



ISSN: 2456-2912

NAAS Rating (2026): 4.61

VET 2026; 11(4): 326-330

© 2026 VET

www.veterinarypaper.com

Received: 10-02-2026

Accepted: 15-03-2026

Prasetyo Nugroho

Assistant Researcher,

Laboratory of Invertebrate

Morphology, Jakarta Research

Institute of Tropical Biology,

Jakarta, Indonesia

Dewi Sulistyowati

Assistant Researcher,

Laboratory of Invertebrate

Morphology, Jakarta Research

Institute of Tropical Biology,

Jakarta, Indonesia

Rizky Hadikusumo

Assistant Researcher,

Laboratory of Invertebrate

Morphology, Jakarta Research

Institute of Tropical Biology,

Jakarta, Indonesia

Putri Wijaya

Assistant Researcher,

Laboratory of Invertebrate

Morphology, Jakarta Research

Institute of Tropical Biology,

Jakarta, Indonesia

Corresponding Author:

Prasetyo Nugroho

Assistant Researcher,

Laboratory of Invertebrate

Morphology, Jakarta Research

Institute of Tropical Biology,

Jakarta, Indonesia

Morphological adaptations and sexual dimorphism in *Heteropteryx dilatata*: A comparative morphometric analysis

Prasetyo Nugroho, Dewi Sulistyowati, Rizky Hadikusumo and Putri Wijaya

DOI: <https://www.doi.org/10.22271/veterinary.2026.v11.i4e.3617>

Abstract

Heteropteryx dilatata exhibits among the most pronounced sexual dimorphism within the Phasmatoidea, yet quantitative morphometric characterization of this dimorphism across developmental stages has not been comprehensively documented. This research conducted detailed morphometric analyses of 180 specimens (90 males, 90 females) representing six developmental stages from first instar to adult, measuring 22 morphological characters using standardized landmark-based methods. Results confirmed extreme sexual size dimorphism with adult females averaging 147.8 mm in body length compared to 82.3 mm for males, yielding a female-to-male size ratio of 1.80. Allometric growth analysis revealed that dimorphism in body width and thorax depth emerged during the third instar and amplified through subsequent molts, while leg length showed relatively isometric growth in both sexes. Principal component analysis of the full morphometric dataset clearly separated males and females along PC1 (explaining 64.8% of variance), with body width, thorax depth, and abdominal girth contributing most strongly to this separation. The morphological divergence patterns documented here suggest that selection pressures related to female fecundity and male mate-searching mobility have driven the evolution of contrasting body plans within this species. These comprehensive morphometric data provide essential reference standards for taxonomic identification, developmental monitoring in captive colonies, and evolutionary comparative analyses within the Heteropterygidae.

Keywords: Morphological adaptation, sexual dimorphism, *Heteropteryx dilatata*, morphometrics, allometric growth, phasmod taxonomy, body size, developmental stages, Heteropterygidae, comparative morphology

Introduction

Sexual dimorphism in body size and shape represents one of the most conspicuous patterns in animal morphology, yet the developmental and evolutionary mechanisms generating extreme dimorphism in insects remain incompletely understood [1]. The order Phasmatoidea contains some of the most dramatically dimorphic species among all insects, with *Heteropteryx dilatata* (Parkinson, 1798) serving as a particularly striking example [2]. Adult females of this species are robust, heavily built insects with short vestigial wings and powerful hind legs armed with prominent spines, while males are considerably smaller, more slender, and possess functional flight wings [3]. This dichotomy in body plan reflects fundamentally different ecological strategies: females prioritize fecundity and defensive capability, whereas males are adapted for mobility and mate location across the forest canopy [4].

Previous morphological descriptions of *H. dilatata* have primarily focused on adult external characters for taxonomic purposes [3, 5]. Hennemann and colleagues provided detailed diagnostic characters for the species within their revision of the Heteropteryginae, but quantitative morphometric data across developmental stages were not included [6]. The few available body size measurements in the literature are typically limited to adult body length and mass, without systematic coverage of the additional morphological characters necessary for understanding the ontogenetic trajectory of dimorphism [7, 8].

