while for MCA-MCF, the CI ranged from 1.02 (isometric) to 1.05 (positive). These findings suggest that the relationship of both DML-TL and MCA-MCF falls within the range of positive growth (b>1). Similarly, the FL- FW and MCA-MCF variables exhibit isometric growth (b=1) when considering the upper 95% confidence limit of *b*. This indicates that the relationship between these variables is directly proportional, meaning that as one variable increases, the other variable increases at a consistent rate.

Earlier, Karnik and Chakraborty (2001) observed a similar growth pattern for DML-TL (1.1270) with an R^2 value of 0.8698 in *L. duvauceli* from Mumbai waters, on the west coast of India. This indicates that the growth relationship between DML and TL in *U. duvaucelii* was highly proportional. Similarly, the linear relationship of DML-TL (1.0266) indicates isometric growth, while DML-TCL (0.2739) shows negative allometric growth. A similar study was carried out by Chembian and Mathew (2014) on *Sthenoteuthis oualaniensis,* analysing DML- TL, DML-TCL for both dwarf and medium forms. Their results showed that TL shows positive allometric growth in both forms, whereas TCL shows negative allometric growth relative to DML. They concluded the divergence occurs during squid growth, supporting the findings of the present study. Correspondingly, the trend line for the growth of all variables gradually increases; as the X axis increases, the Y axis also increases in a positive linear manner. Additionally, the P value of b for all parameters indicates high significance. The main reason for studying the morphological measurements of the species is that it gives the relevant information on the growth pattern as well as the mortality of the population. Earlier, Kashiwada and Recksiek (1978) studied morphological indicators of *Loligo opalescens* to know the population structure. So, the growth of morphometric variables directly gives the critical (environmental or physical) condition of the species.

Table 4. Morphometric relationship of *Uroteuthis duvaucelii* of pooled sexes in the Southeastern Coast of India

Parameters	n	R^2	a+ b x	CI (b)	Growth	P (b)
DML-FL	673	0.97	- 11.959 + 0.6112x	(0.60, 0.61)	-Allometric	0.000
DML- FW	648	0.88	- 7.3604 + 0.6087x	(0.59, 0.62)	-Allometric	0.000
DML-TL	653	0.64	47.308 + 1.0266x	(0.96, 1.08)	+Allometric	0.000
DML-TCL	653	0.64	13.526 + 0.2739x	(0.24, 0.29)	-Allometric	0.000
DML-AL1	656	0.58	4.7762+ 0.342x	(0.31, 0.36)	-Allometric	0.000
DML-AL2	662	0.62	7.5695 + 0.3981x	(0.37, 0.42)	-Allometric	0.000
DML-AL3	661	0.63	10.51 + 0.4374x	(0.41, 0.46)	-Allometric	0.000
DML-AL4	670	0.62	10.035 + 0.3758x	(0.35, 0.39)	-Allometric	0.000
DML-MCA	672	0.79	31.325 + 0.3865x	(0.37, 0.40)	-Allometric	0.000
DML-MCF	673	0.81	26.804 + 0.4183x	(0.40, 0.43)	-Allometric	0.000
FL- FW	648	0.89	5.1996 + 0.9828x	(0.95, 1.0)	-Allometric	0.000
TL-TCL	653	0.53	4.4452+ 0.2433x	(0.22, 0.26)	-Allometric	0.000
MCA-MCF	672	0.94	-4.1759+ 1.0406x	(1.02, 1.05)	+Allometric	0.000
TWt-MWt	897	0.95	0.182+0.52x	(0.51, 0.52)	-Allometric	0.000

* R^2 – Correlation coefficient. a+bx – equation, CI (b) – Confidence interval of the coefficient b (95%), b coefficient is highly significant; P (b)- Hypothesis testing for slope parameter equal to 1 using the p-value approach

