International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 09 Issue 03 March 2026
DOI: 10.47191/ijcsrr/V9-i3-36, Impact Factor: 8.048
IJCSRR @ 2026
www.ijcsrr.org

The Effect of Deforestation on Araceae Hemiepiphyte Populations in Toili-Bulan Track Area, Central Sulawesi

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ABSTRACT: Tropical forests are highly dynamic ecosystems that support diverse plant communities, including hemiepiphytes that depend on stable microclimatic conditions and complex forest structures. However, increasing deforestation has altered these environments, potentially affecting the survival and distribution of sensitive plant groups. This study aims to analyze the impact of deforestation on the population structure and diversity of Araceae hemiepiphytes in the Toili–Bulan track area, Central Sulawesi. The research integrates remote sensing analysis of land cover change from 2019 to 2023 with field-based vegetation surveys conducted in 2023. Land cover analysis using Sentinel-2 imagery revealed a significant decrease in forest area by 10.85%, accompanied by a substantial increase in mixed dryland agriculture (29.46%), indicating that agricultural expansion is the primary driver of deforestation. Vegetation analysis recorded 285 individuals/ha of Araceae hemiepiphytes across 13 species, with Pothos tener and Rhaphidophora species showing the highest abundance and ecological importance. The Shannon–Wiener diversity index (H' = 2.39) indicated moderate species diversity. The findings demonstrate a strong relationship between forest degradation and hemiepiphyte populations, where reduced canopy cover and loss of mature host trees negatively affect habitat availability and microclimatic stability. Consequently, areas experiencing higher levels of deforestation exhibit lower population density and diversity of hemiepiphytic species. This study highlights the ecological sensitivity of Araceae hemiepiphytes to forest disturbance and underscores the importance of conserving forest structure to maintain biodiversity and ecosystem stability in tropical forests.

KEYWORDS: Araceae, biodiversity, deforestation, hemiepiphytes, land cover change, Central Sulawesi.

INTRODUCTION

Tropical forests are among the most biodiverse ecosystems on Earth, supporting a wide range of plant life forms, including epiphytes and hemiepiphytes, which contribute significantly to overall species richness and ecosystem complexity (Barlow et al. 2018; Shimamoto et al. 2018). These ecosystems play a critical role in maintaining ecological balance, regulating climate, and sustaining global biodiversity through intricate biotic interactions and nutrient cycling processes. In addition, tropical forests function as important carbon sinks, helping to mitigate climate change while providing essential ecosystem services for human well-being (Mishra et al. 2025). However, deforestation has emerged as a major threat to tropical forests, particularly in Southeast Asia, where land-use change driven by agricultural expansion, logging, mining activities, and infrastructure development continues to accelerate at an alarming rate (Hoang & Kanemoto, 2021). This rapid transformation of forest landscapes results not only in habitat loss and fragmentation but also in substantial alterations in microclimatic conditions, including increased temperature, reduced relative humidity, and greater light penetration into the forest interior (Tabor et al. 2018). Such environmental changes can disrupt ecological stability and profoundly affect plant groups that depend on shaded, humid, and structurally complex habitats, especially hemiepiphytic species within the family Araceae, which are highly sensitive to microenvironmental fluctuations (Edwards et al. 2019; Brancalion et al. 2020).

Hemiepiphytic Araceae constitute a unique ecological group characterized by a dual life strategy that combines both terrestrial and epiphytic growth phases (Riordan et al. 2023). These plants typically establish on the forest floor during early developmental stages, where they rely on soil nutrients and moisture, and subsequently transition to a climbing or epiphytic phase by attaching to host trees as they mature. This adaptive growth strategy allows them to exploit vertical forest stratification, enabling access to higher light availability in the canopy while reducing competition in the understory (Zotz et al. 2021; Riordan et al. 2023). Genera such as

Philodendron, *Rhaphidophora*, and *Scindapsus* exhibit a range of specialized morphological and physiological adaptations, including the development of aerial roots for anchorage and water absorption, as well as efficient mechanisms for nutrient uptake from organic debris accumulated on tree surfaces (Zuluaga et al. 2019). These adaptations are essential for survival in environments where direct access to soil resources becomes limited during later life stages (Yusoff et al. 2013). Consequently, the distribution, abundance, and long-term survival of hemiepiphytic Araceae are closely associated with forest structure, particularly the presence of large and mature host trees, as well as stable microclimatic conditions characterized by high humidity and moderate temperature (Croat & Ortiz, 2020).

