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RESEARCH ARTICLE

Forest structure and conservation status of tree species in Gunung Inas Forest Reserve, Kedah, Peninsular Malaysia

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Abstract

This study explored the floristic composition, diversity and biomass in Gunung Inas Forest Reserve (GIFR), Kedah, an area facing potential threats from large-scale monoculture durian plantations. Three 0.53 ha plots were established to assess trees with a diameter at breast height ≥ 5 cm. As a result, a total of 53 individuals were identified, representing 16 species, 16 genera and 12 families. The Shannon-Weiner Diversity Index was recorded at H'=2.77 and Margalef's Richness Index at DMG=8.7, indicating low level of diversity and richness of tree in the forest. Moderate Evenness Index of E=0.71 portrayed the almost equal distribution of the tree species in the forest. Anacardiaceae had the highest FIVi at 24.79 % while *Swintonia schewenkii* was the most important species with SIVi = 12.48. Total tree biomass was estimated at 76.3 t/ha which was contributed by 66.04 t/ha and 10.22 t/ha of above ground biomass and below ground biomass, respectively. Furthermore, the study identified 2 of the 16 recorded tree species within the study area as threatened, highlighting the potential conservation concerns within this ecosystem. Overall, this study provides baseline data for future ecological research and calls for conservation efforts to protect this forest's biodiversity against potential threats.

Keywords: conservation status; endemism; floristic composition; SDG 15; tree communities

Introduction

The Bintang Hijau mountain range, spanning 140 km across Peninsular Malaysia's west coast, harbours diverse ecosystems characterized by dramatic elevational gradients. These montane forests, often fragmented and vulnerable, contribute significantly to regional biogeography yet receive less research attention compared to lowland counterparts. Tropical montane cloud forests have received only 5 % of biodiversity research in Southeast Asia in relative to 74 % for lowland forests in the past 20 years. GIFR within the Baling district of Kedah showcases this intricate landscape. Spanning around 37000 ha, it encompasses lowland and hill dipterocarp forests, transitioning to upper and lower montane forests (1). However, recent developments, including the conversion of 2.80 % (9583 ha) for monoculture plantations, particularly Musang King durian, raise concerns about potential threats to its rich biodiversity. This development threatens the vital water resources, climate regulation, soil protection and carbon sequestration functions of the reserve, further endangering critically endangered species like the Malayan tiger and Asian elephant.

While Kedah boasts studies on species diversity in Ulu Muda (2) and Sungai Merbok reserves (3), tree species diversity specifically within GIFR remains understudied, with existing research primarily focusing on reptiles and amphibians (1, 4). Addressing this gap, this study delves into the floristic composition and diversity of tree species within GIFR. Through detailed inventories, we aim to map the spatial distribution of tree individuals and species, revealing patterns within the forest ecosystem. This knowledge is crucial for understanding biodiversity, informing conservation efforts and ensuring the long term sustainability of this valuable forest for future generations. The data documented by this study will provide knowledge about the forest ecosystem and to plan for necessary action by the authorities in conserving and protecting the forest ecosystems. By providing quantitative data on the current tree population, this research directly supports Sustainable Development Goal 15 (Life on Land) and lays the foundation for long-term preservation of this irreplaceable ecosystem.

Materials and Methods

Study area

This study was conducted within the GIFR, Kedah, Peninsular Malaysia, approximately 30 km east of Kulim town (5° 32' 60" N, 100° 35' 60" E) (Fig. 1). Spanning roughly 36979 ha, the reserve primarily comprises lowland dipterocarp forest ecosystems (1). Notably, the fast-flowing and rocky Sungai Sedim River traverses the compartment, originating from Gunung Inas and

