Assessing the effect of anthropogenic disturbance on epiphytes in Khasi Hills of Meghalaya, India

by

Tiewlyngksiar Lyngdoh Nongrang
Enrolment no: 50BB22A73020

Dissertation Thesis

Submitted to the Academy of Scientific and Innovative Research

for the partial fulfilment of the degree

Master of Science
in
Wildlife Science

Under the supervision of

Amit Kumar, Ph.D
Department of Habitat Ecology
Wildlife Institute of India, Dehradun

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

AcSIR

July, 2024

DECLARATION

I hereby declare that the work conducted under the thesis entitled ***"Assessing the effect of anthropogenic disturbance on epiphytes in Khasi Hills of Meghalaya, India",*** is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master's in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Dr. Amit Kumar, Scientist-D, Department of Habitat Ecology, Wildlife Institute of India, Dehradun**. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my work, analysis, observation, and understanding and the particulars given in it are true to the best of my knowledge.

Tiewlyngksiar Lyngdoh Nongrang
Enrolment No: 50BB22A73020
Place: WII, Dehradun
Date: 31st July 2024

Amit Kumar, Ph. D
Supervisor

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that the thesis by **Tiewlyngksiar Lyngdoh Nongrang** entitled ***"Assessing the effect of anthropogenic disturbance on epiphytes in Khasi Hills of Meghalaya, India"*** is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

Tiewlyngksiar Lyngdoh Nongrang has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

(Amit Kumar, PhD)
Supervisor

(Dr. Ruchi Badola
Dean
Faculty of Wildlife Science

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून-248001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun-248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स. :+91-135-2640111 से 2640115, फैक्स :0135-2640117
EPABX : +91-135-2640111 to 2640115, Fax : 0135-2640117
ई–मेल/E-mail : wii@wii.gov.in, वेब/website : www.wii.gov.in

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE OF PLAGIARISM CHECK

It is certified that the Master's dissertation thesis titled **"Assessing the effect of anthropogenic disturbance on epiphytes in Khasi Hills of Meghalaya, India"** submitted by **Tiewlyngksiar Lyngdoh Nongrang** has been examined by us for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

a) Thesis has significant new work/knowledge as compared to already published work or work under consideration for publication elsewhere.
b) No sentence, equation, diagram, table, paragraph or section is found to have been copied verbatim from previous work unless it was placed under quotation marks and the source was duly cited.
c) The work presented is original work of the author (i.e. there is no plagiarism) and there is no fabrication of data or result by manipulating research materials, equipment or processes, or by changing or by omitting data or results such that the research is not accurately represented.

The similarity indices for the individual chapters as reported by the software iThenticate are as follows:

S. No	Chapter	iThenticate® similarity index
1.	Chapter 1	3 %
2.	Chapter 2	7%
3.	Chapter 3	7%
4	Chapter 4	5%
5	Chapter 5	1%
	Overall	**8%**

Manohar Pathak
Librarian

पुस्तकालयाध्यक्ष
Librarian
भारतीय वन्यजीव संस्थान, देहरादून
Wildlife Institute of India, D.Dun

Dr Amit Kumar

Supervisor

पत्रपेटी सं0 18, चन्द्रबनी, देहरादून – 248 001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun - 248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स. :+91–135–2640114, 2640115, 2646100 फैक्स : 0135–2640117
EPABX : +91-135-2640114, 2640115, 2646100 Fax: 0135-2640117
ई–मेल / E-mail : wii@wii.gov.in वेब / Website: www.wii.gov.in

Table of Contents

List of Figures

List of Tables

List of Plates

Acknowledgments

The completion of this dissertation would not have been possible without the support, guidance, and encouragement of numerous individuals and the Wildlife Institute of India, Dehradun. It is with immense gratitude that I would like to acknowledge their contributions.

First and foremost, I extend my deepest gratitude to my supervisor, Dr. Amit Kumar, whose expertise, patience, and unwavering support guided me through every stage of this journey. Your insightful feedback and constructive criticism have been invaluable in shaping this dissertation. I am profoundly thankful for your commitment to my academic and personal growth. A heartfelt thank you goes out to Dr. Navendu Page, MSc Course Director for guiding in synopsis, developing study design & methodology, and identification of plant species. I also wish to thank Dr. Sachin Sharma, Scientist, ICFRE, Dr. Mahesh, Scientist, BSI, and Mr. Tousif who have helped me with plant identification without which my data analysis would have not been completed. I wish to extend sincere gratitude to Dr. Vishnupriya Kolipakam, Prof. Qamar Qureshi, and Dr. Sutirtha Dutta for helping in data analysis and providing critical comments in improving the thesis. I would also like to acknowledge the administrative support from the Registrar of the institute Dr. S. Sathyakumar. Without this support, the completion of this research would have been significantly more challenging. Your investment in my work is deeply appreciated and has made a lasting impact on my academic journey. I would also like to thank Dr. Lallianpuii Kawlni for your support right from the start of my work till now.

I would also like to thank my field assistants, Mr. Jamely Kshiar, Mr. Edmond Kongsya, Mr. Special Kongmawpat, Mr. Jerry Khongsya, and Ms. Bawanbiang Mylliem for their time, and effort throughout my field days.

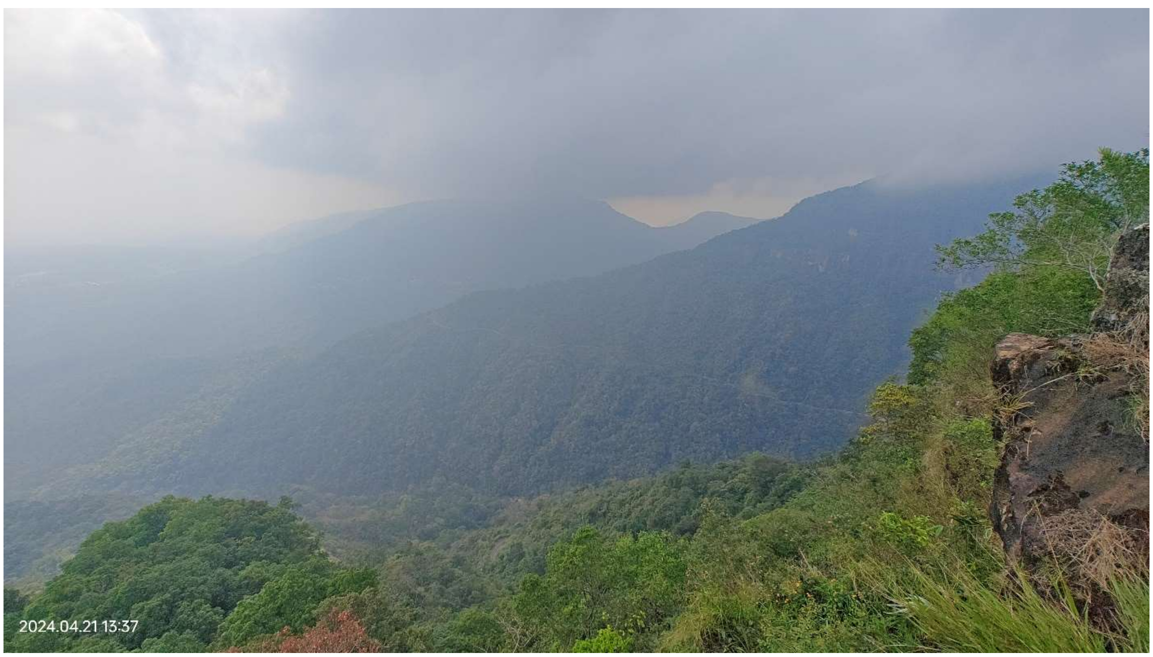
I am also grateful for the support of my friends Mr. Manas Shukla, Charu, Nandita, Mukul, Prakruthi, Aslam, Aditya, Rishi, Niyaz, David, Arnab, and Rakshith. Your camaraderie, intellectual discussions, and moral support have been a constant source of motivation throughout this process.

A special mention goes to all who have been a part of my work, Mr. T. Swett, Mr. Betwonsao Passah, and Mr. Maaz Alam (your unwavering support has been my source of strength and inspiration, thank you for standing by me through the highs and lows and for always believing in my potential), Ms. Aimon Bushra for helping preparation of map, and Mr. Rajit Jana for helping the thesis writing. Your willingness to contribute your time and knowledge has been essential to the success of this dissertation.

On a personal note, I am eternally grateful to my family, especially to my mom, Mr. Nee Wong Fu Khriam, and Mrs. Saralin Lyngdoh Nongrang, thank you for your unconditional love, encouragement, and sacrifices. Your belief in me has been the foundation of my perseverance. To my siblings, Ms. Ibankyrsoi, Ms. Phira, Ms. Baia, Mr. Arnold, Mr. Pynthymmai, and Mr. Maitshaphrang your support and understanding have meant the world to me.

In conclusion, this dissertation is a culmination of the collective efforts of many individuals, and I am profoundly grateful to each one of you. Your contributions, in various forms, have been instrumental in shaping this work. This achievement is as much yours as it is mine.

- Tiewlyngksiar Lyngdoh Nongrang



The key findings emerged from this study include-

- A total of 66 epiphytes comprising 32 species of orchids, 09 species of ferns, and 25 species of hemi-epiphytes & holo-epiphytes were recorded from the study area. Orchids had the highest species richness followed by ferns and hemi-epiphytes & holo-epiphytes.
- Among orchids, species of *Bulbophyllum, Pholidota* and *Vanda* were dominant. The dominant species among ferns included *Lepisorus* sp., *Davallodes hymenophylloides* and *Pyrrosia flocculosa* whereas, among hemi-epiphytes and holo-epiphytes, the dominant species were *Piper longum, Pothos chinensis, Rhaphidophora decursiva, Scurrula parasitica* and *Ficus* sp.
- The abundance of epiphytes was observed highest in the Private Forest followed by the Village Forest and Reserve Forest.
- Species richness, using sampled-based Rarefaction curves of epiphytes showed that the curve is not reaching an asymptote and observed species were highest in the Village Forest followed by Reserve Forest and Private Forest.
- The most abundant groups of epiphytes in Private Forest were hemiepiphytes mainly dominating on the lower trunk. In the village forest, orchids were found occupying the inner canopy. In Reserve Forest, ferns were in abundance and occupied the upper trunk.
- Species correlation shows no difference in species composition.
- Environmental variables are factors that can explain the difference in species richness and abundance of epiphytes.