Deforestation disrupts these essential ecological conditions by significantly altering canopy structure and reducing the availability of suitable host trees required for hemiepiphyte establishment and growth (Runyan et al. 2012). The removal of large and mature trees, which serve as primary substrates for hemiepiphytes, directly limits habitat availability and reduces opportunities for vertical colonization. In addition, canopy opening caused by logging or land clearing increases exposure to solar radiation and wind, resulting in decreased humidity and greater temperature fluctuations within the forest environment. These altered microclimatic conditions create physiological stress for hemiepiphytic species, which are generally adapted to stable and humid environments (Barlow et al. 2016; Maurya, & Vivek, 2025). Furthermore, deforestation often leads to simplification of forest structure, reducing niche diversity and disrupting ecological interactions that support plant communities. Previous studies have consisteant declines in species richness, abundance, and diversity observed in degraded or secondary forests compared to primary forests (Zeni et al. 2019). These patterns are largely attributed to the combined effects of microclimatic changes, loss of suitable substrates, and reduced structural complexity, all of which are critical factors influencing the survival and regeneration of hemiepiphytic Araceae (Zhang et al. 2023).

Despite the recognized sensitivity of epiphytic plants to environmental disturbance, research specifically addressing hemiepiphytic Araceae remains limited, particularly within the Indonesian context, where biodiversity is exceptionally high but ecological data are still insufficient (Nadkarni, 2023). Central Sulawesi, as part of the Wallacea region, is known for its remarkable levels of endemism and unique biogeographical characteristics, making it a priority area for biodiversity conservation. Nevertheless, this region is increasingly subjected to anthropogenic pressures such as agricultural expansion, plantation development, and illegal logging, all of which contribute to ongoing forest degradation. The Toili-Bulan track area represents a heterogeneous landscape that exhibits varying degrees of forest disturbance, ranging from relatively intact forest ecosystems to highly modified and fragmented habitats. Such environmental heterogeneity provides an important opportunity to examine how different levels of disturbance influence plant communities (Michaux, 2010; Ali, & Heaney, 2021). However, the extent to which these disturbances affect the population dynamics, distribution patterns, and ecological resilience of hemiepiphytic Araceae has not been comprehensively investigated (Voig et al. 2021). This lack of empirical data highlights a significant knowledge gap in understanding species-specific responses to deforestation, thereby limiting the development of effective conservation strategies and sustainable forest management practices in tropical ecosystems (Struebig et al. 2022).

METHODOLOGY

Study Area

This research was conducted in a forest area along the Toili–Bulan track, covering approximately 1,367.38 hectares within the Forest Management Unit (KPH) Toili–Baturube. Administratively, the study site is located in Uemea Village, Toili District, Banggai Regency, Central Sulawesi, Indonesia. The area represents a tropical forest landscape experiencing varying levels of anthropogenic disturbance, making it suitable for assessing the ecological impacts of deforestation on plant communities, particularly hemiepiphytic Araceae.

Land Cover Change Analysis

Land cover change between 2019 and 2023 was analyzed using satellite image interpretation and digital image processing techniques to extract meaningful spatial information. The analysis involved several stages, including pre-processing, visual image interpretation, manual digitization of land cover classes, and change detection analysis.

The primary data source consisted of Sentinel-2 satellite imagery obtained from the Copernicus Programme via the Copernicus Open Access Hub. Sentinel-2 Level-1C or Level-2A datasets for the years 2019 and 2023 were selected based on specific criteria, including cloud cover of less than 10–20%, acquisition during comparable seasonal periods, and a spatial resolution of 10 meters (Bands 2, 3, 4, and 8). Pre-processing steps included atmospheric correction (for Level-1C data), image clipping to the study area, and band composition. Land cover classes were visually interpreted and digitized manually using GIS software, followed by overlay analysis to quantify spatial changes in forest cover over the study period.