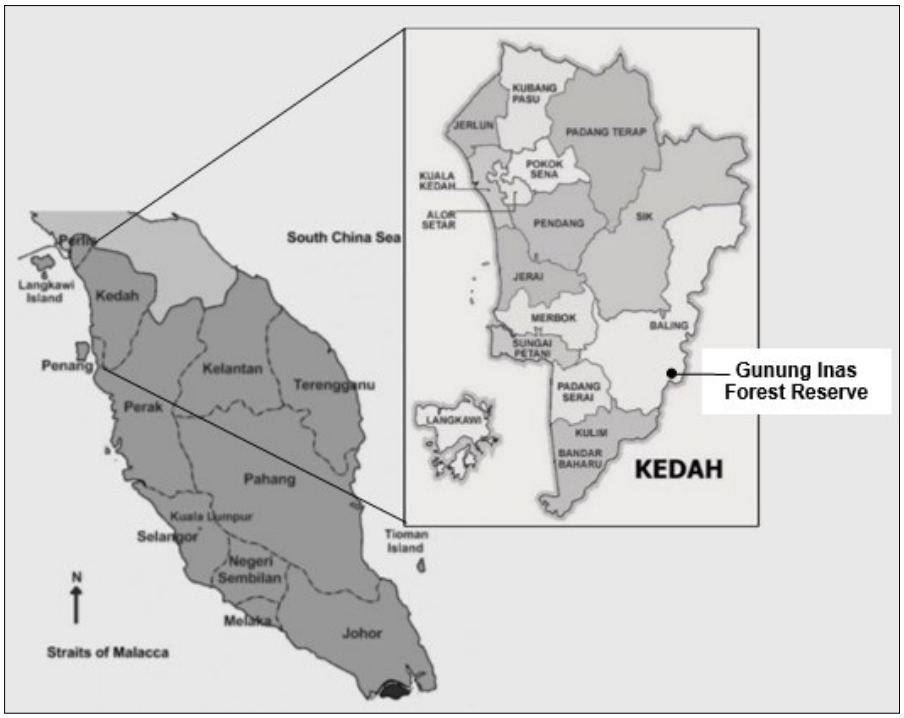

Fig. 1. Map of GIFR, Kedah, Peninsular Malaysia (5° 32' 60" N, 100° 35' 60" E).

ultimately draining into Sg. Muda. This river plays a crucial role in shaping the local hydrology and nutrient dynamics.

The forest boasts a diverse array of dominant plant species, including commercially valuable timber trees like *Shorea curtisii* (Dark Red Meranti), *Shorea leprosula* (Red Meranti), *Shorea macroptera* (Light Red Meranti), *Scorodocarpus borneensis* (Bawang Hutan), *Artocarpus lanceifolius* (Keledang) and *Callophyllum spp.* (Bintangor) (4). Gunung Inas itself rises an impressive 1454 meters above sea level, with its base around 240 m above sea level. Its scenic beauty and diverse ecology have contributed to its growing popularity as a hiking destination for enthusiasts across Peninsular Malaysia.

Tree sampling

To assess the tree species composition and diversity within GIFR, a quadrat sampling method was implemented. Three permanent plots, each measuring 70 m x 25 m (0.53 ha), were randomly established within the reserve (5). All trees with a diameter at breast height (DBH) exceeding 5 cm within each plot were tagged, identified and measured at 1.3 m above ground level. Additionally, leaf and fruit samples were collected from everyone for voucher specimen preparation and species identification (6). Morphological characteristics of the collected samples were compared against herbarium specimens housed at Universiti Kebangsaan Malaysia. Taxonomical nomenclature followed keys described in Tree Flora of Malaya (7, 8), supplemented by references from Keys in Malaya's Tree Flora (9) and The International Plant Name Index (10).

Data analysis

Data from all surveyed tree communities were systematically tabulated and analyzed to characterize the floristic composition of GIFR, Kedah. Sampling adequacy was assessed by constructing a species accumulation curve using EcoSim version 7 (11). To quantify species abundance, both density (individuals per unit area) and basal area (sum of individual cross-sectional areas at DBH) were calculated. The Importance Value Index (IVI) was computed for each species and family, providing an estimate of their relative significance within the community based on combined density, dominance and frequency values ([IVI = (RD + RB + RF)/3]) (12). Species diversity and richness were further assessed using three established ecological indices: Shannon-Wiener Diversity Index, Evenness Index and Margalef's Richness Index (13). All calculations were performed using PAST software version 2.17c (14). Total tree species biomass was estimated by summing aboveground biomass (AGB) and belowground biomass (BGB) values (15, 16) using appropriate allometric equations. Finally, the conservation status of each identified species was evaluated according to the International Union for Conservation of Nature (IUCN) Red List categories (17): Extinct (E), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), or Not Evaluated (NE). Species categorized as CR, EN and VU were collectively identified as threatened, providing insights into potential conservation concerns within GIFR.

