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Research Article

Analysis of Length/Width-Weight and Condition Factor Revealed Smaller Crab Sizes of *Thalamita crenata* (Rüpell, 1830) in Butuan Bay, Philippines

Jess H. Jumawan[1,2], Paul John B. Pastor[2,4*], Ronald B. Cadavez[2,3]
1)Biodiversity and Computational Ecology Research Laboratory, Department of Biology, College of Mathematics and Natural Sciences, Caraga State University, Butuan City, 8600, Philippines
2)Department of Biology, College of Mathematics and Natural Sciences, Caraga State University, Butuan City, 8600, Philippines
3)Department of Education, Tungao National High School, Butuan City, 8600, Philippines
4)Office of Research, Asian College of Technology - International Educational Foundation, Cebu City, 6000, Philippines
* Corresponding author, email: pastor@act.ph.education

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ABSTRACT

The marine ecosystem of Butuan Bay, Philippines, supports a diverse array of crab species, including the *Thalamita crenata* (crenate swimming crab), which plays a vital role in coastal ecology and fisheries. The study examined *T. crenata* samples from sites with remaining occurrences in Butuan Bay, Philippines and aimed to understand the ecological and biological dynamics of *Thalamita crenata* in Butuan Bay by analysing their morphometric relationships, condition factors (CF), and spatial-sexual dimorphism. Morphometric data from Butuan Bay were analysed to determine growth relationships, condition factors, and spatial-sexual differences in size and marketable sizes between sexes and locations (Cabadbaran and Buenavista). Results showed significant spatial and sexual dimorphism, with larger crabs and higher median CF values ($p < 0.01$) found in Cabadbaran site than in Buenavista site. Male crabs were larger than females, consistent with crustacean patterns. The power model best described the weight-carapace length (WT-CL) and width (WT-CW) relationships, revealing negative allometry (WT-CL: $b = 0.3286$, $R^2 = 0.6820$, $p < 0.01$; WT-CW: $b = 0.3014$, $R^2 = 0.7478$, $p < 0.01$. The study highlights the influence of localised environmental factors and emphasizes the need for targeted conservation efforts, including enforcing size limits, protecting habitats, and regulating fishing practices. Restoration efforts and continued monitoring are essential to ensure the sustainable exploitation of *T. crenata* and maintain its ecological and economic importance.

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INTRODUCTION

Thalamita crenata, also known as crenate swimming crab is a common swimming crab that thrives in shallow seas throughout the tropical Indo-Pacific Region, Western Pacific, Indian Ocean, and Red Sea, as well as along the African Coast (Susanto & Irnawati 2014). *T. crenata* prefers brackish water, notably nearby river mouths and the extreme seaward fringe of mangrove swamps; it rarely lives in clear sea water, such as coral reefs (Cannicci et al. 1996). The species can be recognised by distinct six rounded lobes which are nearly equal sizes, located between the eyes along the anterior margin of the carapace (Motoh 1980). Additionally, it is identified by its olive to dark natural colour with its five fine sharp spines on the antero- lateral margin of the carapace—characterised by six rounded lobes between its eyes and five sharp spines along its sides (Pastor et al. 2024).

This species is frequently captured in intertidal zones (high tides) by traps and as bycatch in gillnets and is generally smaller than most other commercially targeted crab species (Muhd-Farouk et al. 2017). Nevertheless, it is collected by the local coastal communities and highly favoured for its flesh quality. Due to its abundance and the relative ease of capture compared to mud crabs, it constitutes a significant component of the daily diet among coastal towns in the Philippines. It was used to be commonly sold as fresh catch in traditional market and as local delicacy in food stalls (Pastor et al. 2024).

Ecological studies have shown that *T. crenata* is one of the predators in the food web of mangrove habitat contributing to the balance of the ecosystem it belongs (Eeckhaut et al. 2020). *T. crenata* is known to scavenge on carrion, with larger individuals often displacing smaller ones at feeding sites (McKillup & Mckillup 1996). Generally, crabs play an important role as prey, predators, or detritus feeders in the complex food web of coastal ecosystems (Sharifian et al. 2021). Overexploitation of this species would disrupt the ecosystem balance and has cascading effect to the food web in the aquatic habitat (Muhd-Farouk et al. 2017). In the Philippines, mangrove ecosystems have significantly decreased largely due to conversion into fishponds and overharvesting of mangrove woods (Natividad et al. 2014). The *T. crenata* thriving in mangrove ecosystems consequently declined along with its overexploitation as source of food. Yet there are limited studies of this species given its ecological importance and source of protein to local communities (Hamid et al. 2019). Studies in *T. crenata* in the Philippines were limited only as part of field guide for edible crustacea (Motoh 1980), indicator species of mangrove rehabilitation (Walton et al. 2007), checklist of commonly harvested crabs (Subang et al. 2020), and morphometric variations (Pastor et al. 2024).

Analysis using LWR is an important aspect in fishery biological investigations, growth model of the species, ecology, and habitat suitability of crustacean populations (Susanto & Irnawati 2014; Jumawan et al. 2022). The link between length, width, and weight is essential to comprehending the biological and ecological dynamics of species, particularly crabs like *T. crenata.* The study on relationship evaluation makes it possible to estimate a crab's weight based on its parameters, which is a vital information for managing the population and conducting population surveys (Suryandari et al. 2018; Marchessaux et al. 2023). In morphometric studies, the weight relationship between length and width are two crucial factors to consider. *T. crenata* study was explored which emphasises that this type of crab has a fundamental length-weight relationship that is typical of many marine crabs, indicating that the crabs' weight increases with their growth. Presently, the information about the length width/weight relationship (LWR) of *T. crenata* in the Philippines is not fully understood. Conservation and environmental management initiatives benefit from the monitoring of the LWR values (Noori et al. 2015).

The health and status of a species can be evaluated through relationships. Using these factors, which can represent environmental conditions and food availability in their habitats and nutritional state of individuals can be evaluated (Jumawan et al. 2022). The condition factor (CF) provides details about a habitat's environmental quality to its organisms. Excessive deviations from expected condition parameters could indicate overfishing, pollution, or habitat degradation-related changes in habitat quality (Rohmayani et al. 2018).

