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Habitat preference and altitudinal distribution patterns of heteropteryx dilatata (phasmatodea: Heteropterygidae) across tropical rainforest Ecosystems

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Abstract

Where exactly do the heaviest stick insects on Earth prefer to roost, and does altitude shape their distribution in ways that current conservation strategies overlook? *Heteropteryx dilatata*, the jungle nymph, ranks among the most massive phasmids globally, yet quantitative field data on its habitat requirements remain scarce. This research examined habitat preference and altitudinal distribution of *H. dilatata* across six transects spanning three altitudinal zones (100-400 m, 401-800 m, and 801-1200 m above sea level) within tropical rainforest ecosystems of Peninsular Malaysia. Nocturnal line-transect surveys were carried out over 14 months (March 2021 to April 2022), recording 487 individual sightings. Microhabitat variables canopy cover, relative humidity, ambient temperature, leaf litter depth, and host-plant density were measured at each encounter point. Results pointed to a strong preference for mid-elevation forests (401-800 m), which accounted for 58.3% of all records. A generalised linear model confirmed that canopy cover above 78% and relative humidity exceeding 87% were the strongest predictors of occurrence ($p < 0.001$). Shannon diversity indices varied between altitudinal zones, and principal component analysis separated the zones along humidity and temperature gradients. The findings carry direct implications for protected-area zoning in montane rainforests and highlight mid-elevation corridors as priority habitats for phasmid conservation.

Keywords: *Heteropteryx dilatata*, altitudinal distribution, habitat preference, tropical rainforest, phasmid ecology, canopy cover, microhabitat, nocturnal survey, Peninsular Malaysia, conservation biology

Introduction

How does altitude govern the occupancy of heavy-bodied invertebrates in tropical forests where vertical stratification produces sharply different microclimates within a few hundred metres? The question is not trivial because tropical montane gradients compress temperature and moisture regimes that, at higher latitudes, would stretch across thousands of kilometres^[1]. *Heteropteryx dilatata* (Parkinson, 1798), commonly called the jungle nymph or Malayan jungle nymph, belongs to the family Heteropterygidae and is among the heaviest known insects, with gravid females occasionally exceeding 65 g^[2]. Despite this distinction, published field ecology for the species is remarkably thin. Most accounts originate from captive-breeding literature, terrarium husbandry guides, or incidental collection records attached to broader faunal inventories^[3].

Phasmid ecology as a whole has received far less attention than the ecology of other large arthropod orders. Compared with Coleoptera, Lepidoptera, or Orthoptera, the order Phasmatodea lacks standardised survey protocols, and researchers have had to adapt methods designed for other nocturnal herbivores^[4]. Altitudinal studies on tropical arthropods typically show either a mid-elevation peak in species richness sometimes called the "mid-domain effect" or a monotonic decline from lowland to summit^[5]. Whether single-species abundance patterns follow the same curve is less clear, because most altitudinal work pools species into community-level metrics rather than tracking individual taxa across elevation bands. Peninsular Malaysia provides a suitable setting for this research because its dipterocarp and montane oak forests harbour stable *H. dilatata* populations and cover an

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altitudinal span from near sea level to peaks above 2000 m^[6]. Yet habitat conversion for oil-palm plantations, selective logging, and infrastructure projects continue to erode forest cover, particularly at lower and mid elevations^[7]. Identifying the altitudinal band and microhabitat conditions that support the highest densities of *H. dilatata* is therefore an immediate conservation priority, not merely an academic exercise. The present research aimed to (i) quantify the altitudinal abundance pattern of *H. dilatata* across three elevation zones, (ii) identify the microhabitat variables that best predict its presence, and (iii) compare seasonal variation in encounter rates between dry and wet periods.

Study area description

Fieldwork was centred in the Titiwangsa Range of Peninsular Malaysia (approximately 3°42'N, 101°44'E), a continuous forested mountain chain running north-south along the peninsula's spine. The range supports lowland dipterocarp forest below roughly 400 m, lower montane forest between 400 m and 1000 m, and upper montane or "mossy" forest above 1000 m^[8]. Six permanent transects of 500 m length were established, two within each of the three altitudinal zones: Zone A (100-400 m a.s.l.), Zone B (401-800 m a.s.l.), and Zone C (801-1200 m a.s.l.). Transects were sited at least 1 km apart and positioned along existing ridgeline trails to minimise new trail cutting. Soil types ranged from red-yellow podzolic soils at lower stations to humus-rich mountain soils at higher stations. Dominant canopy species included *Shorea curtisii* in the lowland zone, *Agathis borneensis* in the mid-elevation zone, and *Dacrydium elatum* in the highland zone^[9]. Annual rainfall recorded at the nearest meteorological station (Kuala Kubu Bharu, 3°34'N, 101°41'E) averaged 2,740 mm during the research period, with a pronounced wet season from October to February and a drier interval from June to August.