Vegetation Analysis

Data on Araceae hemiepiphyte populations were collected through field observations conducted in 2023. The study employed a belt transect method combined with systematic sampling to determine sampling locations. Sampling intensity was set at 0.1% of the total study area, resulting in 13 observation transects distributed systematically across the research site. Each transect measured 100 m × 10 m and was specifically designed to assess pole- and tree-level vegetation serving as host plants for hemiepiphytic Araceae. Within each transect, all host trees and associated hemiepiphytic Araceae individuals were recorded. Species identification was carried out based on morphological characteristics, referring to Mayo et al. (1997) for specific to the genus Araceae hemiepiphytes and Mustaqim et al. (2024) in the Digital Flora of Indonesia. Additional supporting references were used when necessary to ensure taxonomic accuracy.

Population data of Araceae hemiepiphytes were analyzed using standard vegetation ecology parameters, including density, frequency, and Important Value Index (IVI). Species diversity was assessed using the Shannon–Wiener diversity index (H'). These metrics were used to evaluate the structure and composition of hemiepiphytic populations across different levels of forest disturbance.

Data Analysis

To examine the relationship between deforestation and hemiepiphyte populations, spatial data on land cover change were integrated with field-based vegetation data. Comparative analyses were conducted to assess differences in population structure, abundance, and diversity of Araceae hemiepiphytes across areas with varying degrees of forest cover change. Statistical analyses, including correlation or regression tests where applicable, were performed to determine the strength and significance of the relationship between deforestation intensity and hemiepiphyte population parameters. This integrated approach combining remote sensing and field ecology provides a comprehensive framework for understanding the ecological impacts of deforestation on hemiepiphytic plant communities in tropical forest ecosystems.

RESULTS

Land Cover Change in Toili–Bulan Track Area (2019–2023)

The analysis of land cover change along the Toili–Bulan track area revealed significant alterations in forest ecosystems over the five-year period. The study area, located at an elevation of 400–500 m above sea level, is classified as lowland tropical forest and is predominantly composed of secondary dryland forest. This ecosystem supports a relatively high diversity of woody plant species, including commercially valuable timber such as *Agathis dammara*, *Shorea* spp., *Heritiera javanica*, *Palaquium obtusifolium*, *Calophyllum soulattri*, and *Octomeles sumatrana*. Between 2019 and 2023, substantial changes in land cover were observed, particularly in forested areas and agricultural expansion. The spatial distribution and trend of these changes are illustrated in Figure 1, which shows the pattern of deforestation and land conversion across the study area.

