

Research Article

First report on analysis of length-weight relationship and condition factors of *Ganjampenaeopsis uncta* (Alcock, 1905) from the Balasore coast, India

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Abstract

Length-weight relationship and condition factors are fundamental to stock assessment and growth analysis in fisheries science. However such biological data remain undocumented for *Ganjampenaeopsis uncta* from Indian waters. The present study aimed to establish the length-weight relationship and condition factors of *G. uncta* collected from Balasore coast, Odisha, India. A total of 224 fresh specimens were collected monthwise from commercial trawlers at Bhabalpur fishing harbour between July 2024 and February 2025. Ten morphometric character measured and statistical analyses were conducted to determine sexual variation, growth structure and condition factors. Significant differences ($p < 0.01$) were observed between males and females morphometric traits, with high effect sizes (Cliff's delta: 0.94–1.00), indicating minimal overlap between sexes. Females exhibited higher mean morphometric values with highest coefficient of variance (33.08%). The highest growth rate was observed in carapace length, followed by the abdominal length and carapace height. Total length-weight relationships were significant in both sexes ($p < 0.05$). Females displayed positive allometric growth, while males showed growth below the isometric expectation due to restricted size range. The carapace length-weight relationship was highly significant for both sexes ($p < 0.001$), with negative allometry. Most morphometric characters were significantly correlated. Condition factors was higher in females, while relative condition factors exhibit no significant sex differences. This research provide a baseline information on the length-weight relationship of *G. uncta* along the Balasore coast. These findings are crucial for conservation aspects, stock assessments, and formulation of minimum catch size regulation in the Indian fisheries .

Keywords: Allometric, Condition factors, *Ganjampenaeopsis uncta*, Length-weight

INTRODUCTION

Crustaceans play a vital role in the aquatic ecosystem. Marine crustaceans, especially shrimp, are highly prized in global fisheries due to their high nutritional value, high energy content, and low fat content (Behringer and Duermit-Moreau, 2021). Shallow water shrimps are widely distributed along tropical and sub-

tropical coasts (Munga *et al.*, 2013) and belong to the families Penaeidae, Sicyoniidae, and Solenoceridae within the suborder Dendobranchiata, as well as Palaeomonidae, Alpheidae, Hippolytidae, Atyidae, and Crangonidae within the suborder Caridea. Parapenaeopsis species (Bauer, 2023a; Kannupandi, Soundarapandian, and Rajendran, 2003), which are part of Penaeidae, comprise 13 genera and form a dominant group

of shrimps in artisanal and small-scale trawl fisheries along the Indian coast (Bauer, 2023b; Rajakumaran *et al.*, 2014). A total of 28 species of the genus *Parapenaeopsis* have been identified globally (Borichangar *et al.*, 2024a), with nine species documented in Indian waters (Borichangar *et al.*, 2024b). Of these, six species occur specifically in Odisha (Pati and Mohapatra, 2018; Valarmathi, 2024). *Ganjampenaeopsis uncta* (Alcock, 1905; also known as *Parapenaeopsis uncta* Hall, 1961) belongs to the family Penaeidae (Holthuis, 1980). It inhabits shallow tropical and subtropical waters across the Indo-west Pacific region, at depths of 10-60 meters, and prefers muddy or sandy bottoms (Chanda, 2017). *G. uncta* is harvested as part of small-scale coastal shrimp fisheries through bottom trawling along India's east and west coasts. Assessing small-scale fishery resources provides crucial biological information for sustainable management along India's east coast. Morphometric analysis in aquatic animals is essential for fisheries and aquaculture, providing valuable data for species identification and taxonomic classification, and contributing to evolutionary research and the understanding of species distribution patterns (Lishchenko and Jones, 2021). Morphometrics also help distinguish between different populations within a species and assess the health, growth, population structure, reproductive strategies, condition indices, and life history traits of various species (Ahirwal *et al.*, 2023). The morphological diversity among these species presents challenges for phylogenetic studies, particularly within Penaeidae, owing to limited fossil records and paleogeographic evidence (Flegel, 2007; Lee and Palci, 2015; Mahbub Alam and Pálsson, 2018). So, the length-weight relationship (LWR)—a mathematical formula predicting the average weight of a shrimp based on its length—is vital for estimating population sizes under different environmental conditions (Beneditto *et al.*, 2022; Dash *et al.*, 2023). In biological evolution, species size plays a crucial role, offering insights into ecological and physiological factors that influence population sustainability and inform the development of effective management strategies tailored to specific environmental needs (Kalinkat *et al.*, 2015). Understanding species size is crucial for assessing population health and promoting biodiversity and ecosystem resilience. Few studies have explored the morphometric features, biology, and population dynamics of species within the *Parapenaeopsis* genus, such as *Parapenaeopsis hardwickii* (Borichangar *et al.*, 2024a), *P. coromandelica* (Borichangar *et al.*, 2024b), and *P. stylifera* (Pillai *et al.*, 2021; Rajakumaran *et al.*, 2014). Among these, *G. uncta* remains particularly under-researched, with no biological data available globally. To address this research gap, this study presents the first in-depth exploration of the morphometric features, Fulton's condition factor (K), and simple condition index

(Kn) of *G. uncta* from Bhabalpur, located along the scenic Balasore coast of India. The study closely examines key morphometric traits across a range of sizes and shapes. Additionally, it explores the relationship between length-weight and length-length measurements, providing valuable insights into growth patterns. The K and Kn values will also be analysed to evaluate the health and vitality of *G. uncta* in its natural environment. Through this work, we aim to contribute valuable knowledge that can inform conservation efforts and enhance our understanding of this elusive species.

MATERIALS AND METHODS

The *G. uncta* (Fig. 1) specimens were collected by daily operating commercial trawlers (mesh size 38 mm) in waters ranging from 10 to 50 meters in depth at Bhabalpur (21°30'38.87"N and 87°7'5.02"E), Odisha, situated on the eastern coast of India along the eastern periphery of the Bay of Bengal (Fig.2). This region is renowned for its rich biodiversity and small-scale marine fisheries, which contribute significantly to marine biodiversity and serve as an active centre for fishing activities. The specimen collection period spanned from July 2024 to February 2025 (Table 1) (Fig. 3) through random sampling methods and transportation in a thermocouple with ice to the P. G. Department of Zoology laboratory at Fakir Mohan University, Balasore, Odisha, India, for detailed analysis. Specimens were systematically categorised into male and female groups based on external reproductive features, such as the petasma in males and the thelycum in females (Fransozo *et al.*, 2011). The present study assessed several morphometric characteristics of the species, including Total weight (TW), Total length (TL), Rostrum length (RL), Carapace length and height (CL and CH), Second segment height (SSH), Sixth segment length (SSL), Telson length and width (TEL and TEW) and Abdominal length (AL). Weights were measured with an electronic balance (accuracy 0.1 g), and lengths were measured with a digital vernier calliper (precision 0.1 mm) (Oyebola *et al.*, 2024). For very small morphometric traits, this resolution may introduce higher relative measurement error; however, all measurements were taken consistently by the same observe to minimize systematic bias.