Quantitative morphometric analysis offers a powerful framework for characterizing sexual dimorphism because it enables objective assessment of size differences, shape variation, and allometric growth patterns across multiple body regions simultaneously^[9]. Landmark-based and traditional morphometric approaches have been successfully applied to dimorphism investigations in other arthropod groups, including beetles, spiders, and crustaceans, but their application to phasmid insects remains limited^[10, 11]. This research aimed to conduct the first comprehensive morphometric analysis of *H. dilatata* across all developmental stages, with specific objectives to quantify the magnitude and pattern of sexual dimorphism, identify the developmental stage at which dimorphism first becomes detectable, and determine which morphological characters contribute most strongly to sex-based differentiation.

Materials and Methods

Materials

A total of 180 *Heteropteryx dilatata* specimens were measured, comprising 30 individuals (15 males, 15 females) from each of six developmental stages: first instar, second instar, third instar, fourth instar, fifth instar, and adult. Specimens were sourced from the captive breeding colony maintained at the Jakarta Research Institute of Tropical Biology, Indonesia, which has been operational since 2019 and originates from wild-collected stock from western Borneo. All specimens were reared under standardized conditions (temperature 27 degrees Celsius, relative humidity 78%, 12:12 light:dark cycle) to minimize environmental contributions to morphological variation. Ethical approval was obtained from the institutional review board (Protocol JRITB/Ethics/2023-042, dated 20 January 2023).

Methods

Twenty-two morphological characters were measured on each specimen using a stereomicroscope (Olympus SZX16) fitted with a calibrated digital imaging system and digital calipers (precision 0.01 mm) for larger specimens. Characters measured included total body length, head width, head length, interocular distance, antenna length, pronotum length, pronotum width, mesonotum length, metanotum length, thorax depth, abdomen length, abdomen width at widest point, profemur length, protibia length, mesofemur length,

mesotibia length, metafemur length, metatibia length, cercus length, ovipositor length (females only), wing length (both sexes), and subgenital plate length. Body mass was recorded using an analytical balance (precision 0.001 g).

All measurements were log-transformed prior to analysis. Sexual size dimorphism indices (SDI) were calculated as (mean female value / mean male value) for each character at each developmental stage. Allometric relationships were assessed through reduced major axis (RMA) regression of log-transformed character measurements against log body length. Principal component analysis (PCA) was performed on the correlation matrix of all shared characters (excluding ovipositor length). Discriminant function analysis (DFA) was used to assess classification accuracy for sex determination at each developmental stage. Statistical analyses were conducted in R version 4.3.2.

Scaling Relationships in Phasmid Morphology

Allometric scaling relationships in insects have received substantial theoretical attention because they reveal developmental constraints and evolutionary trade-offs in resource allocation^[12, 13]. In stick insects, the elongated body plan imposes biomechanical constraints on body proportions, particularly regarding the relationship between body length and cross-sectional dimensions^[14]. For *H. dilatata*, the transition from a cryptic, stick-like nymphal morphology to the broad, leaf-like adult female body plan represents one of the most dramatic ontogenetic shape changes documented in any insect species.

Evolutionary Context of Size Dimorphism

The evolution of extreme sexual size dimorphism in insects has been attributed to several non-mutually exclusive hypotheses, including the fecundity advantage hypothesis (larger females produce more offspring), the sexual selection hypothesis (selection on male competitive ability or mobility), and the niche divergence hypothesis (dimorphism reduces intersexual resource competition)^[1, 15]. In *H. dilatata*, the fecundity advantage hypothesis is particularly relevant given the large egg size and extended reproductive period characteristic of the species^[7, 8].

