ASM Sc. J., 21(1), 2026

https://doi.org/10.32802/asmscj.2026.0103

Morphometrics Allometry of the Endangered Tri-spine Horseshoe Crab, *Tachypleus tridentatus* Leach, 1819 (Xiphosura: Limulidae), and Fishers' Perceptions from the Philippines

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The tri-spine horseshoe crab (*Tachypleus tridentatus* Leach, 1819) is an endangered species whose population status and human interactions remain poorly understood in the Philippines. This study aimed to integrate morphometric and allometric analyses of *T. tridentatus* with fishers' perceptions to inform species conservation. A total of 118 adult specimens (63 males and 55 females) were measured for prosomal length (PL), opisthosomal length (OL), carapace length (CL), carapace width (CW), telson length (TEL), total length (TL), and body weight (BW). Statistical comparisons using analysis of variance (ANOVA) revealed significant sexual dimorphism, with females exhibiting larger body dimensions than males. Growth patterns differed by sex, with females showing isometric growth for PL and CW, while males exhibited negative allometry for BW. Principal Component Analysis (PCA) indicated strong correlations among morphometric parameters, with the first component explaining 44.7% (males) and 46.4% (females) of total variance. To assess human dimensions, 90 fishers were interviewed across different ethnic groups. Univariate analysis revealed that Visayan fishers were the most supportive of proactive conservation actions, while PCA showed education and age as major factors shaping perception. These findings highlight the need for integrated biological and social approaches to strengthen conservation strategies for *T. tridentatus* in the Philippines.

Keywords: marine biology; Bycatch Practices; local ecological knowledge; marine conservation survey; Southeast Asia

I. INTRODUCTION

Horseshoe crabs, often called "living fossils", have remained morphologically unchanged since the Cambrian period (Akbar John *et al.*, 2018). From four species of horseshoe crab, three species including *Tachypleus tridentatus* are found in Asia (Chiu & Morton, 2003). Morphometric and allometric analyses effectively differentiate species and assess size variations, offering insights into the relationship between morphology and environmental factors (Srijaya *et al.*, 2010; Fauziyah *et al.*, 2021). Habitat, diet, developmental stage, and genetics further influence these variations (Jawahir *et al.*, 2017).

Morphometric and allometric assessments are not only useful for identifying morphological variation but also crucial in conservation decision-making, as they help determine maturity stages, suitable reproductive sizes, and habitat use across different life stages (Fauziyah *et al.,* 2021). However, these scientific insights are often inaccessible to the public and local resource users, which limits awareness and community participation in conservation actions. Therefore, integrating scientific data with fishers' local ecological knowledge (LEK) and perceptions provides a more holistic understanding of species status and enhances support for conservation initiatives.

Tachypleus tridentatus, classified as Endangered by the IUCN, faces multiple threats from habitat degradation, pollution, and overexploitation (Carmichael *et al.*, 2003; Laurie *et al.*, 2019). In Palawan, the species has been reported

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since 1958, with studies focusing on juvenile populations and sex differentiation (Sekiguchi, 1988; Schoppe, 2002; Almendral & Schoppe, 2007; Baylon & Alcantara-Creencia, 2022). Morphometric and allometric analyses are critical tools in conservation biology, as they help determine maturity stages, suitable sizes for reproduction, and habitat preferences across life stages (Fauziyah *et al.*, 2021). Nevertheless, information derived solely from morphometric and allometric patterns is insufficient for formulating effective conservation strategies, as it overlooks socio-cultural and behavioural factors influencing human-wildlife interactions. Understanding fishers' perceptions and practices provides essential context for applying scientific findings in real-world conservation efforts.

Length-weight relationship models are essential for assessing wild populations, though their accuracy diminishes with small sample sizes (Mohamad *et al.*, 2016). In many regions, horseshoe crabs are killed as bycatch or in ghost nets, including in Palawan, where habitat destruction and fishing activities threaten their survival (Almendral & Schoppe, 2005; Iwaoka & Okayama, 2009; Manca *et al.*, 2017). Despite these challenges, horseshoe crabs remain classified as "data deficient" (Almendral & Schoppe, 2005). This ecological uncertainty highlights the vulnerability of the species, which exhibits slow growth, late sexual maturity, and limited dispersal capability. These life-history traits make populations highly sensitive to habitat loss and localized exploitation (Wang *et al.*, 2020). Addressing these challenges requires not only biological monitoring but also the inclusion of LEK to ensure conservation actions are contextually grounded and socially supported.

Understanding the perspectives of local communities regarding wildlife and their natural surroundings is essential for crafting appropriate conservation strategies and implementing effective management actions (Hasan & Csányi, 2023). This is especially important for species like *T. tridentatus*, which often receive less attention in conservation efforts (Pati *et al.*, 2020). The most recent live specimen measurements of the adult population of *T. tridentatus* in Palawan were conducted by Baylon and Alcantara-Creencia (2022). However, their study was limited to differentiating males and females based on morphological characteristics (see Figure 2 for the abbreviations of morphometric parameters used).

This study aimed to establish size classifications and perform sex-specific allometric analyses using six morphological indicators. Additionally, it assessed fishers' perceptions, bycatch practices, and how socio-demographic factors influence attitudes toward horseshoe crab conservation Palawan. By combining morphometric analyses with community-based perception data, this study bridges biological and social dimensions of conservation, contributing to evidence-based and participatory strategies for protecting *T. Tridentatus* in Palawan.

II. MATERIALS AND METHOD

A. Location of the Study

Allometric data for adult *T. tridentatus* were collected from Honda Bay (9°50'21"N, 118°46'12"E), Puerto Princesa City, Palawan, between September 2015 and August 2016 (Figure 1). Local fishers targeting blue swimming crab occasionally caught *T. tridentatus* as bycatch, often killing or discarding them. Researchers purchased 118 specimens and advised releasing tangled live individuals due to population declines. Samples were measured on-site and at Western Philippine University. Fishers' perceptions were assessed in three neighbouring coastal villages, Tagburos, San Jose, and San Pedro.

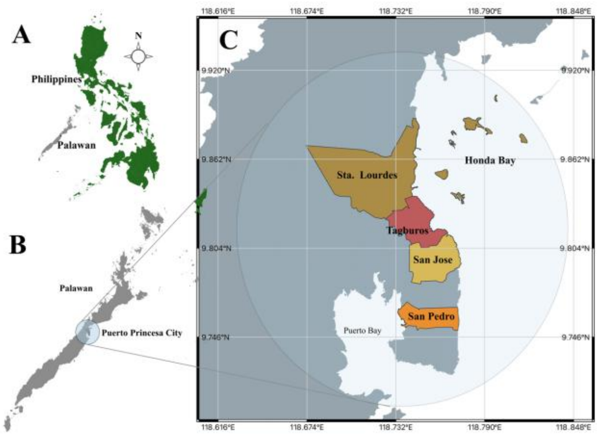


Figure 1. A map of the Philippines (A) and Palawan (B), showing the sampling sites in Barangays Sta. Lourdes, Tagburos, San Jose, and San Pedro, Puerto Princesa City, Palawan (C).

B. Species Identification and Morphometry

Species identification followed Yamazaki *et al.* (1988) and Chiu and Morton (2003). *Tachypleus tridentatus* was identified by its triangular telson cross-section and three opisthosoma spines, with additional smaller spines (Cartwright-Taylor *et al.*, 2011). Sex differentiation was based on genitalia and chelae on the second and third prosomal appendages. Six morphometric indicators (PL, OL, CL, CW, TEL, TL) were measured to 0.1 cm accuracy using a vernier calliper, and body weight (BW) to 0.01 kg accuracy using a digital balance. Morphometric ratios (PL/OL, CL/TL, and (PL+OL)/TEL) were calculated for sex comparisons (Chiu & Morton, 2003).

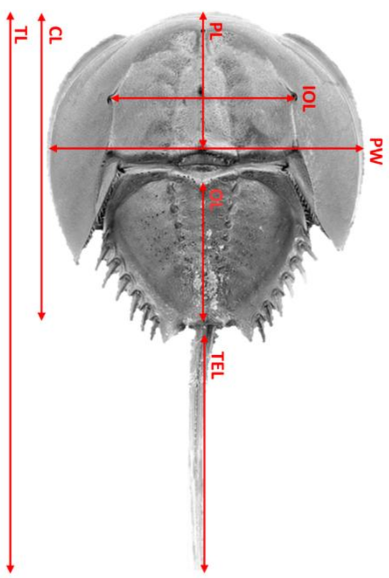


Figure 2. Body parameters used for morphological and allometric analyses of *Tachypleus tridentatus*; TL (total length), TEL (telson length), PL (prosoma length), OL (opisthosoma length), CL (carapace length), CW (carapace width), and BW (body weight).

C. Allometric Data Analysis

The measurements were grouped according to sex before the analyses. The Shapiro-Wilk and Levene's tests were used to determine the residuals' normality and the variance's homogeneity in the datasets (Zar, 1996). However, when the parameters largely did not meet criteria for normal distribution and homoscedasticity, the data were logarithmically transformed following the Kruskal–Wallis tests comparison of means between the two sexes.