There is limited information on monitoring of fisherman catch and sizes of *T. crenata* crabs in the Philippines. This is partly due to its smaller sizes and lower market value compared to mud crabs (*Scylla* spp.) and blue swimming crabs (*Portonus pelagicus*). Given its relatively small size, the *T. crenata* is still included as economically important crab species despite its lower price in the market (Susanto & Irnawati 2014; Muhd-Farouk et al. 2017). There are observations and anecdotal reports pertaining to decreasing marketable sizes of *T. crenata* sold in local markets in the Philippines. However, this claim needs to be verified and supported by data analysis. The intention of the study is also to conduct LWR and condition factor as part of investigating the marketable sizes of *T. crenata* sampled in the Philippines.

MATERIALS AND METHODS

Study Area

Crab samples were collected using traditional fisherman traps designed to catching *T. crenata* as marketable sizes. Collected *T. crenata* crabs, representing various size classes, were promptly transported to the laboratory for storage under cool conditions from two specific sites within Butuan Bay: Cabadbaran City and Buenavista, Agusan del Norte. These locations, with coordinates 9.1222° N, 125.5376° E and 8.7859° N, 125.3686° E, respectively (Figure 1), were selected for this study. Butuan Bay is a complex ecosystem influenced by both freshwater from the Agusan River and saltwater from the ocean. It is situated in northeastern Mindanao and opens into the Bohol Sea, also referred to as the Mindanao Sea (Navarro et al. 2022). The bay also faces environmental challenges such as heavy metal pollution (Elvira et al. 2016; Cabuga et al. 2020). Species identification was carried out using the field guide summary from SeaLifeBase (Ng 1998).

Species Identification, sex determination, and Measurement of Morphometric Indices

Species was identified based on existing taxonomic records. Sex was identified based on abdomen shape: males possess a V-shaped abdomen (Figure 2B), while females have a rounder abdomen (Figure 2C) (Ng 1992). Crab morphometrics were determined using a vernier caliper for measurements (mm) and a digital weighing scale for total weight (g). Specific measurements included maximum carapace width (CW), length (CL), frontal width (FW), natatory leg dactylus length (NDL) and width (NDW), cheliped dactylus length (CDL), palm cutting edge (CE), length (PL), and width (PW) (Figure 2) (Shahdadi et al. 2018; Asaduzzaman et al. 2021).

Regression Modeling of Morphometric Traits in *T. crenata*

Morphometric data, including carapace width (CW), length (CL), and weight (WT), were analysed to determine length-width and weight relationships. Data were categorised by sex (male, female) and pooled for comparative analysis. Exponential, linear, and power regression models were fitted to the data, with the model exhibiting the highest R^2 value selected to represent the crab's allometric growth (Jumawan et al. 2022). The preferred regression equation was graphically illustrated.

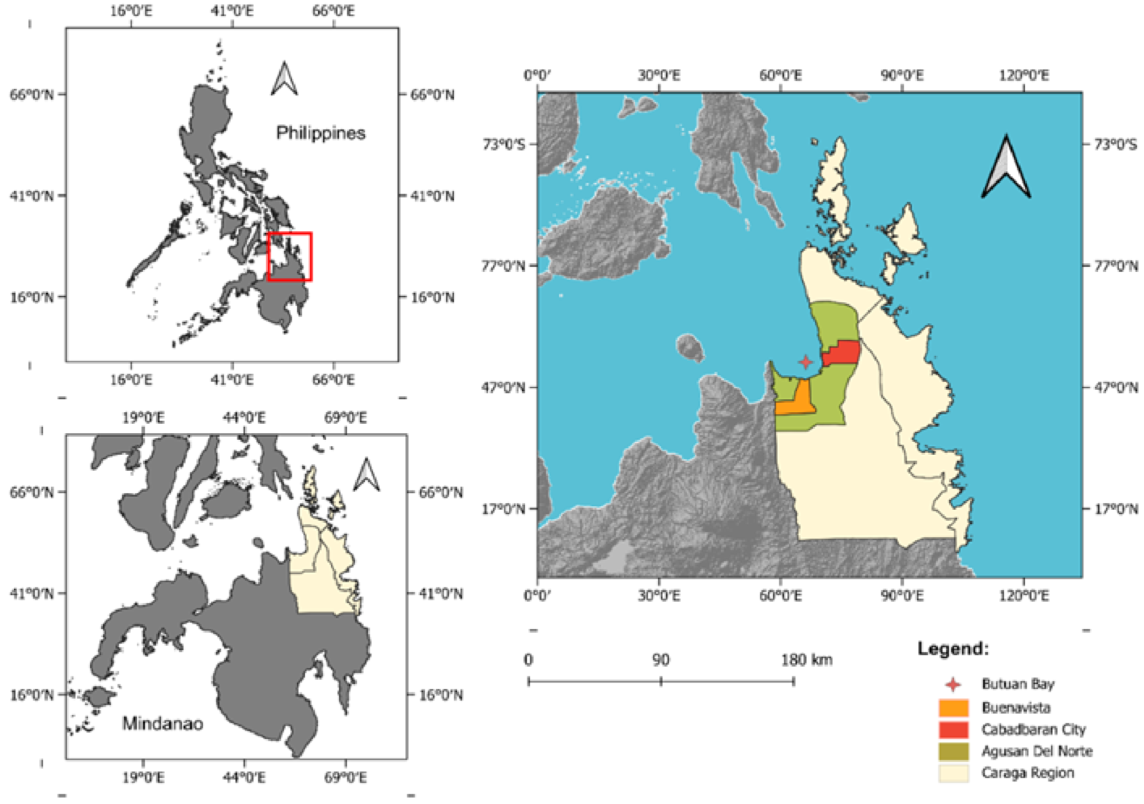

Figure 1. Map showing the sampling area in Butuan Bay.