1.1 Background and Rationale

Except for Antarctica, epiphytes thrive throughout all continents albeit most prevalent in the tropics. Depending on the host for either growth, support and germination (Benzing 1990; Zotz 2016; Flores-Argüelles et al. 2022), these species fall under the category of vascular epiphytes comprising hemiepiphytes and holoepiphytes (Benzing 1998; Padmawathe et al. 2004). Often called real epiphytes, holoepiphytes spend most of their life on their host plants, including ferns, orchids, and aroids (Benzing 1995). Conversely, hemiepiphytes devote half of their life cycle to their host trees before extending their roots into the soil and relying on them for support (Madison 1977; Todzia 1986; Putz and Holbrook 1986). Additionally, smaller epiphytes than their vascular counterparts are known as non-vascular epiphytes. Depending on the class to which they belong, epiphytes grow on tree trunks, branches, rocks, and other substrates. Epiphytes include ferns (Pteridophytes), aroids (Araceae), orchids (Orchidaceae) and several groups of pothos, philodendrons, mosses, and liverworts (Zotz 2016) comprising approximately 28,000 species (Benzing 1990). The angiosperms make up the bulk of the epiphytes which are mainly prominent in the groups of monocotyledons (orchids) and Polypodiales (ferns) (Zotz 2016).

The country's various climates can explain India's floristic diversity over its geological history (Singhvi and Krishnan 2014) and the altitudinal variation from sea level to 8000 metres. The Indian subcontinent can be broadly divided into three sections based on the floristic diversity, however out of the overall flora, orchids distributions in the region include; in the Himalayan region (with 868 taxa and 79 genera), Peninsular region (with 107 taxa), Andaman and Nicobar Islands (with 20 taxa), and 30 taxa are found in both the Himalayan and the Peninsular regions, this makes up the overall of 1025 taxa and 167 genera. Arunachal and Sikkim have the highest orchid diversity and endemism (Sarat 2007).

The North-East Biogeographic Zone (9A-Brahmaputra valley and 9B-North East hills) comprising of the states of Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura (Rodgers et al. 2000) harbour diverse species of flora and fauna. Endowed with a variety of climates, the state of Meghalaya (Cherrapunji and Mawsynram) has been reported for the highest rainfall in the globe. As a result, the state has a wide variety of different taxa groups with 256 families i.e., dicotyledons account for the greatest number (with 183 taxa; 1070 genera and 3010 species), followed by monocotyledons (with 33 taxa; 371 genera and 1233 species) with Orchidaceae family having the most with (116 genera and with 476 species), pteridophytes (with 30 taxa; 146 genera and 484 species), and lastly gymnosperms (with 10 taxa; 19 genera and 29 species) (Mao et al. 2016). Unfortunately, studies on epiphytes have not received enough attention in the North-East region or Eastern Himalaya.

1.2 Present Study

While there have been several botanical studies carried out on understanding the diversity of vascular plant species including orchids and pteridophytic flora in North-East region, no in-depth research has been done on the epiphytic species across disturbance gradients, especially across different community reserves or habitat types such as village forests, private forests and reserve forests. In order to fully understand the diversity pattern, ecology, and interactions of epiphytes with environmental conditions, further research is needed. Hence, as the information on the distribution of epiphytes to anthropogenic activities is crucial for future conservation planning, the present study aimed to address the effect of anthropogenic disturbance on epiphytes in the Khasi Hills of Meghalaya, India.

1.2.1 Objectives

I. To study species richness and abundance of epiphytes across different habitat types.

II. To understand the variation in species composition across the different habitat types.

III. To investigate the disturbance variables that underline the variation in species composition.

1.2.2 Key research questions

To achieve the proposed objectives, key research questions are:

Objective I

- Do the different habitat types exhibit different species richness?

Objective II

- Is there any variation in species composition across the different habitat types?

Objective III

- What are the factors affecting the diversity of epiphytes?

2.1 North-East Biogeographic Zone

The North-East biogeographic zone, which encompasses the states of Assam, Meghalaya, Nagaland, Manipur, Mizoram, and Tripura, is divided into two biotic provinces: the Brahmaputra valley (9A) and the North-East hills (9B) (Rodgers et al. 2000). Covering about 5.2% of the total geographical area of India, the region borders Bangladesh to the west, Myanmar to the east, and Bhutan to the north. The region serves as a meeting place between Peninsular India and the Himalayan Mountains and as a transitional zone between the geographical regions of Indo-Malayan and Indo-Chinese (Mani, 1974). Owing to its high levels of humidity and highest rainfall region in the world, the North-East zone is a biogeographic area rich in endemism and distinctive flora and fauna. This zone consists of nearly 58.66% area under forests (ISFR 2019). According to Champion and Seth (1968); Dikshit and Dikshit (2014) and Tripathy et al. (2016), tropical evergreen forests, tropical semi-evergreen forests, tropical moist deciduous forests, sub-montane hill: valley swamp forests, eastern wet alluvial grassland, sub-tropical broadleaved hill Forests, sub-tropical pine forests, and montane temperate forests are the major forest types in the region. It harbours 876 species of orchids, which constitute 70% of the total orchid flora of India (Dikshit and Dikshit, 2014).

2.2 Meghalaya: the abode of clouds

Located in the North-East biogeographic zone, Meghalaya lies between 25°1' to 26°5' N latitudes and 85°49' to 92°52' E longitudes. The state covers an area of 22,429 km2 in which Khasi Hills and Jaintia Hills form the central and eastern parts of Meghalaya, having plateaus with rolling grasslands, hills and river valleys. The Mawsynram village receives the highest rainfall globally, averaging about 750cm. As per Champion and Seth (1968), alluvial Sal, foothill and plateau Sal, very moist sal bearing forests-Khasi hills Sal, mixed deciduous forests, evergreen forests, bamboo forests, grasslands- northern tropical moist deciduous forests, Assam sub-tropical pine forests are the major types of forests in the state. Haridasan & Rao (1985−1987) broadly classify the state's vegetation into tropical forests, sub-tropical broadleaved and pine forests, temperate forests and grasslands. The geographical distribution of Meghalaya's plant life reveals that 548 plant species (302 genera under 100 families) are endemic to the eastern Himalayan area, north-eastern India, or Indo-Burma (Mir et al., 2019). Out of these, Meghalaya is home to 115 endemic species. Epiphytes account for 25.4% of all living forms, with trees (25%), shrubs (21.7%), herbs (21%), climbers (6.6%), and parasites (0.4%) following in order of dominance (Mir et al., 2019).

2.2.1 Forest areas and their ownership

According to the management level, Meghalaya's forests are divided into several categories under the Meghalaya Biodiversity Strategy & Action Plan (MBSAP): 2017–2030. These categories include community reserves (CF), unclassified, private, village, protected, and community (Raij) forests. CF also comprises sacred groves, village forests, rain forests, *syiemship* forests, clan forests, church forests, society forests, and cemetery forests. All of these areas are managed by community people or traditional Institutes (TI), which are headed by Syiem (Chief), Sirdar, Wahdar, Lyngdoh (religious priest), Rangbah Shnong (Head man of the village), Rangbah Kur (Head of the Clan), Syiem Raid, etc. Other non-traditional institutes, such as the Khasi Hills Autonomous District Council, established under the sixth schedule of the Indian Constitution, have administrative control over this community forest.

2.2.2 Topography

The East Khasi hills comprise a number of rolling hills with deep gorges and ravines towards the southern slope from the Shillong plateau to Bangladesh. The district experiences a variety of climates, from mild in the plateau area to warmer tropical and subtropical areas in the northern and southern sections. The southwest monsoon, which usually starts in May and lasts until September, has an impact on the entire district. Except for a comparatively dry stretch that often occurs between December and March, the entire year is humid (Das and Sudhakar 2014).

2.2.3 Geology, Rock and Soil

The East Khasi Hills is geomorphologically undulating, it comprises rolling grassland hills and river valleys that flow through the ravines to the southern slope between Mawsynram, Shella, and Cherrapunji. It is the land that holds the ancient remnants plateau of the Indian Peninsular Shield during the tectonic movements. The rocks beneath are from the ancient Purana group. Geology, relief, climate, and vegetation are some of the variables that affect an area's soil type. Alluvial soils are found mostly in the southern slopes and are rich in potash poor in phosphate context and acidic, red loamy soil is found in the region as a product of weathering of rocks like granites, gneisses, etc. in the north of East Khasi Hills minerals like quartzite, schist, conglomerate etc, are found there. Still, the soil texture varies from clay to sandy clay loam with a different gradient of fertility and organic matter.

According to Das and Sudhakar (2014), the district's soils range in composition from Ultisols (50%) to Alfisols (31%) to Inceptisols (19%), with thermic and udic temperature regimes and moisture regimes. The pH range of the soils is 5.12 to 5.96. They are well-drained to excessively drained, moderately acidic to slightly acidic, and moderately deep to extremely deep. The district's remaining areas are mostly slightly acidic, with about 46% being moderately acidic. The texture of soil can range from sandy clay loam to clay. About 85% of the land area is made up mostly of loamy soils, which include clay loam and sandy loam.

2.2.4 Climate and Rainfall

East Khasi Hills has the unique distinction of having the wettest place on earth that is Mawsynram with annual rainfall of about 12,270 mm (www.ceicdata.com). According to the data by the CEIC which is reported by the India Meteorological Department, averaging 0.800 mm from June 2018 to 26 Nov 2023, with 1963 observations, the data reached an all-time high of 400.400 mm on 17 June 2022 and a record low of 0.000 mm on 26 November 2023 (www.aws.imd.gov.in). In the monsoon season because of the southwest monsoon, almost all parts of the district receive heavy rainfall between May to September.

2.3 Intensive Study Area

East Khasi Hills is one of the 11 districts of the state of Meghalaya covering an area of 2,748 km^2 and lies between the latitude of 25°07" & 25°41" N and longitude of 91°21" & 92°09" E. The current study was conducted in the Thangkarang Community Reserve (25°13.030' lat & 91°43.800' long) and Ryngud Community Reserve (25°13.476 lat & 91° 46.151 long) of the East Khasi Hills District, which is managed by the Community Reserve Management Committee of the region. Map showing study sites, elevation, slope, and aspect are provided in Figures 1.1 to 1.4.