Results

Floristic composition

Within the surveyed plots, a total of 53 trees with a diameter at breast height (DBH) exceeding 5 cm were identified, representing 16 distinct species across 16 genera and 12 families. The family Myrtaceae exhibited the highest species diversity, encompassing four species (25 % of total) including *Eugenia oleina, Gymnacranthera bancana, Palaquium burckii and Pometia pinnata*. This family also boasted the highest abundance with 14 individuals. *Swintonia schewenkii* (Anacardiaceae) stood out as the most abundant single species, with 12 individuals identified, followed by *P. burckii* (8 individuals) and *Eugenia stellata* (7 individuals), both belonging to Myrtaceae. Notably, Dipterocarpaceae, Hypericaceae, Myristicaceae and Sapindaceae were recorded as singleton

families, each represented by a single species and individual within the study area (Fig. 2).

Comparing GIFR's tree diversity to other Peninsular Malaysian forests highlights potential influences of sampling area size. A significantly higher species richness was reported in Temengor Forest Reserve, Perak with 65 families, 204 genera and 419 species within a larger study area (18). Similarly, Bukit Panchor State Park, Pulau Pinang harbored 42 families (19), 112 genera and 171 species. Even within a smaller area (0.98 ha), Bukit Lagong Forest Reserve, 53 species and 47 genera across 25 families were documented (20). In contrast, GIFR's 0.53 ha plots yielded 16 species, 12 genera and 11 families. This disparity suggests a positive correlation between sampling area size and species richness, potentially driven by increased habitat heterogeneity and microclimatic variations within larger forests. Further investigations utilizing larger sampling areas within GIFR could provide a more comprehensive understanding of its true tree diversity and potentially reveal additional species not captured in this study (Table 1).

Species diversity, evenness and richness

This study evaluated tree species diversity within GIFR using established indices. The Shannon-Wiener Diversity Index (H') was calculated as 2.66 (H'max = 2.77), which is considered lower than values reported for many other tropical rainforests (Fig. 3). For example, a study in Gunung Belumut Recreational Forestreported a H' of 4.82 (21), while Redang Island and Kota Damansara Forest Reserve recorded H' values of 4.05 and 3.43, respectively (22, 23). This lower diversity in GIFR could be attributed to its status as a secondary forest, impacted by past deforestation. Additionally, the relatively small sampling area (0.53 ha) compared to other studies might have contributed to the lower index value. Furthermore, abiotic factors within GIFR may be less hospitable for a wider variety of tree species. The

Table 1. Floristic composition from previous study on various forest types in Peninsular Malaysia in comparison to this study

References	Location	Size of study area (ha)	Family	Genus	Species
(18)	Temengor Forest Reserve, Perak	3.84	65	204	419
(19)	Bukit Panchor State Park, Pulau Pinang	1.00	42	112	171
(20)	Bukit Lagong Forest Reserve, Selangor	0.98	25	47	53
This study	Gunung Inas Forest Reserve	0.53	12	16	16

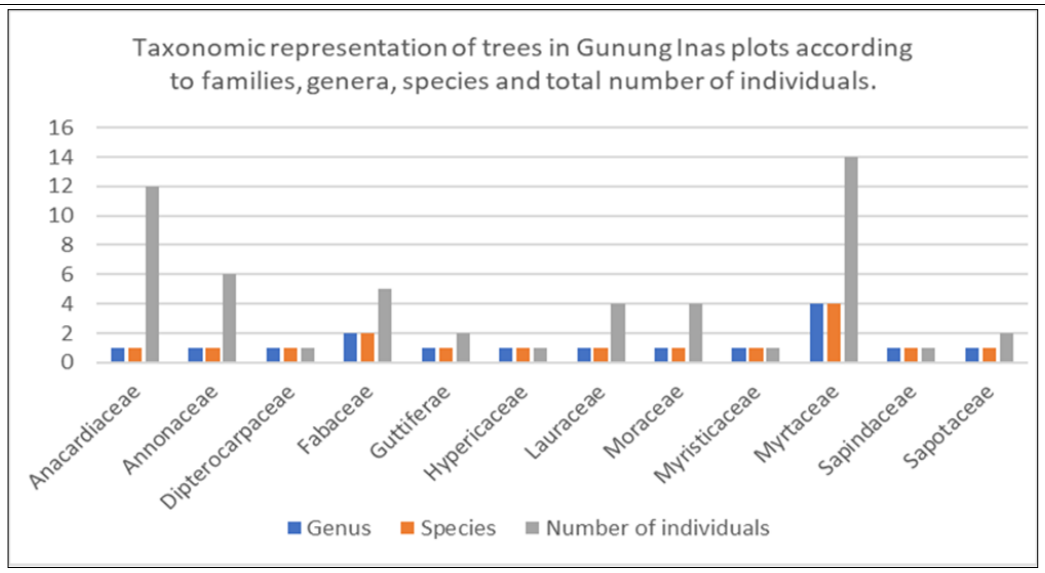

Fig. 2. Taxonomic representation of trees in Gunung Inas plots according to families, genera, species and total number of individuals.