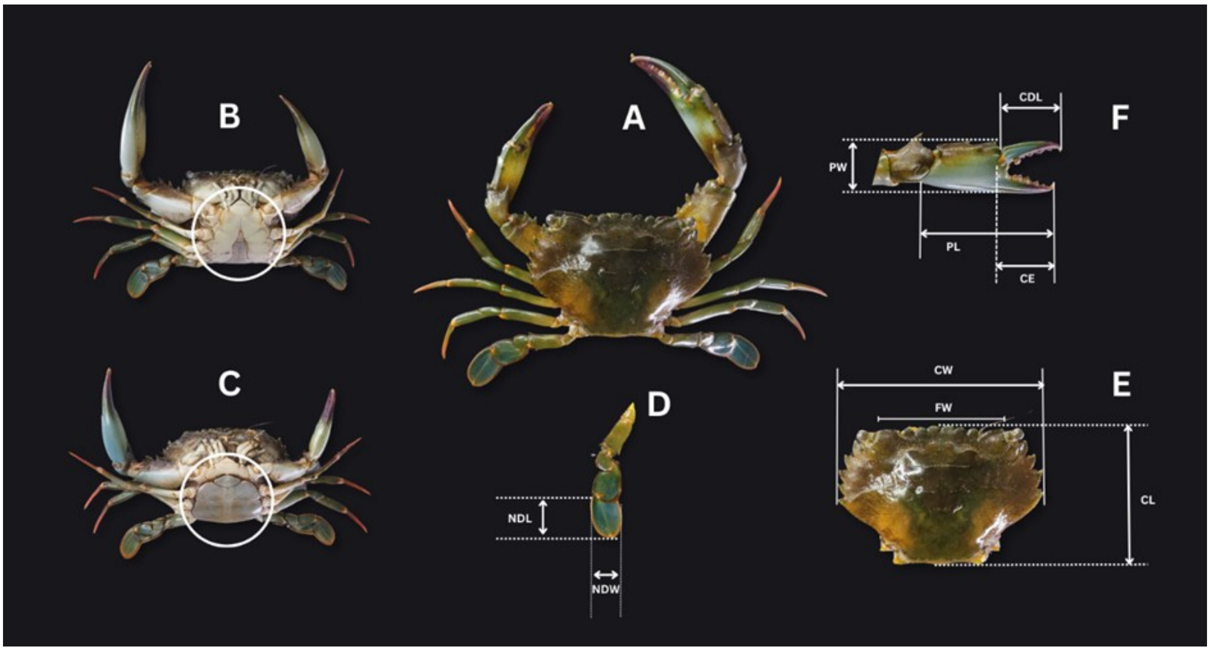

Figure 2. Actual collected sample of *T. crenata* with the studied morphometric indices. A) Dorsal view of the species; B) Ventral part showing the distinct V-shaped abdomen of male species; C) Female with distinct round shaped abdomen; D) natatory leg dactylus length (NDL) and natatory leg dactylus width (NDW); E) Frontal width (FW) carapace width (CW), and carapace length (CL); F) maximum palm width (PW), maximum palm length (PL), palm cutting edge (CE), and cheliped dactylus length (CDL).

Evaluation of length/width-weight relationships and Fulton's condition factor

The allometric growth equation, $Y = aX^b$, where Y represents weight (WT), X represents carapace width (CW) or length (CL), a is the y-intercept, and b is the allometric growth coefficient, was applied to describe growth patterns. Growth pattern was classified as isometric when $b = 3$, positively allometric when $b > 3$, and negatively allometric when $b < 3$. The strength of the relationship between variables was assessed using the coefficient of determination (R^2). To compare length-weight relationships among female, male, and pooled data, the power equation was log-transformed into linear form $\log Y = a + b \log X$, and linear regression analysis was conducted. The significance of differences in relationships (CW, CL to weight) was tested using MANCOVA ($p < 0.05$). Condition factor (CF), calculated using the modified Fulton's formula ($CF = (100WT)/CW^b$) (Jumawan et al. 2022), evaluate the overall health of crabs. Chi square analysis was performed to compare between area and sex datasets. Differences in CF among sex and pooled groups were assessed using the Kruskal-Wallis test ($p < 0.05$). Statistical analyses and graph generation were performed using R software, JASP, and Microsoft Excel.

RESULTS AND DISCUSSION

Morphometrics, size and sex-specific distribution

The descriptive statistics presented in Table 1 provide a comprehensive overview of the morphometric traits of *T. crenata* crabs across different areas and sexes. The data revealed that crabs caught from Area 1 observed to be larger compared to those samples from Area 2, as indicated by the higher mean values for weight (WT), carapace width (CW), carapace length (CL), and other morphometric variables. Comparably, *T. crenata* male crabs exhibit a larger mean value for most traits compared to *T. crenata* female crabs. The values of standard deviation provide insights into each group's variability. A higher SD suggests greater variations in the traits within that group. As projected (Table 1), the higher standard deviation for weight in Area 2 indicates that there is more variability in weight among *T. crenata* crabs from Area 2 (Buenavista) than Area 1 (Cabadbaran). Female body size is the principal determinant of reproductive output in the case of brachyuran crabs, considering the demographic pressure on fecundity being the primary selective mechanism influencing its annual reproductive effort (Somers 2020). Variability in the weight of crab samples can be attributed to sex, maturity, molt stage, and carapace form which significantly affect the weight of blue crabs, with males being heavier than females of equal width and mature males weighing more than immature females (Sundet 2014). The minimum and maximum value highlights the range of variations within each trait and group. For instance, the minimum CW is 30 mm, while 70 mm is recorded as the maximum CW value, indicating a wide range of sizes among the crabs. The carapace shape variation in crabs is explained by the interaction between sex and habitats, in a study of rocky shore crabs it was observed having more slender and lenghtent carapaces than salt marsh individuals (Lezcano et al. 2015).

A bar chart was displayed to compare the categorical variables between Areas (dependent variable) and crab sex (grouping variable) (Figure 3). Chi-square analysis revealed higher values of *T. crenata* samples in Area 1 than Area 2 samples ($\chi^2 = 5.13$; $p = 0.024$). The female crab samples (52 %) were similar ($p = 0.604$) between Area 1 (52 %) and Area 2 (48 %). While the male crab samples were significantly higher ($p = 0.024$) in Area 1 (63 %) compared to Area 2 (37 %). These findings imply potential sex-specific preferences for various habitats or behaviours which resulted in differing distribution patterns between areas.