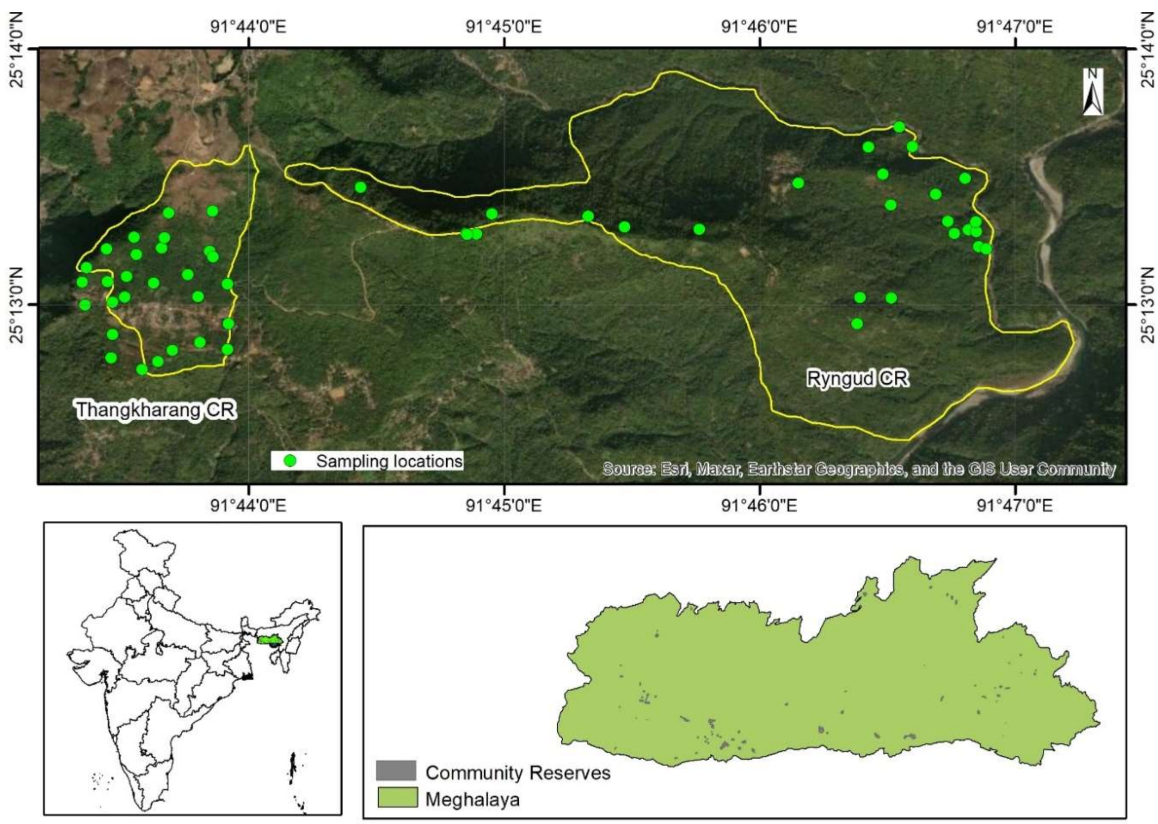


Figure 1.1: Map showing study sites in East Khasi Hills District, Meghalaya.

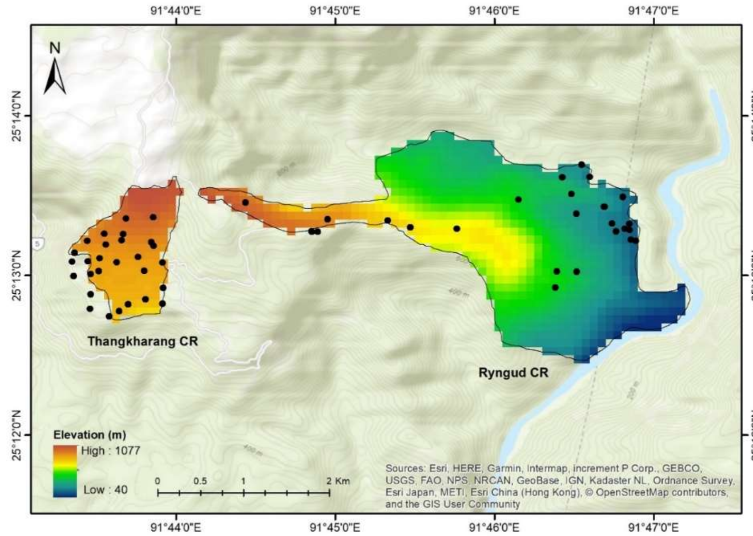


Figure 1.2: Map showing the elevation of the study area.

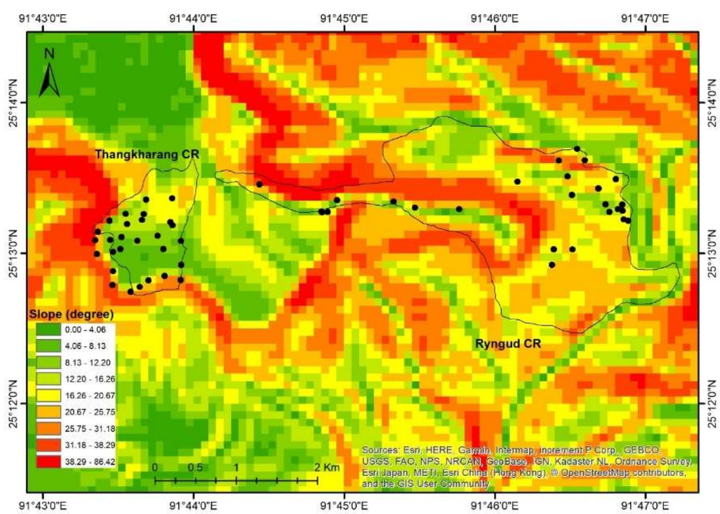


Figure 1.3: Map showing the slope of the study area.

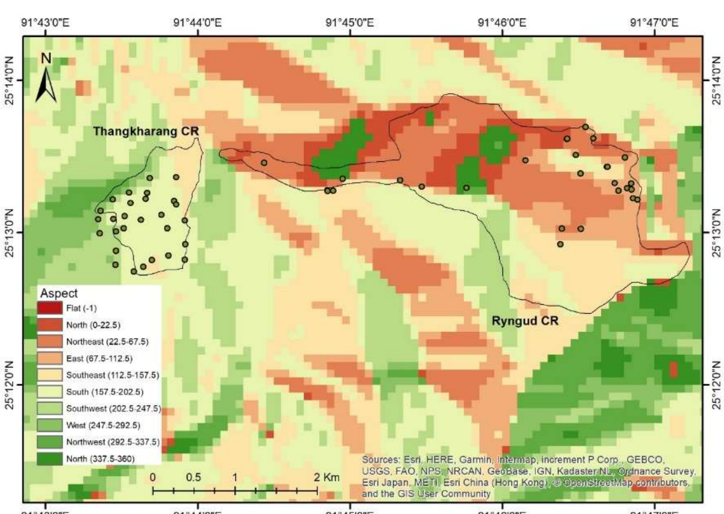
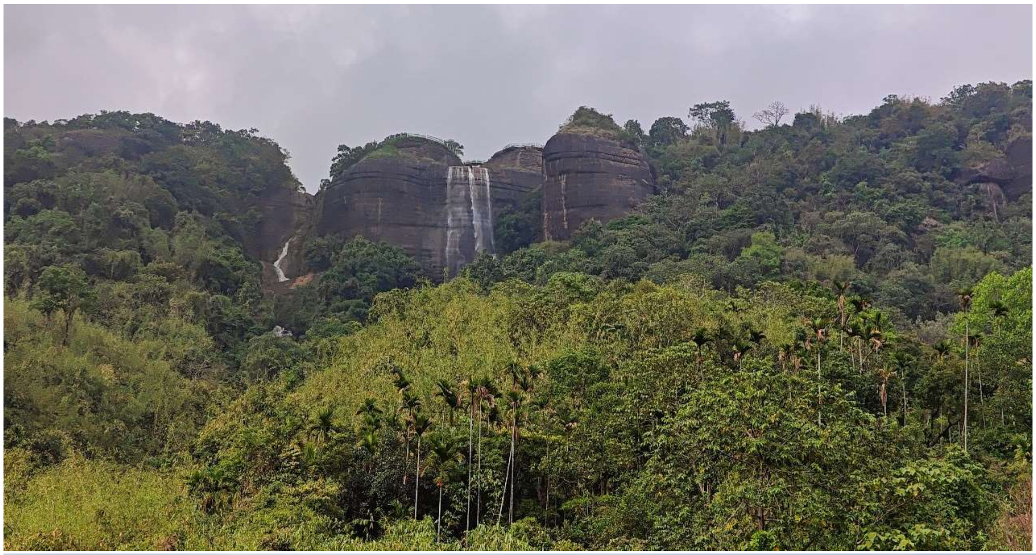
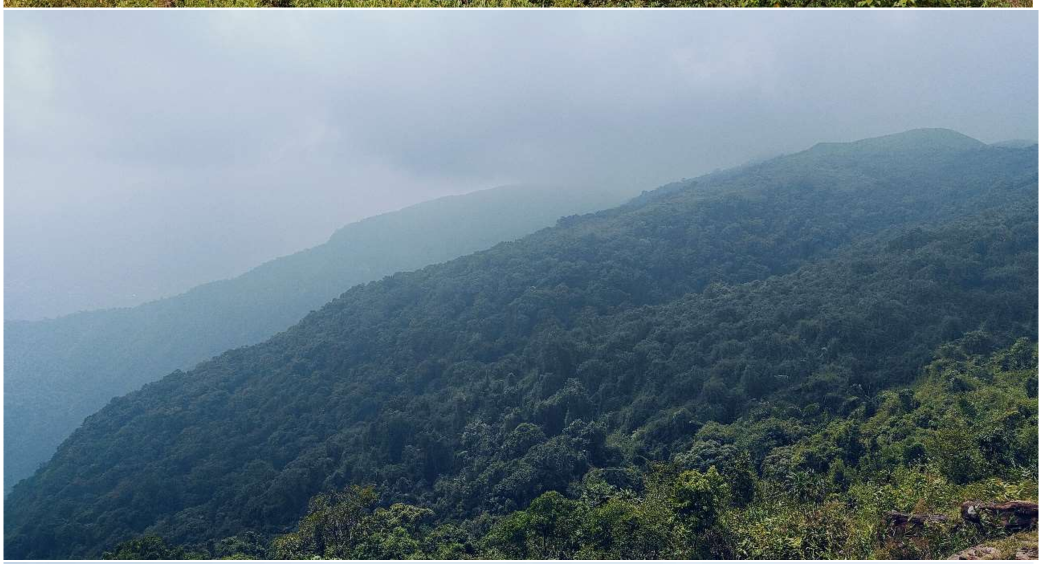


Figure 1.4: Map showing the aspect of the study area.