Principal Component Analysis (PCA) was performed to summarise morphometric variation and identify correlated body dimensions contributing most to size and shape variation within each sex. Each morphometric variable (PL, OL, CL, CW, TEL, TL, BW) was standardised (z-score normalisation) to eliminate unit-scale effects. Separate PCAs were constructed for males and females to evaluate internal morphological variability rather than direct sex comparison. Components with eigenvalues greater than 1 were retained, and factor loadings above 0.40 were considered significant (Fauziyah *et al.*, 2021). The first principal component (PC1) generally represented overall size variation, while subsequent components reflected shape differences independent of size. PCA biplots were used to visualise relationships among morphometric traits (Figure 3).

A log-transformed exponential equation was applied to calculate and express the BW-TL, BW-PL, BW-OL, BW-CL, and BW-CW measurements for males and females (Froese, 2006; Jawahir *et al.*, 2017) (Eq 1):

$$W_i = aL_i^b \qquad (1)$$

where Wi represents the body weight, Li denotes the corresponding length parameter, a represents the intercept of the relationship and *b* is the slope between logLi and logWi. The length and length/width relationships were analysed using a backward stepwise elimination linear regression equation (Ming *et al.*, 2016; Mohamed *et al.*, 2021), expressed as (Eq 2):

$$Y_i = a + bX_i \qquad (2)$$

where Yi represents one length parameter of *T. tridentatus* and Xi denotes a different length parameter of the same individual, a is the intercept of the relationship and b represents the slope between logLi and logWi. In TEL-TL, TEL-CL, TEL-CW, PL-TL, PL-CW, and PL-CL relationships (Ming *et al.*, 2016), b coefficient < 1 indicates negative allometric growth where the Y-axis (TEL, PL) parameters grow relatively more slowly than the X-axis (TL, CL, CW). In contrast, a b coefficient > 1 signifies positive allometric growth, whereas a b value of exactly 1 denotes isometric growth.

However, because the dimensions of X and Y differed at the length-weight relationships (BW-TL, BW-PL, BW-OL, BW-CL, BW-CW), a negative-allometric growth is referred to when the b value < 3, whereas the b coefficient > 3 indicated a positive-allometric growth, and the b value = 3 showed an isometric growth. Consequently, the b coefficient serves as an indicator of the growth pattern in this study (Syuhaida *et al.*, 2019). Using Bailey's t-test at a significant level of 5%, differences from the isometric values (H0: b = 3 or H0: b = 1) were determined to be significant using the equation below (Nair *et al.*, 2015) (Eq 3):

$$t_s = \left|\frac{3-b}{Sb}\right| \text{ or } t_s = \left|\frac{1-b}{Sb}\right| \quad (3)$$

In Bailey's t-test, b refers to the slope of the linear regression, Sb represents the standard error of the b coefficient, 3 indicates the isometric value for length-weight relationships, and 1 corresponds to the isometric value for length-length or length-width relationships.

D. Questionnaire Design and Collection of Fishers' Perceptions Data

A survey was conducted from 20 November to 2 December 2022, targeting fishers in three local communities who had substantial experience with or general familiarity with horseshoe crabs. The selection of respondents employed a snowball sampling method, focusing on individuals with significant interaction with the marine environment (cf. Newing *et al.*, 2011). Eligibility was limited to individuals aged 19 to 90, with one respondent per household. Ninety participants voluntarily completed anonymous face-to-face interviews in Tagalog using a semi-structured questionnaire.

The questionnaire was adapted from Meilana and Fang (2020) and Pati *et al.* (2020), comprising three sections: sociodemographic information, bycatch experiences and consumption behaviour, and fishers' perceptions of horseshoe crab status and management. Sociodemographic variables included age group (19-29, 30-39, 40-49, 50-59, 60-90 years), educational attainment (elementary, secondary, tertiary), years as a fisher (<1, 1-2, 3-4, 5-10, >10 years), religion (Roman Catholic, Born Again Christian, Iglesia Ni Cristo, Saksi Ni Jehovah, Seventh Day Adventist, Islam), and ethnicity (Visayan, Cuyonon, Tagalog).

Section 2 consisted of eight questions exploring the respondents' interactions with horseshoe crabs, their consumption patterns, and the ecological contexts of their encounters (mudflats, mangroves, coral reefs, others). It also investigated unintentional captures during fishing, the condition of captured specimens, and the impacts on fishing nets, including costs associated with repairs. Section 3 gathered respondents' perspectives on horseshoe crab populations, their ecological significance, and anticipated future trends. This section employed a 4-point Likert scale to assess opinions on population trends and explored attitudes towards protection, the legality of intentional killing, willingness to support conservation efforts, and preferred engagement levels (personal, household, educational campaigns, advocacy).

E. Reliability and Validity Measurements of the Questionnaire and Data Analysis

The questionnaire was piloted with academe and community members, and validated using Pearson's correlation, Corrected item-total correlation, and Cronbach's α (Fauziyah *et al.*, 2023). Binary responses (yes/no) were scored as 1 or 0, and Likert scale responses (3 to 5 points) were standardised to 1-3, 1-4, and 1-5 (Fauziyah *et al.*, 2023). Open-ended responses were coded as 0 (no answers) and 1 (answered responses). Sections 2 and 3 were categorised into four aspects: societal relationships, bycatch practices, LEK, and conservation. A significance threshold of $p < 0.05$ was used, and the corrected item-total correlation coefficient surpassed the corresponding critical value from the Pearson correlation table (Corradini *et al.*, 2022). Reliability was confirmed with Cronbach's α > 0.7, indicating acceptable internal consistency (Barbera *et al.*, 2021). Principal Component Analysis with a factor loading threshold > 0.40 visualised the association of sociodemographic variables with fishermen's perceptions of *T. tridentatus* (Pati *et al.*, 2020; Fauziyah *et al.*, 2021).

This study confirmed the questionnaire's reliability and internal consistency in evaluating fishers' perceptions of horseshoe crab interactions and conservation attitudes (Supplementary Table 1). Corrected item-total correlations and Pearson's coefficients were calculated for all 16 items across four constructs, with a validity test r-table value of 0.486 at 120 degrees of freedom. All analyses were conducted using the R statistical software (R Core Team, 2016).

III. RESULT AND DISCUSSION

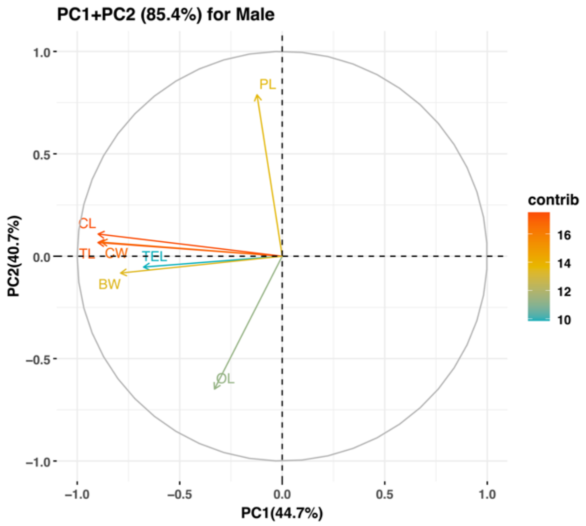
A. Morphometric Analyses

A total of 118 adult *T. tridentatus* (Males = 63, Females = 55) were analysed and no juvenile individuals were found. The mean values (±SD) of six morphometric indicators, stratified by sex, along with normality and homoscedasticity test results are presented in Supplementary Table 2. These indicators include TL (54.34±8.72 cm), CW (26.29±3.45 cm), CL (26.19±4.06 cm), PL (14.81±2.20 cm), OL (11.69±2.23 cm), TEL (27.64±4.60 cm), and BW (1.45±0.70 kg). Females exhibited higher mean values across all parameters compared to males. Females of *T. tridentatus* had significantly larger TL (57.50±10.69 cm vs. 51.58±5.22 cm), CW (27.58±4.06 cm vs. 25.17±2.29 cm), CL (28.00±4.85 cm vs. 24.62±2.29 cm), PL (15.81±2.58 cm vs. 13.93±1.30 cm), OL (12.29±2.48 cm vs. 11.17±1.86 cm), TEL (29.15±4.88 cm vs. 26.33±3.92 cm), and BW (1.86±0.81 kg vs. 1.09±0.29 kg) than males ($p \leq 0.008$). Morphometric ratios (PL/OL, CL/TL, and (PL+OL)/TEL) showed no significant differences ($p > 0.05$; Supplementary Table 3).

Barlett's test confirmed the adequacy of the data for PCA ($p < 0.05$). The contributions of morphometric characters of *T. tridentatus* to PCA highlighting those that distinguish between males and females. The PCA reduced six morphometric characters into one factor per sex, with eigenvalues above one. In males, the first principal component (PC1) explained 44.7% of the variance, and the second (PC2) accounted for 40.7%. For females, PC1 explained 46.4% of the variance, with PC2 contributing 41.3% (Figure 3).