The observed sex-specific distribution patterns may have significant implications for *T. crenata* population dynamics. Female-dominated areas may experience increased reproductive output, while male-dominated areas may exhibit heightened competition for mates. These differences could influence growth rates, survival, and fecundity, ultimately impacting fisheries management and conservation strategies (Kuris 2020; Somers 2020; Nair et al. 2024). Additionally, the variation in distribution patterns between Area 1 and Area 2

Table 1. Descriptive statistics of collected *T. crenata* samples categorised into Areas (1-Cabadbaran, 2-Buenavista), sex, and pooled datasets.

Indices (mm)	Mean ± Standard Deviation					Range Values (min-max)				
	Area 1 (*n=122*)	Area 2 (*n=104*)	Female (*n=134*)	Male (*n=92*)	Pooled (*N=226*)	Area 1 (*n=122*)	Area 2 (*n=104*)	Female (*n=134*)	Male (*n=92*)	Pooled (*N=226*)
WT	33.53 ± 9.22	24.89 ± 12	26.6 ± 9.33	33.8 ± 12.9	29.55 ± 11.44	11-57	7-76	7-55	10-76	7-76
CW	54.77 ± 6.04	49.2 ± 7.64	50.5 ± 6.52	54.6 ± 7.86	52.21 ± 7.36	36-67	30-70	33-66	30-70	30-70
CL	38.54 ± 3.97	31.95 ± 5.3	34.4 ± 5.11	37.2 ± 6.05	35.51 ± 5.67	29-47	23-47	23-44	25-47	23-47
FW	33.46 ± 3.65	31.24 ± 5.86	31.8 ± 4.52	33.4 ± 5.32	32.44 ± 4.91	15-42	14-45	20-45	14-45	14-45
NDL	12.84 ± 2.06	12.32 ± 2.56	12.1 ± 2.23	13.3 ± 2.28	12.6 ± 2.31	8-17	1-20	1-19	8-20	1-20
NDW	8.71 ± 2.21	7.56 ± 1.95	7.63 ± 1.74	8.99 ± 2.47	8.18 ± 2.17	5-20	5-20	5-19	6-20	5-20
CDL	20.04 ± 2.87	15.99 ± 3.32	16.9 ± 3.08	20.1 ± 3.69	18.18 ± 3.68	13-28	9-25	9-23	12-28	9-28
CE	16.73 ± 3.66	14.46 ± 4.21	14.4 ± 2.85	17.5 ± 4.87	15.69 ± 4.08	12-45	8-30	9-30	8-45	8-45
PL	41.07 ± 6.98	35.75 ± 7.9	35.7 ± 5.85	42.8 ± 8.53	38.62 ± 7.86	14-58	10-60	10-49	14-60	10-60
PW	11.89 ± 2.31	12.7 ± 3.82	11.6 ± 2.94	13.3 ± 3.09	12.27 ± 3.11	8-19	7-34	7-34	8-24	7-34

may also be influenced by environmental factors, such as water quality, substrate composition, or food availability (Mokhtari et al. 2015; Pati et al. 2023). Moreover, understanding these patterns can inform spatial management approaches, ensuring sustainable exploitation of *T. crenata* populations. Future studies should investigate these potential drivers, incorporating multivariate analysis to disentangle the complex relationships between ecological factors and *T. crenata* distribution.

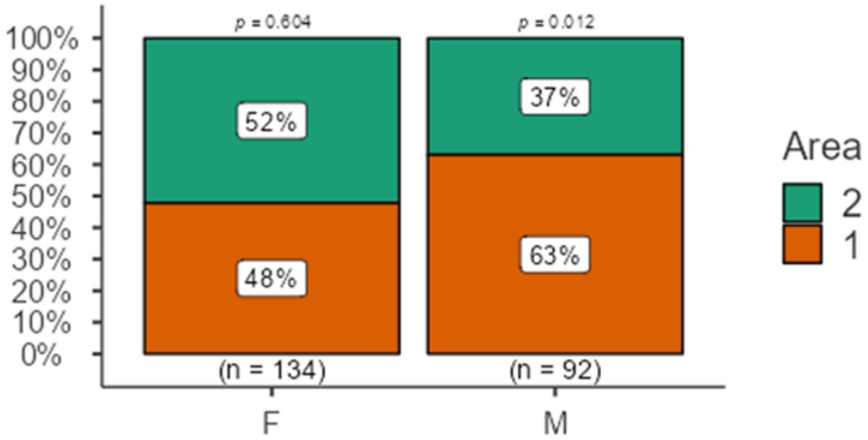

Figure 3. Comparison of crab samples between areas and sex as factors indicate significant differences using Chi-square analysis. (Area: χ^2= 5.13, p=0.024).

This pattern was also observed in separate study on Armases crabs which also exhibited a sex-specific habitat choice and preference in food, which then potentially acted as key biotic vector or spatial subsidies across habitat borders (Hübner et al. 2015). Even male hermit crabs also play as better intraspecific competitors compared to females in the acquisition of vacant shells, which could allow them to grow better and larger than females (Plasman et al. 2023). Similar to observations in blue swimming crabs (*Portunus pelagicus*) from coastal Thailand (Hisam et al. 2020), our *T. crenata* samples exhibited ontogenetic habitat shifts, with juveniles predominantly found in shallower waters and larger individuals occurring in deeper areas, suggesting a comparable pattern of habitat use during growth. Further research is required to explore its underlying ecological and behavioral factors influencing such variations.

The class sizes of *T. crenata* samples were categorised in three classes representing small, medium, and large, based on weight and carapace sizes. The comparative histograms visually depict the distribution of crab weight (Figure 4A), carapace width (Figure 4B), and carapace length (Figure 4C) across different size classes. Based on weight data it showed that small size ranged from 7-28 g, the medium size ranged from 29-51 g, and the large size ranged from 52-76 g. The carapace width values showed small size ranged from 30-43 mm, medium size ranged from 44-57 mm, and large size ranged from 58-70 mm. The carapace length values indicate small size ranged from 23-30 mm, medium size ranged from 31-38 mm, and large size ranged from 39-47 mm.