Plate1: STUDY AREA: IN AND AROUND THANGKARANG CR





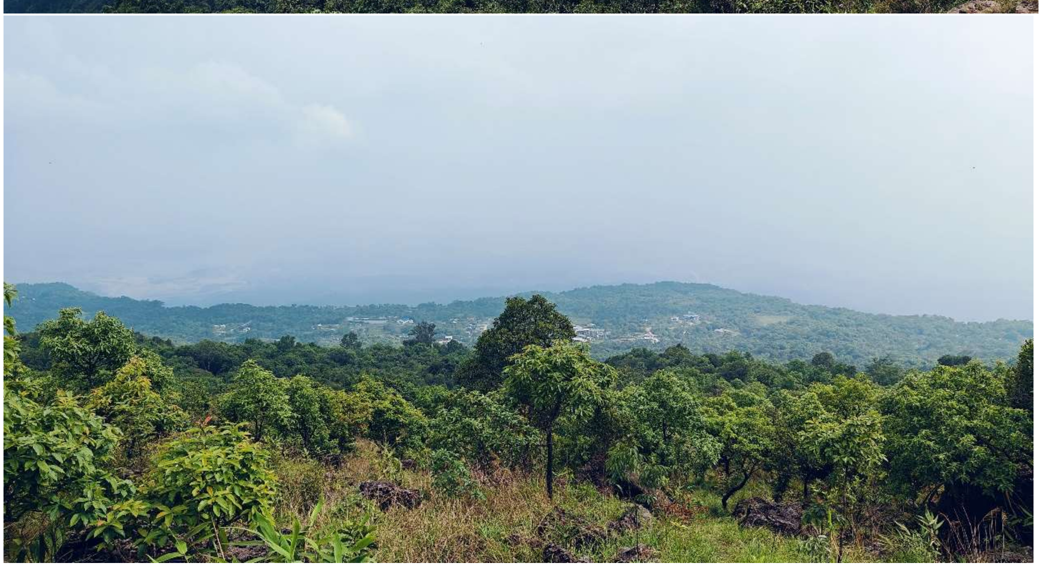
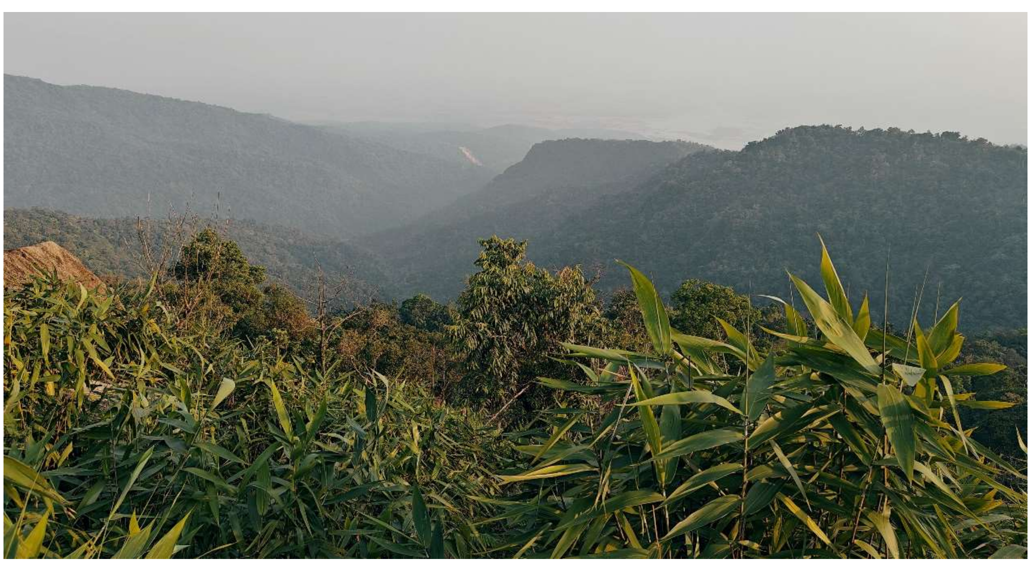


Plate2: STUDY AREA: IN AND AROUND RYNGUD CR



3.1 Global epiphyte distribution

Epiphyte lineages evolved in the tropical forest and represent more than one-third of vascular plant species (Benzing, 2008; Barthlott et al., 2001; Zotz, 2016; Pinho, 2020); global patterns of the epiphytes are primarily found in the tropics and decrease towards the poles (Benzing 1990; Gentry & Dodson, 1987; Madison, 1977; Zotz, 2016). Due to speciation, the Neotropical region has more species than any other region on Earth. However, the southern Peruvian Andes have the highest elevation vascular epiphytes yet discovered globally (Sylvester et al., 2014). A study by Taylor et al., (2022) claims that during the previous 30 years, limited research has been done on the quantification of global patterns of epiphyte distribution. Thus, more research is required to comprehend the diversity pattern of epiphytes, their ecology, and their interactions with environmental factors (Currie et al., 2004; Ricklefs, 2004; Kreft & Jetz, 2007).

3.2 Impact on Epiphytes

Epiphytes are susceptible to changes in the global climate (Lugo & Scatena 1992; Benzing 1998; Zotz 2009). It is one of the factors contributing to the anthropogenic strain on many plants, and it is pretty concerning, particularly in regions with rich plant diversity like the tropics (Lovejoy & Hannah, 2005; Solomon et al., 2007; Zotz, 2009). Due to climate change, phenological patterns may also be affected, resulting in species shifting upwards to higher elevations (Zotz, 2009). Another reason is that they adapt well to moist environments (Gentry & Dodson, 1987; Zotz, 2009), changes in the precipitation pattern (Solomon et al. 2007; Zotz, 2009), and temperature, which are the drivers of diversity along the latitudinal and longitudinal gradient (Archibold, 1995; Zotz, 2009) and the temperature changes will alter germination of epiphytes (Downs, 1964; Zotz, 2009). Another factor that causes the decline of epiphytic species is pollution (D'Cunha et al., 2013).

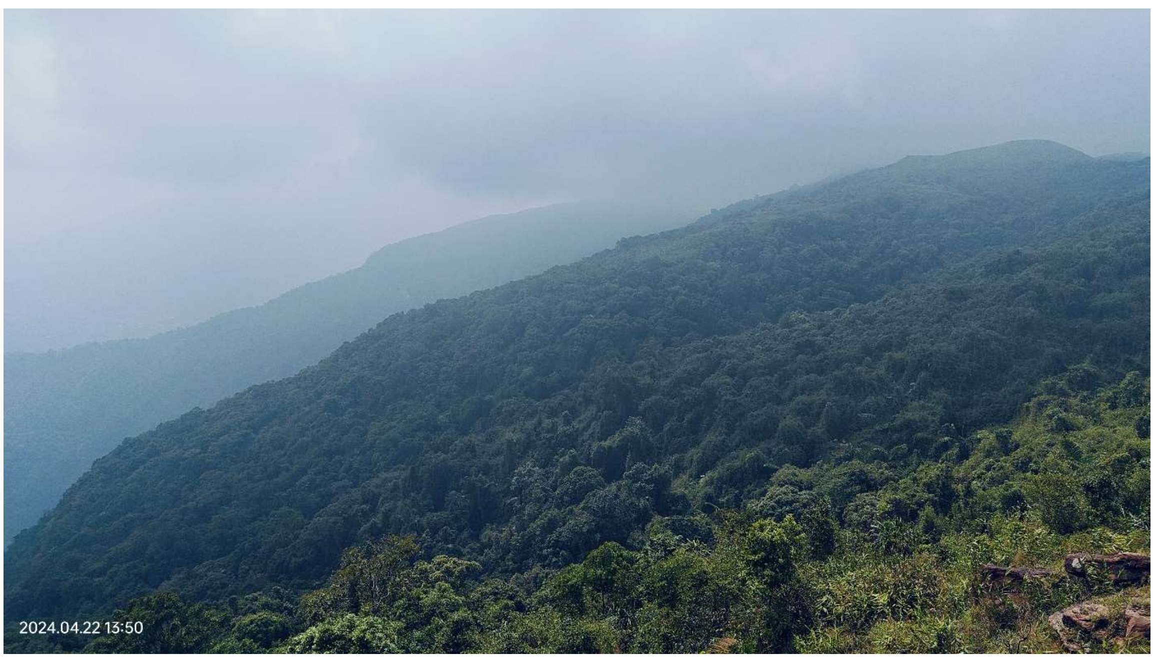
3.3 Impacts of Forest Transformation: India

The epiphytic flora is impacted by replacing primary forest with secondary forest since primary forest is one of the places where many epiphyte species are still found (Gradstein et al., 2003). Sometimes, deforestation in the lowlands affects the cloud forest in the mountains, which directly affects cloud formation and, as a result, reduces moisture inputs in the nearby highlands, causing the moist air to be pulled away (Lawton et al., 2001). Some epiphytic families, like bromeliads, do thrive well in the secondary forest, and the reason for this is being speculated (Barthlott et al., 2001). Tree logging is also one of the reasons for the decline in vascular epiphytes due to habitat loss (Barthlott et al., 2001; Padmawathe et al., 2004). therefore, trees are the primary determinants of their composition and diversity since they are closely related to the species they host. (Adhikari et al., 2012) Of epiphytes. Other studies have also shown that not all epiphytes prefer a host species like the heliophilic epiphytes (Wagner et al., 2015; Pinho, 2020), yet the majority of species, such as many bark ferns, orchids, and atmospheric bromeliads are located close to main trees (Woods et al., 2015; Gómez González et al., 2017; Pinho 2020).