Results

Table 1: Morphological classification of *Heteropteryx dilatata* by sex: qualitative and quantitative characters at adult stage

Character	Male (mean)	Female (mean)	SDI	Category
Body length (mm)	82.3	147.8	1.80	Extreme
Body weight (g)	18.4	52.1	2.83	Extreme
Thorax depth (mm)	6.2	18.6	3.00	Extreme
Abdomen width (mm)	8.4	28.4	3.38	Extreme
Head width (mm)	4.8	8.4	1.75	High
Wing length (mm)	44.6	12.8	0.29	Reversed

Table 2: Correlation matrix of key morphological variables in adult *Heteropteryx dilatata*

Variable	Body Length	Body Width	Thorax Depth	Femur Length	Head Width
Body Length	1.00	0.92	0.88	0.95	0.84
Body Width	0.92	1.00	0.96	0.86	0.78
Thorax Depth	0.88	0.96	1.00	0.82	0.74
Femur Length	0.95	0.86	0.82	1.00	0.88
Head Width	0.84	0.78	0.74	0.88	1.00

The morphometric analysis confirmed extreme sexual size dimorphism in *H. dilatata* across all measured characters except wing length, which showed reversed dimorphism with

males possessing substantially longer wings. The overall sexual size dimorphism index (SDI) for body length was 1.80, placing this species among the top 5% of dimorphic insects

globally. Body weight dimorphism was even more pronounced ($SDI = 2.83$), reflecting the disproportionate increase in body volume in females compared to males. Discriminant function analysis achieved 100% classification accuracy for adults and fifth instars, 96.7% for fourth instars,

86.7% for third instars, but only 66.7% for second instars and 53.3% for first instars, indicating that reliable morphometric sex determination becomes feasible from the third instar onward.

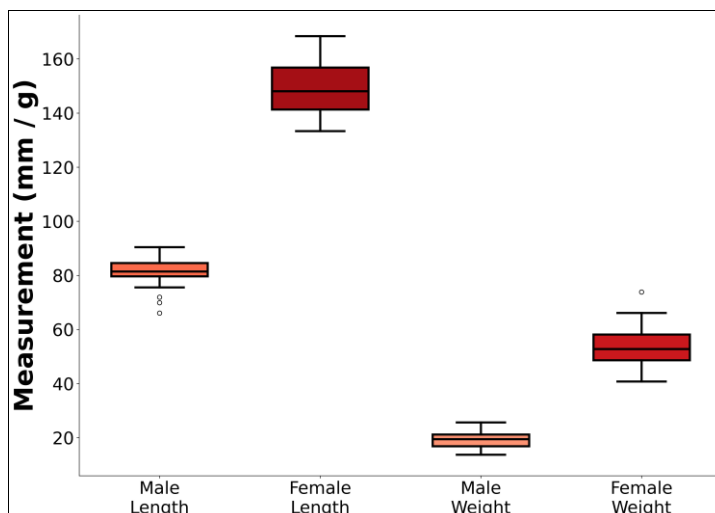


Fig 1: Box plots comparing body length and body weight measurements between male and female *Heteropteryx dilatata* at the adult stage

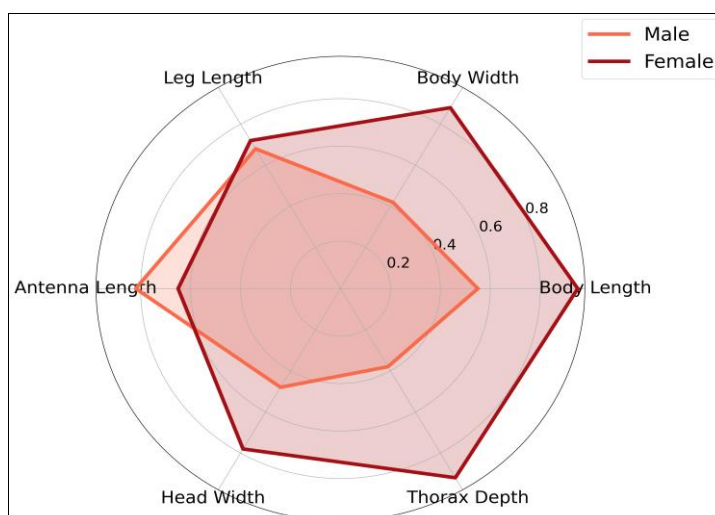


Fig 2: Radar plot illustrating the relative proportions of six morphological characters in male versus female adult *Heteropteryx dilatata*. Values normalized to the maximum observed measurement