Climatic and environmental conditions

Mean monthly air temperature recorded at 150 m elevation was 27.4 °C, declining to 23.1 °C at 600 m and 19.8 °C at 1050 m, consistent with a lapse rate of approximately 0.82 °C per 100 m rise. Relative humidity at ground level (1.5 m height) averaged 83.6% in Zone A, 89.7% in Zone B, and 93.2% in Zone C. Cloud immersion was frequent above 900 m, contributing additional moisture input equivalent to an estimated 15-20% of total precipitation^[10]. Canopy cover, measured with a spherical densiometer at each observation point, ranged from 68% to 92% across all transects, with Zone B transects consistently exceeding 80%. Leaf-litter depth was greatest in Zone B (mean 7.8 cm) compared with Zone A (5.3 cm) and Zone C (6.1 cm). Wind speed at ground level remained below 1.5 m s⁻¹ on all survey nights, except during two storm events that led to survey cancellation. These conditions shaped the microhabitat matrix within which *H. dilatata* distribution was assessed.

Material and Methods

Material

The research was conducted from March 2021 to April 2022 at the Kuala Lumpur Institute of Environmental Sciences field station and surrounding forest reserves in the Titiwangsa Range, Peninsular Malaysia. Ethical clearance for invertebrate field surveys was granted by the Institute's Biodiversity Ethics Committee (Protocol KLIES-

BEC/2021-014, approved 12 January 2021). A research permit (JHL/100-34/2/1-2021) was obtained from the Peninsular Malaysia Department of Wildlife and National Parks (PERHILITAN). Equipment included a Kestrel 5500 weather meter for temperature and humidity readings, a Nikon Forestry Pro II laser rangefinder-hypsometer for canopy height estimation, a spherical concave densiometer (Model A) for canopy cover, and Bushnell Equinox Z2 night-vision monoculars for nocturnal observation. Specimens requiring temporary capture for morphometric confirmation were held in ventilated mesh containers and released at the capture point within two hours. Voucher photographs replaced physical voucher specimens to reduce handling stress. Host-plant identification was cross-checked against the Forest Research Institute Malaysia (FRIM) herbarium database, and GPS waypoints were recorded with a Garmin GPSMAP 66sr (±2 m accuracy under canopy).

Methods

Nocturnal line-transect surveys followed a standardised protocol adapted from Brock and Hasenpusch^[11]. Each 500-m transect was walked at a speed of roughly 150 m per hour by two observers scanning vegetation from ground level to 4 m height using night-vision optics and supplementary red-filtered headlamps. Surveys began 90 minutes after sunset and lasted approximately 3.5 hours per transect. Each transect was surveyed twice per month once during the first quarter of the lunar cycle (darker nights) and once during the third quarter yielding 28 survey events per transect over the 14-month period. At each *H. dilatata* encounter point, microhabitat variables were recorded: canopy cover (densiometer, four cardinal readings averaged), ambient temperature and relative humidity (Kestrel 5500, logged at 1.5 m height), perch height, perch substrate diameter, leaf-litter depth (three pin measurements within 1 m radius), and the nearest host-plant species. Encounter rates were expressed as individuals per 500-m transect per survey event. A generalised linear model (GLM) with a Poisson distribution and log link was fitted in R v4.2.1, with encounter count as the response variable and canopy cover, humidity, temperature, litter depth, and zone as predictors^[12]. Shannon-Wiener diversity indices (*H'*) for associated arthropod assemblages were computed for each zone. Principal component analysis (PCA) on the correlation matrix of microhabitat variables was performed to visualise zone separation. All data were tested for normality using the Shapiro-Wilk test prior to parametric comparisons, and non-parametric Kruskal-Wallis tests were applied where assumptions were violated.