3.4 Impacts of Forest Transformation: Meghalaya

Around 100,000 sacred groves are reported to exist in India, making it the country with the most in the world (Malhotra et al. 2007; Ormsby 2013). Despite the enormous diversity of plants and animals found in these woods, their quality has declined as a result of population growth and shifting human lifestyles (Chandrakanth et al. 2004; Ormsby 2013). Mostly, the forests of Meghalaya are remarkably rich due to high endemism (Balakrishnan 1981–1983; Mishra 2003). Primary forest habitats have been destroyed as a result of extensive deforestation caused by horticultural plantations, mining, illicit logging, towns, Jhum farming or shifting cultivation (Mishra 2003), and agricultural fields (Lyngdoh et al., 2023). Furthermore, as a result of the overexploitation of orchid species, all orchids are protected by the Convention on

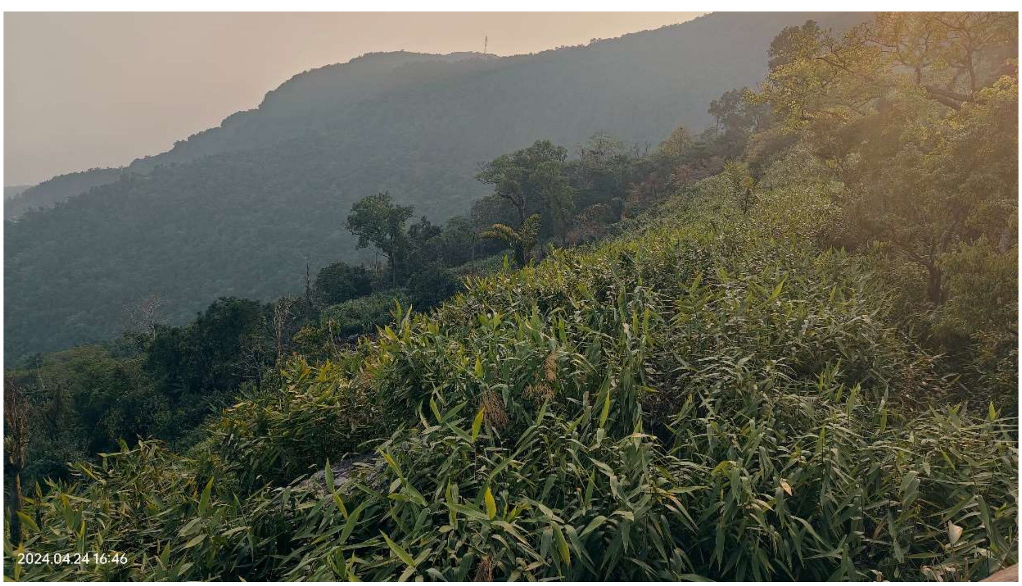
International Trade in Endangered Species of Wild Fauna and Flora (CITES), which are listed in Appendix II (Mir, 2023). Therefore, any depletion of biodiversity is most likely to reduce diversity which is caused by anthropogenic disturbance itself (Mishra, 2003). Collection of NTFPs is also one of the reasons for the depletion of community forest in Meghalaya, for example, firewood extraction (Lynser, 2020) and others such as *Calamus* sp., *Bambusa* sp., *Phrynium* sp., Honey, *Cinnamomum tamala, Eurya acuminata, Piper khasianum*, Mushrooms, Orchids, *Thysanolaena maxima, Flemingia vestita, Phoenix* sp. and *Luffa* sp. are collected by the locals from wild.



Thangkharang Community Reserve, East Khasi Hills

4.1 Site selection

The community reserves (CR) were selected based on the similarity in site conditions such as topography, altitude, aspect, slope, distance of one site to another, and vegetation. According to the level of management and habitat types, three habitat types within CRs were identified such as (a) Reserve forests (RF) which are under the management of the state forest department, and local people have very limited access to them, (b) Private forests (PF) which are owned by an individual and are primarily utilized for personal use and (c) Village forests (VF) which are under the United Khasi-Jaintia Management of Forest Acts 1958 control and are available for village use and administrative authority for these community forests is vested in the Khasi Hills Autonomous District Council. Considering the disturbance gradients and management, lopping was the only disturbance variable taken and RF was considered as a control site as these forests comparatively have no disturbance, the village forest has intermediate disturbance, and the private forest as the high disturbance site (**Table 1.1**). A total of 56 plots (28 in each site) were laid in the selected CRs. Of these, 22, 17, and 17 plots were laid in PF, RF, and VF, respectively.



Ryngud Community Reserve, East Khasi Hills

Table 1.1. Different habitat types, disturbance gradients, and management in the study area.

Habitat types	Gradient of disturbance	Management	Vegetation plots studied (radius=10m)
Private Forest (PF)	High	Individual	22
Village Forest (VF)	Intermediate	Villagers (United Khasi-Jaintia Management of Forest Act 1958).	17
Reserve Forest (RF)	Low	State Forest Department	17

4.2. Sampling design

4.2.1. Trees

The following parameters were kept in mind while collecting the data such as name of the species, number, girth at breast height (GBH, above 1.37m), height, and canopy cover were measured. Plants with >10 cm GBH were considered as trees which was measured using measuring tape. The height of the tree was estimated using a rangefinder and by visual interpretation. For canopy cover, a densiometer was used to record where 5 readings at a time were taken. For sampling, 7–10 plots were laid in each habitat type based on the size of the area. 10m radius (314m^2 area) was demarcated with the help of nylon rope/measuring tape for tree sampling. In the event that an identification of the species could not be made in the field, specimens were gathered and the species were photographed.

4.2.2. Epiphytes

Sampling of epiphytes was carried out in the 10m radius plots. Direct observations were taken along with the help of binoculars and photographs. The vascular epiphytes (hemi-epiphytes and holo-epiphytes). The host species was stratified into four different zones such as Zone 1, Zone 2, and Zone 3 also known as the 'Johansson zones' (Zotz, 2016) covering the inner branch and outer branch (**Figure 1.5**). Dividing trees into these zones helped in recording the epiphyte's location on the host plant and was correlated with disturbance data to check the scale of lopping.

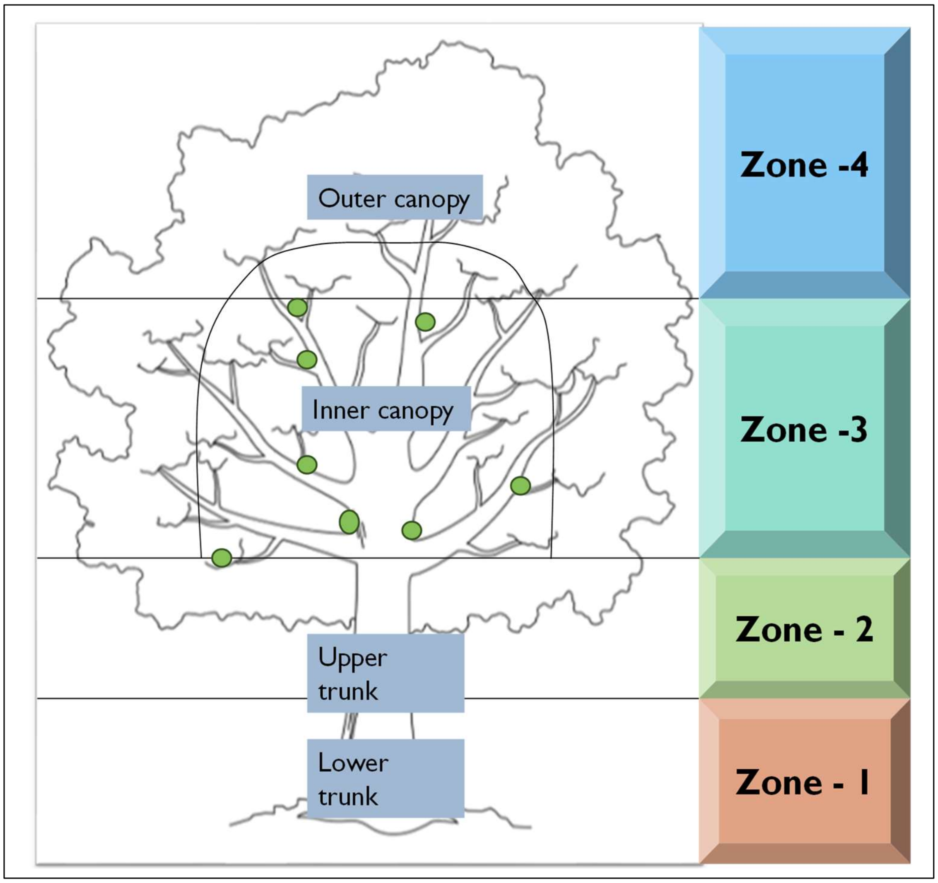


Figure 1.5: Diagrammatic representation of the Johansson zones for sampling epiphytes in the present study.

4.3. Data analysis

Major analysis was carried out to find out whether the different habitat types namely private forest (PF), reserve forest (RF), and village forest (VF) were different in terms of species richness, abundance, composition, and disturbance across all sites.

For performing analysis, for species richness and abundance, several species richness estimator was used, these are -

- **Species accumulation curve:** Since sampling efforts were based on species accumulation curve, therefore this curve was used to test if the sampling efforts were enough across habitat types.
- **Species Rarefaction curve:** This curve was used to give an estimate of the assemblages or groups of epiphytes (Fern, orchid, hemi-epiphyte, and holo-epiphytes), of what will be the richness if sampling efforts increase.
    - Randomizations of samples were done using R Software.
- **Diversity indices:** Since epiphytes are modular species, therefore their indices could not be calculated (Padmawathe 2004)
- **Non-parametric Estimator:** Chao 1 was used to estimate the absolute number of groups of epiphytes. The estimates given by Chao 1 are based on the presence of singletons and doubletons in a sample. To check for unsampled species across habitat types R software was used.
- **Rank abundance curve:** This curve was used to see how common a species is and how rare the species is, therefore those species that have low ranks are more common and species with high ranks are rare species in the sample.

Species correlates and composition

For performing analysis, for species correlates and composition, Non-metric Multidimensional Scaling (**NMDS**) was used, this was done to test paired-wise differences between species composition across habitat types. Here the data is usually converted to a dissimilarity matrix and incorporated in ordination.

Comparison analysis

Exploratory analysis **(Box and Whiskers)** was done to see the difference in lopping pressure across habitat types, most importantly it was also used to see the differences in the environmental variables affecting the variation in species composition.

5.1 Richness of vascular epiphytes

A total of 66 epiphytes comprising 32 species of orchids, ferns (09 species), and hemi-epiphytes & holoepiphytes (25 species) were recorded from the study area. Orchids had the highest species richness (although less abundant) dominated by *Bulbophyllum* sp.*, Pholidota* sp., and *Vanda* sp. The dominant species of ferns include *Lepisorus* sp., *Davallodes hymenophylloides,* and *Pyrrosia flocculosa*. Among hemi-epiphytes & holo-epiphytes, the dominant species were *Piper longum, Pothos chinensis, Rhaphidophora decursiva, Scurrula parasitica,* and *Ficus* sp. The details of the dominant species of orchids, ferns, and hemi-epiphytes & holo-epiphytes are provided in **Table 1.2.**

Table 1.2. Dominant species of orchids, ferns, and hemi-epiphytes & holo-epiphytes

Habitat type	Orchids	Ferns	Hemi-epiphyte & holo-epiphytess
Private Forest	*Pholidota sp.1*	*Davallodes hymenophylloides*	*Piper longum*
	Papilionanthe teres	*Lepisorus sp.*	*Hoya parasitica*
	Cymbedium alaifolium	*Pyrrosia flocculosa*	*Piper mullesua*
Village Forest	*Dendrobium densiflorum*	*Davallodes hymenophylloides*	*Piper longum*
	Pholidota sp.1	*Lepisorus sp.*	*Pothos chinensis*
	Cymbedium alaifolium	*Pyrrosia flocculosa*	*Ficus foveolata*
Reserve Forest	*Dendrobium densiflorum*	*Davallodes hymenophylloides*	*Piper longum*
	Pholidota sp.1	*Lepisorus sp.*	*Pothos chinensis*
	Cymbedium alaifolium	*Pyrrosia flocculosa*	*Rhaphidophora decursiva*

5.2 Species accumulation curve (Trees) across habitat types

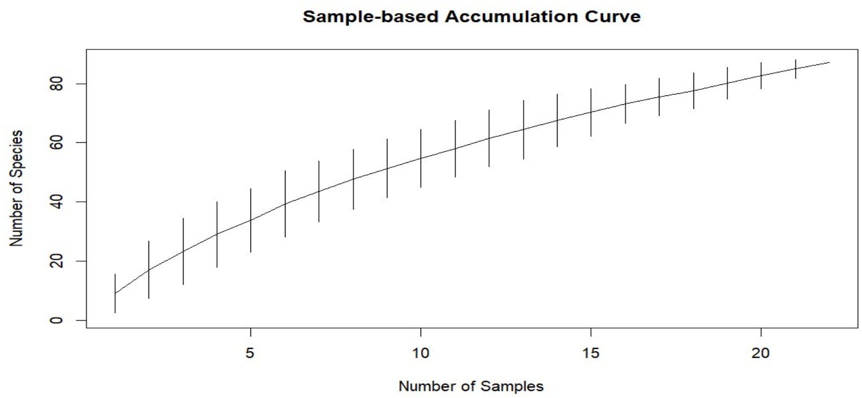


Figure 1.6: Species accumulation curve of trees in Private Forest.