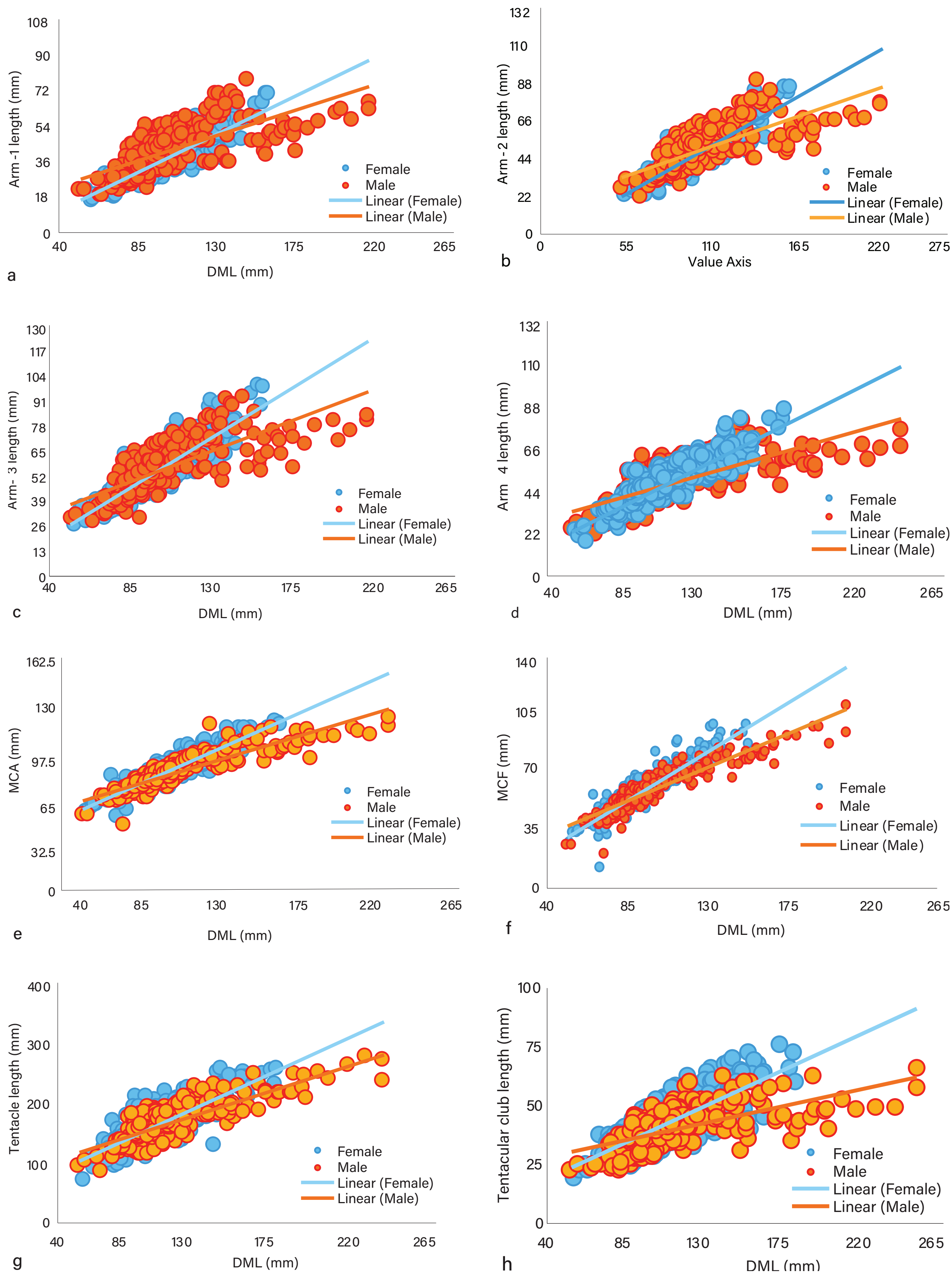
Sexual dimorphism

The linear relationship of variables for males and females was observed to identify any differences in the development of biometric characteristics for the variables (Table 5). In females, the b value ranged from 0.2724 to 1.2549 with R^2 ranged from 57 to 97 and for males, the b value range was 0.191 to 1.0343 with R^2 ranged from 37 to 98 (Fig. 6). Among these parameters, the b value of DML-TL and FL-FW of females shows positive allometric growth (b=1.2549 and 1.1211); the rest of the variables in females show a negative allometric growth pattern. Previously, Rashad *et al.* (2010) observed a similar value for DML-TL of females, b=1.489, with R^2 0.47. Likewise, Peter and Chembian (2022) in *Loliolus (Nippono loligo)* observed the relationship of FL-FW in females showing positive allometric growth. It indicates that the growth of DML-TL and FL-FW was directly proportional to each other. Also, in the current study, the male variable MCA-MCF shows isometric allometric growth (b=1.0343) with R^2 0.95, and the rest of the variables in males show negative allometric growth. So, the relationship of MCA-MCF growth in males is proportional to one another. From the result of ANCOVA, all the variables show highly significant differences between males and females, except MCA-MCF, which did not show a statistically significant difference. Though the development of the ovary and oviduct during the maturation process in females, the circumference of the mantle cavity shows a slight variation from males in the higher size range, but it's not a statistically highly significant difference (Fig. 6).