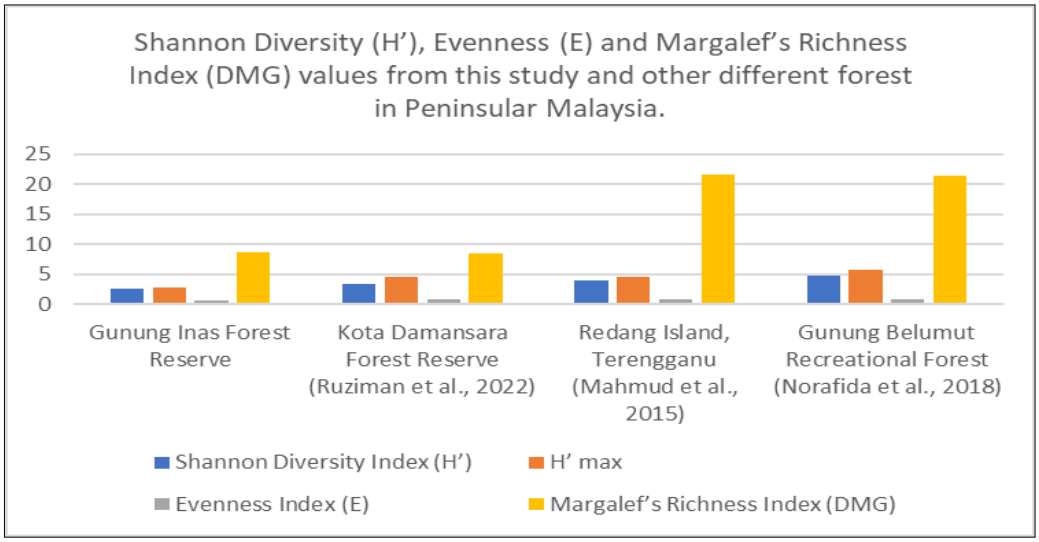

Fig. 3. Shannon Diversity (H'), Evenness (E) and Margalef's Richness Index (DMG) values from this study and other different forest in Peninsular Malaysia.

Evenness Index (E) in GIFR was 0.71, indicating moderate evenness in species distribution, while the Margalef Index (D_{MG}) was 8.7. These values are again lower than those reported for other tropical rainforests like Redang Island and Gunung Belumut forest reserves. This suggests that the low species richness in GIFR might be associated with anthropogenic activities impacting the abundance of tree species. Additionally, the Margalef index's dependence on sample size could explain its lower value in GIFR, considering the relatively small number of trees (53) and species (16) encountered compared to other studies.

Species accumulation curves

Species accumulation curves (SACs) were employed to assess the potential completeness of our sampling effort in capturing the tree species diversity within GIFR. As expected, the SACs depicted an increasing trend in species richness with increasing sample size, indicating that more species would likely be discovered with further sampling effort (Fig. 4). Notably, the curves did not reach an asymptote within the 0.53 ha area covered by our plots, suggesting that the current sampling effort may not have captured the full range of tree species present in GIFR.

Fig. 5 summarizes the diameter at breast height (DBH) distribution of tree individuals across all studied plots in GIFR. The observed DBH range spanned from 5.0 cm to 65.0 cm, indicating a varying size structure within the forest. The largest proportion of trees (20 individuals) fell within the DBH class of 15.0-24.9 cm (class II), representing 8 families, 8 genera and 10 species. This suggests a relatively high abundance of young to mid-sized trees in the current stand. The second most abundant size class was 5.0-14.9 cm (class I) with 16 individuals belonging to 7 families, 7 genera and 11 species. Notably, only one individual was recorded in the largest size class (55.0-64.9 cm, class VI), classified as a large tree and identified as *S. schwenkii* with a DBH of 58.2 cm.

The tree size distribution within GIFR, as depicted in Fig. 6, aligns with the established concept of an inverse J-shaped stand structure (24). This pattern signifies a negative exponential relationship between DBH class and the number of individuals, with the majority of trees falling within smaller size classes and a decreasing abundance of larger trees. This observation is consistent with the characteristic of natural forest regeneration, where successful recruitment leads to a dominance of younger individuals in the stand (25).