Statistical analysis

The present study used Pearson's chi-squared test ($p < 0.05$) to determine whether the observed sex ratio differed from the expected 1:1 ratio (Teles *et al.*, 2022). The Mann-Whitney U test assessed differences in morphometric traits between the sexes across all 10 morphometric characters at both 1% and 5% significance levels (Fatma *et al.*, 2024). To test all morphometric character differences between males and females, the study calculated PERMANOVA (Permutational Multi-



Fig. 1. Muddy or sandy bottoms shrimp, *Ganjampenaepsis uncta* (Alcock, 1905) collecting from Bhabalbur landing center, Balasore, Odisha

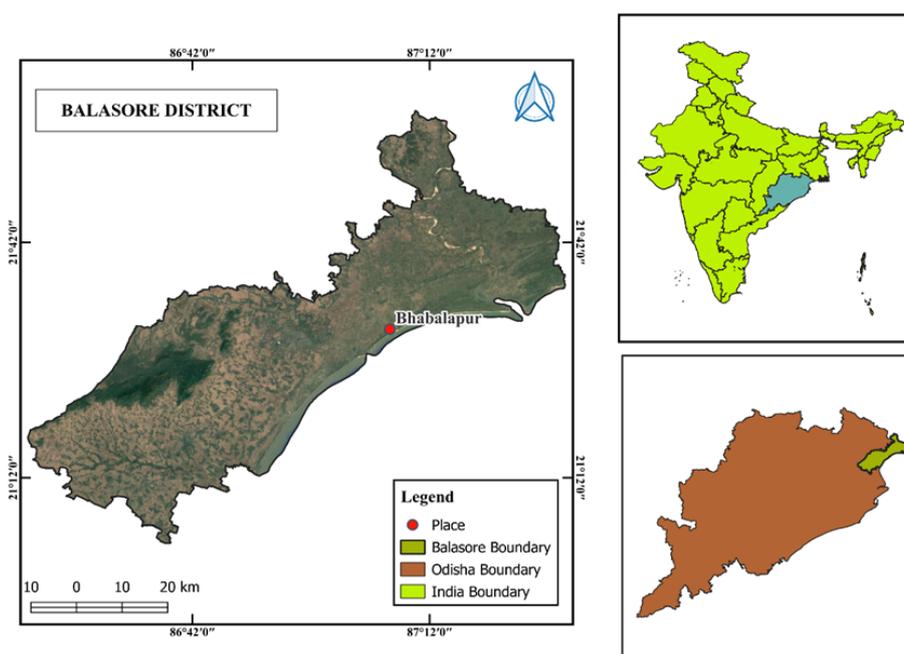


Fig. 2. Study area of Bhabalbur landing center, Balasore, Odisha, east coast of India represents as a red colour

variate Analysis of Variance) to confirm overall significant differences across all variables ($p = 0.001$) (Morales et al., 2018). To elucidate sex-specific growth patterns, structure, and population dynamics within the species, we calculated and compared length-frequency distributions of TL for males and females. Various statistical analyses were employed for all morphometric characteristics, and a scatter plot is constructed using the independent variable (TL) and the dependent variables (CL, RL, AL, and CH). Linear regression analysis and the coefficient (r) were calculated to quantify the relation between the independent variable and the dependent variable. This length-length relationship equation is represented as $Y = a + bX$. Where 'Y' is a dependent variable of various body lengths, 'X' is an independent variable of the total length of morphometric

traits, 'a' is the intercept, which is constant and 'b' is the slope, which is represented as a regression coefficient (Snedecor and Cochran, 1967). Furthermore, the length-weight relationships (LWRs) were estimated after log transformation of the power equation: $W = aL^b$, where 'W' is total body weight, 'L' is total length (Le Cren, 1951). The Theil-Sen regression analysis estimated the parameters a (intercept) and b (slope) belong to the robust regression family, fitted using a non-parametric median-based method over raw data then it automatically adapted log-transformed data, $\text{Log}W = \log(a) + b \cdot \log(X)$ (Theil, 1950). Furthermore, log-log plots were used for visual assessment of data distribution and model fit; however, no observation were excluded from the analysis and all 224 sample were retained in the final stage. The quality and regres-

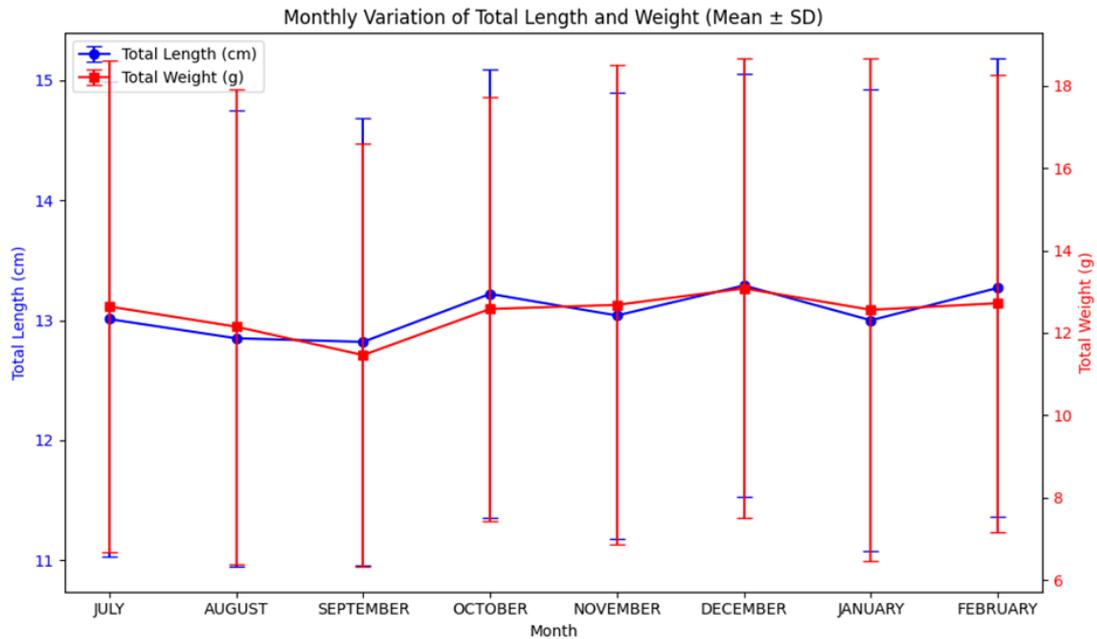


Fig. 3. Monthly variation in the number and length and weight of *Ganjampenaeopsis uncta*

sion indicators of these relationships between length and weight were quantified using the coefficient of determination, also known as the coefficient of regression (r^2) (King, 2013). Moreover, growth patterns of the estimated b value were statistically compared to the theoretical value of 3 (indicative of isometric growth) (Kuberan et al., 2022; Ricker, 1975) using a regression analysis with a significant level of $p < 0.05$. When $b > 3$, allometry indicates positive growth patterns, and when $b < 3$, allometry indicates negative growth patterns (Froese, 2006; Zar, 1999).

Further PCA and DFA analyses were conducted for males' and females' morphometric traits, revealing visually distinct grouping patterns and identifying the trait that contributed most to sex differentiation (Kiliçli et al., 2025). Although DFA assumes multivariate normality and homogeneity of covariance matrices, these assumptions were not strictly met; therefore, the results are interpreted as exploratory and descriptive. Spearman's correlation was analysed for growth allometry studied in both males and females, with a correlation coefficient (r_s) ranging from -1 to +1, and a significant relationship ($p < 0.05$) (Pirie, 2004). The Fulton's condition factor 'K' was calculated using the formula (Froese, 2006) $K = 100 \times (W / L^3)$, where W is the weight (g) of the shrimp, L is the total length (cm), and 100 is a factor used to adjust 'K' to be close to unity (Fulton, 2022). Further, the relative condition factor 'Kn' was analysed, which reflects the physical condition of the *G. uncta* in their environment by using the formula $Kn = Wo / Wc$, where Wo = is the observed weight, $Wc = aL^b$ (calculated body weight derived from the length-weight relationship) (Le Cren, 1951). In the present study, the length-weight parameters (a and b) were

calculated from the same dataset and The Kn values are therefore represent as a descriptive index to explore relative variation in body condition among individuals and between sexes of *G. uncta*, rather than as indicator of condition relative to an external or species wide standard. Statistical analysis for this study was performed using SPSS software version 27, Microsoft Excel 2021, PAST software version 4.17 and the BioPython package.

Animal ethics committee statement

Ethical approval from the Institutional Animal Ethics Committee was not required for this study as, as specimens of *G. uncta* were obtained from directly from commercial trawl landing. No live experimental manipulation or rearing procedure were conducted. Nonetheless, the study adhered to all institutional and national guidelines regarding ethical research practices and the responsible use of aquatic organism.