Table 5. The linear relationship between DML and morphometric measurements of male and female of *U. duvaucelii* (d'Orbigny, 1835) in the Southeastern Coast of India

Parameters	Sex	n	R^2	a+ b x	CI (b)	Growth	P (b)
DML-AL1	F	332	0.77	-5.4444+0.4281x	(0.40, 0.45)	-Allometric	0.000
	M	324	0.48	12.576+0.2827x	(0.25, 0.31)	-Allometric	0.000
DML-AL2	F	337	0.78	- 5.2001+0.5204x	(0.49, 0.54)	-Allometric	0.000
	M	325	0.52	16.036+0.3224x	(0.28, 0.35)	-Allometric	0.000
DML-AL3	F	337	0.78	-3.5824+0.5802x	(0.54, 0.61)	-Allometric	0.000
	M	324	0.54	19.205+0.352x	(0.31, 0.38)	-Allometric	0.000
DML-AL4	F	341	0.79	- 3.3452+0.5145x	(0.48, 0.54)	-Allometric	0.000
	M	329	0.54	17.832+0.2962x	(0.26, 0.32)	-Allometric	0.000
DML-MCA	F	342	0.87	21.814+0.492x	(0.47, 0.51)	-Allometric	0.000
	M	330	0.79	36.244+0.3291x	(0.31,0.34)	-Allometric	0.000
DML-MCF	F	343	0.86	17.252+0.5266x	(0.50, 0.54)	-Allometric	0.000
	M	330	0.84	31.496+0.3605x	(0.34, 0.37)	-Allometric	0.000
DML-TL	F	339	0.67	27.882+1.2549x	(1.16, 1.34)	+ Allometric	0.000
	M	314	0.68	57.983+0.8871x	(0.82, 0.95)	-Allometric	0.000
DML-TCL	F	339	0.57	1.9547+0.409x	(0.37, 0.44)	-Allometric	0.000
	M	314	0.37	19.959+0.191x	(0.16, 0.21)	-Allometric	0.000
DML-FL	F	343	0.96	10.696 +0.6001x	(0.58, 0.61)	-Allometric	0.000
	M	330	0.98	-12.892+0.6187x	(0.60, 0.62)	-Allometric	0.000
DML- FW	F	330	0.89	- 13.44+0.6812x	(0.65, 0.70)	-Allometric	0.000
	M	318	0.90	-4.8515+0.5728x	(0.55, 0.59)	-Allometric	0.000
FL-FW	F	330	0.90	-0.6079+1.1211x	(1.08, 1.15)	+Allometric	0.000
	M	318	0.90	7.7324+0.913x	(0.87, 0.94)	-Allometric	0.000
TL-TCL	F	338	0.61	0.48+0.2724x	(0.24, 0.29)	-Allometric	0.000
	M	314	0.53	7.6366+0.2142x	(0.19, 0.23)	-Allometric	0.000
MCA-MCF	F	342	0.87	1.05+0.95x	(0.93, 0. 97)	-Allometric	0.000
	M	330	0.95	-3.9262+1.0343x	(1.00, 1.05)	+Allometric	0.000
TWt-MWt	F	483	0.97	1.42+0.49x	(0.44, 0.46)	-Allometric	0.000
	M	414	0.97	-2.15+0.6059x	(0.59, 0.61)	-Allometric	0.000

* R^2 – Correlation coefficient. a+bx – equation, CI (b) – Confidence interval of the co efficient b (95%), b coefficient is highly significant; P (b)- Hypothesis testing for slope parameter equal to 1 using the p-value approach


a
Arm -1 length (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)
b
Arm - 2 length (mm)
Value Axis
Female
Male
Linear (Female)
Linear (Male)
c
Arm- 3 length (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)
d
Arm 4 length (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)
e
MCA (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)
f
MCF (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)
g
Tentacle length (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)
h
Tentacular club length (mm)
DML (mm)
Female
Male
Linear (Female)
Linear (Male)