Importance Value Index (IVI)

This study employed the IVI to assess the relative dominance of individual species and families within the GIFR tree community. As per established guidelines (12), an IVI exceeding 40 % at the

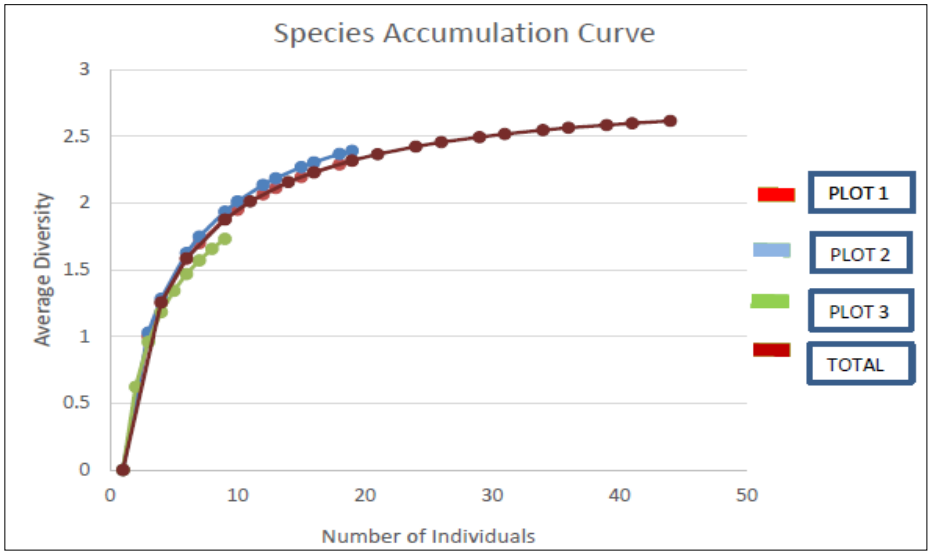

Fig. 4. Species accumulation curve plotted for each tree plots in GIFR.

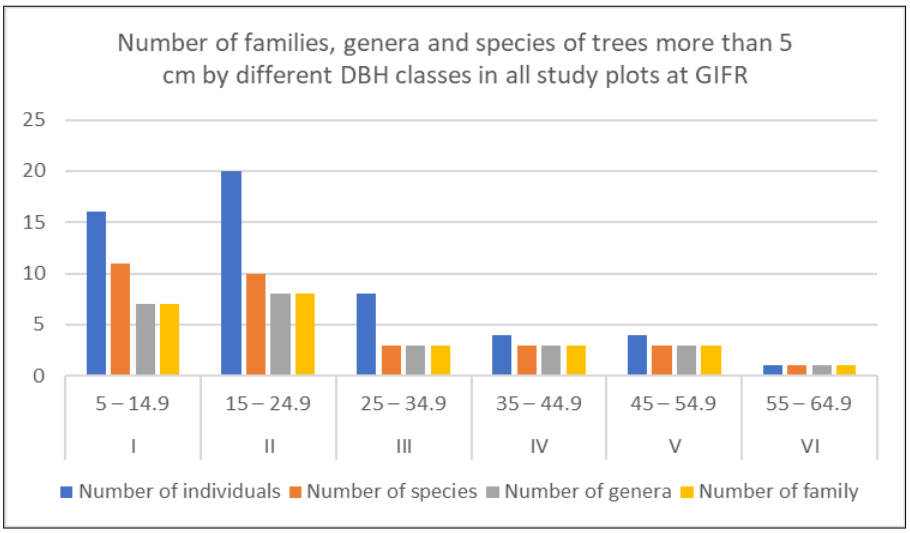

Fig. 5. Number of families, genera and species of trees more than 5 cm by different DBH classes in all study plots at GIFR.

family level and 10 % at the species level indicates absolute dominance. Analyzing the species-level IVI (SIVI) revealed that *S. schwenkii* emerged as the most dominant species with a value of 12.48 %, followed by *E. oleina* (SIVI = 8.09 %), *Parashorea stellata* (SIVI = 1.73 %), *P. burckii* (SIVI = 1.0 %) and *Cinnamomum camphora* (SIVI = 0.88 %). Only *S. schwenkii* surpassed the 10 % threshold for absolute dominance, while the remaining species does not exhibit dominance within the community. At the family level, Anacardiaceae held the highest Family Importance Value Index (FIVI) of 24.78 %, followed by Myrtaceae (FIVI=20.87 %) and Fabaceae (FIVI = 10.36). While none of the families achieved the 40 % threshold for absolute dominance, these three families emerged as relatively dominant families compared to others in the study area (Fig. 7).