In males, the PCA identified TL, CW, CL, TEL, and BW as the key loadings on PC1, while all body parameters were significant for females. Factor loadings greater than 0.40 were considered significant. The first principal component (PC1) for both sexes represents the overall body size, as all measured morphometric parameters loaded positively. Higher PC1 scores therefore correspond to larger individuals, confirming that females, which exhibit higher PC1 scores, are generally larger in size. PC2 likely captures proportional differences in body shape, such as relative telson or opisthosoma lengths.

Also, Figure 3 illustrates PCA biplots, demonstrating positive correlations among CW, CL, PL, OL, TEL, and BW in both sexes according to PC1. The biplot angles indicate strong correlations among all morphometric characters, except OL and PL. The PC1 exhibited robust correlations with eigenvalues greater than one. The direction and length of vectors in the biplot indicate the strength and correlation of each morphometric variable with the principal components. Longer vectors reflect stronger influence on the component, while the angles between vectors show the degree of correlation among variables (Greenacre *et al.*, 2022).



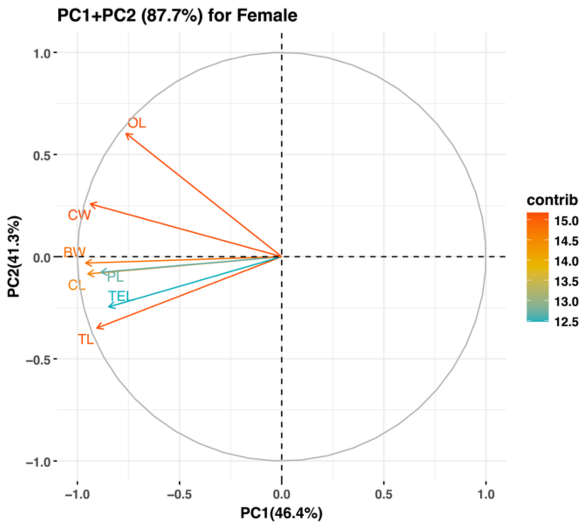


Figure 3. The PCA graphs of variables and PCA biplot of morphometric parameters for male and female *Tachypleus tridentatus* from Honda Bay, Puerto Princesa City, Palawan, Philippines.

The closest references to this study are Almedral and Schoppe (2007), who focused on the juvenile *T. tridentatus* in Puerto Princesa City, and Baylon and Alcantara-Creencia (2022), who examined the morphology of *T. tridentatus* and *C. rotundicauda* in Honda Bay. In contrast to previous studies, this research is the first to document the allometric patterns of adult horseshoe crabs in Palawan, Philippines. Understanding the relationship between body parameters is essential for assessing growth patterns (Panda & Naik, 2017), with morphometric variations reflecting population maturity (Syuhaida *et al.*, 2019). The data confirm the maturity of the population, as prosomal widths for females and males were ≥27.8 cm and ≥24.4 cm, respectively (Sekiguchi, 1988).

Females were significantly larger and heavier than males, consistent with findings from Hong Kong (Chiu & Morton, 2003), Malaysia (Manca *et al.*, 2021; Mohamad *et al.*, 2016), and China (Yamasaki *et al.*, 1988; Chen *et al.*, 2015). These differences are characteristic of horseshoe crabs (Chiu & Morton, 2001; Chatterji *et al.*, 2011) and are linked to females' additional instar stage during maturation (Sekiguchi *et al.*, 1988). Factors such as continuous juvenile hormone production (Levin, 2003) and egg presence in the prosoma (Mohanty *et al.*, 2014) further explain the larger size and weight of females.

Size differences also relate to mating behaviours, with smaller males often more successful in amplexing females (Sugg *et al.*, 2002). However, this study found no significant differences in PL/OL, CL/TL, and (PL+OL)/TEL ratios between sexes, aligning with observations from Hong Kong (Chiu & Morton, 2003). This suggests possible regional variations between the *T. tridentatus* populations of Palawan and other locations (Yamasaki *et al.*, 1988).

B. Allometric Analyses

Generally, the coefficient of determination for body parameters varied, with female *T. tridentatus* exhibiting a superior model fit compared to males (Table 1, Figures 4-7). The allometric coefficient (*b*) for the weight-length relationships ranged from 0.338 to 2.783, while length-length relationships varied from 0.035 to 1.350. The weight-length relationships demonstrated that the BW parameter scaled proportionally with the PL and CW parameters in females, revealing an isometric growth pattern ($t_s < t_{tab}$, $p < 0.05$). Conversely, the males BW parameter grew relatively slower than the TL, TEL, PL, OL, CL, and CW parameters (negative allometric, $b < 3$, $t_s > t_{tab}$, $p < 0.05$). For females, TL, TEL, OL, and CL showed hypoallometric growth patterns.

In the length-length relationships, the TEL-TL, TEL-CL, and TEL-CW relationships for males showed isometric growth ($t_s < t_{tab}$, $p < 0.05$), while females exhibited hyperallometric growth (positive allometric, $b > 1$, $t_s < t_{tab}$, $p < 0.05$) (Figure 6, Figure 7). The males' PL parameter grew relatively faster than the TL, CL, and CW parameters (positive allometric, $b < 1$, $t_s > t_{tab}$, $p < 0.05$). In females, similar growth patterns were exhibited for the PL parameter, but with isometric growth relative to CW parameter. The BW-TEL, PL-TL, and PL-CW relationships for males were non-significant ($p > 0.05$) in the models.

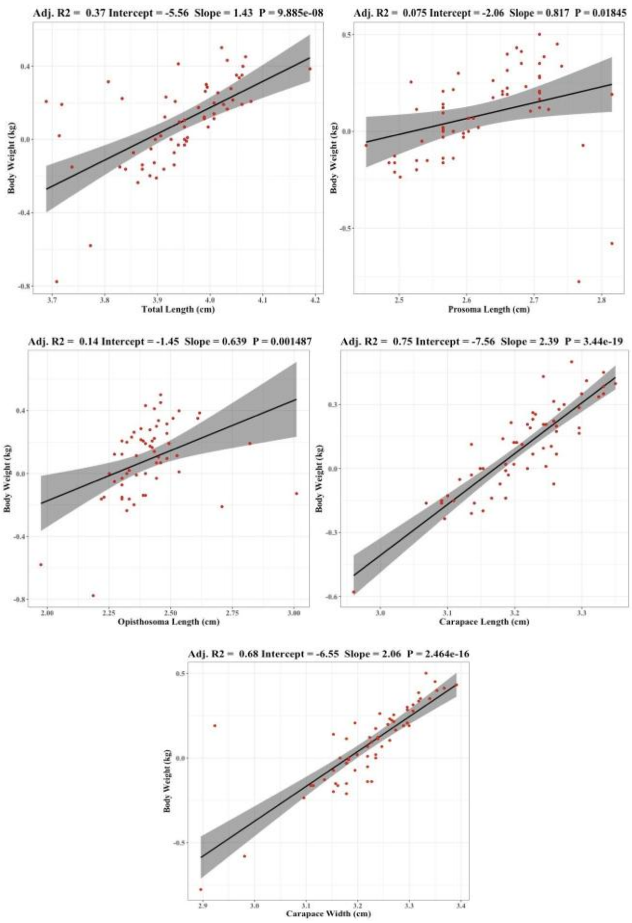


Figure 4. Total weight-length relationships of male *Tachypleus tridentatus* from Honda Bay, Puerto Princesa City, Palawan.

Table 1. The morphometric parameters relationships and growth pattern for male and female *Tachypleus tridentatus* from Honda Bay, Puerto Princesa City, Palawan, Philippines. The value of $t_s < t_{tab}$ indicated isometric growth, while $t_s > t_{tab}$ indicated allometric growth