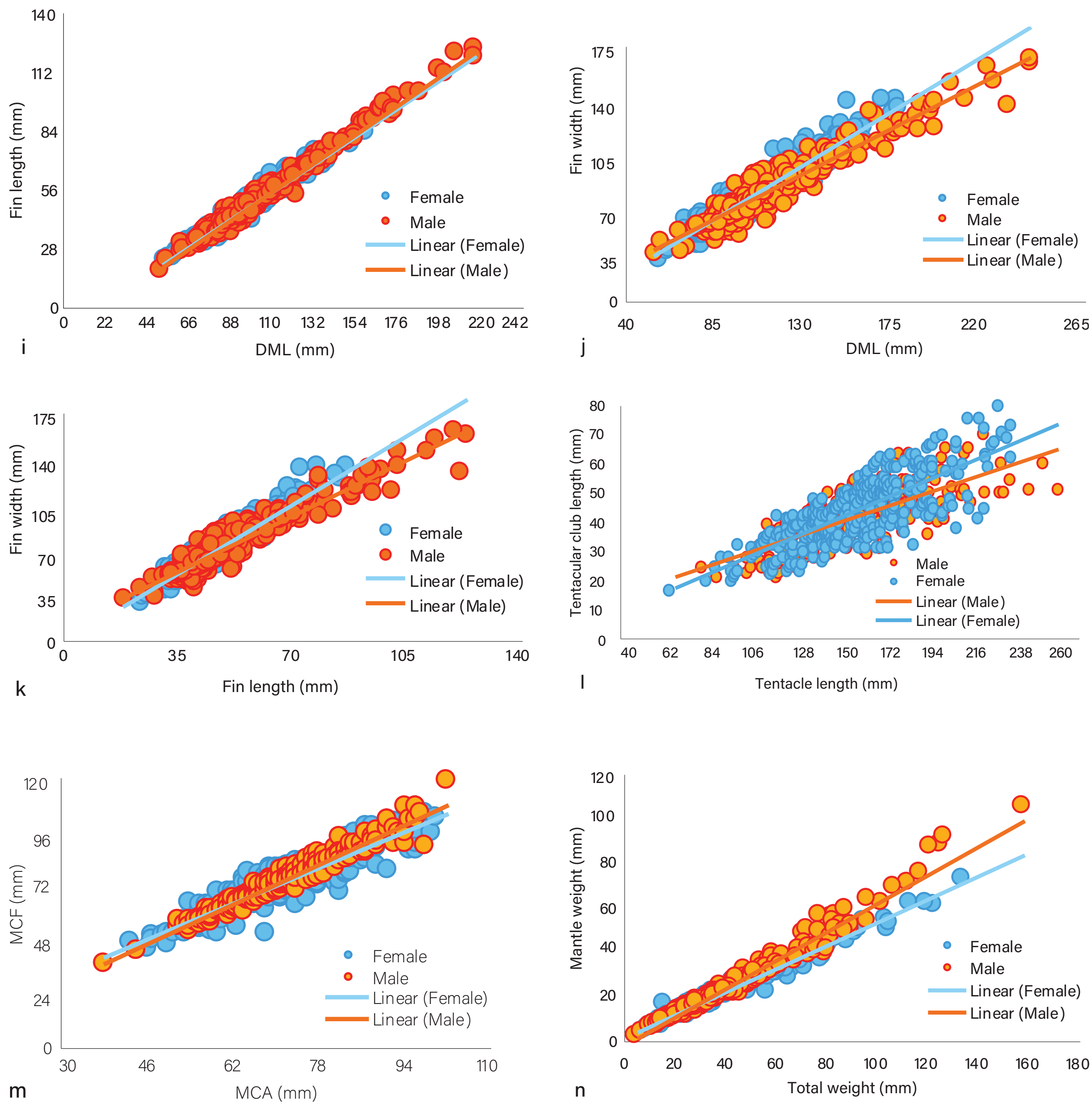


Fig. 6. Sexual dimorphic relationship of *Uroteuthis (Photololigo) duvaucelii* (d'Orbigny, 1835) in the east coast of India (a) DML-AL1, (b) DML-AL2, (c) DML-AL3, (d) DML-AL4, (e) DML-MCA, (f) DML-MCF, (g) DML-TL, (h) DML-TCL, (i) DML-FL, (j) DML-FW, (k) DML-FL vs FW, (l) TL-TCL, (m) MCA-MCF, (n) TWt-MWt

Sex-wise length frequency

The percentage of frequency of species (both male and female) studied during the study period was plotted based on the DML ranged from 41mm to 250 mm range with 30 mm class interval (Fig. 7). From the observation, the occurrence of females was high in percentage up to the DML range of 160 mm and the maximum size observed in females was 184 mm. As the DML increases above 160 mm, males dominated the percentage frequency in availability, and it reaches 100% in the DML range of 191 mm to 250 mm. It indicates that males grow larger than females. A similar observation was made by Rashad *et al.* (2010) in *U. duvaucelii* from Karachi, in that the maximum DML of males was 217 mm and of females 192 mm. So, the result of the present study supports the convincing statement of Karnik and Chakraborty (2001) and Rashad *et al.* (2010), that females grow faster than males but males attain a greater size.