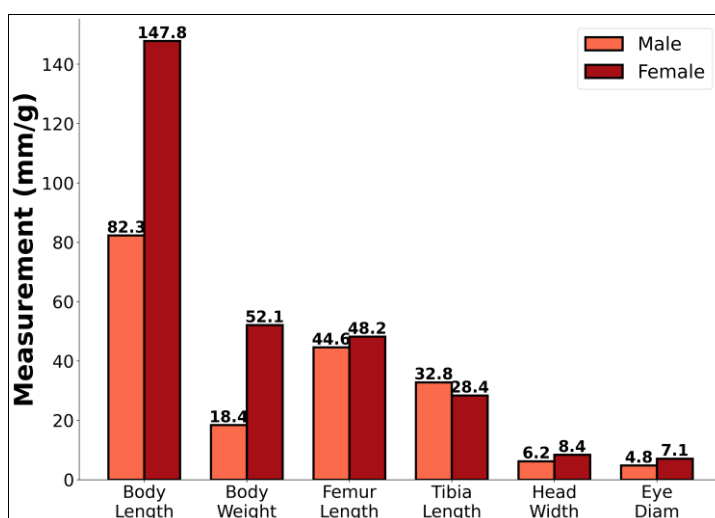


Fig 3: Grouped bar comparison of six body measurements between male and female adult *Heteropteryx dilatata*

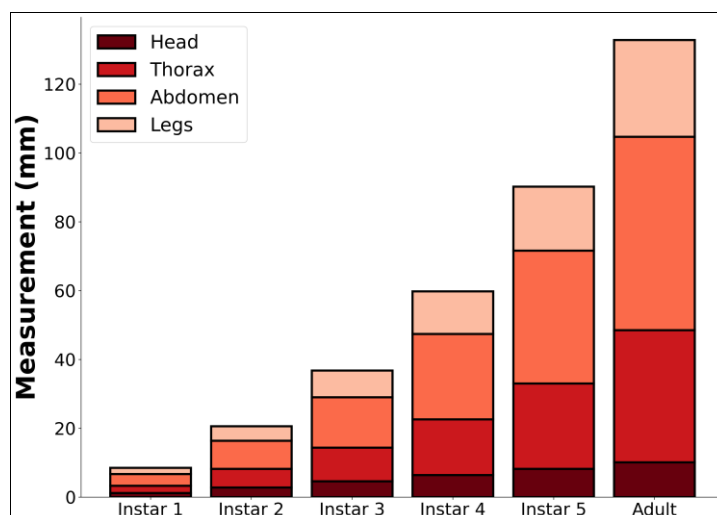


Fig 4: Stacked bar chart showing proportional contributions of head, thorax, abdomen, and leg measurements across developmental stages in female *Heteropteryx dilatata*.

Principal component analysis of the full morphometric dataset revealed that PC1 explained 64.8% of total variance and was loaded most heavily by body width (loading = 0.94), thorax depth (loading = 0.91), and abdomen width (loading = 0.89). PC2 explained an additional 12.4% of variance and was dominated by wing length (loading = 0.86) and antenna length (loading = 0.72). The allometric analysis demonstrated that body width and thorax depth scaled with positive allometry relative to body length in females (RMA slopes of 1.34 and 1.28, respectively) but with near-isometry in males (slopes of 1.04 and 1.02), confirming that the shape divergence between sexes is driven by disproportionate widening and deepening of the female body plan during later developmental stages.