Body Parameters Relationship	Statistical Parameters					Allometric Equation	Bailey's test			Growth Pattern
	b (95% CI)	S*b*	t_b	$b_{p\text{-value}}$	Adj. R^2		β	t_{tab}	t_s	
Males										
BW-TL (N=59)	1.432 (0.96, 1.90)	0.236	6.07	$<0.001^{S}$	0.37^{S}	$W_i=-5.555L_i^{1.432}$	3	2.00	6.644^{S}	Allometric$^{(-)}$
BW-TEL (N=60)	0.338 (−0.16, 0.84)	0.252	1.34	0.180^{NS}	0.01^{NS}	$W_i=-1.044L_i^{0.338}$	3	2.00	10.563^{S}	Allometric$^{(-)}$
BW-PL (N=59)	0.817 (0.14, 1.49)	0.337	2.42	0.018^{NS}	0.07^{S}	$W_i=-2.059L_i^{0.817}$	3	2.00	6.478^{S}	Allometric$^{(-)}$
BW-OL (N=59)	0.639 (0.25, 1.02)	0.192	3.33	0.001^{NS}	0.14^{S}	$W_i=-1.451L_i^{-0.639}$	3	2.00	12.297^{S}	Allometric$^{(-)}$
BW-CL (N=57)	2.385 (2.03, 2.74)	0.179	13.30	$<0.001^{S}$	0.75^{S}	$W_i=-7.562L_i^{2.385}$	3	2.00	3.436^{S}	Allometric$^{(-)}$
BW-CW (N=59)	2.060 (1.69, 2.43)	0.183	11.30	$<0.001^{S}$	0.68^{S}	$W_i=-6.554L_i^{2.060}$	3	2.00	5.137^{S}	Allometric$^{(-)}$
TEL-TL (N=61)	1.350 (1.16, 1.54)	0.097	13.87	$<0.001^{S}$	0.75^{S}	$Y_i=-2.057-2.057X_i$	1	2.00	-3.508^{NS}	Isometric
TEL-CL (N=58)	0.609 (0.05, 1.16)	0.278	2.19	0.032^{S}	0.06^{S}	$Y_i=1.310+0.609X_i$	1	2.00	1.406^{NS}	Isometric
TEL-CW (N=61)	0.532 (0.12, 0.94)	0.203	2.61	0.011^{S}	0.09^{S}	$Y_i=1.546+0.532X_i$	1	2.00	1.205^{S}	Isometric
PL-TL (N=61)	0.126 (−0.10, 0.35)	0.113	1.11	0.270^{NS}	0.00^{NS}	$Y_i=2.135+0.126X_i$	1	2.00	7.734^{S}	Allometric$^{(+)}$
PL-CL (N=58)	0.663 (0.41, 0.92)	0.128	5.17	$<0.001^{S}$	0.30^{S}	$Y_i=0.491+0.663X_i$	1	2.00	2.633^{S}	Allometric$^{(+)}$
PL-CW (N=61)	0.035 (−0.21, 0.28)	0.123	0.29	0.780^{NS}	0.00^{NS}	$Y_i=2.516+0.035X_i$	1	2.00	7.845^{S}	Allometric$^{(+)}$
Females										
BW-TL (N=53)	2.116 (1.76, 2.47)	0.176	12.10	$<0.001^{S}$	0.73^{S}	$W_i=-8.025L_i^{2.116}$	3	2.01	5.023^{S}	Allometric$^{(-)}$
BW-TEL (N=53)	2.136 (1.56, 2.72)	0.289	7.40	$<0.001^{S}$	0.50^{S}	$W_i=-6.664L_i^{2.136}$	3	2.01	2.990^{S}	Allometric$^{(-)}$
BW-PL (N=53)	2.657 (2.26, 3.06)	0.200	13.3	$<0.001^{S}$	0.76^{S}	$W_i=-6.791L_i^{2.657}$	3	2.01	1.715^{NS}	Isometric
BW-OL (N=52)	1.618 (1.04, 2.19)	0.287	5.63	$<0.001^{S}$	0.37^{S}	$W_i=-3.512L_i^{1.618}$	3	2.01	4.815^{S}	Allometric$^{(-)}$
BW-CL (N=53)	2.578 (2.32, 2.84)	0.129	20.0	$<0.001^{S}$	0.88^{S}	$W_i=-8.040L_i^{2.578}$	3	2.01	3.271^{S}	Allometric$^{(-)}$
BW-CW (N=53)	2.783 (2.25, 3.31)	0.264	10.54	$<0.001^{S}$	0.67^{S}	$W_i=-8.693L_i^{2.783}$	3	2.01	0.822^{NS}	Isometric
TEL-TL (N=53)	0.679 (0.55, 0.80)	0.064	10.55	$<0.001^{S}$	0.67^{S}	$Y_i=0.620+0.679X_i$	1	2.00	5.016^{S}	Allometric$^{(+)}$
TEL-CL (N=53)	0.690 (0.52, 0.86)	0.083	8.35	$<0.001^{S}$	0.56^{S}	$Y_i=1.070+0.690X_i$	1	2.00	3.735^{S}	Allometric$^{(+)}$
TEL-CW (N=53)	0.767 (0.54, 0.99)	0.114	6.74	$<0.001^{S}$	0.45^{S}	$Y_i=0.823+0.767X_i$	1	2.00	2.044^{S}	Allometric$^{(+)}$
PL-TL (N=53)	0.590 (0.43, 0.74)	0.077	7.63	$<0.001^{S}$	0.51^{S}	$Y_i=0.368+0.590X_i$	1	2.00	5.324^{S}	Allometric$^{(+)}$
PL-CL (N=53)	0.731 (0.58, 0.88)	0.073	9.99	$<0.001^{S}$	0.68^{S}	$Y_i=0.322+0.731X_i$	1	2.00	3.685^{S}	Allometric$^{(+)}$
PL-CW (N=53)	0.909 (0.73, 1.09)	0.089	10.23	$<0.001^{S}$	0.66^{S}	$Y_i=-0.259+0.909X_i$	1	2.00	1.022^{NS}	Isometric

BW: body weight, CL: carapace length, TEL: telson length, TL: total length, PW: prosoma width, OL: opisthosoma length, N: total number of samples analyzed after removing outliers, *b*: represents the slope of the relationship between $\log X_i$ and $\log Y_i$, CI: 95% confidence interval of the slope coefficient, S*b*: standard error of the b coefficients, t_b: the t-test statistic for H_o of *b*: 0, $b_{p\text{-value}}$: *p*-value of the slope coefficient, Adj. R^2: adjusted coefficient of determination, β: allometric value, t_{tab}: critical values of the t distribution, t_s: Bailey's t-test for allometric values, S: Significant, and NS: Not significant.

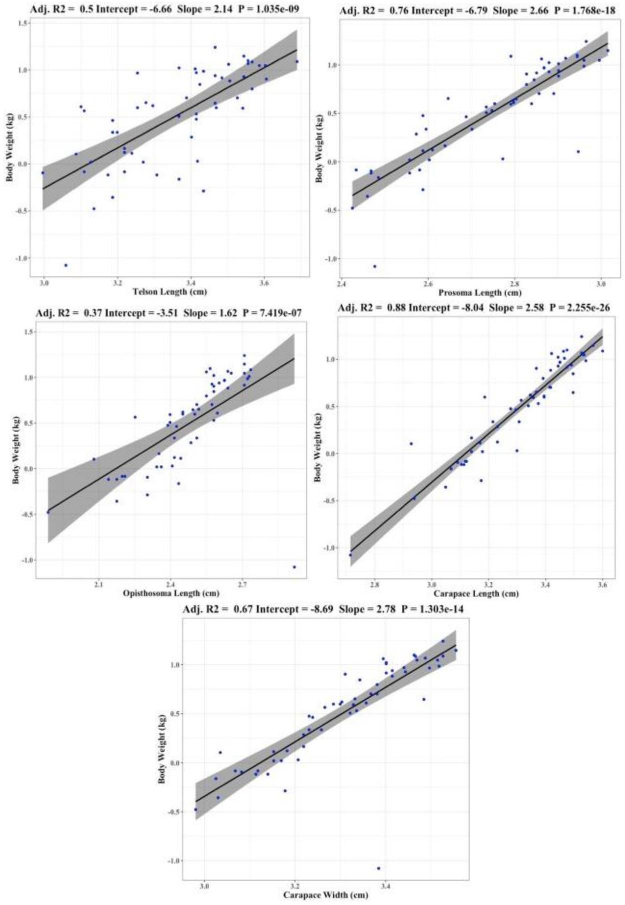


Figure 5. Total weight-length relationships of female *Tachypleus tridentatus* from Honda Bay, Puerto Princesa City, Palawan.

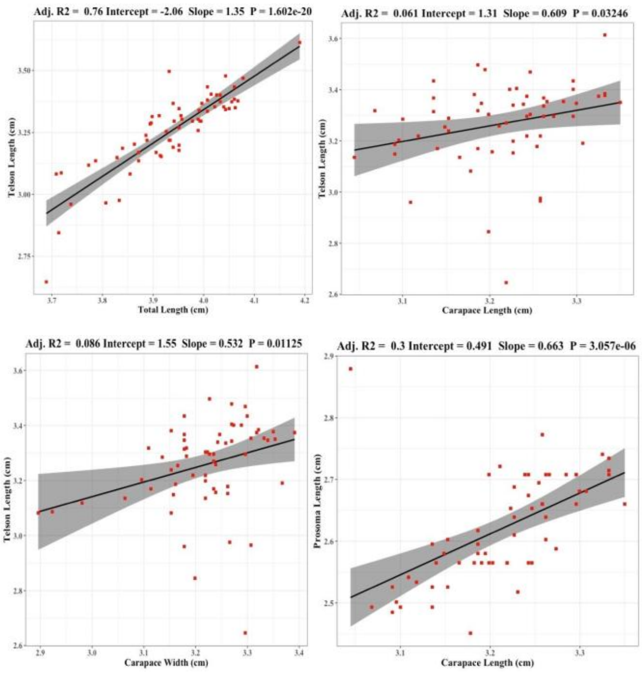


Figure 6. Total length-length relationships of male *Tachypleus tridentatus* from Honda Bay, Puerto Princesa City, Palawan.