RESULTS

A total of 224 specimens of *G. uncta* were collected and analysed to examine their population structure, morphometric traits, growth variance, and length and weight characteristics. The sample consisted of 39 males and 185 females, and the observed sex ratio (1:4.74) deviated significantly from the expected 1:1 ratio ($\chi^2 = 95.16$, $df = 1$, $p < 0.001$). However, this deviation may reflect sampling bias associated with gear selectivity rather than true population structure. There is a significant deviation from the expected 1:1 sex ratio, suggesting that the observed sex ratio may reflect gear selectivity rather than intrinsic population structure. Further,

Table 1. Month-wise variation in number, total length and weight of *Ganjampenaeopsis uncta* at Bhabalpur sampling centre, Odisha

Month	Number	Total length (in cm)		Total weight (in g)	
		Range	Mean ± SD	Range	Mean ± SD
July	26	9.45-15.95	13.01 ± 1.98	3.4-22.5	12.64 ± 5.97
August	31	9.48-15.89	12.85 ± 1.90	3.4-22.7	12.15 ± 5.76
September	33	9.34-16.02	12.82 ± 1.86	4.3-22.9	11.46 ± 5.13
October	25	9.43-16.13	13.22 ± 1.87	4.4-22.8	12.58 ± 5.14
November	28	9.56-15.78	13.04 ± 1.86	3.5-22.7	12.68 ± 5.82
December	26	9.38-15.95	13.29 ± 1.76	3.3-22.9	13.08 ± 5.58
January	28	9.68-16.12	13.00 ± 1.92	4.6-23.1	12.56 ± 6.10
February	27	9.38-15.95	13.27 ± 1.91	3.3-22.6	12.72 ± 5.55

this study explored all 10 morphometric parameters in detail. The Mann-Whitney U test found a significant difference between males and females ($p < 0.01$) in their morphometric traits (TL, TW, RL, CL, CH, SSH, SISL, TEL, TEW, and AL) and effect sizes (Cliff's delta) were extremely high (0.94 – 1.00), indicating that the morphometric distributions of males and females were almost entirely non-overlapping (Table 2). Therefore, each morphometric characteristic was analysed separately through various statistical methods for each group and trait. Females exhibited higher mean morphometric values than males, with statistically significant ($p < 0.05$) differences across all measured parameters: TL (13.7 ± 0.09), TW (14.10 ± 0.03), RL (1.68 ± 0.02), CL (3.28 ± 0.01), TEL (1.32 ± 0.01), and AL (5.38 ± 0.03) (Table 3). In males, the coefficient of variation ranged from 4.09% for TL to 13.38% for TW, while in females it ranged from 8.95% for AL to 33.08% for TW. Among all parameters, total weight in females had the highest coefficient of variance (33.08%). The permutational multivariate analysis of variance test revealed significant differences in all morphometric variables and a highly significant difference between males and females. Analysis of 999 permutations revealed a significant group difference (pseudo-F = 261.25, $r^2 =$

0.540, $p = 0.001$) (Fig. 4). Sex explained approximately 54% of the total variation in body measurements. Analysis of total length frequency indicates that the majority of females were observed in the 14-15 cm length group (49 female), whereas most males are present in the 9-10 cm length group (26 male) (Fig. 5). All females were recorded in the group with a total length greater than 12 cm, indicating that females are generally larger than males, who mainly fall into the smaller length group. The linear length-length relationships (LLRs) between Total length and other morphometric characters of AL, CL and CH were calculated with a linear regression equation: $Y = a + bX$. The dependent variables, AL, CL, and CH, are represented on the Y-axis, whereas the independent variable, TL, is represented on the X-axis. The highest growth rate was shown in CL ($b = 0.3141$), followed by AL ($b = 0.3099$) and CH ($b = 0.3165$) (Fig. 6). Both sexes have exhibited statistically significant total length-weight relationship ($p < 0.05$), with an r^2 of 0.75 in females, indicating a strong fit, and an r^2 of 0.37 in males, indicating a moderate fit. The LWRs show that male have $W = 0.036 \times TL^{2.136}$ (Fig. 7a), and females have $W = 0.002 \times TL^{3.303}$ (Fig. 7b). A significant positive allometry was observed in females ($b > 3$), ($p < 0.05$), where the model explained 75% of the vari-

Table 2. Non-parametric test for morphometric traits of two independent groups of *Ganjampenaeopsis uncta* indicates the magnitude of differences

Morphometric character	Group 1	Group 2	Median (Female)	Median (Male)	U Statistic	p-value	Effect size (r)
TL			13.78	9.74	7215.0	0.000*	0.655
TW			14.6	4.6	7215.0	0.000*	0.655
RL			1.86	0.83	7215.0	0.000*	0.655
CL			3.35	2.05	7020.0	0.000*	0.619
CH			1.68	1.06	7215.0	0.000*	0.655
SSH	Fe- male	Male	1.39	0.92	7215.0	0.000*	0.655
SISL			1.21	0.85	7215.0	0.000*	0.655
TEL			1.28	0.85	7137.0	0.000*	0.641
TEW			0.51	0.35	7214.5	0.000*	0.655
AL			5.29	4.07	6998.5	0.000*	0.616

Table 3. Different statistical analysis of morphometric characters of *Ganjampenaeopsis uncta*

Female										
Morphometric Character	TL	TW	RL	CL	CH	SSH	SISL	TEL	TEW	AL
Range (cm/g)	11.68 - 16.13	8 - 23.1	1.11 - 2.29	1.81 - 4.13	1.35 - 2.22	1.21 - 1.8	1.02 - 1.52	0.14 - 1.71	0.42 - 0.69	4.52 - 6.68
Median (cm/g)	13.78	14.6	1.86	3.35	1.68	1.39	1.21	1.28	0.51	5.29
Mean (cm/g) ± SD	13.72 ± 1.25	14.10 ± 4.66	1.68 ± 0.35	3.28 ± 0.46	1.72 ± 0.22	1.4 ± 0.17	1.25 ± 0.11	1.32 ± 0.21	0.54 ± 0.07	5.38 ± 0.46
SE	0.09	0.34	0.02	0.03	0.01	0.01	0.008	0.01	0.005	0.03
CV (%)	9.1	33.08	20.86	14.02	12.84	12.09	9.43	15.94	13.95	8.59
Male										
Morphometric Character	TL	TW	RL	CL	CH	SSH	SISL	TEL	TEW	AL
Range (cm/g)	9.34 - 11.06	3.3 - 5.7	0.75 - 0.95	1.85 - 2.26	0.9 - 1.2	0.88 - 1.08	0.78 - 0.91	0.76 - 0.95	0.3 - 0.42	3.74 - 4.97
Median (cm/g)	9.74	4.6	0.83	2.05	1.06	0.92	0.85	0.85	0.35	4.07
Mean (cm/g) ± SD	9.85 ± 0.40	4.61 ± 0.61	0.83 ± 0.04	2.06 ± 0.12	1.06 ± 0.07	0.94 ± 0.04	0.84 ± 0.03	0.85 ± 0.04	0.35 ± 0.03	4.20 ± 0.35
SE	0.06	0.09	0.007	0.02	0.01	0.007	0.005	0.007	0.004	0.05
CV (%)	4.09	13.38	5.74	6.25	7.41	5.18	4.12	5.1	8.62	8.41