The results showed varying distributions across the three morphometric traits. For crab weight, the medium size class (29-51 g) has the highest number of individuals, with 104 crabs falling within this range. However, the small size class (7-28 g) has a slightly higher number of individuals, with 114 crabs, while the large size class (52-76 g) has the fewest number of crab samples, with only 8 individuals. In contrast, the distribution of carapace width is skewed towards the medium size class (44-57 mm), with 142 individuals falling within this range. The large size class (58-70 mm) has a notable number of individuals, with 58 crabs, while the small size class (30-43 mm) has the fewest number of crab samples, with only 26 individuals. The distribution of carapace length is more evenly spread across the three categories, with the medium size class (31-38 mm) having the highest number of crab samples, with 101 individuals, followed by the large size class (39-47 mm) with 67 crabs, and the small size class (23-30 mm) with 58 crabs. The prevalence of medium-sized crabs may reflect optimal environmental conditions, food availability, or reproductive strategies favouring this size class (Jaramillo et al. 2017). Factors influencing size-class distribution, such as habitat quality (Griffen & Norelli 2015), predation pressure (Noè et al. 2018), genetic factors (Mashar et al. 2017), and overfishing practices (Hamid & Wardiatno 2015), which warrant investigation.

While the abundance of medium-sized crabs may suggest optimal conditions, it's also essential to consider the limitations of the dataset. The comparison of size classes was only within the range of the actual collected samples, which may not represent the entire population or historical trends. In other words, the dominance of medium-sized crabs may not necessarily indi-

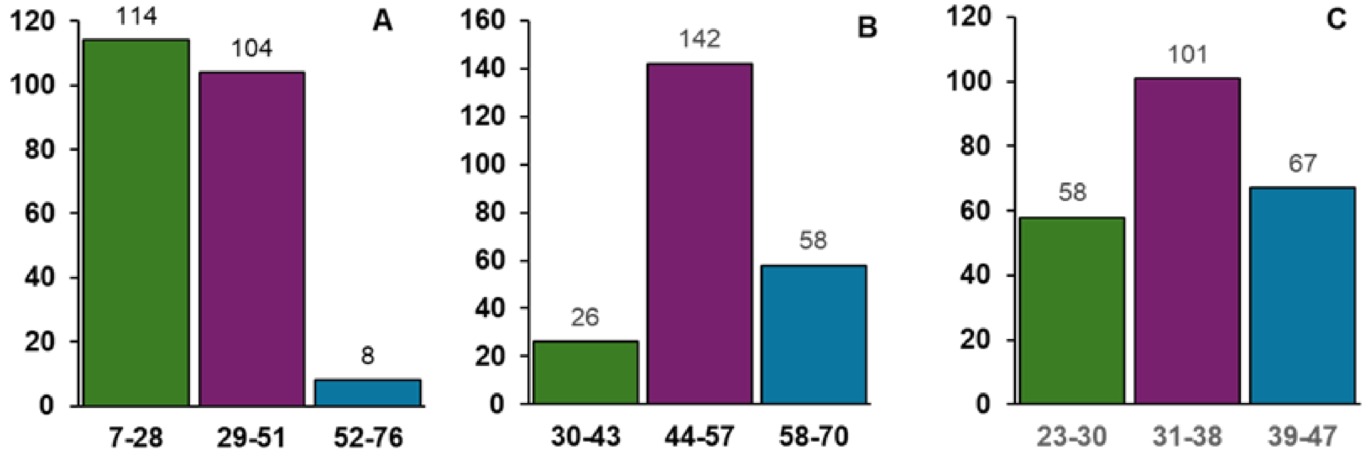

Figure 4. The histogram of the crab weight (A), carapace width (B), and carapace length (C) categorized into small, medium, and large classes.

cate optimal conditions, but rather a snapshot of the current population structure. It's possible that environmental or ecological factors may be limiting the growth or survival of larger crabs, leading to their underrepresentation in the sample. Furthermore, if there are existing records of more abundant larger sizes in the past, it could suggest that the current population is not thriving as well as it once did. This highlights the importance of considering historical data and long-term trends when interpreting population dynamics (Alberts-Hubatsch et al. 2016; Young & Elliott 2019).

Power regression model revealing allometric growth patterns

The results of fitting various data models of the correlation between body weight (WT) and carapace length (CL) alongside to weight and carapace width (CW) in the collected crabs was presented in Table 2. Data reveals that the relationship between the length/width and weight of *T. crenata* is best described by a non-linear power regression model. The WT-CL relationship, the power model ($y = 11.825x^{0.3286}$) provided the best fit with an $R^2=0.6820$. This suggests that approximately 68.2 % of the variation in weight can be illustrated by variations in the length of *T. crenata's* carapace. The power model also suggested that the association between weight and carapace length is nonlinear, where weight increasing at a decreasing rate as carapace length increases. For the WT-CW relationship, the power model ($y = 19.076x^{0.3014}$) also suggested the best fit, with an $R^2=0.7478$, indicated that approximately 74.78 % of the variation in weight can be explained by variations in the width of carapace. This model, which outperforms both exponential and linear models, indicates a strong and highly significant correlation between the crab's weight and its carapace dimensions (width and length) for pooled, female, and male data sets.

Building on the non-linear power regression model, the study also utilized a linearized form of the power equation to furtherly analyse the length/width-weight relationship of *T. crenata* (Table 3). The linearised form confirmed the strong correlation between the weight and carapace dimensions ($p<0.01$), with high coefficients of determination (R^2) values for all data sets. For instance, the R^2 value for the weight-carapace width relationship 0.7478,

Table 2. Fitting data models to LWR data. Body weight to carapace length (WT-CL), and body weight to carapace width (WT-CW).

Relationship	Data Models	Equations	R^2 values
WT-CL	Linear	$y = 0.4018x + 23.636$	$R^2 = 0.6571$
	Exponential	$y = 24.868e^{0.0116x}$	$R^2 = 0.6206$
	Logarithmic	$y = 11.16\ln(x) - 1.3834$	$R^2 = 0.6749$
	Power	$\mathbf{y = 11.825x^{0.3286}}$	$\mathbf{R^2 = 0.6820}$
WT-CW	Linear	$y = 0.5489x + 35.985$	$R^2 = 0.7288$
	Exponential	$y = 37.686e^{0.0107x}$	$R^2 = 0.7003$
	Logarithmic	$y = 15.151\ln(x) + 2.1237$	$R^2 = 0.7391$
	Power	$\mathbf{y = 19.076x^{0.3014}}$	$\mathbf{R^2 = 0.7478}$

Table 3. Allometric growth patterns of *T. crenata* with the corresponding R^2 value and p-value.