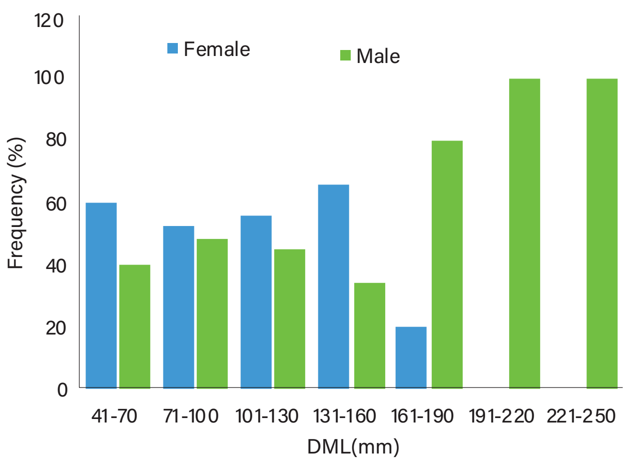


Fig. 7. Sex-wise length frequency chart of the females and males

Relative condition factor

The condition factor (Kn), reflecting the relative health and well-being of individuals, showed notable variations between sexes and size classes. In males, Kn ranged from 0.702 to 1.369, while in females, it ranged from 0.681 to 1.447, with a combined average of 1.007. Females exhibited higher variability in Kn, likely due to energy allocation for gonadal development and spawning, while lower Kn values in males could be linked to post-spawning energy depletion. These findings align with prior studies emphasising sexual dimorphism in cephalopods due to differences in energy demands for growth, reproduction, and metabolism (Moltschaniwskyj and Semmens, 2000; Rosa *et al.,* 2005; Pecl and Jackson, 2008). Furthermore, analysis of Kn values across dorsal mantle length (DML) intervals revealed distinct trends between sexes, with males showing an average Kn of 1.009 for a DML range of 51-220 mm and females averaging 1.010 for a DML range of 51-190 mm. Peak Kn values were recorded at 51–70 mm DML in males and 71–90 mm DML in females, indicative of optimal somatic growth phases (Fig. 8). Lower values at larger DML ranges (Emam *et al.,* 2014) were likely related to energy depletion due to reproduction or senescence, highlighting the role of size-related energy dynamics in life-history strategies, consistent with findings in other Cephalopods (Moltschaniwskyj and Semmens, 2000; Rosa *et al.,* 2005). Additionally, monthly fluctuations in Kn values from November 2018 to October 2020 (excluding March to May 2020) showed that male Kn values ranged from 0.996 to 1.120, averaging 1.043, while females ranged from 1.015 to 1.217, averaging 1.082. The highest Kn values were recorded in December 2018 for males and February 2019 for females, suggesting optimal energy reserves during favorable environmental conditions or reproductive phases (Fig. 9). In contrast, the lowest Kn values, recorded in June 2020 for males and September 2020 for females, likely reflected post-spawning depletion or adverse ecological factors. Environmental factors such as temperature, salinity, and prey availability significantly influence the relative condition factor (Kn) in squids, with higher Kn values often linked to optimal conditions and energy-rich diets. Conversely, exposure to stressors like pollution or prey scarcity can reduce Kn, reflecting compromised physiological status and feeding efficiency (Pecl and Jackson, 2008; Purwiyanto *et al.,* 2020). Further, the influence of reproductive energy allocation and environmental conditions on cephalopod physiological health, offering insights into life-history strategies crucial for sustainable fisheries management (Purwiyanto *et al.,* 2020). Earlier, Le Cren (1951) stated that a Kn value above 1 indicates a good condition of well-being and a favourable feeding condition. Later, Bennet (1970) suggested that a Kn value of 0.56 was the critical point, with values above this indicating a good condition of well-being. In the current study, both males and females were combined and plotted (Fig. 10), and it was observed that all individuals had values above the critical threshold. So, the growing of males and