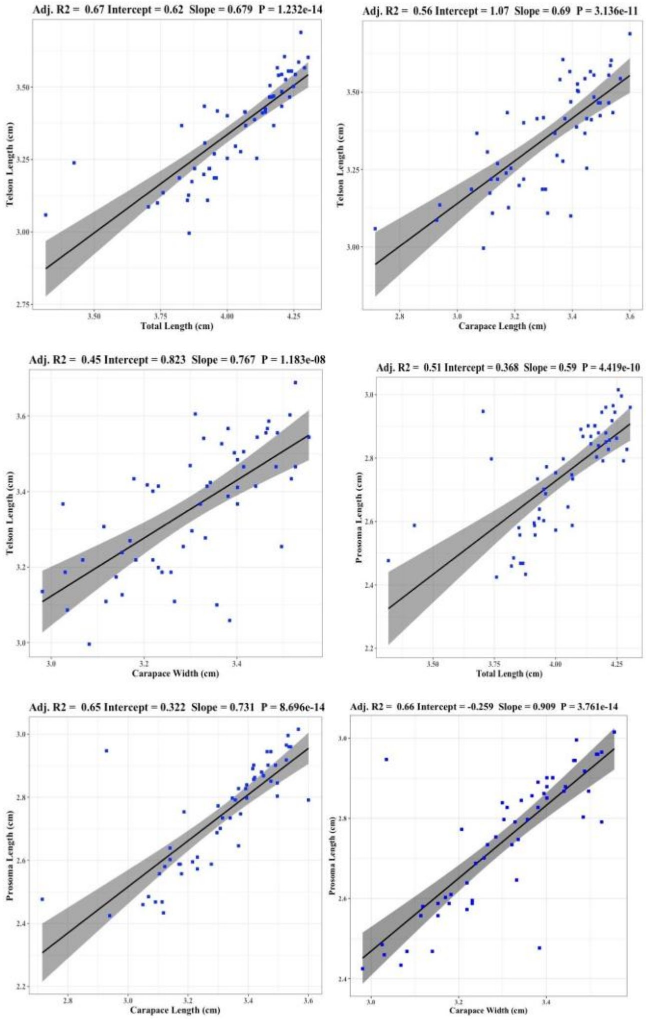


Figure 7. Total length-length relationships of female *Tachypleus tridentatus* from Honda Bay, Puerto Princesa City, Palawan.

Horseshoe crabs exhibit a logarithmic growth pattern, with growth slowing at each stage and ceasing upon maturity after multiple molts (John, 2012). Length-weight relationships showed negative allometry for both sexes, except for females, whose BW and CW displayed isometric growth. Due to the lack of published data on the allometry of *T. tridentatus*, direct comparisons with other species like *T. gigas* in Malaysia (Jawahir *et al.*, 2017; Razak & Kassim, 2018), Indonesia (Fauziyah *et al.*, 2021), and West Peninsular Malaysia (Chan *et al.*, 2022) were not possible. Notably, *T. gigas* in South Sumatra exhibited an isometric BW-CL relationship (Fauziyah *et al.*, 2021).

Both sexes exhibited negative allometric growth in the TL-BW relationships, a trend similarly noted in previous studies on *C. rotundicauda* on the West Coast of Peninsular Malaysia (Mohamed *et al.*, 2021) and Bintan Bay, Indonesia (Anggraini *et al.*, 2017). Various factors, including habitat, water quality, maturity stage, diet, population density, and genetics, can influence horseshoe crab morphometrics. Further research using molecular tools is recommended to better understand growth variations across populations (Srijaya *et al.*, 2010).

C. Fishers' Perceptions on Horseshoe Crab Interactions and Conservation

Fishers from Tagburos, San Jose, and San Pedro showed no significant differences in their LEK and attitudes toward horseshoe crab conservation ($p > 0.05$ for all items; Supplementary Table 4). The survey included 90 male fishers, averaging 39.36±13.75 years of age with 15.76 years of fishing experience. Most had lower educational attainment, with 46.67% completing elementary and 45.56% secondary school. Predominantly Catholic (70%), respondents were mainly Visayan (44.44%) or Cuyonon (42.22%). Kruskal-Wallis tests showed no significant differences ($p > 0.05$) in LEK or conservation attitudes across sites (Supplementary Table 5).

Younger fishers (19-29 years) reported frequent horseshoe crab encounters (87.5%) and higher bycatch rates (50%), with net damage being most common among older fishers (60-90 years; 86.7%) and those with over 10 years of experience (100%). Bycatch consumption was highest among older (44.4%-46.7%) and secondary-educated fishers (43.9%), while 71.3% of tertiary-educated fishers returned crabs to the sea (Supplementary Table 6).

Perceptions of population stability varied, with 62.5% of younger fishers believing in population decline, while 83.3%-85.7% of older fishers perceived populations as stable or increasing (Supplementary Table 7). Support for protection was highest among older fishers (91.3%) but lower among younger ones (62.5%). Secondary-educated fishers (82.9%) supported protection more than tertiary-educated fishers (43%), who often viewed bycatch as legal (71.4%) (Supplementary Table 8). Conservation willingness was strongest among those aged 40-49 years (33.3%), elementary and secondary-educated fishers (93%-95%), and Catholics (92.1%). Fishers with over 10 years of experience (100%) and Visayan fishers (83.3%) exhibited the highest conservation commitment.

In the PCA analysis of Societal Relationships, PC1 and PC2 explained 61.5% and 18.3% of the variance, respectively (Figure 8). For Bycatch Practices, PC1 accounted for 71.8% of the variance, with PC2 contributing 17.1%. PCA analyses indicated that squared cosine values were highest at PC1. 'Age group' (Age) and 'Number of years as a fisher' (Fishing) negatively correlated with 'Areas of Sightings' (SoI) and 'Incident of Bycatch' (IoB). These negative correlations suggest that older and more experienced fishers report fewer sightings or bycatch incidents, possibly due to differences in fishing zones, reduced effort, or shifting perception of abundance (Sáenz-Arroyo *et al.*, 2005). In line with Sy's findings, older fishers tend to perceive fewer depleted species than previous generations, whereas younger fishers report more frequent encounters. This indicates that conservation potential may be higher among younger fishers who encounter horseshoe crabs more frequently and may therefore be more receptive to management or protection measures.

'Education' had no correlation with SoI and IoB but showed a strong positive relationship with 'Frequency of Encounter' (FoE). The 'Fishing' also positively correlated with FoE but was unrelated to SoI and IoB. The correlation between 'Age' and FoE was weak. Vector length in the biplot represents each variable's contribution to the components, while vector direction shows correlations among variables and relationships to respondent profiles. Longer vectors for 'Fishing' indicate that years of fishing experience significantly explain variability in societal interactions, while shorter vectors for 'Education' and 'Ethnicity' indicate minimal contributions. Consistent with Fu *et al.* (2019), younger, less experienced fishers tend to report more frequent sightings and bycatch, reflecting greater awareness of horseshoe crab populations and potentially higher receptiveness to management or conservation interventions.

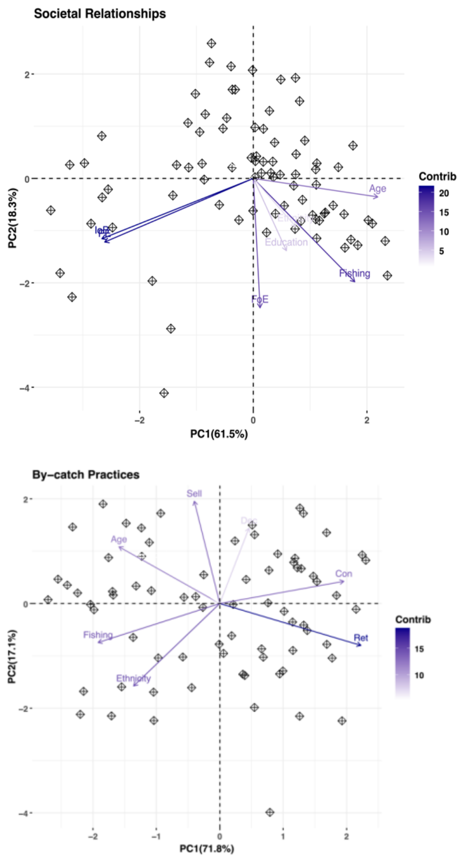


Figure 8. Principal component analysis showing the interaction between the demographic characteristics of the respondents and the community's perception based on societal relationships and bycatch practices of *Tachypleus tridentatus* from Puerto Princesa City, Palawan. Age=Age Group (18–24, 25–34, 35–44, 45–54, and 55–64), Fishing=Number of years as a fisher, FoE=Frequency of encounter, AoS = Areas of sighting, IoB=Incident of bycatch, PE = Problems encountered, Con=Consumed in the household, Ret=Returned to the sea, Sell=Sell it informally, and Dec=Decorative purposes. Vector length represents variable contribution to the component, and vector direction indicates correlations among variables and sample distribution.

For Bycatch Practices, the PC1 explained 71.8% of the variance, with PC2 contributing an additional 17.1%. The variables representing different uses of bycatch—consumption at home (Con), returning to the sea (Ret), selling informally (Sell), and decorative use (Dec)—showed varying associations with demographic factors. Older and more experienced fishers were more closely linked to selling crabs rather than consuming or returning them, suggesting that demographic characteristics shape bycatch utilisation patterns.