Relationship	Linearised Power Function	a	b	R^2 value	p-value	Type of growth
WT-CL	$\ln(y)= 0.3286 \ln(x) + 2.469$	0.32	2.47	$R^2 = 0.6820$	$p<0.01$	negative allometry
WT-CW	$\ln(y)= 0.3014 \ln(x) +2.949$	0.3	2.95	$R^2 = 0.7478$	$p<0.01$	negative allometry

indicated a strong fit. Similarly, the weight-carapace length relationship also showed high R^2 value (0.6820), further validating the robustness of the model.

The use of the linearised form not only reinforces the findings of the non-linear analysis but also provides a clearer understanding of the growth patterns (Jumawan et al. 2022). It highlights that the carapace dimensions increase at a slower rate compared to the weight, consistent with the negative allometric growth pattern observed. Hence, the linearized form of the power regression model provides a comprehensive and accessible way to analyse and to interpret the length/width-weight relationships in *T. crenata.* It confirms the non-linear nature of the growth patterns and offers valuable insights into the health and growth dynamics of this crab species in its natural habitat (Voje 2016).

The power regression models presented (Figure 5) illustrates the relationship between carapace length (CL), carapace width (CW), and weight in *T. crenata* crab samples. The model for the CW-Weight relationship ($y=11.825x^{0.3286}$, $R^2= 0.682$) where a strong positive correlation between was observed from these two variables which implies that as the carapace width of a crab increases, its weight also directly increases. Similar patterns of the model for the CL-Weight relationship ($y = 19.076x^{0.3014}$, $R^2 = 0.7478$) also illustrates a strong positive correlation which implies that a larger carapace length is directly associated with a greater weight. It was observed in the study from 2016, where carapace width has a positive growth pattern in weight for males, and a negative allometric pattern for females in the blue swimming crab, *Portunus segnis* (Hajjej et al. 2016). The R^2 values for both models demonstrate a substantial point of variation in weight made evidently through observed variations in carapace width and length. The strong relationships observed between carapace dimensions and weight highlight their potential utility in fisheries management, as reliable weight predictions can inform more efficient and sustainable harvesting practices while minimising bycatch (Mullowney et al. 2020). Although carapace width and length proved to be effective predictors of weight in this study, incorporating species-specific traits, environmental variables (e.g., temperature, salinity), and additional morphometric data could further refine predictive models and improve understanding of the biological and ecological factors influencing weight variation in *T. crenata.*

Crabs frequently display negative allometric growth, where carapace size increases more slowly than body weight during maturation. This pattern reflects energy allocation priorities, as the carapace's primary role in protection reduces the need for proportional scaling with body mass, which is instead driven by tissue and organ growth (Leite et al. 2014; Din et al. 2017). Sexual dimorphism is evident in many species: female mud crabs (*Scylla tranquebarica*) exhibit negative allometry, while males show positive allometry, gaining weight disproportionately relative to carapace size (Din et al. 2017). Similarly, in *Ucides cordatus*, females display negative allometric growth, whereas males grow isometrically, resulting in higher weight for equivalent carapace dimensions (Leite et al. 2014). These differences underscore sex-specific strategies in energy investment, often linked to reproductive roles.

Such patterns are influenced by life cycle stages; during maturation, energy may shift from growth to reproduction or survival, altering the condition factor (a health and energy reserve metric) and reinforcing negative allometry (Leite et al. 2014). These dynamics carry ecological and evolutionary consequences, such as stabilising selection on male genitalia for reproductive success (Voje 2016), though positive allometry can emerge in specific traits under environmental or biological pressures (Simpson et al. 2016).

Stress concentration and clamping behaviors play a critical role in de-

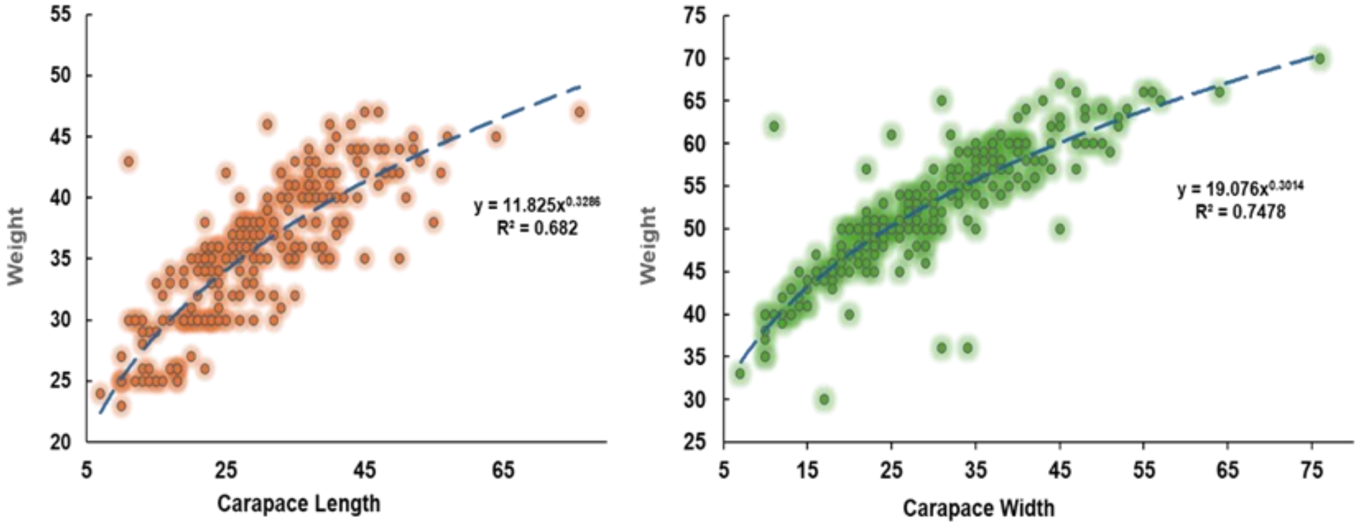

Figure 5. The power regression model of the length/width-weight of crab samples. The CW-CT and CW-CL relationship of pooled samples.

termining the effective bite force, with crabs adjusting their muscle force to avoid overload and potential damage to the claws—a trade-off against other positively or isometrically growing structures (Zhang et al. 2021). Energy allocation further prioritises muscles and reproductive organs over carapace expansion. Male spider crabs, for instance, may invest energy differentially: smaller males reproduce repeatedly, while larger males focus on a single reproductive event (Rosen et al. 2020). Similarly, in *Carcinus maenas*, males develop larger claws for competition, potentially inducing negative allometry in other body parts (Cothran & Thiel 2020).