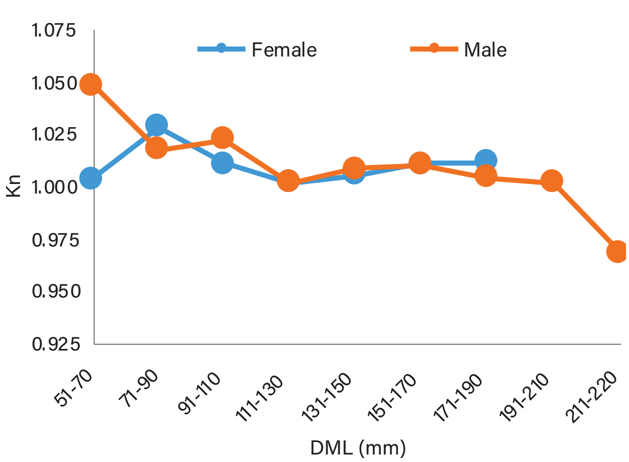


Fig. 8. DML-wise relative condition factor (Kn) plot of the females and males

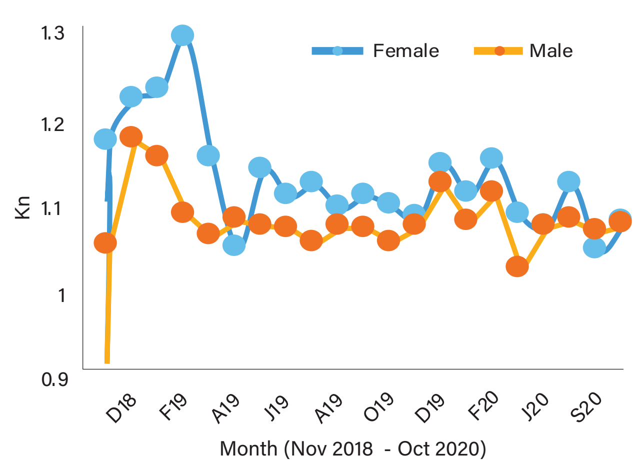


Fig. 9. Month-wise relative condition factor (Kn) plot of the females and males

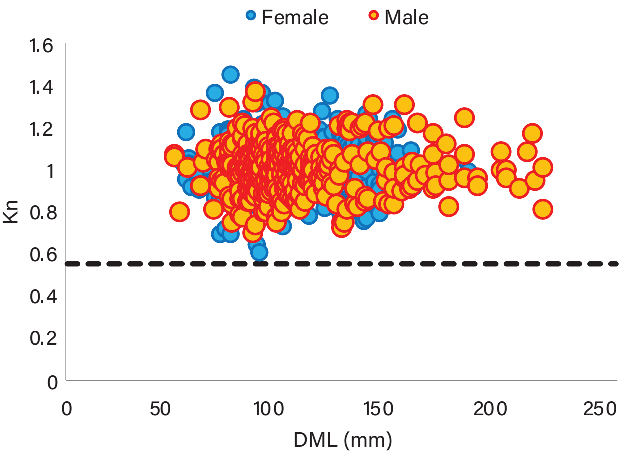


Fig. 10. Variation in relative condition factor (Kn) of *U. duvaucelii* in south east coast of India is higher than the critical point value (Kn=0.56)

females of *U. duvaucelii* from the southeast coast of India were in good condition.

Conclusion

The present study provides comprehensive insights into the length-weight relationships, linear morphometric relationships, sexual dimorphism, and condition factor of *U. duvaucelii* from the southeastern coast of India. The results indicated that negative allometric growth patterns occurred across sexes, with females exhibiting slightly higher growth rates due to gonadal development. Morphometric analyses highlight proportional growth in key body parameters, with noticeable sexual dimorphism in tentacular club and fin length. The condition factor underscores the role of reproductive energy allocation and environmental conditions in shaping squids' health. These findings are critical for understanding the biological characteristics of *U. duvaucelii* and for developing sustainable fisheries management strategies.

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Author contributions

Conceptualization: JP; Methodology: JP; Data curation: JP; Formal analysis: JP; Writing-Review and Editing: JC, KS; Supervision: JC

Data availability

The data are available and can be requested from the corresponding author.

Conflict of interest

The authors declare that they have no conflict of financial or non-financial interests that could have influenced the outcome or interpretation of the results.

Ethical statement

No ethical approval is required as the study does not include activities that require ethical approval or involve protected organisms/ human subjects/ collection of sensitive samples/ protected environments

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