ance ($r^2 = 0.75$, $p=0.02$). The resulting male LWR parameters are likely skewed, reflecting a lack of a comprehensive size distribution that specifically omits the extreme small and large size ranges compared to the female population (Table 4). Whereas $r^2 = 0.37$ and $p = 0.04$ for males, the estimated slope ($b = 2.13$) of the length-weight relationship was lower than the isometric expectation, due to a narrow total length range (9.34–11.06 cm), indicating limited reliability of the regression trends (Table 4). Furthermore, the carapace length-weight relationship was found to be highly significant ($p < 0.001$) in both males and females. Consequently, a separate equation was derived; for males for males, $W = 1.892 \times CL^{1.268}$ with $r^2 = 0.50$ (Fig. 7c) and for females, $W = 0.825 \times CL^{2.364}$ with $r^2 = 0.42$ (Fig. 7d). The slope was significantly lower than the isometric growth value of 3 in females and males, indicating negative allometric growth, which reflects a slower increase in weight relative to the carapace (Table 4). The pattern variation among males and females was calculated using principal component analysis (PCA) with six morphometric characters: TL, TW, RL, CL, CH, and AL. The PCA biplot shows that PC1 accounts for 81.24% of the total variance, suggesting that variation in overall size is the primary source of morphometric differences among individuals, as is typical when all measurements are strongly and positively correlated. Moreover, PC2 likely represents shape variation independent of size, accounting for 11.18%. The PC1 and PC2 together accounted for 92.42% of the total variation, suggesting that most morphometric variation can be described using two principal axes (Fig. 8). The remaining components account for PC3 (3.99%), PC4 (2.29%), PC5 (0.94%), and PC6 (0.36%), which have negligible variance (<4%), indicating that these components contribute minimally to explaining morphometric variation in both male and female shrimp. A discriminant function analysis based on 10 morphometric characters has confirmed that the canonical correlation of the discriminant value was $r^2 = 0.50$, indicating that 50% variation between the sexes was explained by the discriminant function, with Wilks' $\lambda = 0.50$; $X^2(10) = 150.41$, $p < 0.001$, indicating the discrimination was statistically significant between the two groups (Fig. 9a). The structure coefficient suggested that TL, CH, and SISL contributed most strongly to group discrimination, with the sign reflecting the direction of association with the canonical score. The group centroids for males are 2.10, and for females, they are -0.85, indicating that males are associated with higher trait values than females (Fig. 9b). The discriminant function correctly classified 98.7% of individuals under cross-validation, indicating high predictive performance with no evidence of overfitting. The overall classification accuracy without cross-validation was 99.1%, with 98.4% for females and 100% for males. Spearman's rank correlation analysis

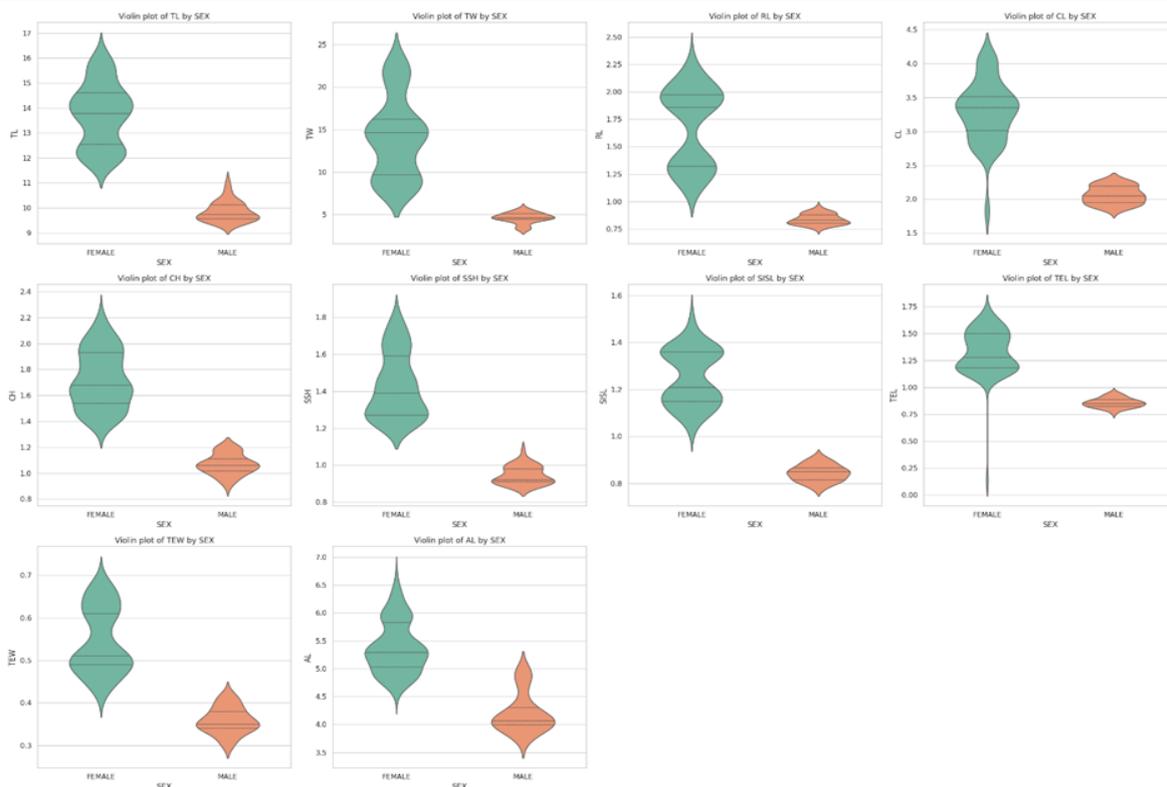


Fig. 4. Violin plot of morphometric traits variation in *Ganjampenaepsis uncta* of both sexes. PERMANOVA indicated significant difference among group significant group difference (pseudo-F = 261.25, $r^2 = 0.540$, $p = 0.001$).

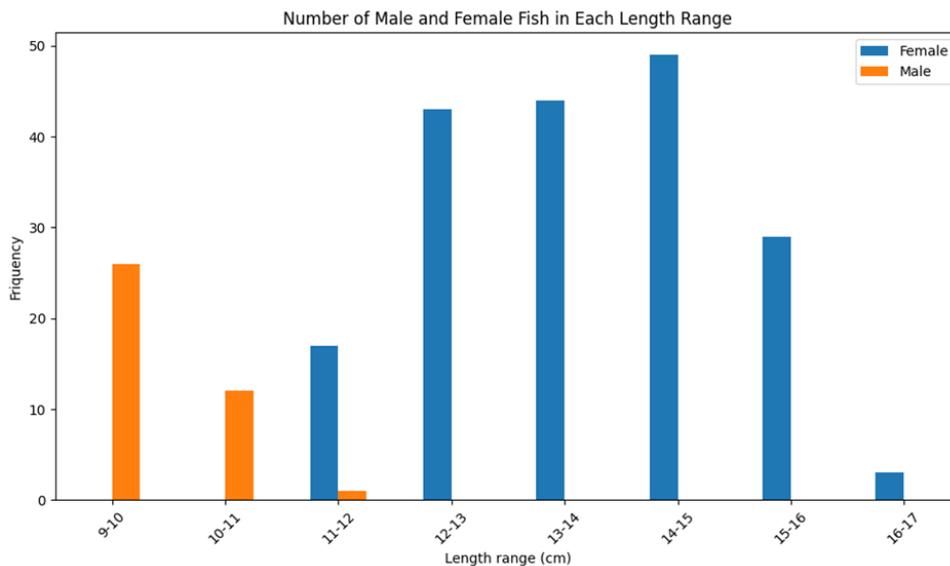


Fig. 5. Length frequency distribution of *Ganjampenaepsis uncta* (males and females), collected from Bhabalpur landing center, Odisha

Table 4. Length-weight and Carapace length-weight relationships of *Ganjampenaepsis uncta*

Sex	Character	Sample size	Length range in cm	Weight range in grams	Intercept (a)	Slope (b)	Coefficient of Determination (r^2)
Female	Total length-weight relationship	185	11.68 - 16.13	8 - 23.1	0.002	3.30	0.75
Male		39	9.34 - 11.06	3.3 - 5.7	0.036	2.13	0.37
Female	Total carapace length-weight relationship	185	1.81 - 4.13	8 - 23.1	0.825	2.36	0.42
Male		39	1.85 - 2.26	3.3 - 5.7	1.892	1.26	0.50