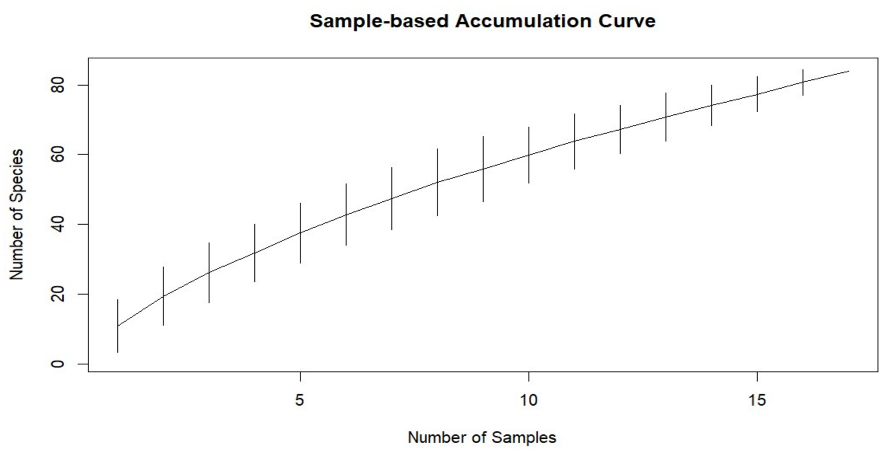


Figure 1.7: Species accumulation curve of trees in Reserve Forest.

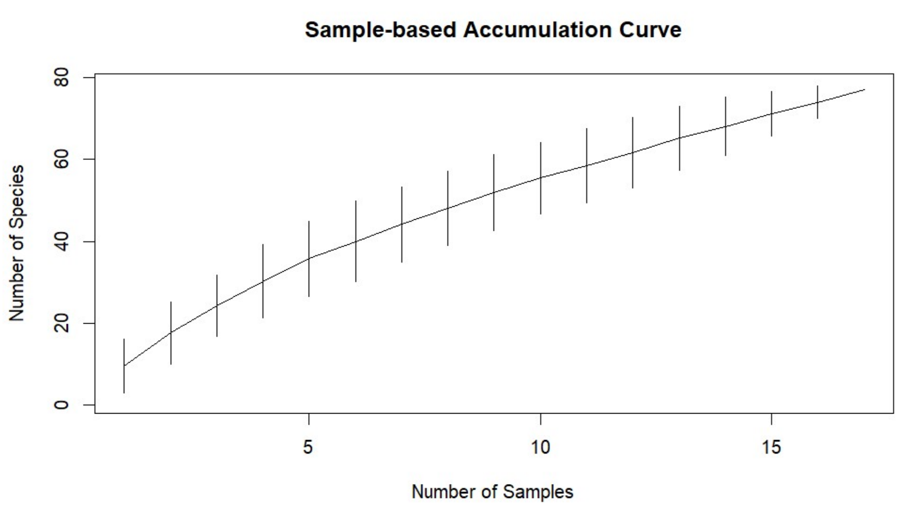


Figure 1.8: Species accumulation curve of trees in Village Forest.

The species accumulation curve of trees across habitat types shows an increasing trend and not reaching an asymptote, therefore more sampling efforts would be required across habitat types (**Figures 1.6, 1.7, and 1.8**).

5.3 Species accumulation curve (Epiphyte) across habitat types

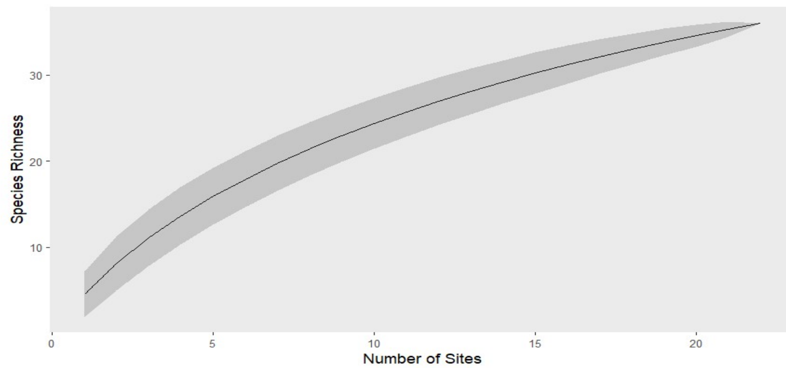


Figure 1.9: Species accumulation curve of epiphyte in Private Forest.

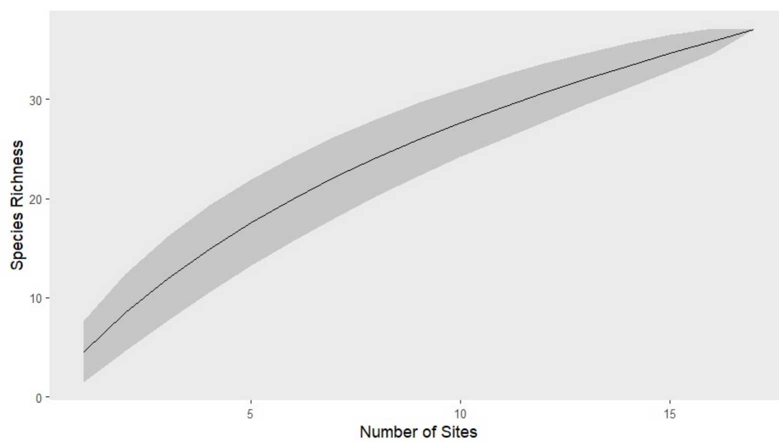


Figure 1.10: Species accumulation curve of epiphyte in Reserve Forest.

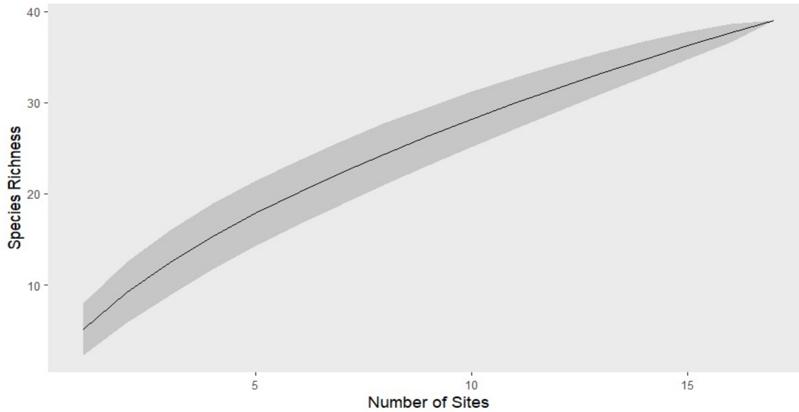


Figure 1.11: Species accumulation curve of epiphyte in Village Forest.

The species accumulation curve of epiphytes across habitat types also shows a similar trend and not reaching an asymptote, therefore more sampling efforts would be required across habitat types.

5.4 Sample-based rarefaction curve of epiphytes across habitat types

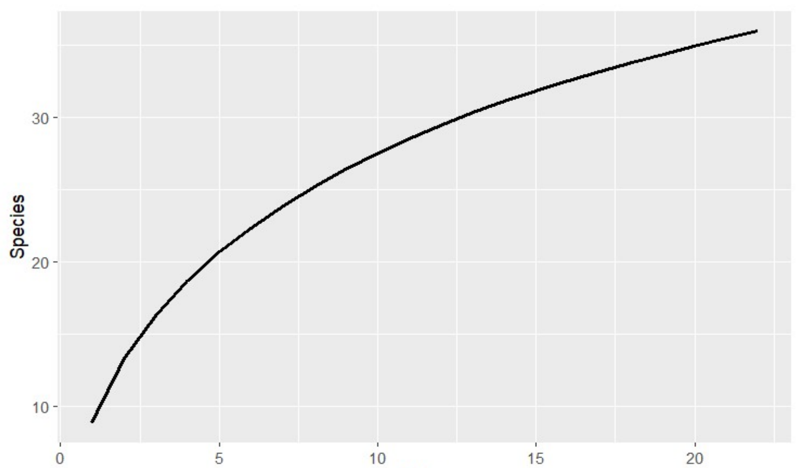


Figure 1.12: Sample-based rarefaction curve of epiphyte in Private Forest.

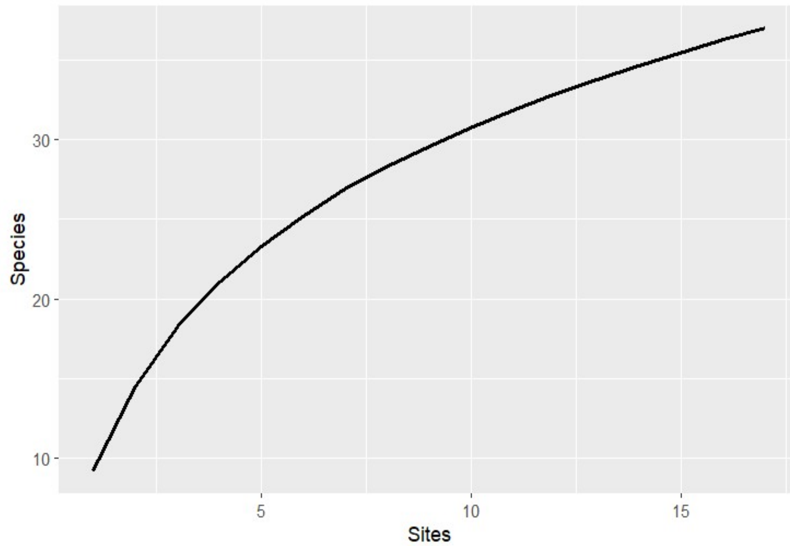


Figure 1.13: Sample-based rarefaction curve of epiphyte in Reserve Forest.