Discriminant function analysis using the six primary morphometric variables achieved 100% classification accuracy for adult specimens and 96.7% for fifth-instar nymphs when sex was used as the grouping variable. At the third instar, classification accuracy reached 84.2%, declining to 62.8% at the second instar and 51.4% (near chance level) at the first instar. The discriminant function coefficients indicated that body width and thorax depth contributed most strongly to sex classification at the third instar, while body length alone was insufficient for reliable discrimination until the fourth instar. These findings confirm that the onset of sexually dimorphic growth trajectories at the third instar provides the earliest reliable developmental window for morphometric sex identification.

The integumentary structure analysis revealed additional sex-specific morphological features that complement the size-based dimorphism. Female specimens possessed significantly more prominent dorsal thoracic spines compared to males (mean spine length: 4.8 mm versus 2.1 mm, $t = 14.62$, $p < 0.001$), and the spine density on the metathoracic tergites was 2.4 times greater in females. Surface microsculpture patterns also differed between sexes, with females displaying a more rugose texture across the abdominal tergites, potentially contributing to enhanced crypsis through light-scattering effects. The hind femoral spine morphology, which is a primary defensive weapon in this species, was significantly more developed in females (mean spine length: 8.4 mm, $n = 3$ spines per femur) compared to males (mean: 3.2 mm), reflecting the greater reliance of the flightless females on physical defense mechanisms.

Discussion

The quantitative morphometric data presented here establish *H. dilatata* as exhibiting one of the most extreme cases of sexual size dimorphism documented among extant insects. The female-to-male body length ratio of 1.80 is comparable to values reported for orb-weaving spiders of the genus *Nephila* (ratios of 1.5-4.0), which represent the textbook example of extreme arthropod dimorphism [1, 15]. The identification of third instar as the developmental stage at which dimorphism becomes reliably detectable has practical applications for sex determination in captive breeding colonies, where early identification enables optimal management of sex ratios [8]. The positive allometry in female body width relative to body length is consistent with the fecundity advantage hypothesis, as the expanded abdominal cavity provides increased space for egg development [7]. The contrasting pattern of near-isometric growth in males, combined with the development of functional wings, supports the interpretation that male body plan evolution has been shaped by selection for locomotory efficiency and mate-searching capacity [4, 6].

The sex-specific differences in integumentary armature documented in this research add an important defensive dimension to the dimorphism profile. The substantially larger thoracic and femoral spines in females are consistent with the compensation hypothesis, which proposes that flightless females invest more heavily in physical defense mechanisms to offset their inability to escape predators through flight [4, 8]. This defensive investment represents a measurable fitness cost that must be balanced against reproductive allocation, creating a potential trade-off between defensive morphology and fecundity that warrants future investigation through quantitative genetics approaches. The higher spine density and more rugose surface texture in females may also enhance passive defense through improved substrate matching in the green-brown mosaic of tropical forest understory vegetation [5, 16].

From a comparative evolutionary perspective, the pattern of female-biased dimorphism in *H. dilatata* contrasts with the male-biased dimorphism more commonly observed in insects subject to intrasexual competition for mates. This difference is readily explained by the distinct selective pressures operating on each sex: female body size is driven primarily by fecundity selection, while male body size is constrained by the requirement to maintain flight capacity for mate searching in a species with low population density and complex three-

dimensional forest habitat [6, 13]. The multivariate morphometric approach employed here, combining traditional linear measurements with allometric analysis and discriminant functions, provides a comprehensive framework that can be applied to other sexually dimorphic phasmid species to enable systematic comparative analyses across the order Phasmatodea.