Table 5. Fulton's condition factor (K) and relative condition factor (Kn) of *Ganjampenaeopsis uncta*

Sex	Sample size	Condition factor (K)		Relative condition factor (Kn)		K (Mean ± SD)	Kn (Mean ± SD)
		Minimum	Maximum	Minimum	Maximum		
Female	185	0.3004	0.7091	0.5649	1.4085	0.5285 ± 0.0782	1.0129 ± 0.1490
Male	39	0.3769	0.5281	0.7617	1.1121	0.4812 ± 0.0464	1.0011 ± 0.0991
Polled	224	0.3004	0.7091	0.5649	1.4085	0.5202 ± 0.0757	1.0109 ± 0.1414

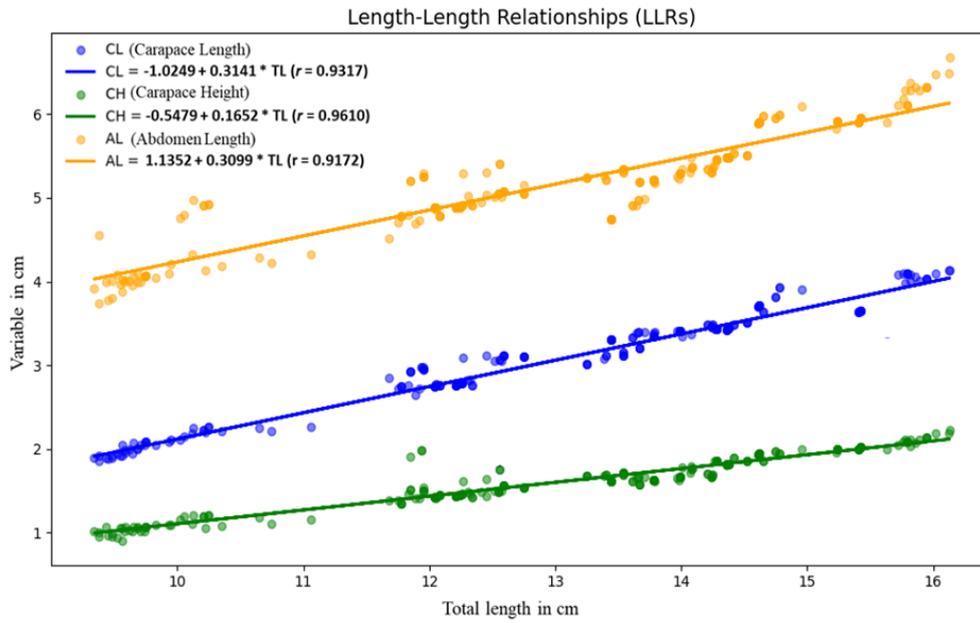


Fig. 6. -Scatter plot showing of linear length-length relationship of TL with CL, CH and AL of *Ganjampenaeopsis uncta*

showed that most morphometric characters are significantly and positively correlated. TL exhibited strong correlations with TW ($\rho = 0.922, p < 0.01$), CL ($\rho = 0.933, p < 0.01$), CH ($\rho = 0.944, p < 0.01$), SSH ($\rho = 0.883, p < 0.01$), SISL ($\rho = 0.873, p < 0.01$), TEL ($\rho = 0.894, p < 0.01$), TEW ($\rho = 0.957, p < 0.01$), AL ($\rho = 0.914, p < 0.01$), while its correlation was moderate RL ($\rho = 0.425, p < 0.01$) (Fig. 10). Moreover, RL showed weaker positive correlations with CL ($\rho = 0.298, p < 0.05$) and TW ($\rho = 0.359, p < 0.05$). Furthermore, CH was strongly correlated with AL ($\rho = 0.964, p < 0.01$) and TL ($\rho = 0.944, p < 0.01$), with CH and CL being highly interrelated ($\rho = 0.964, p < 0.01$) (Fig. 10). Furthermore, the condition factors (K and Kn) of males and females of *G. uncta* are presented in Table 5. The 'K' value for the pooled sample was 0.5202 ± 0.0757 , and the average value of females (0.5285 ± 0.0782) was slightly higher than that of males (0.4812 ± 0.0464) (Welch's t-test, $p < 0.001$) (Fig. 11a). Similarly, the value of 'Kn' in pooled sample was 1.0109 ± 0.1414 , with females (1.0129 ± 0.1490) was slightly higher than that of males (1.0011 ± 0.0991) (Fig. 11b). Welch's t-test indicated no significant difference in Kn between sexes ($p = 0.543$). Shapiro-Wilk tests indicated that K and Kn deviated from normality in both sexes ($p < 0.05$).

DISCUSSION

Morphometric relationships from the backbone of biological research on fishery assessment, resource evaluation, and population assessments. Morphometric relationships facilitate the estimation of size and weight vital for managing emerging marine fisheries along the east coast of India. The sample was collected between July, 2024 and February, 2025, covering the post-monsoon to winter seasons in the present study (Table 1). The rest of the period from March, 2024 to June, 2024 (pre-monsoon and peak summer seasons) was a fish ban period along the Odisha coast; therefore, this period was not suitable for sampling penaeid shrimp. Higher relative error and variance in small morphometric traits, stemming from the 0.1 mm precision; therefore PCA loading and correlation should be careful interpreted. Moreover, this study represents the first report of *Ganjampenaeopsis uncta* from the Balasore coast, and compares sex ratio, length-weight relationship, and variance in B-value with other penaeid shrimp. The sex ratio was skewed (1:1), suggesting habitat or behavioural differences and potential impact on breeding success. The present study recorded a

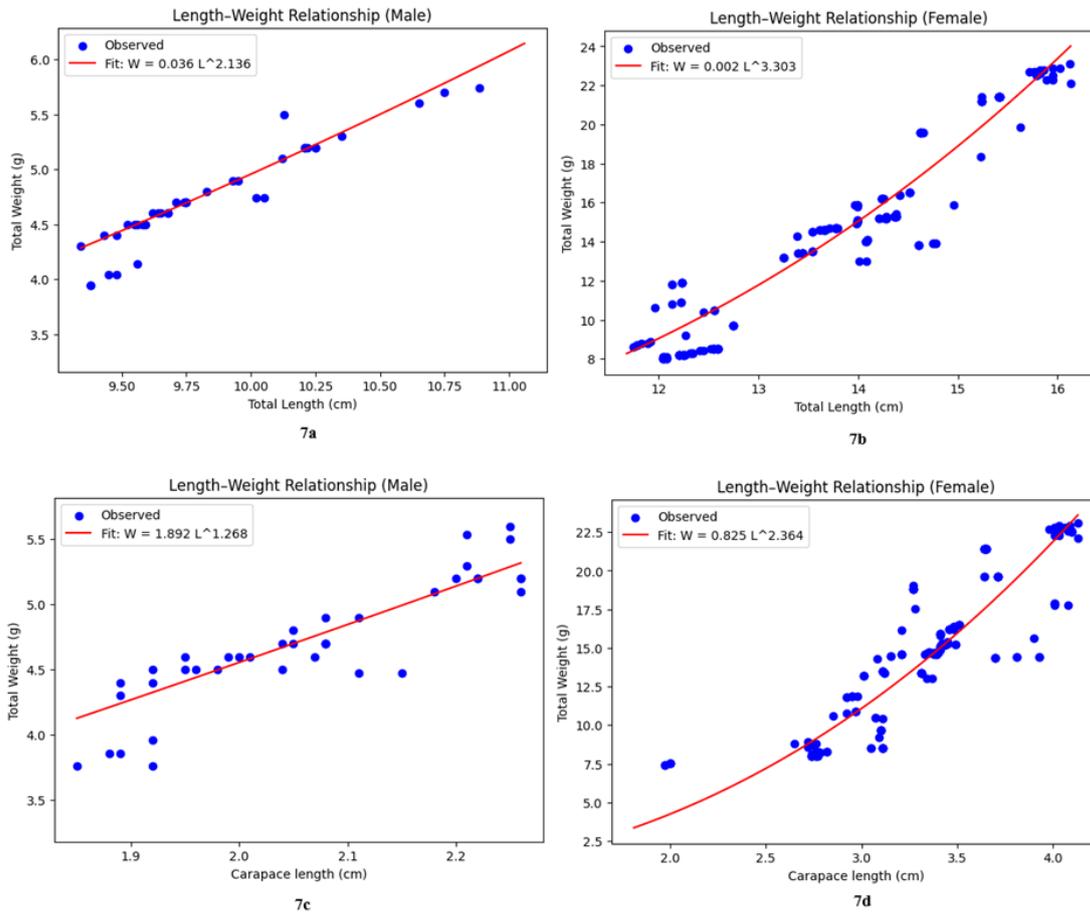


Fig. 7. Total length-weight relationship of male (7a), female (7b) and carapace length-weight relationship of males (7c), females (7d) of *Ganjampenaepsis uncta*