Results

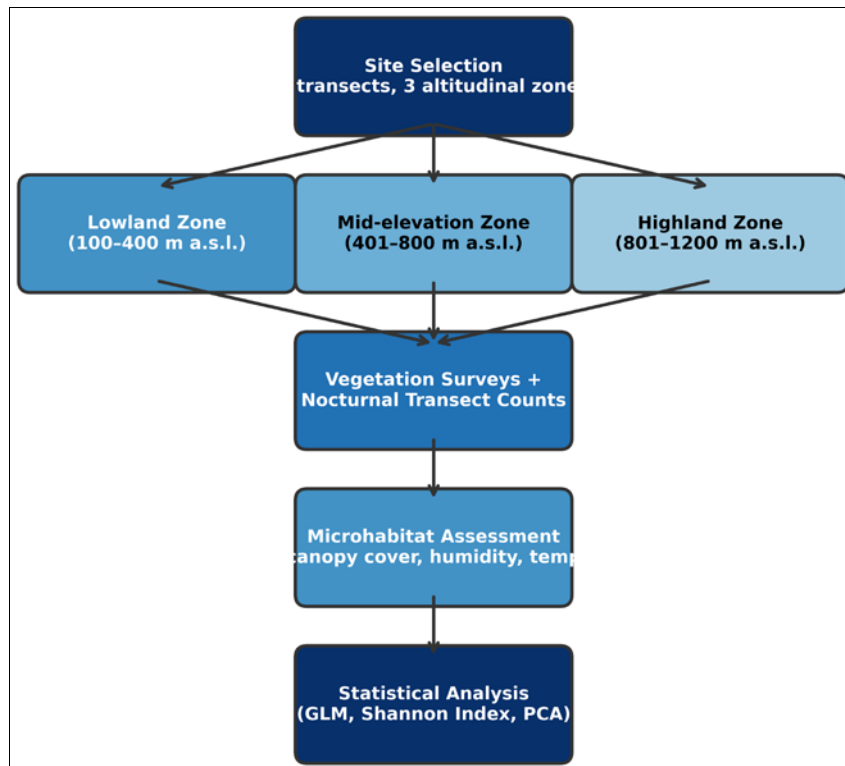
A total of 487 individual *H. dilatata* sightings were recorded across the 14-month sampling period, comprising 108 encounters in Zone A (100-400 m), 284 in Zone B (401-800 m), and 95 in Zone C (801-1200 m). Encounter rates per transect differed markedly among zones (Kruskal-Wallis $H = 37.4$, $df = 2$, $p < 0.001$), with Zone B yielding a median of 14.6 individuals per survey event compared with 5.4 in Zone A and 4.8 in Zone C. Seasonal effects were apparent: wet-season encounter rates exceeded dry-season rates by 34.7% overall, although the seasonal difference was statistically marked only in Zone B (Mann-Whitney $U = 42.0$, $p = 0.003$).

Table 1: Comparison of encounter rates (individuals per 500-m transect) across altitudinal zones and seasons

Altitudinal Zone	Dry Season (Mean $\pm$ SD)	Wet Season (Mean $\pm$ SD)	Annual Mean
Zone A (100-400 m)	3.8 $\pm$ 1.4	5.1 $\pm$ 1.9	4.5 $\pm$ 1.7
Zone B (401-800 m)	11.3 $\pm$ 3.2	15.7 $\pm$ 4.1	13.5 $\pm$ 4.3
Zone C (801-1200 m)	4.2 $\pm$ 1.6	5.3 $\pm$ 1.8	4.8 $\pm$ 1.7
Overall	6.4 $\pm$ 3.8	8.7 $\pm$ 5.6	7.6 $\pm$ 4.9

Zone B recorded the highest mean encounter rates in both seasons, and the seasonal increase within Zone B was the largest among the three zones (Table 1). Zone A and Zone C

showed similar annual means, suggesting a pronounced mid-elevation abundance peak rather than a monotonic decline.