Biomass estimation

This study estimated the total above ground biomass (AGB) of trees in GIFR at 66.04 t/ha and the below ground biomass (BGB) at 10.22 t/ha, resulting in an overall biomass of 76.3 t/ha. Based on these calculations, the Anacardiaceae family contributed the highest biomass in GIFR at 31.28 t/ha contributing 41 % of overall biomass, followed by Myrtaceae at 12.93 t/ha (17 %) and Dipterocarpaceae at 9.95 t/ha (13 %). At species level, *S. schwenkii* contributed a total biomass of 31.29 t/ha (43.1 %), followed by *E. oleina* with 19.39 t/ha (25.4 %) and *Cynometra malaccensis* at 3.28 t/ha (4.26 %) (Fig. 8).

Conservation status

This study employed the IUCN Red List of Threatened Species to assess the conservation status of the 16 tree species identified in GIFR. The analysis revealed that two species require significant conservation attention. *Palaquium burckii* from the family Sapotaceae was classified as Critically Endangered (CR), indicating an extremely high risk of extinction in the wild. Meanwhile, *Parashorea stellata* (Dipterocarpaceae) was categorized as Vulnerable (VU), highlighting its susceptibility to threats that could lead to endangerment soon.

Discussion

Floristic composition, species diversity, evenness and richness

The lower tree species diversity observed in GIFR compared to other studied forests highlights potential ecological

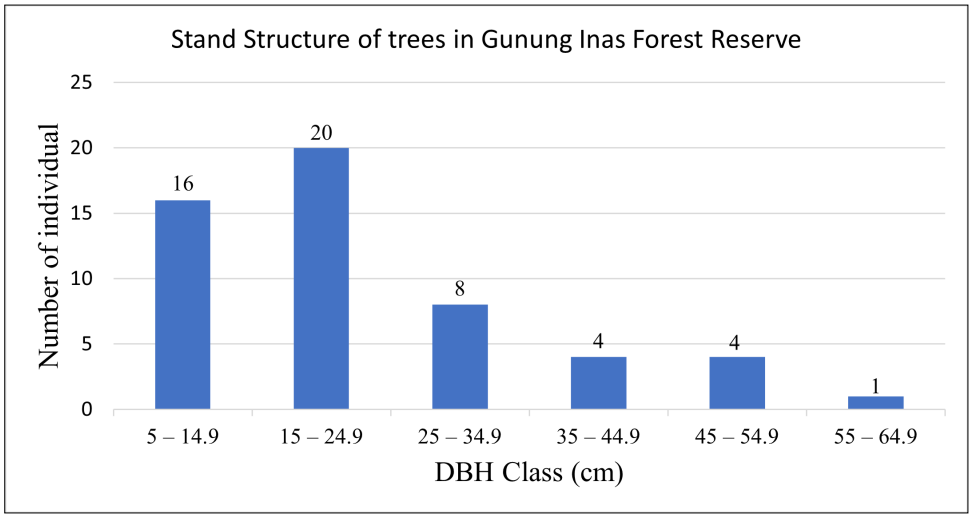

Fig. 6. Stand structure in all study plots at GIFR, Kedah.