female-biased operational sex ratio (1:4.74) in *G. uncta* sampled from the coastal waters of Balasore, Odisha. The specimens were collected from commercial trawler nets with a 38mm mesh, which may preferentially retain larger females while smaller males facilitating the escaped capture, leading to an over-representation of females in the samples. Therefore, the observed sex ratio may reflect catch composition rather than true population structure. Nevertheless, previous studies have shown that the operational sex ratio of *Pacifastacus leniusculus* was 1M:4F, suggesting that the observed bias in the present study does not inherently imply reduced reproductive potential (Celada *et al.*, 2004). However, *P. hardwickii* was recorded as 1:1.12 from Samboja, Kutai Kartanegara, Indonesia (Rahimah and Ramang, 2024)), and *P. stylifera* was 1:1.06 from Qeshm Island, Iran (Safaie, 2017) and 1:1.13 from the south-west coast of Kerala, India (Pillai *et al.*, 2021). Moreover, *S. hextii* from Veraval harbour, Gujarat (Sureandiran and Karuppasamy, 2025), *S. crassicornis* from the Gulf of Suez, Egypt (Abbas *et al.*, 2020), *Solenocera acuminata* from the Colombian Caribbean (Pacheco and Pérez, 2021), *Macrobrachium jelskii* from Sao Paulo, Brazil (Gasparotto and Costa, 2024) and

Acetes japonicas were recorded from the West coast of Peninsular, Malaysia (Aziz Arshad *et al.*, 2013); there is no significant deviation from the expected ratio 1:1. Non-parametric tests were employed based on distribution and variance of data, which is vital for morphometric traits between sexes (Table 2). These differences are crucial for sexual dimorphism to be observed between the sexes. In the present study, females had significantly higher average morphometric values than males ($p < 0.05$). The coefficient of variation ranged from 4.09% (TL) to 13.38% (TW) in males, and from 8.59% (AL) to 33.08% (TW) in females, with the highest variation in total weight at 33.08% (Table 3). Moreover, most females ($n = 49$) are 14-15 cm in length, while most males ($n = 26$) are 9-10 cm in length (Fig. 5). All females (100%) have a TL greater than 12 cm, indicating that males are generally smaller in size. In the present study, the PERMANOVA found significant differences across all morphometric variables and between males and females (Fig. 4). In 999 permutations, it yielded a pseudo-F of 261.25, an r^2 of 0.540, and a p-value of 0.001, indicating that sex accounts for approximately 54% of the variation in body measurements. The PERMANOVA analysis confirmed that morphomet-

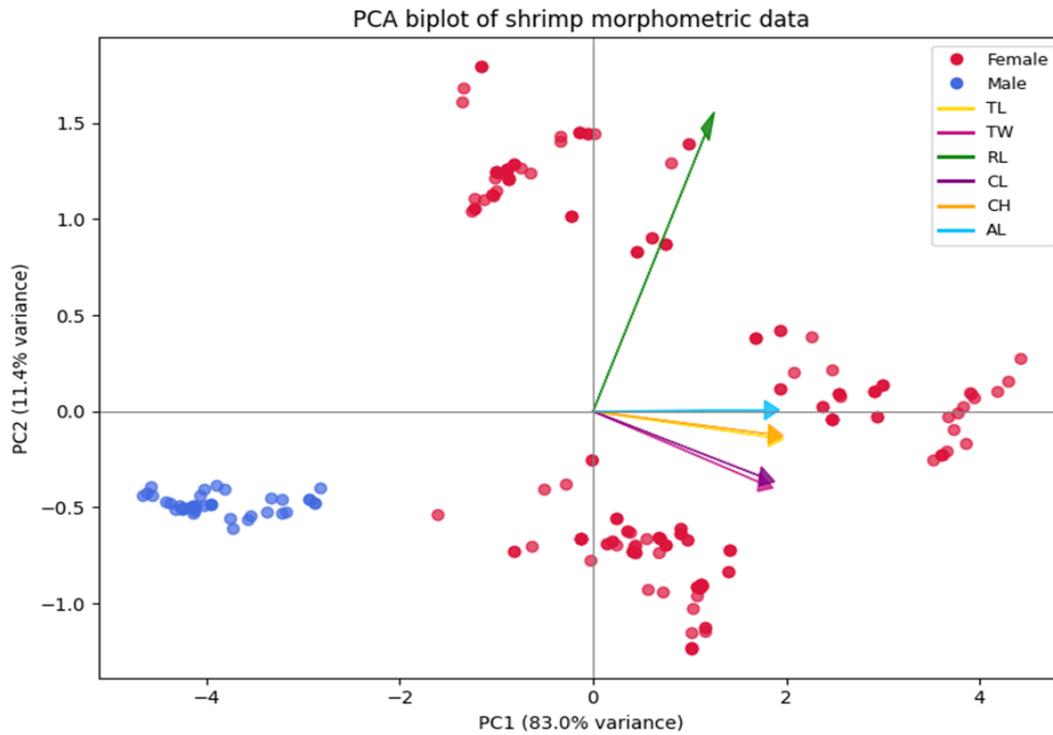


Fig. 8. PCA analysis of morphometric traits in *Ganjampenaepsis uncta* revealed that the first two principal components (PC1 and PC2) explain 81.24% and 11.18% of the total variance

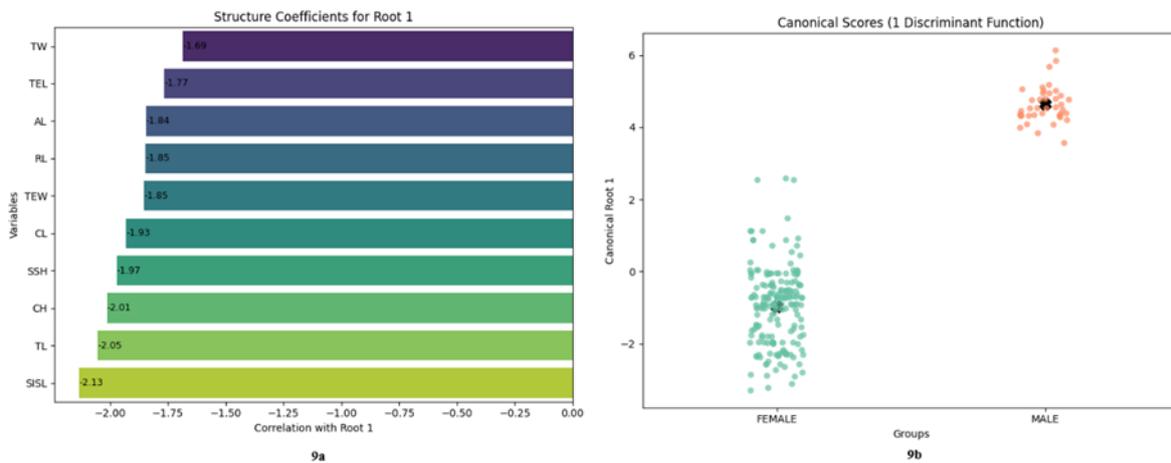


Fig. 9a. Plot represents as structure coefficients from Canonical discriminant analysis Wilks' $\lambda = 0.50$ of *Ganjampenaepsis uncta*; **b.** The graph displays centroids along Canonical Root 1, indicating a clear separation between females' participants at -0.98 and males' participants 4.63