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www.ijcsrr.org

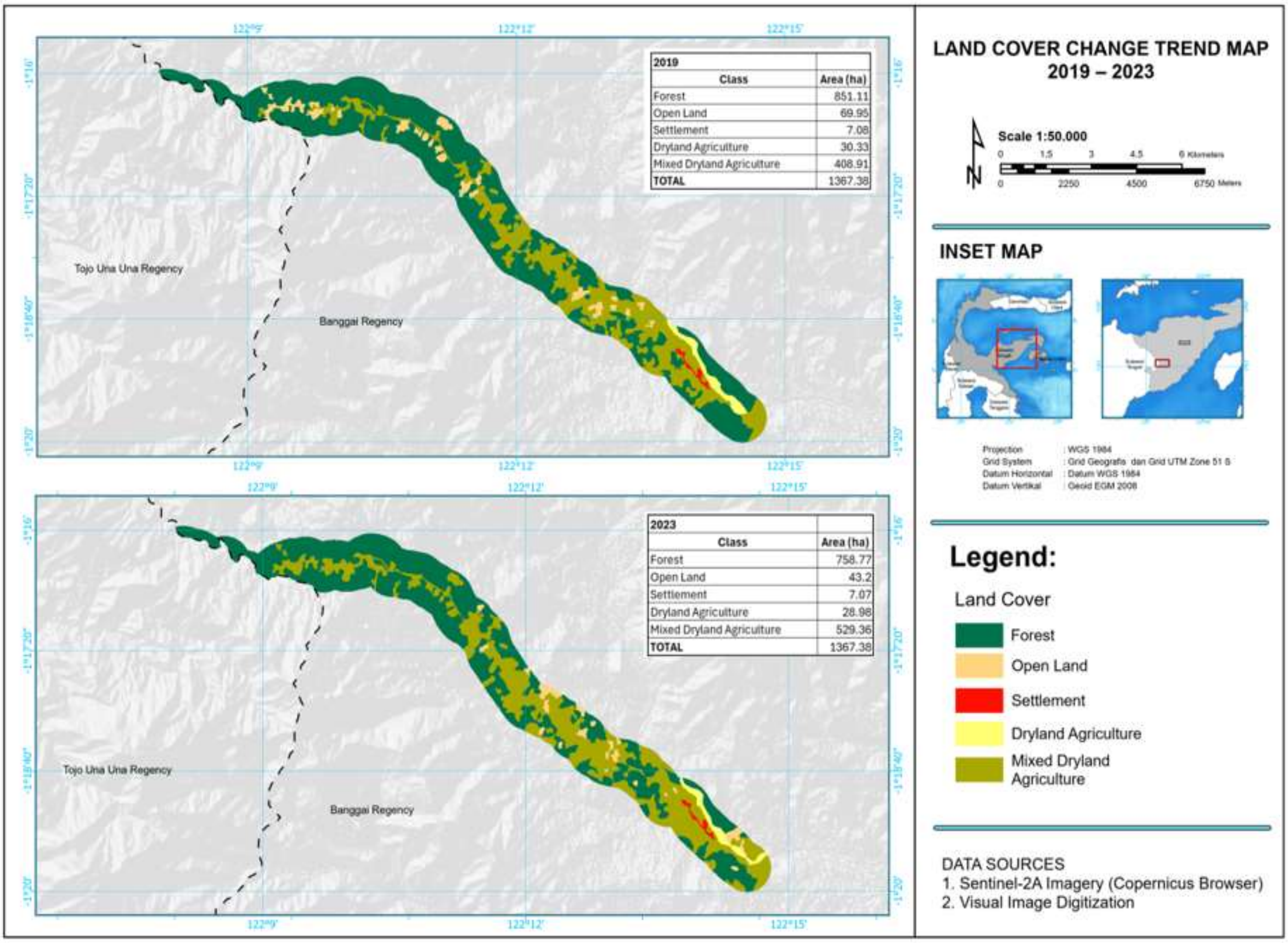

Figure 1. Land cover change trends along the Toili–Bulan track area from 2019-2023.

Quantitatively, forest cover decreased from 851.11 ha in 2019 to 758.77 ha in 2023, representing a reduction of 10.85% (Table 1). In contrast, mixed dryland agriculture increased significantly from 408.91 ha to 529.36 ha (29.46%), indicating that agricultural expansion is the primary driver of deforestation in the area. Other land cover types showed relatively minor changes, including a slight increase in settlements (0.14%) and dryland agriculture (4.45%), while open land decreased by 38.24%.

Table 1. Land cover changes in the Toili–Bulan track area from 2019-2023.

No	Land Cover Class	Area (ha) 2019	Area (ha) 2023	Description
1.	Forest	851.11	758.77	Decreased by 10.85%
2.	Open Land	69.95	43.2	Decreased by 38.24%
3.	Settlement	7.08	7.07	Increased by 0.14%
4.	Dryland Agriculture	30.33	28.98	Increased by 4.45%
5.	Mixed Dryland Agricuture	408.91	529.36	Increased by 29.46%
	Total	1367.38	1367.38	

These findings indicate that forest conversion into agricultural land has intensified due to increasing dependence of local communities on land resources. Logging activities, both for commercial purposes and fuelwood, further accelerate forest degradation. Such changes in land cover directly influence habitat structure, particularly the availability of mature trees and canopy cover that are essential for supporting hemiepiphytic plant communities.

Population Structure and Diversity of Araceae Hemiepiphytes

The vegetation analysis conducted in 2023 recorded a total population of 285 individuals/ha of Araceae hemiepiphytes associated with host plants along the Toili–Bulan track. These individuals were distributed across host vegetation consisting of 60 pole-level trees (∅ >10 m) and 225 tree-level individuals (∅ >20 m), indicating that larger trees serve as the primary structural support for hemiepiphytic growth.