Recent studies corroborate these trends. *Scylla* spp., *Callinectes sapidus*, and *Barytelphusa guerini* all demonstrate slowed carapace growth relative to biomass gain, with sex-based variations in scaling exponents (Devi & Smija 2015; Waiho et al. 2016; Widigdo et al. 2017). *Goniopsis cruentata* further highlights ontogenetic shifts, with negative allometry across morphometric traits (Silva et al. 2024). This conserved growth strategy optimizes energy use; smaller carapaces suffice for protection, freeing resources for locomotion and reproduction. In *Uca tangeri*, claw size—critical for mating—exemplifies how negative allometry balances reproductive success and foraging efficiency (Moruf & Ojetayo 2017). Even digestive anatomy reflects this pattern, as stomach allometry in brachyuran crabs aligns with dietary adaptations to habitat resources (Griffen et al. 2018). Thus, negative allometry in crabs represents a multifaceted adaptation, balancing biomechanical constraints, reproductive strategies, and environmental pressures through differential growth trajectories.

Spatial, sexual dimorphism, and condition factors

The substantial F-value of 56.743 and p-value less than .001 for the "Area" parameter indicate that *T. crenata* from different regions display distinct morphological characteristics (Table 4). In the same manner, the significant F-value of 23.018 and p-value below .001 for the "Sex" parameter implied that male and female *T. crenata* exhibit differences in their morphological characteristics. The non-significant interaction effect between area and sex (F-value = 0.558, p-value = 0.83) suggested that the effects of these factors on morphometric traits are independent from each other, which simply means that the effect of area on morphology is consistent across both sexes and vice versa. Weight was validated as a significant covariate (F-value = 77.518, p-value < .001), which suggest that heavier crabs tend to have different morphologi-

Table 4. MANCOVA analysis of morphometric traits and weight as covariate compared between factors area and sex of crabs, with *T* Test to comparing the LWR of crab samples.

Parameters	Wilk's Lambda Value	F-value	df1	df2	p-value
Area	0.294	56.743	9	213	<.001
Sex	0.507	23.018	9	213	<.001
Area * Sex	0.977	0.558	9	213	0.83
Weight	0.234	77.518	9	213	<.001
Parameters	Morphometry	x^{-} = Area 1	x^{-} = Area 2	T Test Value	p-value
Area	Weight	33.5	24.9	-4.87	<.001
	CW	54.8	49.2	-4.26	<.001
	CL	38.5	32	-3.71	<.001
	Morphometry	x^{-} = Female	x^{-} = Male	T Test Value	p-value
Sex	Weight	26.6	33.8	-4.87	<.001
	CW	50.5	54.6	-4.26	<.001
	CL	34.4	37.2	-3.71	<.001

cal traits compared to less heavier crabs. Morphological traits in intertidal crabs are influenced by sexual, allometric, and habitat factors, with claw size being particularly prominent and carapace shape often associated with habitat preferences (Vermeiren et al. 2021). Vermeiren et al. (2021) also emphasised that morphological variation arises from an intricate interplay of environmental, genetic, and physiological factors, highlighting the combined effects of sex, growth patterns, and habitat conditions. Further research could investigate the specific mechanisms driving these effects and examine the potential ecological implications of morphological variation in crabs.

The observed spatial and sexual dimorphism in *T. crenata* morphology has significant implications for ecological and evolutionary studies. Distinct morphological traits may influence feeding behaviors, mating success, and predator avoidance strategies (Daly et al. 2021). Additionally, understanding these variations can inform conservation efforts, focusing on habitat preservation and sustainable fishing practices.

Analysis of the condition factor (CF) for different categories of *T. crenata* (Figure 6). CF is a metric used to assess the overall health and well-being of a crab, with higher values indicating better condition. The box plots show the distribution of CF values for each category, with the box representing the middle 50 % of the data, the whiskers extending to the minimum and maximum values, and dots representing outliers. The Kruskal-Wallis test results ($p<0.01$) indicate significant differences in CF between some categories. Differences between areas could be attributed to environmental factors like food availability or water quality. While not highly significant, there might be subtle sex-specific differences in CF. Considering food availability is a critical environmental determinant influencing the distribution and behavior of crabs' species. Variations in crabs' habitat quality, namely: availability of prey, can significantly impact the reproductive success and morphological adaptations of crabs (Griffen & Norelli 2015), suggesting that food availability directly impacts the reproductive potential and overall fitness of crabs. Water quality, which includes salinity and sediment characteristics, also plays a key significant role in the distribution and habitat preference of crabs indicating water quality parameters are crucial in determining habitat suitability for various crab species (Mokhtari et al. 2015). Overall, higher CF values suggest well-nourished and healthy crabs, while lower values could indicate potential stress or nutritional deficiencies.

The data in Table 5 provides a comparative analysis of *T. crenata* size variations across Butuan Bay (Philippines), Panjang Island (Indonesia), and Setiu Wetlands (Malaysia), using carapace width (CW) and length (CL) as key metrics. Notably, crabs in Butuan Bay exhibit smaller average dimensions