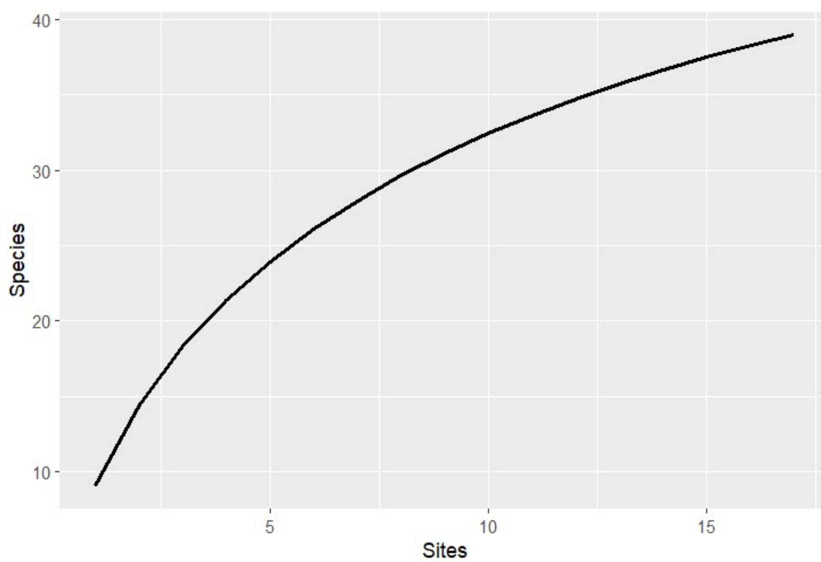


Figure 1.14: Sample-based rarefaction curve of epiphyte in Village Forest.

The sample-based rarefaction curve of epiphytes shows the faster accumulation of species across habitat types (**Figures 1.12, 1.13, and 1.14**). **Table 1.3** shows that the observed species richness in the private forest is 37, and Chao estimator estimates show that 47.74 more species will be observed if sampling efforts are increased, and Chao standard error is showing 7.28 which means that the species encountered are more common, comparing the standard error in the reserve forest which is 24.5, this means that there are many species with singletons and doubletons and also reserved forest is more riched according to the expected value given by Chao if sampling efforts are increased.

Table 1.3. Chao estimator for species richness of epiphytes

Habitat types	No. of plots (r=10m)	Observed richness	Chao	Chao SE
Private Forest	22	37	47.74	7.28
Reserve Forest	17	38	75.65	24.5
Village Forest	17	40	71.12	17.9

5.5 Rank Abundance curve of epiphytes across habitat types

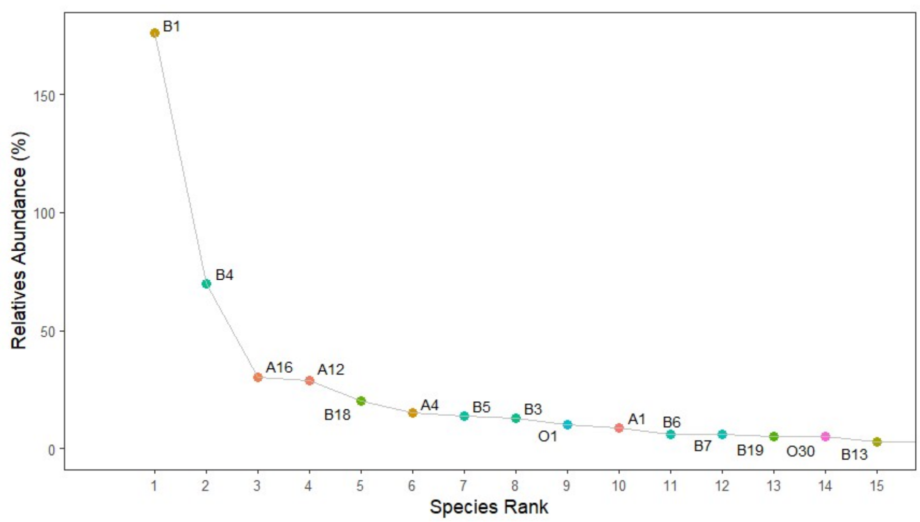


Figure 1.15: Rank abundance curve of epiphyte in Private Forest.

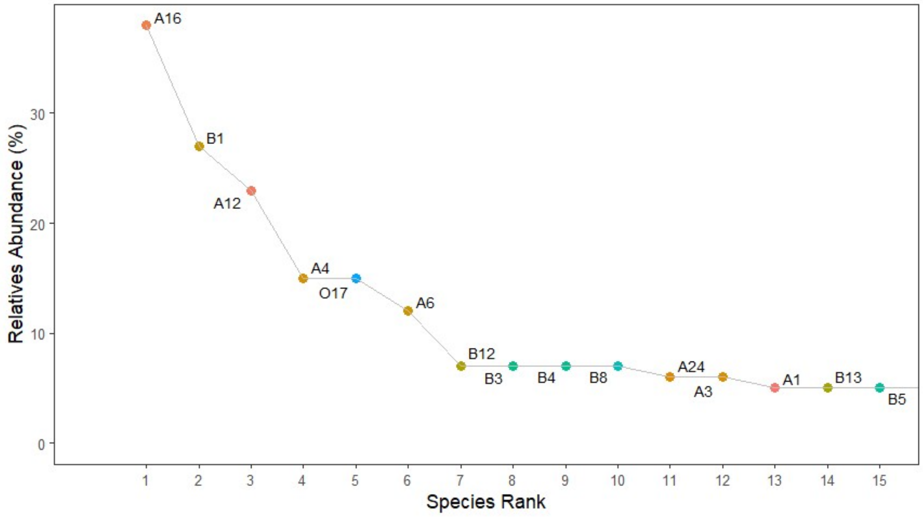


Figure 1.16: Rank abundance curve of epiphyte in Reserve Forest.

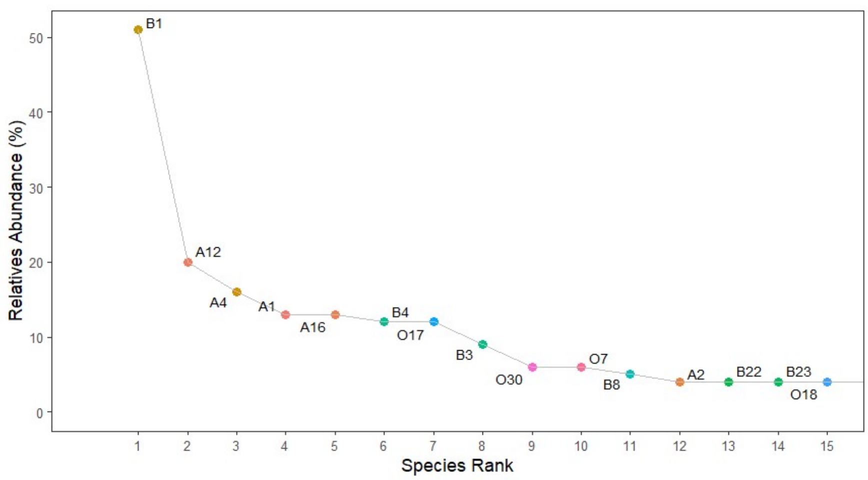


Figure 1.17: Rank abundance curve of epiphyte in Village Forest.

Piper longum (B1), *Pothos chinensis* (B4), *Pyrrosia flocculosa* (A4), *Davallodes hymenophylloides* (A12), and *Lepisorus* sp. (A16).

B1, B4, A16 and A12 were the low rank species in PF (**Figure 1.15)**, A16, B1, A12 and A4 in RF (**Figure 1.16)** and B1, A12, A4 and A1 in VF (**Figure 1.17).**

5.6 Abundance of epiphytes with respect to host trees

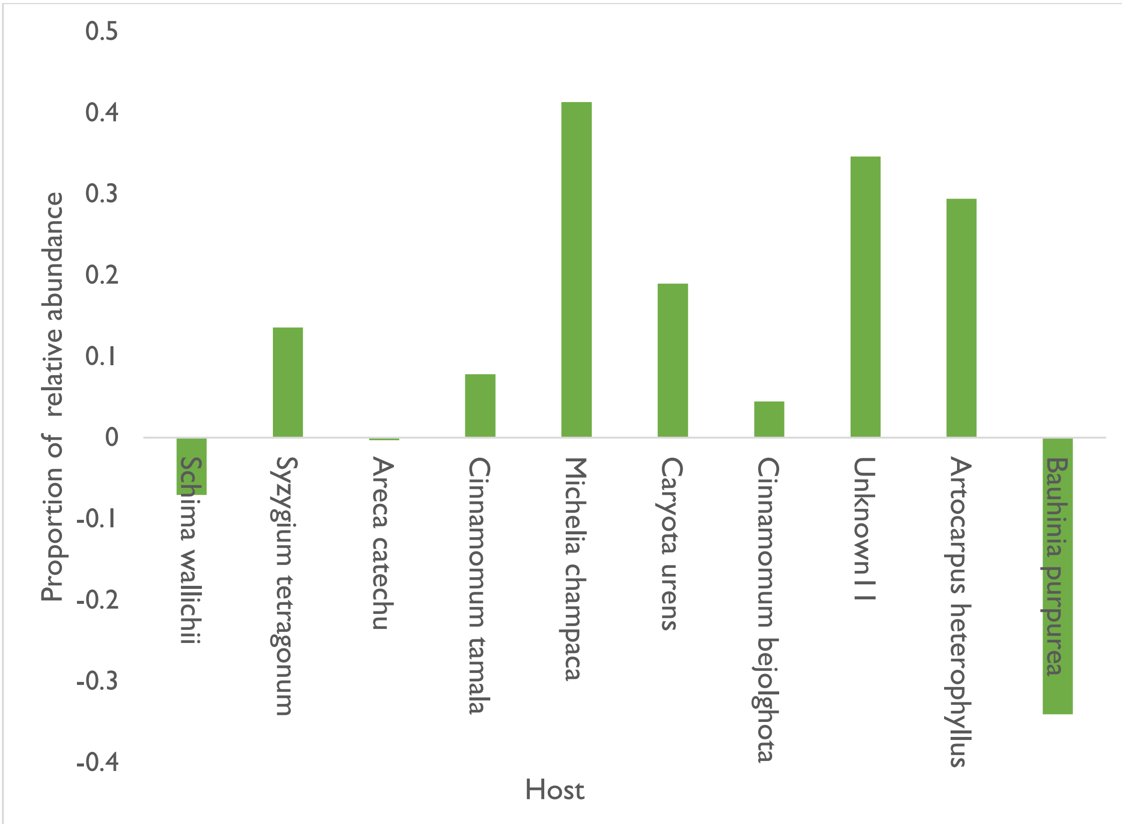


Figure 1.18: Abundance of epiphyte with respect to host trees.