ric traits clearly distinguish sexes, even if individual differences are sometimes subtle. However, in *S. hextii*, the weight-size relationship varies by sex: males have an 11.58% shell width, and females have a 13.34% shell width.. (5.85 cm)(Sureandiran et al., 2025). In *P. hardwickii*, all morphometric variables significantly relate to total length, with p-values of 0.00, supporting the hypothesis that each influences total length (Rahimah et al., 2024). In *S. crassicornis*, males weighed between 0.89 and 10.77 g, whereas females ranged from 1.55 to 19.24 g (Abbas et al., 2020). In *M. amazonicum*, the descriptive statistics showed wide variation,

with the CVs ranging from 12.33% (female) to 50.04% (male)' palm length (Freire and da Silva, 2017). Morphometric analysis using one-way ANOVA revealed only 0.2% variability ($p > 0.05$) in *Penaeus canaliculatus* of the carapace length (Kaka and Karisa, 2019). In *Acetes japonicus*, females were 2.73 mm longer than males with significant difference ($p > 0.05$) in TL and SL, whereas females showed a significant difference ($p < 0.05$) in TL, SL, CL and AL (Aziz Arshad et al., 2013). In *S. acuminata*, females have higher TL, CL, and weights than males, showing significant sexual dimorphism with males being smaller ($p < 0.05$) (Pacheco et

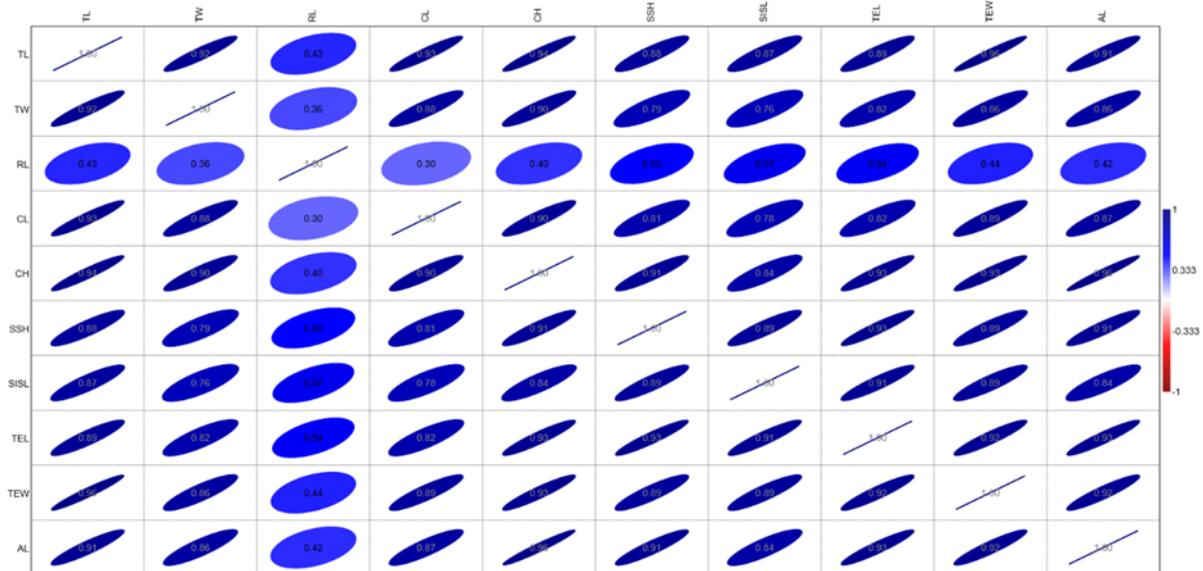


Fig. 10. Spearman's rank correlation analysis indicates that majority of morphometric traits in *Ganjampenaepsis uncta* exhibit significant positive correlation

al., 2021). The statistical analysis revealed a significant difference ($p < 0.05$) among the different morphological morphotypes of *M. rosenbergii* traits (Ibrahim et al., 2023). Furthermore, the ANCOVA indicated significant sex differences ($p < 0.05$) across all morphometric traits in *M. jelskii*, with females showing larger values than males ($p < 0.01$) (Gasparotto et al., 2024). The regression coefficient indicated the length-weight relationship; a value near 1.0 indicates significance ($p < 0.05$) in the present study. Consequently, early life stages of *G. uncta* were under represented in the present study, which limits compressive interpretation of growth dynamics and size structure due to 38 mm mesh size was used during collection. In this study, the LLRs showed that CL has the highest growth value among AL and CH in both sexes (Fig. 6). Moreover, in the present study, the LWRs of both sexes were statistically significant ($p < 0.05$), with females showing positive allometric growth ($b = 3.30$) (Fig. 7b), while males showed lower than the isometric expectation growth ($b = 2.13$) (Fig. 7a)(Table 4). The significant positive allometry found in females ($b > 3$) suggests that the population is thriving in a nutrient-rich environment, potentially nearing reproductive maturity. However, in CLWRs, both sexes showed highly significant differences ($p < 0.001$), with females ($b = 2.36$) (Fig. 7d) and males ($b = 1.26$) (Fig. 7c) exhibiting significantly lower values than the isometric growth value of 3, indicating negative allometric growth in both sexes (Table 4). Moreover, the LWRs were recorded in females as $b = 3.3$ ($r^2 = 0.77$) and in males as $b = 3.2$ ($r^2 = 0.86$) in *P. stylifera* from the Kerala coast. The difference in slope was not statistically significant ($p > 0.01$), indicating that both sexes exhibit positive allometric growth (Pillai et al., 2021).

But the length-weight relationship between carapace CL and TL showed allometric growth in both sexes of *P. stylifera* (Safaie, 2017). In *S. hextii*, recorded females have higher growth value than males, with both sexes growing faster in length than weight ($b < 3$) (Sureandiran et al., 2025). Males show negative allometric growth ($b = 2.275$), while females show near isometric to positive growth ($b = 3.036$) in *S. crassicornis*, indicating females tend to be heavier than males (Abbas et al., 2020). In *Heterocarpus chani*, the length-weight relationship exhibits both positive ($b = 3.57$) and negative ($b = 2.79$) allometric relationships in females and males, respectively (Kuberan et al., 2022). In *A. japonicus*, a positive correlation was observed between TL-TW and CL-TW in both sexes ($p < 0.01$), indicating proportional growth among the body traits (Aziz Arshad et al., 2013). Males exhibited isometric growth ($b = 3$), with deviations attributed to variations in food, location, sample size, and type. Females exhibited positive allometric growth ($b > 3$) in *S. acuminata* (Pacheco et al., 2021). In *P. monodon*, the partial carapace length-weight relationship exhibited a strong correlation and positive path coefficient in both males and females (Rebello et al., 2013). The PCA and DFA successfully differentiated the sexes and highlighted key discriminant features, the limited male sample size ($n=39$) may impact the stability of multivariate boundaries and allometric coefficients. Consequently, these findings are robust for females but should be considered exploratory regarding the male population. Sex was determined using PCA and DFA, which identified CL, TL, and AL as the most informative traits in both sexes. In this present study found that high DFA classification accuracy reflect strong sexual dimorphism. The PCA biplot indi-