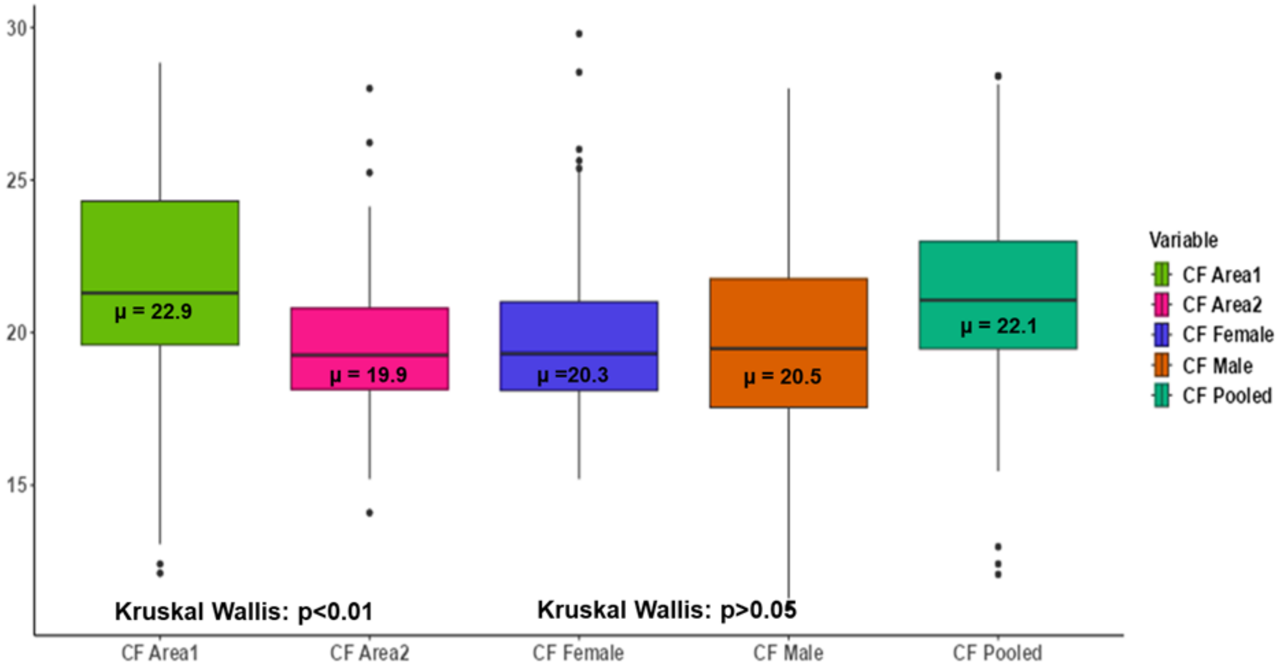

Figure 6. Condition factor of *Thalamita crenata.*

than those in other regions. Males in Butuan Bay measure 54.6 mm CW (max 70 mm) and 37.2 mm CL (max 47 mm), while females are smaller, averaging 50.5 mm CW (max 66 mm) and 34.4 mm CL (max 44 mm). In contrast, males from Panjang Island are significantly larger, with a mean CW of 59.53 mm (max 78 mm) and CL of 41.62 mm (max 55 mm), and females similarly surpass Butuan Bay specimens at 53.76 mm CW (max 70 mm) and 38.23 mm CL (max 57 mm). This trend is further emphasised by data from Setiu Wetlands, where males average 66.9 mm CW (max 81.9 mm)—markedly larger than Butuan Bay males—though CL data for this region is unavailable.

Pooled data for Butuan Bay, combining both sexes, reinforces the observed size disparity, with a mean CW of 52.21 mm (max 67 mm) and CL of 35.51 mm (max 47 mm), consistently lower than other locations. The inclusion of CL measurements strengthens evidence of potential size reduction, as differences persist across both metrics. These findings suggest environmental or anthropogenic pressures may be influencing growth patterns in Butuan Bay, warranting further investigation into factors such as habitat conditions, fishing practices, or genetic diversity.

The observed size reduction in Butuan Bay may stem from multiple stressors. Environmental degradation, such as pollution or habitat loss, could limit resource availability and impede growth. Overfishing is another critical concern, as selective harvesting of larger individuals may truncate population structure, leaving smaller, younger crabs to dominate the breeding pool (Pastor et al. 2024; Elvira et al. 2016). Over time, this pressure could drive genetic changes favouring smaller body sizes, as larger crabs are removed before reproducing. Smaller females may produce fewer eggs, reducing reproductive output and threatening population resilience. Such shifts in size structure could destabilise local ecosystems, altering predator-prey dynamics and diminishing the species' ecological role as a key intertidal engineer.

These comparison highlights the need for targeted conservation strategies. Mitigating environmental stressors through habitat restoration, enforcing size-based fishing regulations to protect mature individuals, and monitoring genetic diversity are essential steps to curb further decline. Future research should prioritise comprehensive data collection across all regions, including female specimens from Malaysia, to enable robust comparisons and clarify the mechanisms driving size differences.

Table 5. Comparison of mean sizes of CW and CL from previous studies in Indonesia and Malaysia.

Study Area	Dataset	Carapace Width (mm)			Carapace Length (mm)			Reference
		Mean	Min	Max	Mean	Min	Max	
Butuan Bay	Pooled	52.21	30	67	35.51	23	47	This Study
	Male	54.6	30	70	37.2	25	47	
	Female	50.5	33	66	34.4	23	44	
Panjang Island, Indonesia	Male	59.53	40	78	41.62	27	55	Susanto & Irnawati 2014
	Female	53.76	42	70	38.23	30	57	
Setiu Wetlands, Terengganu, Malaysia	Male	66.9	38.9	81.9	NA	NA	NA	Muhd-Farouk et al. 2017

CONCLUSION

This study on *Thalamita crenata* in Butuan Bay, Philippines, revealed significant sexual and spatial differences in morphometric relationships and condition factors based on 226 samples. Crabs from Cabadbaran (Area 1) were larger and in better condition than those from Buenavista (Area 2), with males generally larger than females, consistent with typical crustacean dimorphism. The weight–carapace length and width relationships showed negative allometry, and overall crab sizes were smaller compared to populations in Indonesia and Malaysia, likely due to overfishing, habitat degradation, or environmental stress. These findings highlight concerns for population sustainability and underscore the need for targeted management, such as size regulations, habitat protection, and improved fishing practices. Future studies should incorporate environmental variables (e.g., temperature, salinity) and genetic analyses to better understand the drivers of morphological variation and to support effective and localised conservation strategies.

AUTHOR CONTRIBUTION

JHJ conceptualised the study design, spearheaded the data analysis, and finalised the manuscript for publication. PJBP conducted the sampling and data collection and contributed to the discussion and data interpretation. RBC performed the literature review and participated in the discussion and data interpretation.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests, whether financial, personal, or professional, that could impact the validity or interpretation of the research findings presented in this article.

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