Vector direction and length indicate that fishing experience is the main driver of variability, followed by age and ethnicity, while education has minimal influence. The negative correlations between fishing experience and practices like consumption or returning crabs suggest that more seasoned fishers are less likely to release or eat the crabs, likely due to cultural norms or economic motivations. This behaviour likely reflects economic incentives and cultural norms, as experienced fishers are more aware of market opportunities for horseshoe crabs, including sale for consumption or traditional medicine (Fu *et al.*, 2019).

The prominent loading of 'Fishing' in both societal relationship and bycatch PCAs indicates substantial demographic variance among respondents—specifically that fishers with longer experience exhibit distinct behavioural patterns and perceptions. Older, more experienced fishers, often those with the longest years of livelihood dependence, tended to prioritise practical or economic decisions, such as selling bycaught horseshoe crabs or using them decoratively, rather than releasing them. In contrast, younger and less experienced fishers were more likely to release captured crabs, reflecting a more conservation-oriented disposition.

This demographic gradient indicates that fishing experience functions not only as a structural driver within the PCA but also as a proxy for generational and attitudinal variation. Years of fishing experience influence how individuals perceive ecological change: those with prolonged exposure to resource fluctuations may exhibit either conservation fatigue—accepting current depletion as normal (Reid & Vogel, 2006)—or pragmatic conservationism, supporting protection efforts while balancing livelihood constraints (Glanznig & Jellinek, 2006). Consequently, the link between experience and conservation support is multifaceted. Experienced fishers often possess deeper ecological understanding and express stronger support for conservation, yet their practices may remain shaped by subsistence needs. In contrast, younger fishers, though less informed by long-term ecological history, may show higher willingness to participate in conservation when it aligns with social or economic incentives. This distinction clarifies the observed PCA structure and the varied significance of socio-demographic factors.

In the LEK PCA, PC1 explained 65.4% and PC2 20.6% of the variance. The PC1 captured general knowledge about horseshoe crab distribution, abundance, and ecological role, while PC2 reflected subtle differences in respondents' understanding of species condition over time. 'Fishing' and 'Age' showed minimal correlations with current status (CS-HSC), importance (I-HSC), and availability (A-HSC), but negative correlations with the predicted population condition in 10 years (C10-HSC). This indicates that more experienced fishers anticipate future declines, perhaps due to accumulated ecological observations, whereas younger fishers may overestimate current abundance. Similar generational differences in perceptions of species decline have been documented in other contexts, where older community members recall historical abundance and changes more accurately than younger individuals (de Azevedo *et al.*, 2012; Forth, 2016). The LEK PCA therefore highlights demographic influence on temporal perception of species status, which is crucial for targeting education and outreach.

The Conservation PCA showed that the first two components explained 59.8% and 17.9% of the variance, respectively. Fishing experience was strongly linked to support for conservation initiatives (LoS), while showing only weak negative correlations with beliefs about illegality (IKC) and whether species deserve protection (DP). Age and ethnicity had a smaller effect. More experienced fishers were generally more supportive of conservation, even if they did not always fully recognise legal restrictions, indicating the importance of awareness programs. The second component captured differences in willingness to conserve (WC) and perceptions of ecological importance, with younger or less experienced fishers requiring additional guidance to align perceptions with conservation goals. These patterns align with previous studies showing that older individuals possess deeper ecological knowledge from years of experience (Nevo & Levin, 2025), while younger fishers may overestimate species abundance (Sáenz-Arroyo *et al.*, 2005). Recognising these demographic differences allows for conservation strategies that effectively engage all fisher groups.

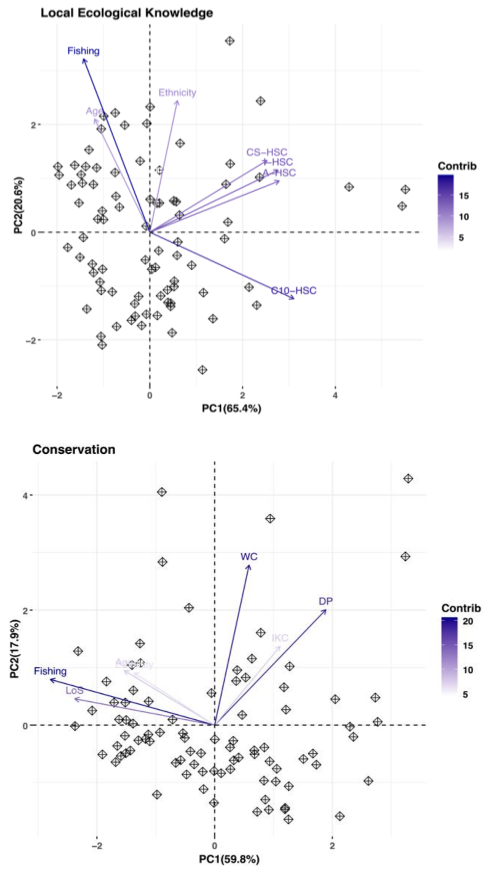


Figure 9. Principal component analysis illustrating the relationship between respondents' demographic profiles and community perceptions regarding local ecological knowledge and conservation involving *Tachypleus tridentatus* in Puerto Princesa City, Palawan. Age=Age Group (18–24, 25–34, 35–44, 45–54, and 55–64), Fishing=Number of years as a fisher, CS-HSC=Current Status of Horseshoe Crab, I-HSC=Importance of Horseshoe Crab, A-HSC=Availability of Horseshoe Crab in the sea, C10-HSC=Condition of the population of Horseshoe Crab in the next 10 years, DP=Deserve Protection, IKC=Illegal to Kill or Catch, WC=Willing to Conserve, and LoS=Level of Support.

Fishers frequently reported bycatch in coral reefs, mangroves, and muddy areas, although no recent population data exist for *T. tridentatus* in the Philippines (Laurie *et al.*, 2019). Historical records confirm their presence in Palawan and Busuanga Island (Schoppe, 2002). Horseshoe crabs' preference for shallow, sandy, or muddy habitats with seagrass and coral reefs highlights their role as indicators of ecosystem health (National Wildlife Federation, 2023). Conservation education is necessary to address shifting baseline syndrome (O'Bryhim & Parsons, 2015).

High bycatch rates are primarily linked to passive fishing gear like fish corrals, crab nets, and gill nets commonly used in Palawan (Balisco, 2019), similar to patterns in Malaysia (Mohamad *et al.*, 2016), Japan (Iwaoka & Okayama, 2009), Indonesia (Meilana & Fang, 2020), and China (Hong, 2019). Bottom trawling remains a major threat to adult horseshoe crabs (Laurie *et al.*, 2019), alongside habitat loss, pollution, biomedical harvesting, and illegal trade. Fishers reported consuming horseshoe crabs, especially gravid females, reflecting trends in Indonesia (Meilana *et al.*, 2015) and Malaysia (Manca *et al.*, 2015).

Unlike findings from India (Pati *et al.*, 2020), this study found no significant associations between socio-demographic factors and bycatch practices or conservation perceptions, possibly due to sample size limitations. Expanding future research to include broader community perspectives could provide deeper insights. While some fishers released horseshoe crabs, others consumed them, citing flavour preferences. This practice mirrors traditions in Native American communities (Carolina, 1998). Concerns about toxicity also influenced releases, aligning with reports of tetrodotoxin poisoning in China (Liao & Li, 2001).

The prominence of 'Fishing' as a key loading variable in the conservation PCA represents more than a statistical outcome—it illustrates a continuum of conservation perception. Fishers with longer experience tend to recognise the ecological significance of *T. tridentatus*, shaped by years of environmental observation and interaction. Yet sustained reliance on fishing for livelihood often limits behavioural change, indicating that ecological awareness does not necessarily translate into conservation practice. This pattern, increasingly recognised in recent literature (e.g., Sene-Harper *et al.*, 2019; Willemen *et al.*, 2013; Wright *et al.*, 2016), underscores the importance of developing context-sensitive conservation strategies that value experiential knowledge while addressing economic and livelihood constraints.

Fishers widely acknowledged horseshoe crabs' ecological significance as bioturbators, prey, and regulators of benthic populations (Botton *et al.*, 2003). Many expressed a strong desire for their protection, recognizing their association with turtles and their vital ecosystem roles. Despite legal protections, overfishing and illegal harvesting persist, contributing to the species' near-extinction in China from 2011 to 2016 (Liao *et al.*, 2019).

IV. CONCLUSION

This study's novel integration of allometric analysis and conservation perception assessment enhances the understanding of *T. tridentatus* in Palawan. The identification of sexual dimorphism and growth patterns establishes essential baseline data for monitoring population health in the Philippines. Although statistical tests revealed no significant associations between socio-demographic variables and conservation practices, the multivariate PCA results and narrative responses reveal subtle yet meaningful demographic patterns. Fishing experience, age, and education collectively shape differences in perception, knowledge, and willingness to conserve, even when these do not manifest as statistically significant correlations. These latent influences highlight that quantitative insignificance does not necessarily imply social irrelevance; rather, they underscore the complexity of human–wildlife interactions in small-scale fisheries.