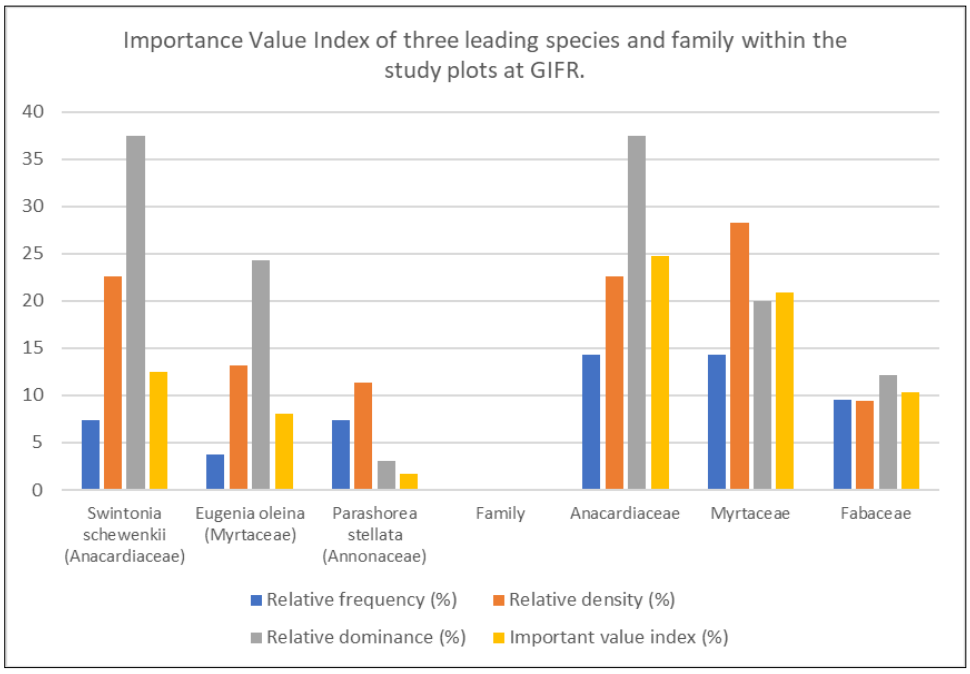

Fig. 7. IVI of three leading species and family within the study plots at GIFR.

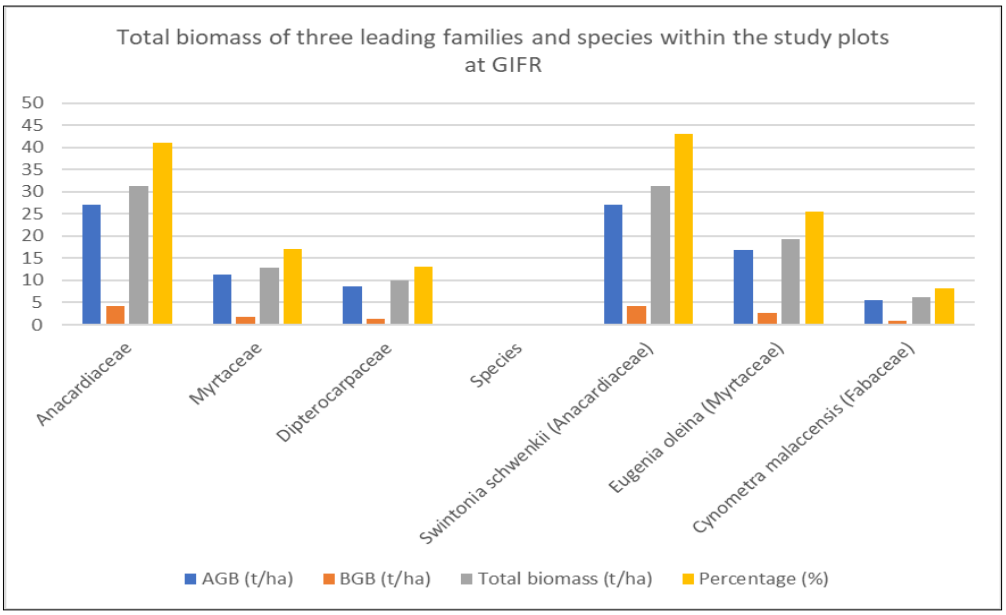

Fig. 8. Total biomass of three leading families and species within the study plots at GIFR.

consequences of past deforestation and the limitations of secondary forest regeneration. This finding aligns with existing literature on the impact of human activities on tropical forest ecosystems. The relatively low evenness and Margalef indices further suggest an uneven distribution of species and potentially a limited capacity for supporting a wider range of tree species within GIFR.

Species accumulation curves

This finding on the species accumulation curves of GIFR aligns with the well documented high biodiversity of rainforests in Peninsular Malaysia, where species richness is known to increase with larger sampling areas. Additionally, it supports the general understanding among tropical ecologists that tree species richness in such regions often reaches an asymptote somewhere between one and three hectares (26). For comparison, a previous study in the 1-hectare Ulu Muda Forest Reserve, Kedah, reported an asymptotic SAC, suggesting that their sampling size captured most of the available tree species richness (27). The lack of asymptote in our SACs highlights the limitations of the current sampling effort in fully characterizing the tree species diversity within GIFR. While the study provides valuable insights into the forest's composition, additional sampling across a larger area is crucial to comprehensively capture its full tree species richness and potentially reveal rare or underrepresented species. This expanded sampling effort could involve establishing additional plots strategically distributed within the reserve to encompass diverse habitat types and microclimates.