A total of 13 species of Araceae hemiepiphytes were identified, with the genus *Rhaphidophora* being the most dominant. Among these, three species: *Rhaphidophora sarasinorum*, *Rhaphidophora koordersii*, and *Rhaphidophora sabit* are endemic to Sulawesi. The detailed vegetation analysis, including Relative Density (RD), Relative Frequency (RF), Important Value Index (IVI), and Diversity Index (H), is presented in Table 2.

Table 2. Vegetation analysis of Araceae hemiepiphytes based on host plant distribution in 2023.

No	Species	Σ Individuals (ha)	RD (%)	RF (%)	IVI	H
1.	*Pothos tener* Wall.	50	17.54	10.42	27.96	0.31
2.	*Rhaphidophora sarasinorum* Engl.	40	14.04	10.42	24.45	0.28
3.	*Rhaphidophora montana* (Blume) Schott	36	12.63	10.42	23.05	0.26
4.	*Rhaphidophora peeploides* Engl.	30	10.53	10.42	20.94	0.24
5.	*Rhaphidophora koordersii* Engl.	24	8.42	10.42	18.84	0.21
6.	*Epipremnum pinnatum* (L.) Engl.	22	7.72	10.42	18.14	0.20
7.	*Rhapidophora decursiva* (Roxb.) Schott	20	7.02	8.33	15.35	0.19
8.	*Scindapsus pictus* Hassk	17	5.96	6.25	12.21	0.17
9.	*Pothos cylindricus* C.Presl	14	4.91	6.25	11.16	0.15
10.	*Amydrium medium* (Zoll. & Moritzi) Nicolson	10	3.51	5.21	8.72	0.12
11.	*Rhaphidophora korthalsii* Schott	8	2.81	4.17	6.97	0.10
12.	*Pothos beccarianus* Engl.	8	2.81	4.17	6.97	0.10
13.	*Rhaphidophora sabit* P.C.Boyce	6	2.11	3.13	5.23	0.08
	Total	285	100	100	200	2.39

The most abundant species was *Pothos tener* (50 individuals/ha), followed by *Rhaphidophora sarasinorum* (40 individuals/ha) and *Rhaphidophora montana* (36 individuals/ha), all of which showed high ecological importance. Conversely, several species exhibited low abundance, including *Pothos cylindricus*, *Amydrium medium*, *Rhaphidophora korthalsii*, *Pothos beccarianus*, and *Rhaphidophora sabit*, indicating limited distribution and potential vulnerability. The Shannon–Wiener diversity index (H') was calculated at 2.39, indicating a moderate level of species diversity and suggesting that the community is relatively stable. However, the presence of low-density and endemic species highlights potential risks of population decline.

These results also reflect a strong relationship between forest condition and hemiepiphyte populations. The reduction in forest cover, particularly the loss of mature host trees, limits suitable substrates and alters microclimatic conditions such as humidity and light intensity. As a result, areas experiencing higher levels of deforestation tend to support fewer individuals and lower species diversity. If this trend continues, it may accelerate the decline of sensitive species, especially endemic taxa such as *Rhaphidophora sabit*. Overall, the findings emphasize that deforestation not only reduces forest area but also significantly affects the structure, diversity, and sustainability of Araceae hemiepiphyte communities in the Toili–Bulan track area.

DISCUSSION

The land cover dynamics observed in the Toili–Bulan track area reflect a broader pattern of tropical forest conversion driven by increasing human dependence on land-based resources. The expansion of mixed dryland agriculture indicates a transition from forest-dominated landscapes toward more intensive land-use systems, which is commonly associated with shifting socio-economic pressures in rural areas. This transformation is not merely a change in land use but represents a fundamental alteration of ecosystem structure, leading to reduced habitat continuity and increased landscape fragmentation (Takandjandji & Heriyanto, 2022). The decline in forest integrity is strongly linked to logging activities and agricultural encroachment, both of which contribute to the simplification of forest structure (Grantham et al. 2020). The removal of large, mature trees disrupts vertical stratification and reduces canopy complexity, which are critical components of tropical forest ecosystems. Such structural degradation has cascading ecological effects, including altered microclimatic conditions, reduced carbon storage capacity, and diminished biodiversity support (Crowe et al. 2023).