Thus, while the data suggest that demographic factors do not directly predict conservation behaviour, they nonetheless mediate awareness, perception, and engagement through generational and experiential pathways. Future programs should therefore integrate demographic-sensitive approaches that strengthen conservation participation across fisher groups, bridging the gap between ecological understanding and sustainable practice.

V. ACKNOWLEDGEMENT

The allometric study is funded by the University of the Philippines Visayas Inhouse Research through the collaborative effort with the College of Fisheries and Aquatic Sciences, Western Philippines University, Princesa City, Philippines. Special thanks to Teresita Ana Venturillo-Hilario for her valuable assistance in the data collection. The study on fishers' perceptions is self-funded by the researchers but were grateful to the positive cooperation of the fishers and village chiefs of the three coastal villages.

VI. ETHICAL STATEMENT

This study was conducted in accordance with the ethical research standards of Western Philippines University and adhered to national guidelines for research involving human participants and wildlife. The survey instrument underwent expert validation by a licensed psychometrician and fisheries scientists to ensure cultural relevance, clarity, and reliability. Informed consent was obtained from all participants, who voluntarily took part without coercion or psychological stress. As a token of appreciation for their time, participants received modest food assistance. For the morphometric assessment, no horseshoe crabs were intentionally collected. Measurements were taken only from individuals incidentally caught by local fishers, and all live specimens were promptly released following established local wildlife handling protocols.

VII. REFERENCES

Akbar, JB, Nelson, BR, Hassan, S, Cheung, SG, Yusli, W, Bisnud, PD, Keiji, T, Yumiko, I & Siddharta, P 2018, 'A review on fisheries and conservation status of Asian horseshoe crabs', *Biodiversity and Conservation*, vol. 27, pp. 3573–3598, viewed https://doi.org/10.1007/s10531-018-1633-8.

Amaral, KDS, Vieira, IM, Osório, FM, Rocha, JDM & Lima, JF 2014, 'Bioecology of the crab *Ucides cordatus* (Crustacea, Decapoda) in mangroves influenced by the Amazon River, Brazil', *Acta Amazonica*, vol. 44, no. 2, pp. 213–222, viewed https://doi.org/10.1590/S0044-59672014000200007.

Anggraini, R, Bengen, DG & Natih, NMN 2017, 'Population structure and morphometry of horseshoe crab *Carcinoscorpius rotundicauda*, Latreille 1802 in Kampung Gisi coastal area of Bintan Bay of Riau Islands Province', *Jurnal Ilmu dan Teknologi Kelautan Tropis*, vol. 9, no. 1, pp. 211–220.

Aydin, İ & Aydin, C 2011, 'Length-length and length-weight relationships in *Nephrops norvegicus* from the Aegean Sea (Linnaeus, 1758)', *Mediterranean Marine Science*, vol. 12, pp. 121–128, viewed https://doi.org/10.12681/mms.56.

Barbera, J, Naibert, N, Komperda, R & Pentecost, TC 2020, 'Clarity on Cronbach's alpha use', *Journal of Chemical Education*, vol. 98, no. 2, pp. 257–258.

Baylon, JC & Alcantara-Creencia, LB 2022, 'Identification and morphology of the two horseshoe crab species, *Tachypleus tridentatus* (Leach, 1819) and *Carcinoscorpius rotundicauda* (Latreille, 1802) (Merostomata: Limulidae) from Honda Bay, Palawan, Philippines', *The Philippine Journal of Fisheries*, vol. 29, no. 2, pp. 176–192, viewed https://doi.org/10.31398/tpjf/29.2.2022-0017.

Botton, ML, Shuster Jr, CN & Keinath, JA 2003, 'Horseshoe crabs in a food web: Who eats whom?', in CN Shuster Jr, RB Barlow & HJ Brockmann (eds), *The American horseshoe crab*, Harvard University Press, Cambridge, MA, pp. 133–150.

Carmichael, RH, Rutecki, D & Valiela, I 2003, 'Abundance and population structure of the Atlantic horseshoe crab *Limulus polyphemus* in Pleasant Bay, Cape Cod', *Marine Ecology Progress Series*, vol. 246, pp. 225–239.

Cartwright-Taylor, L, Bing, YV, Chi, HC & Tee, LS 2011, 'Distribution and abundance of horseshoe crabs *Tachypleus gigas* and *Carcinoscorpius rotundicauda* around the main island of Singapore', *Aquatic Biology*, vol. 13, pp. 127–136, viewed https://doi.org/10.3354/ab00346.

Chan, LY, John, A, Shahimi, S, Meilana, L, Ju Lian, C, Ing Hoe, L et al. 2022, 'From descriptive to accurate horseshoe crab size variations in wild populations', *Journal of Ecological Engineering*, vol. 23, no. 12, pp. 273–284, viewed https://doi.org/10.12911/22998993/154846.

Chatterji, A & Pati, S 2014, 'Allometric relationship in the adult population of the Malaysian horseshoe crab (*Tachypleus tridentatus*; Leach)', *International Journal of Research*, vol. 1, no. 11, pp. 1378–1385.

Chatterji, A, Vijayakumar, R & Parulekar, AH 1988, 'Growth and morphometric characteristics of the horseshoe crab, *Carcinoscorpius rotundicauda* (Latreille) from Canning (West Bengal), India', *Pakistan Journal of Scientific and Industrial Research*, vol. 31, no. 5, pp. 352–353.

Chen, CP, Yang, MC, Fan, LF, Qiu, G, Liao, YY & Hsieh, HL 2015, 'Co-occurrence of juvenile horseshoe crabs *Tachypleus tridentatus* and *Carcinoscorpius rotundicauda* in an estuarine bay, Southwestern China', *Aquatic Biology*, vol. 24, no. 2, pp. 117–126, viewed https://doi.org/10.3354/ab00641.

Chiu, HMC & Morton, B 2001, 'Growth and allometry of two horseshoe crab species, *Tachypleus tridentatus* and

Carcinoscorpius rotundicauda (Xiphosura), in Hong Kong', *Asian Marine Biology*, vol. 18, pp. 129–141.

Chiu, HMC & Morton, B 2003, 'The morphological differentiation of two horseshoe crab species, *Tachypleus tridentatus* and *Carcinoscorpius rotundicauda* (Xiphosura), in Hong Kong with a regional Asian comparison', *Journal of Natural History*, vol. 37, pp. 2369–2382, viewed https://doi.org/10.1080/00222930210149753.

Corradini, E, Wilken, D, Zanon, M, Groß, D, Lübke, H, Panning, D et al. 2020, 'Reconstructing the palaeoenvironment at the early Mesolithic site of Lake Duvensee: Ground-penetrating radar and geoarchaeology for 3D facies mapping', *The Holocene*, vol. 30, no. 6, pp. 820–833, viewed https://doi.org/10.1177/0959683620902234.

de Azevedo, CS, Silva, KS, Ferraz, JB, Tinoco, HP, Young, RJ & Rodrigues, M 2012, 'Does people's knowledge about an endangered bird species differ between rural and urban communities? The case of the greater rhea (Rhea americana, Rheidae) in Minas Gerais, Brazil', *Revista Brasileira de Ornitologia*, vol. 20, pp. 8–18.

Fauziyah, Mustopa, AZ, Purwiyanto, AIS, Rozirwan, Agustriani, F & Putri, WAE 2021, 'Morphometric variation of the horseshoe crab *Tachypleus gigas* (Xiphosura: Limulidae) from the Banyuasin estuarine of South Sumatra, Indonesia', *Biodiversitas*, vol. 22, no. 11, pp. 5061–5070, viewed https://doi.org/10.13057/biodiv/d221143.

Forth, G 2016, *Why the porcupine is not a bird: Explorations in the folk zoology of an Eastern Indonesian people*, University of Toronto Press, viewed https://doi.org/10.3138/9781487510053.

Froese, R 2006, 'Cube law, condition factor and weight-length relationships: History, meta-analysis and recommendations', *Journal of Applied Ichthyology*, vol. 22, pp. 241–253, viewed https://doi.org/10.1111/j.1439-0426.2006.00805.x.

Fu, Y, Huang, S, Wu, Z, Wang, C-C, Su, M, Wang, X, Xu, P, Huang, X, Wu, H, Wang, Y, Wang, J, Xiao, X, Zhou, H, Xie, X, Chen, M, Huang, S-L, Liao, Y, Kwan, BKY, Huang, ASL 2019, 'Socio-demographic drivers and public perceptions of consumption and conservation of Asian horseshoe crabs in northern Beibu Gulf, China', *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 29, no. 8, pp. 1268–1277, viewed https://doi.org/10.1002/aqc.3125.

Glanznig, A & Jellinek, S 2006, *Securing livelihoods and conserving nature's resources: Environmental guidelines for development NGOs working in ecoregions in Lao PDR*, Concern Worldwide and WWF Laos – Greater Mekong Programme, Vientiane, Lao PDR.

Greenacre, M, Groenen, PJF, Hastie, T, Iodice D'Enza, A, Tuzhilina, E & Markos, A 2022, 'Principal component analysis', *Nature Reviews Methods Primers*, vol. 2, Article 100, viewed https://doi.org/10.1038/s43586-022-00184-w.