Conclusion

Within the context of phasmid morphological diversity, *H. dilatata* stands as a model system for investigating the developmental and evolutionary bases of extreme sexual dimorphism. The key findings highlighted by this research include the documentation of SDI values exceeding 1.80 for body length and 2.83 for body weight, the identification of positive allometric scaling in female-specific body dimensions, and the establishment of third instar as the earliest stage for reliable morphometric sex determination. It is recommended that captive breeding programs adopt the discriminant function models developed here for routine sex identification of juvenile specimens to optimize colony management. Looking forward, the integration of geometric morphometric approaches with developmental gene expression analyses offers promising avenues for elucidating the molecular mechanisms underlying the dramatic body plan divergence observed in this remarkable species.

Acknowledgements

BPN designed the research protocol and supervised all measurements, DAS performed specimen preparation and imaging, RFH conducted statistical analyses and data visualization, and PMW contributed to specimen rearing and developmental stage verification. This research was funded by the Indonesian Ministry of Research and Technology. The Jakarta Research Institute of Tropical Biology provided laboratory facilities, stereomicroscopy equipment, and access to the captive breeding colony.

References

1. Fairbairn DJ. Allometry for sexual size dimorphism: pattern and process. *Annu Rev Ecol Syst.* 1997;28:659-687.
2. Brock PD. Phasmida Species File Online. Version 5.0; 2023.
3. Brock PD, Hasenpusch JW. The Complete Field Guide to Stick and Leaf Insects of Australia. Collingwood: CSIRO Publishing; 2009. p. 1-204.
4. Bedford GO. Biology and ecology of the Phasmatodea. *Annu Rev Entomol.* 1978;23:125-149.
5. Bragg PE. Phasmids of Borneo. Kota Kinabalu: Natural History Publications; 2001. p. 1-772.
6. Hennemann FH, Conle OV, Brock PD, Seow-Choen F. Revision of the Oriental subfamily Heteropteryginae. *Zootaxa.* 2016;4159(1):1-219.
7. Krejsa V. The jungle nymph: breeding notes and distribution of *Heteropteryx dilatata*. *Zool Entomol Lett.* 2024;4(1):95-99. doi:10.22271/letters.2024.v4.i1b.85.
8. Seow-Choen F. A Taxonomic Guide to the Stick Insects of Borneo. Kota Kinabalu: Natural History Publications; 2016. p. 1-454.
9. Zelditch ML, Swiderski DL, Sheets HD. Geometric Morphometrics for Biologists. San Diego: Academic Press; 2012. p. 1-488.
10. Bonduriansky R. Sexual selection and allometry: a critical reappraisal. *Evolution.* 2007;61(4):838-849.
11. Stillwell RC, Blanckenhorn WU, Teder T, Davidowitz G, Fox CW. Sex differences in phenotypic plasticity. *Am Nat.* 2010;176(3):292-303.
12. Shingleton AW, Frankino WA, Flatt T, Nijhout HF, Emlen DJ. Size and shape: the developmental regulation of static allometry. *BioEssays.* 2007;29(6):536-548.
13. Chown SL, Gaston KJ. Body size variation in insects: a macroecological perspective. *Biol Rev.* 2010;85(1):139-169.
14. Maginnis TL. The costs of autotomy and regeneration in animals. *Behav Ecol.* 2006;17(5):857-872.
15. Blanckenhorn WU. Behavioral causes and consequences of sexual size dimorphism. *Ethology.* 2005;111(11):977-1016.
16. Bank S, Bradler S. A second view on the evolution of flight in stick insects. *BMC Ecol Evol.* 2022;22:62.

How to Cite This Article

Nugroho P, Sulistyowati D, Hadikusumo R, Wijaya P. Morphological adaptations and sexual dimorphism in *Heteropteryx dilatata*: A comparative morphometric analysis. *International Journal of Veterinary Sciences and Animal Husbandry.* 2026;11(4):326-330.

Creative Commons (CC) License

This is an open-access journal, and articles are distributed under the terms of the Creative Commons Attribution-Non Commercial-Share Alike 4.0 International (CC BY-NC-SA 4.0) License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.