Moreover, the rapid conversion of transitional or open areas into agricultural land suggests that land-use intensification is occurring without sufficient recovery periods for natural regeneration. This continuous pressure limits the resilience of the ecosystem and accelerates the loss of ecological functions (Galinato & Galinato, 2013). In fragmented landscapes, edge effects become more pronounced, resulting in increased light penetration, temperature fluctuations, and reduced humidity. These changes create environmental conditions that differ significantly from those of intact forests, thereby affecting species composition and ecological interactions (Hofmeister et al. 2019; Mendes & Prevedello, 2020). From an ecological perspective, the implications of these changes are profound, particularly for forest-dependent organisms. The loss of structural complexity and stable microclimates reduces habitat suitability for specialized plant groups, including hemiepiphytes (Fanuel et al. 2023). Therefore, deforestation in the study area should be viewed not only as a reduction in forest area but also as a driver of ecological imbalance that threatens long-term ecosystem stability (Thom et al. 2017).

The structure and composition of Araceae hemiepiphyte communities in the study area reveal a system that is still functioning but increasingly under ecological pressure (Riordan et al. 2023). The presence of several dominant species suggests that certain taxa possess adaptive strategies that allow them to persist under disturbed conditions. These strategies may include broader ecological tolerance, efficient dispersal mechanisms, and flexibility in host tree selection, enabling them to survive in environments where canopy cover and humidity are no longer optimal. In contrast, less abundant species appear to be more sensitive to environmental changes, reflecting narrower ecological niches and greater dependence on specific habitat conditions (Quaresma et al. 2017). This disparity in species performance indicates an early stage of community restructuring, where disturbance-tolerant species begin to dominate while sensitive taxa gradually decline. Such patterns are commonly observed in disturbed tropical forests and may lead to long-term homogenization of plant communities if disturbances persist (Croat & Ortiz, 2020; Riordan et al. 2023).

A critical factor influencing hemiepiphyte distribution is the availability of suitable host trees. Mature trees not only provide physical support but also create microhabitats characterized by stable humidity, lower light intensity, and buffered temperature conditions (Balcázar-Vargas et al. 2012). The removal of these trees disrupts these microhabitats, making the environment less favorable for hemiepiphyte establishment and growth. Consequently, even if some host trees remain, changes in canopy structure can significantly reduce habitat quality (Wagner & Zotz, 2020). In addition, microclimatic alterations associated with deforestation such as increased solar radiation and decreased moisture can impose physiological stress on hemiepiphytes. These plants are generally adapted to shaded and humid environments, and deviations from these conditions can affect processes such as water balance, nutrient uptake, and reproduction (Fernandes et al. 2026). Reduced recruitment and survival rates may eventually lead to population decline, particularly for species with limited dispersal capacity. The presence of endemic species within the community further highlights the conservation importance of the study area (Adhikari et al. 2021). Endemic taxa are inherently more vulnerable due to their restricted geographic distribution and specialized habitat requirements. Disturbances that alter forest structure and microclimate can disproportionately affect these species, increasing their risk of local extinction (Yusoff et al. 2013). This underscores the need for targeted conservation efforts that prioritize both habitat protection and species-specific management (Struebig et al. 2022).

CONCLUSION

The rate of forest loss in the Toili–Bulan track area from 2019 to 2023 reached 10.85%, primarily driven by the rapid expansion of mixed dryland agriculture, which increased by 29.46% over the same period. This land-use change reflects intensifying anthropogenic pressure on forest ecosystems, resulting in the removal of structurally important host trees that support 13 species of Araceae hemiepiphytes. The loss of these host substrates has significantly reduced species-specific population densities, indicating a strong dependence of hemiepiphytes on forest structural integrity. In particular, the decline in pole- and tree-level vegetation has disproportionately affected less abundant and habitat-specialist species such as *Pothos cylindricus*, *Amydrium medium*, *Rhaphidophora korthalsii*, and *Pothos beccarianus*. Notably, *Rhaphidophora sabit*, an endemic species to Sulawesi, exhibits the highest level of vulnerability, highlighting the sensitivity of endemic taxa to habitat disturbance. If current deforestation trends persist, continued population decline is inevitable and may ultimately lead to local extinction, especially among species with limited ecological tolerance and restricted distribution. These findings emphasize the urgent need for forest conservation strategies that prioritize the protection of mature host trees and the maintenance of habitat complexity to sustain hemiepiphytic plant diversity.

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