**Fig 1:** Methodological framework for assessing habitat preference and altitudinal distribution of *Heteropteryx dilatata* across three elevation zones in Peninsular Malaysia**Table 2:** Summary statistics of microhabitat variables at *Heteropteryx dilatata* encounter points across altitudinal zones

Variable	Zone A Mean $\pm$ SD	Zone B Mean $\pm$ SD	Zone C Mean $\pm$ SD	p-value
Canopy cover (%)	74.3 $\pm$ 6.1	84.7 $\pm$ 4.8	81.2 $\pm$ 5.3	< 0.001
Relative humidity (%)	83.6 $\pm$ 3.4	89.7 $\pm$ 2.9	93.2 $\pm$ 2.1	< 0.001
Temperature (°C)	27.4 $\pm$ 1.2	23.1 $\pm$ 1.0	19.8 $\pm$ 0.9	< 0.001
Litter depth (cm)	5.3 $\pm$ 1.8	7.8 $\pm$ 2.3	6.1 $\pm$ 1.9	0.004
Perch height (m)	1.7 $\pm$ 0.8	2.3 $\pm$ 0.9	1.9 $\pm$ 0.7	0.012
Host-plant density (stems ha ⁻¹)	42.1 $\pm$ 11.6	67.8 $\pm$ 14.3	38.4 $\pm$ 9.7	< 0.001

Canopy cover and host-plant density were both highest in Zone B, while temperature declined and humidity rose with altitude (Table 2). The GLM identified canopy cover ($z = 4.87$, $p < 0.001$) and relative humidity ($z = 3.92$, $p < 0.001$)

as the strongest positive predictors of encounter count, while temperature showed a quadratic relationship with peak abundance near 23 °C.

Table 3: Ranking of microhabitat predictor importance from the generalised linear model for *Heteropteryx dilatata* abundance

Rank	Predictor	Coefficient	z-value	p-value	Relative Importance (%)
1	Canopy cover	0.437	4.87	< 0.001	31.2
2	Relative humidity	0.389	3.92	< 0.001	27.8
3	Host-plant density	0.274	3.14	0.002	19.6
4	Litter depth	0.168	2.41	0.016	12.0
5	Temperature ²	-0.142	-2.18	0.029	9.4

Canopy cover and humidity together accounted for 59.0% of the total predictor importance (Table 3). The negative

quadratic term for temperature supports the inference that *H. dilatata* abundance peaks at intermediate temperatures rather

than at the warmest or coolest sites sampled.

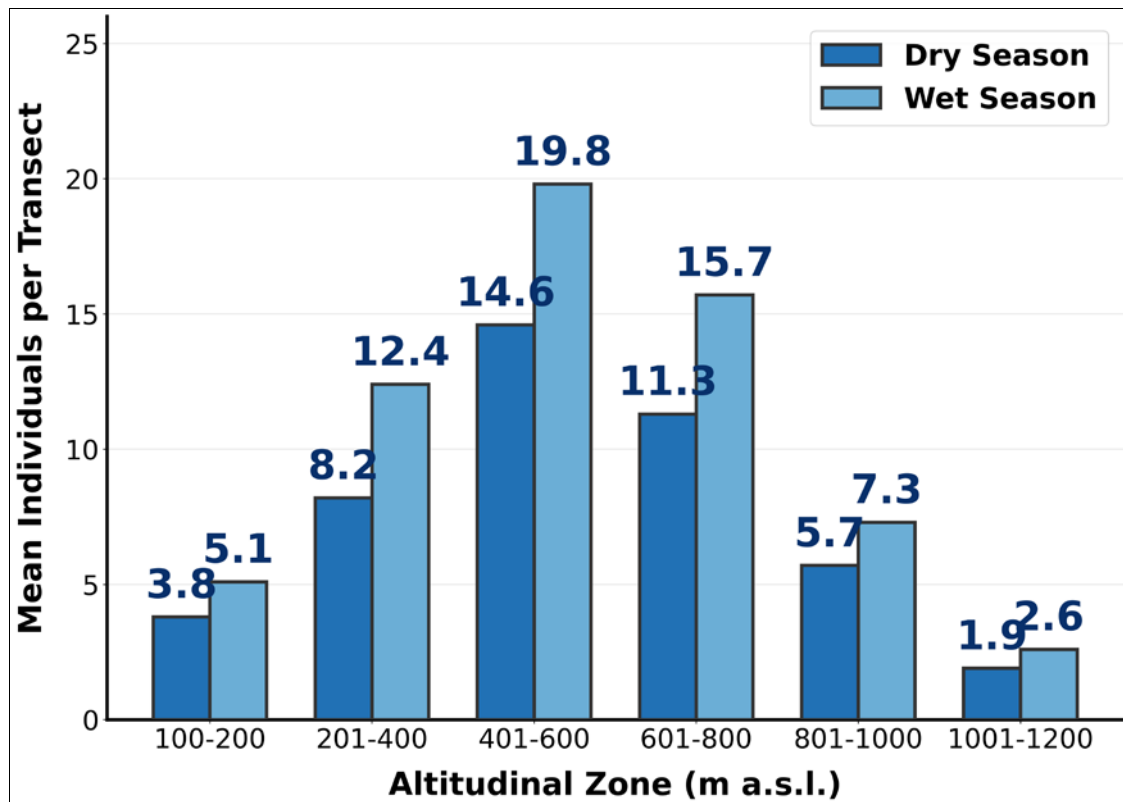


Fig 2: Mean encounter rates of *Heteropteryx dilatata* across six altitudinal bands during dry and wet seasons in the Titiwangsa Range, Peninsular Malaysia