Hasan, SM & Csányi, S 2023, 'Attitude index of local communities toward wildlife and their management methods in Malaysia', *Diversity*, vol. 15, no. 2, p. 202, viewed https://doi.org/10.3390/d15020202.

Iwaoka, C & Okayama, T 2009, 'Public awareness and community-based conservation for the horseshoe crab at Saikai National Park in Nagasaki Prefecture, Japan', in J Tanacredi, M Botton & D Smith (eds), *Biology and Conservation of Horseshoe Crabs*, Springer, New York, pp. 571–583, viewed https://doi.org/10.1007/978-0-387-89959-6.

Jawahir, ARN, Samsur, M, Shabdin, ML & Rahim, KA 2017, 'Morphometric allometry of horseshoe crab, *Tachypleus gigas* at west part of Sarawak waters, Borneo, East Malaysia', *Aquaculture, Aquarium, Conservation & Legislation - International Journal of the Bioflux Society*, vol. 10, pp. 18–24.

John, BA 2012, *Feeding ecology, molecular phylogeny and TAL production from Malaysian horseshoe crabs (Tachypleus gigas* and *Carcinoscorpius rotundicauda)* [PhD thesis], International Islamic University, Malaysia.

Kruskal, WH & Wallis, WA 1952, 'Use of ranks in one-criterion variance analysis', *Journal of the American Statistical Association*, vol. 47, pp. 583–621, viewed http://dx.doi.org/10.1080/01621459.1952.10483441.

Laurie, KCP, Cheung, SG, Do, V, Hsieh, H, John, A, Mhamad, F, Seino, S, Nishida, S, Shin, P & Yang, M 2019, *Tachypleus tridentatus*, *The IUCN Red List of Threatened Species*, viewed https://www.iucnredlist.org/species/21309/121940966

Levin, J, Hochstein, HD & Novitsky, TJ 2003, 'Clotting cells and Limulus amebocyte lysate: An amazing analytical tool', in CN Shuster Jr, RB Barlow & HJ Brockmann (eds), *The American horseshoe crab*, Harvard University Press, Cambridge, MA, pp. 310–340.

Manca, A, Mohamad, F, Ahmad, A, Mohd Sofa, MFA, & Ismail, N 2017, 'Tri-spine horseshoe crab, *Tachypleus tridentatus* (L.) in Sabah, Malaysia: The adult body sizes and population estimate' *Journal of Asia-Pacific Biodiversity*, vol. 10, pp. 355–361, viewed https://doi.org/10.1016/j.japb.2017.04.011.

Meilana, L & Fang, Q 2020, 'Local knowledge-based study on the status of horseshoe crabs along the Indonesian coast', *Regional Studies in Marine Science*, vol. 36, 101252, viewed https://doi.org/10.1016/j.rsma.2020.101252.

Ming, Y, Fujiang, D & Xilin, D 2016, 'Length-length, length-weight relationships and condition factor of the giant freshwater prawn *Macrobrachium rosenbergii* (de Man, 1879) cultured in earthen pond at high density', *Asian Fisheries Science*, vol. 29, pp. 164–177.

Mohamad, F, Manca, A, Ahmad, A, Mohd Sofa, MFA, Alia'M, AA & Ismail, N 2016, 'Width-weight and length-weight relationships of the tri-spine horseshoe crab, *Tachypleus tridentatus* (Leach, 1819) from two populations in Sabah, Malaysia: Implications for population management', *Journal of Sustainability Science and Management*, vol. 11, no. 1, pp. 1–13.

Mohamed, R, Paul, NA, Isa, NS, Damanhuri, JH, Shahimi, S, Pati, S, John, A & Nelson, BR 2021, 'Using applied statistics for accurate size classification of the endangered *Tachypleus tridentatus* horseshoe crab', *Journal of Ecological Engineering*, vol. 22, no. 4, pp. 273–282, viewed https://doi.org/10.12911/229988993/132432.

Mohanty, AK, Nayak, L & Bhatta, KS 2014, 'Length-weight relationship and relative condition factor of Asian seabass, *Lates calcarifer* (Bloch) from Chilika Lagoon, Odisha', *International Journal of Fisheries and Aquatic Studies*, vol. 1, no. 6, pp. 222–224.

Nair, P, Joseph, S & Pillai, V 2015, 'Length-weight relationship and relative condition factor of *Stolephorus commersonii*(Lacepède, 1803) exploited along Kerala Coast', *Journal of Marine Biological Association of India*, vol. 57, pp. 27–31, https://doi.org/10.6024/jmbai.2015.57.2.01856-04.

Nevo, M & Levin, L 2025, 'Nature-based welfare in older adulthood: An eco-appreciation perspective', *The Journals of Gerontology: Series B*, vol. 80, no. 6, gbaf041, viewed https://doi.org/10.1093/geronb/gbaf041.

Newing, H, Eagle, C, Puri, R & Watson, C 2011, *Conducting research in conservation: A social science perspective*, Routledge, viewed https://doi.org/10.4324/9780203846452.

Pati, S, Shahimi, S, Edinur, HA, Nelson, BR, Acharya, D & Dash, BP 2020, 'Extraction of people's perception toward horseshoe crab existence in Northeast Coast of India', *Frontiers in Marine Science*, vol. 7, viewed https://doi.org/10.3389/fmars.2020.587335.

Panda, S & Naik, PK 2017, 'Morphometric study of horseshoe crab (*Carcinoscorpius rotundicauda*) in Odisha', *IJSS Journal of Surgery*, vol. 3, no. 2, pp. 48–53, viewed https://doi.org/10.17354/SUR/2017/81.

Razak, MR & Kassim, Z 2018, 'Comparison of horseshoe crabs (*Tachypleus gigas*) morphometry between different populations using allometric analysis', *AACL Bioflux*, vol. 11, no. 1, pp. 143–157.

Reid, P & Vogel, C 2006, 'Living and responding to multiple stressors in South Africa: Glimpses from KwaZulu-Natal', *Global Environmental Change*, vol. 16, no. 2, pp. 195–206, viewed https://doi.org/10.1016/j.gloenvcha.2006.01.003.

Sáenz-Arroyo, A, Roberts, CM, Torre, J, Cariño-Olvera, M & Enríquez-Andrade, RR 2005, 'Rapidly shifting environmental baselines among fishers of the Gulf of California', *Proceedings of the Royal Society B: Biological Sciences*, vol. 272, no. 1575, pp. 1957–1962, viewed https://doi.org/10.1098/rspb.2005.3175.

Schoppe, S 2002, 'First data on the distribution of horseshoe crabs (Chelicerata: Merostomata) in Palawan, with notes on their status in the Philippines', *UPV Journal of Natural Sciences*, vol. 7, no. 1, pp. 198–206.

Sekiguchi, K, Seshimo, H & Sugita, H 1988, 'Post-embryonic development of the horseshoe crab', *Biological Bulletin*, vol. 174, pp. 337–345.

Sene-Harper, A, Matarrita-Cascante, D & Larson, LR 2019, 'Leveraging local livelihood strategies to support conservation and development in West Africa', *Environmental Development*, vol. 29, pp. 16–28, viewed https://doi.org/10.1016/j.envdev.2018.11.002.

Srijaya, TC, Pradeep, PJ, Shaharom, FM & Chatterji, A 2010, 'A new record on the morphometric variations in the populations of horseshoe crab (*Carcinoscorpius rotundicauda* Latreille) obtained from two different ecological habitats of Peninsular Malaysia', *Our Nature*, vol. 8, pp. 204–211, viewed https://doi.org/10.3126/on.v8i1.4329.

Sugg, DN, Carmichael, RH, Grady, SP & Valiela, I 2002, 'Effects of individual size on pairing in horseshoe crabs', *Biological Bulletin*, vol. 203, pp. 225–227.

Syuhaida, N, Rozihan, M, Akbar, J, Akmal, M & Joni, H 2019, 'Allometry relationship of mangrove horseshoe crab, *Carcinoscorpius rotundicauda* from the West Coast of Peninsular Malaysia', *International Journal of Fisheries and Aquatic Studies*, vol. 7, pp. 223–228.

Wang, C-C, Chen, R, Yang, X, Wen, Y, Kuang, Y, Zhang, C, Zhu, J & Kwan, KY 2022, 'Asian horseshoe crab bycatch in intertidal zones of the northern Beibu Gulf: Suggestions for conservation management', *Journal of Ocean University of China*, vol. 21, no. 3, pp. 611–621, viewed https://doi.org/10.1007/s11802-022-5214-9

Wright, JH, Hill, NA, Roe, D, Rowcliffe, JM, Kümpel, NF, Day, M, Booker, F & Milner-Gulland, EJ 2016, 'Reframing the concept of alternative livelihoods', *Conservation Biology*, vol. 30, no. 1, pp. 7–13, viewed https://doi.org/10.1111/cobi.12607.

Zar, JH 1996, *Biostatistical analysis*, 3rd edn, Prentice Hall, New Jersey.