In GIFR, the tree size distribution clearly exhibits this inverse J-shaped trend, indicating ongoing regeneration within the forest. However, the observed pattern does not constitute a perfect inverse J-shape, suggesting potential deviations from the ideal regeneration process. This finding is not uncommon, as similar deviations have been reported in various tropical forest ecosystems, including Pulau Timun Forest Reserve, Pulau Langkawi Forest Reserve (28), Bukit Nanas Forest Reserve (29) and Bangi Permanent Forest Reserve (30). The prevalence of the inverse J-shaped pattern in tropical forests underscores the importance of understanding factors influencing regeneration dynamics. While the observed distribution suggests ongoing recruitment in GIFR, further investigations are warranted to explore potential limitations or imbalances in the regeneration process. This could involve examining factors such as seed availability, competition and microenvironmental conditions, ultimately aiming to inform conservation and management strategies that promote healthy and sustainable regeneration within the forest.

Importance Value Index

The IVI analysis in GIFR revealed *S. schwenkii* as the most dominant species, exceeding the threshold for absolute dominance. This could be attributed to its relatively high abundance and wide distribution within the study area. While Myrtaceae and Anacardiaceae emerged as the leading families, none achieved absolute dominance, suggesting a more balanced distribution of influence within the community compared to other studied forests. For comparison, previous studies in Bukit Bauk Virgin Jungle Forest, Lesong Forest Reserve and Gunung Belumut Recreational Forest reported Euphorbiaceae as the most dominant family with FIVIs exceeding 26 % (27). Additionally, *Dryobalanops aromatica* was identified as the predominant species in all three forests, with SIVIs exceeding 16 %. These comparisons highlight the varying composition and dominant elements within different tropical rainforest ecosystems. The observed differences in dominant species and families compared to previous studies accentuate the importance of considering specific ecological contexts and potential historical disturbances when interpreting dominance patterns. Further research could explore factors influencing the observed dominance patterns in GIFR, such as current monoculture plantation activities, soil characteristics and competition dynamics. Additionally, investigating the regeneration potential of less dominant species and families could provide valuable insights for informing conservation and management strategies aimed at promoting a more diverse and resilient forest community.

Biomass estimation

The analysis revealed Anacardiaceae as the dominant family in terms of biomass contribution within GIFR, consistent with

observations in other studied forests. *S. schwenkii* emerged as the single most influential species, contributing significantly to the overall biomass. These dominance patterns likely reflect factors such as species abundance, distribution and growth characteristics. The observed differences in total biomass between GIFR and other forests could be attributed to various factors, including forest age, historical disturbances and soil conditions (31). Further study and analysis exploring these factors and their interactions could provide valuable insights into the drivers of biomass accumulation in different forest ecosystems.

Conservation status

The presence of threatened species and the vulnerability of Dipterocarpaceae within GIFR emphasize the need for targeted conservation efforts. Human activities like monoculture plantation and logging, alongside natural disturbances, are known to contribute to the decline of dipterocarp species (32). Furthermore, studies in other Selangor Forest Reserves (Kota Damansara, Bukit Tarek and Ulu Gombak) have similarly identified Dipterocarpaceae as the most threatened family (23), suggesting a broader regional concern. By implementing comprehensive and collaborative conservation efforts, we can safeguard the future of threatened species like *P. burckii* and *P. stellata* within GIFR, ensuring the long-term health and ecological integrity of this valuable forest reserve.

Conclusion

In conclusion, this study established that GIFR exhibits relatively low tree species diversity and a limited floristic composition. While abiotic factors like edaphic conditions and topography are likely contributors to these findings, further research is warranted to gain deeper insights into their specific influences. The present study represents an initial exploration and expanding the sampling effort across a larger area is crucial for achieving a more accurate representation of the reserve's original plant diversity and potentially revealing additional or new species composition. Additionally, incorporating soil parameter analysis such as soil fertility and soil hydrology into future studies could provide valuable insights into potential edaphic controls on tree species distribution. By contributing to the knowledge base on GIFR's tree flora and understanding the factors shaping its composition, this study holds potential to enlighten future conservation and preservation strategies for the GIFR's ecological asset.

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Authors' contributions

HN carried out the forest structure analysis, participated in the design of the study and drafted the manuscript. HHR participated in the design of the study and performed the statistical analysis. FP and VRF conceived of the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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