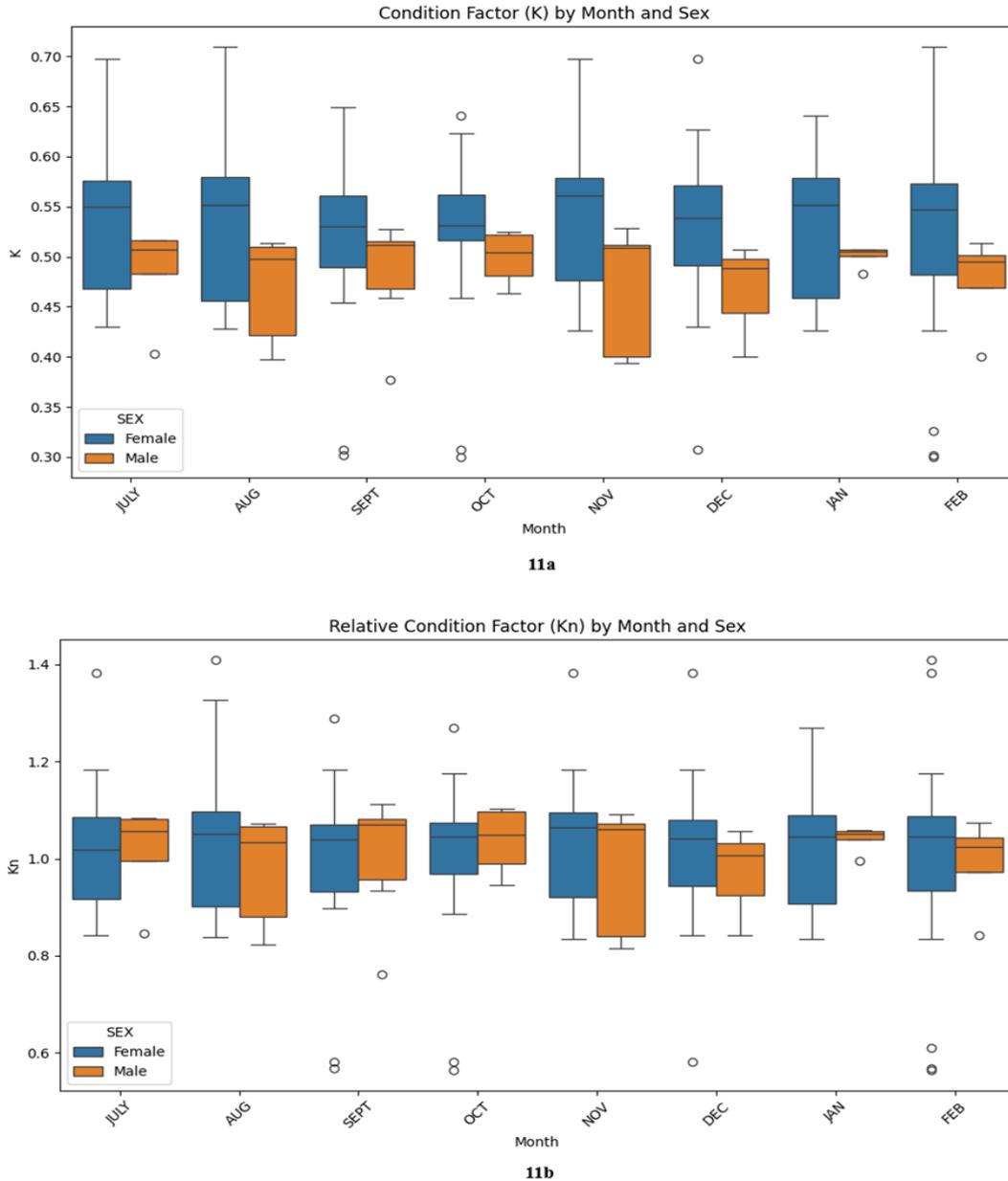


Fig. 11. Box plot of condition factor (*K*) represents of both sexes (11a) and relative condition factor (*Kn*) (11b) of *Ganjampenaeopsis uncta*

cates that PC1 explains 81.24% of the variance, suggesting that size differences are the primary source of variation, a common occurrence when measurements are strongly correlated. PC2 likely represents shape variation independent of size, accounting for 11.18% of the variance (Fig. 8). However, first two PCA significant variables explained 68.37% of the variance in females and 62.74% in males in *M. amazonicum* (Freire et al., 2017). Cephalothorax shows more differences in females than males in PCA and DFA analyses in *M. tenellum* (García-Guerrero et al., 2023). In *Fenneropenaeus indicus*, PCA shows an inverse relationship between BL and CL, while CL and TL are strongly positively correlated (Kaka et al., 2019). Nega-

tively allometric growth was found in both sexes of *Macrobrachium rosenbergii*, with PC1 have 78.30% and PC2 have 8.46% of variation (Ibrahim et al., 2023). In the present study, discriminant function analysis with 10 traits yielded a canonical correlation of $r^2 = 0.50$, indicating that 50% of variation within both sexes and demonstrating significant discrimination (Fig. 9a). The model correctly classified 98.7% of individuals in cross-validation, achieving an overall accuracy of 99.1%, with specific rates of 98.4% for females and 100% for males (Fig. 9b). Discriminant analysis revealed significant differences in females ($p < 0.01$), while canonical analysis was significant for both sexes ($p < 0.01$). However, high trait variation, sex-based differences in variables,

and intense discrimination found among female *M. amazonicum* (Freire et al., 2017). In this study, Spearman's rank correlation analysis exhibit significant and positively correlated within the most morphometric traits. Condition factors (K and Kn) reflect both biotic and abiotic factors on physiological condition, which were higher in females, indicating a greater energy investment in reproductive development than in males. In this study, the average 'K' values for *G. uncta* were slightly higher in females compared to males (Fig. 11a)(Table 5), indicating sex related variation in growth and energy allocation. Such discrepancies in penaeid shrimp are commonly linked to sex-specific physiological differences and reproductive investment. The 'Kn' value of both sexes reflecting individual variability in growth performance during the study period (Fig. 11b) (Table 5). Furthermore, higher K values found in females indicate sex-related in somatic condition commonly found in penaeid shrimps (Udoinyang et al., 2016). Conversely, Kn does not exhibit significant difference between sexes indicates proportional growth relative to the expected length-weight relationship. As this study represents the first report of *G. uncta* from the Balasore coast of Odisha, India, absence of species specific baseline data limits interpretation of these indicator beyond descriptive assessment of growth patterns. Therefore, the present data reflect as baseline information for future comparative and long-term studies. Furthermore, the present study only interpreted as general indices of weight and length condition, except multiple physiological processes or environmental stress.

Conclusion

In contemporary systems biology morphological analysis remains a crucial component to a rigorous quantitative framework essential for biological research. The present study provides first baseline comprehensive data on sex ratio, allometric length-weight relationships, morphometric trait variability, population demography and dynamics for *G. uncta* along the Balasore coast, Odisha, India. The research finding also establishes an important benchmark for a regional reference framework focused on future biological and ecological research, with significant contributions to the Indian fisheries sector. Even though an accurate growth pattern was not represented due to restricted size in penaeid juveniles and adults. However, these baseline data will be very helpful for future studies in fisheries management, such as reproductive biology, gonadal maturity assessments, and longitudinal sampling to mitigate seasonal biases. Therefore, the combined studies will be essential for biological conservation and management of this species. This study confirms that females

of the species exhibit positive allometric growth ($b > 3$), reflecting a robust physical condition likely driven by favourable environmental factors and active gonadal development. However, the sampling gap identified in the male dataset—specifically the lack of small and large size classes—highlights a critical limitation in current stock assessments. Additionally, the present research shows that females have marginally higher K values than males in *G. uncta*, indicating sexual variation in growth conditions. Similarly, the Kn values did not differ significantly between sexes and were close to unity. These findings described growth patterns and condition variability but should not be interpreted as indicators of population health. So, it provides baseline data fill a significant research gap and offer a valuable baseline for understanding tropical interactions, habitat specialisation, biodiversity assessments, reproductive patterns, and ecological dynamics modelling of mud shrimp from the Balasore coast, Odisha. Additional studies are urgently needed to improved understanding of species mortality, reproductive and somatic growth periods, and habitats with associated fauna before initiating targeted fisheries.

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Conflict of interest

The authors declare that they have no conflict of interest.

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