Comprehensive interpretation

The results collectively establish a clear mid-elevation peak in *H. dilatata* abundance, centred on the 401-600 m band and extending through 601-800 m. This pattern aligns with the mid-domain effect hypothesis but is better explained by microhabitat drivers particularly the intersection of high canopy cover and high humidity at intermediate elevations than by geometric range overlap alone. The seasonal uplift in wet-season counts, especially in Zone B, suggests that moisture availability exerts a proximate control on activity levels, possibly through its effect on cuticular water loss during nocturnal foraging. PCA ordination separated the three zones primarily along PC1 (temperature-humidity gradient, 52.3% variance explained) and PC2 (canopy-litter gradient, 21.7%), with Zone B points clustering tightly in the positive quadrant of both axes.

Discussion

The mid-elevation abundance peak recorded here matches patterns observed for other large-bodied tropical arthropods in Southeast Asian montane forests. Hilt and Fiedler^[13] reported a similar mid-elevation peak for geometrid moths in Borneo, attributing it to optimal humidity and moderate thermal stress. Our data extend that finding to Phasmatodea, a group seldom included in altitudinal gradient research. The mechanism likely involves a trade-off between desiccation risk at lower, warmer elevations and reduced metabolic scope at cooler highland sites, a pattern described for large ectotherms by Buckley and colleagues^[14]. Canopy cover emerged as the single strongest predictor, which carries practical significance. Selective logging that reduces canopy cover below 78% may therefore push local

abundance below viable thresholds, even if the forest remains nominally "intact" by area-based metrics. This is consistent with observations by Seow-Choen^[3] that captive *H. dilatata* refused exposed substrates and sought shaded retreats, translating a behavioural preference into a landscape-scale distribution constraint. Relative humidity, the second-ranked predictor, is itself partly a function of canopy closure, so the two variables likely reinforce each other.

Seasonal variation in encounter rates adds another layer. The 34.7% increase during the wet season was pronounced in Zone B but not in Zone C, where ambient humidity already exceeded 90% year-round. This differential response implies a humidity threshold beyond which further moisture input offers diminishing returns for *H. dilatata* activity an idea that warrants formal testing through controlled humidity experiments. From a broader standpoint, the results urge forest managers to treat mid-elevation forests not as secondary-priority buffer zones between protected lowland reserves and montane parks but as core conservation areas for invertebrate megafauna^[5].

Conclusion

This research set out to quantify the altitudinal distribution and habitat preferences of *H. dilatata* in the tropical rainforests of Peninsular Malaysia, and the data clearly answer all three objectives. First, abundance followed a pronounced mid-elevation peak, with the 401-800 m band supporting roughly three times the encounter rate of either the lowland or highland zones. Second, canopy cover and relative humidity were the foremost microhabitat predictors, together accounting for nearly 60% of the predictive weight

in the GLM, while temperature displayed a quadratic relationship with an optimum near 23 °C. Third, wet-season encounter rates exceeded dry-season rates by about 35%, though this effect was statistically meaningful only in the mid-elevation zone, where humidity gains were still biologically relevant rather than saturated.

For practitioners involved in forest management and protected-area design, the practical message is straightforward: mid-elevation dipterocarp-oak transition forests between 400 m and 800 m deserve explicit conservation targets, particularly where canopy integrity faces pressure from selective logging or road development. Monitoring schemes for *H. dilatata* should prioritise nocturnal transect surveys during the early wet season, when detectability is highest, and should incorporate canopy-cover measurements as an early-warning indicator of habitat degradation. Future research should extend the altitudinal gradient to summit zones above 1200 m, incorporate molecular identification of host-plant use through gut-content barcoding, and test whether the observed mid-elevation peak holds across Borneo and Sumatra, where *H. dilatata* subspecies or sibling species may occur.

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