As per **Figure 1.18,** the positive value is the proportion relative abundance of epiphytes and the negative value is the proportion relative abundance of the number of trees. In the present study, *Michelia champaca* showed a high abundance of epiphytes compared to other trees.

5.7 Abundance of epiphytes

In PF, the lower trunk exhibits higher abundance; in RF, the upper trunk exhibits higher abundance, whereas, in VF, the lower trunk exhibits greater abundance. The outer canopy of the studied habitat types exhibited the least abundance (**Figure 1.19).** Details of the abundance of epiphytes in the various zones of the tree for various habitat types is provided in **Table 1.14**.

Table 1.4 Abundance of epiphytes in each zone across habitat types.

Row Labels	Lower trunk	Upper trunk	Inner canopy	Outer canopy	Total
Private Forest	324	223	142	71	760
Reserve Forest	133	160	122	28	443
Village Forest	156	151	145	75	527
Grand Total	**613**	**534**	**409**	**174**	**1730**

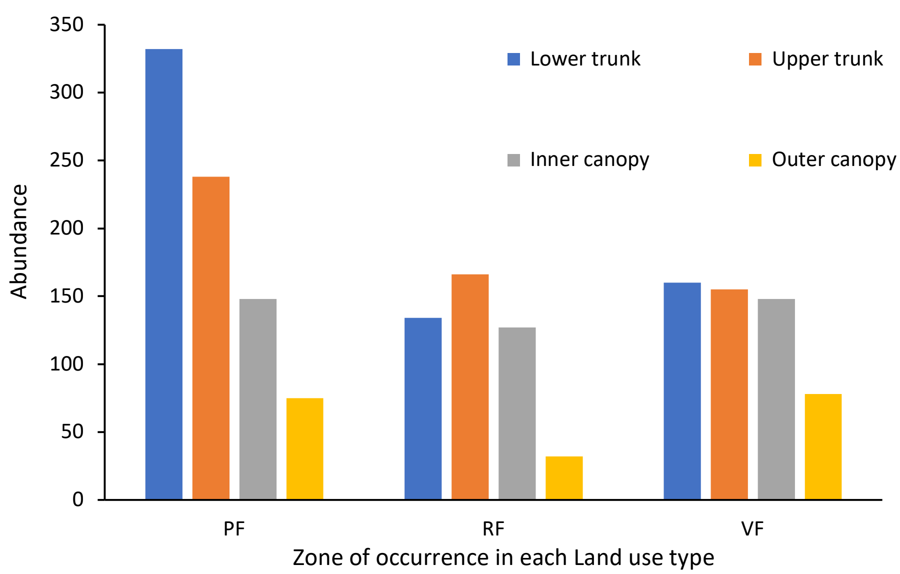


Figure 1.19: Abundance of epiphytes in different zones across habitat types.

Plate3: EPIPHYTES OBSERVED IN THE STUDY AREA

Gastrochilus sp.

Agapetes variegata

Pothos chinensis

Hoya sp.

Hoya arnottiana

Piper sp.

5.7.1 Abundance of different categories of epiphytes across habitat types

Hemi-epiphytes & holo-epiphytes were the abundant epiphytes followed by ferns and orchids in the study area. **Table 1.5** shows the abundance of ferns, orchids, and hemi-epiphytes & holo-epiphytes in the studied sites.

Table 1.5 Abundance of different groups of epiphytes.

Group	Abundance
Orchid	265
Ferns	668
Hemi-epiphytes & holo-epiphytess	797
Total	**1730**

5.7.1.1 Ferns

In private forests, the upper trunk and inner canopy exhibit equal abundances of ferns, whereas the outer canopy shows the least fern abundance as compared to the reserve forests which harbours the highest in the upper trunk and the least number in the outer canopy. Village forests also display a gradient of varying fern abundance across different zones. The details on the abundance of ferns in different zones across various habitat types is provided in **Table 1.6** and **Figure 1.20.**

Table 1.6 Abundance of ferns in different zones across habitat types.

Row Labels	Lower trunk	Upper trunk	Inner canopy	Outer canopy	Total
Private Forest	33	70	70	46	219
Reserve forest	79	88	62	13	242
Village Forest	46	65	61	35	207
Grand Total	158	223	193	94	668

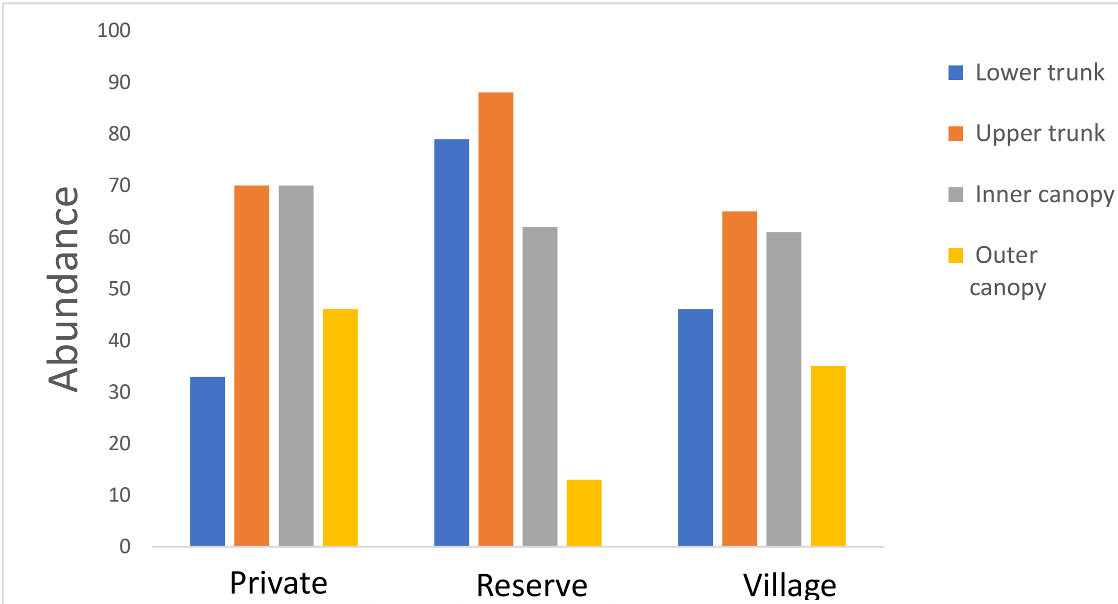


Figure 1.20: Abundance of ferns in different zones across habitat types.

5.7.1.2 Orchids

As compared to other habitat types, the current study observed that orchids harbour more abundance in village forests in which the inner canopy had the highest epiphyte abundance, whereas private forests had the lowest orchid abundance (**Table 1.7** and **Figure 1.21**).

Table 1.7 Abundance of orchids in different zones across habitat types.

Row Labels	**Lower trunk**	**Upper trunk**	**Inner canopy**	**Outer canopy**	**Total**
Private forest	10	31	24	8	73
Reserve Forest	13	33	28	5	79
Village Forest	17	38	39	19	113
Grand Total	40	102	91	32	265

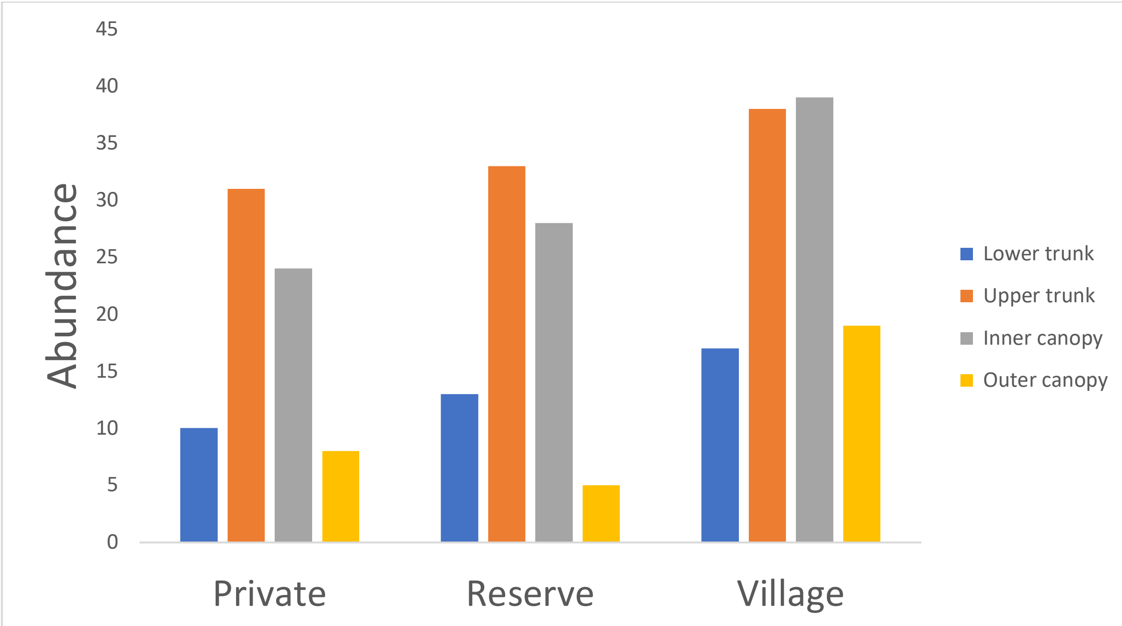


Figure 1.21: Abundance of orchids in different zones across habitat types.

5.7.1.3 Hemi-epiphytes & holo-epiphytes

The highest number of hemi-epiphytes was recorded on the lower trunk in private forests while the least abundance of hemi-epiphytes was recorded in reserve forests (**Table 1.8**).

Table 1.8 Abundance of hemi-epiphytes in different zones across habitat types.

Row Labels	Lower trunk	Upper trunk	Inner canopy	Outer canopy	Total
Private Forest	281	122	48	17	468
Reserve Forest	41	39	32	10	122
Village Forest	93	48	45	21	207
Grand Total	415	209	125	48	797

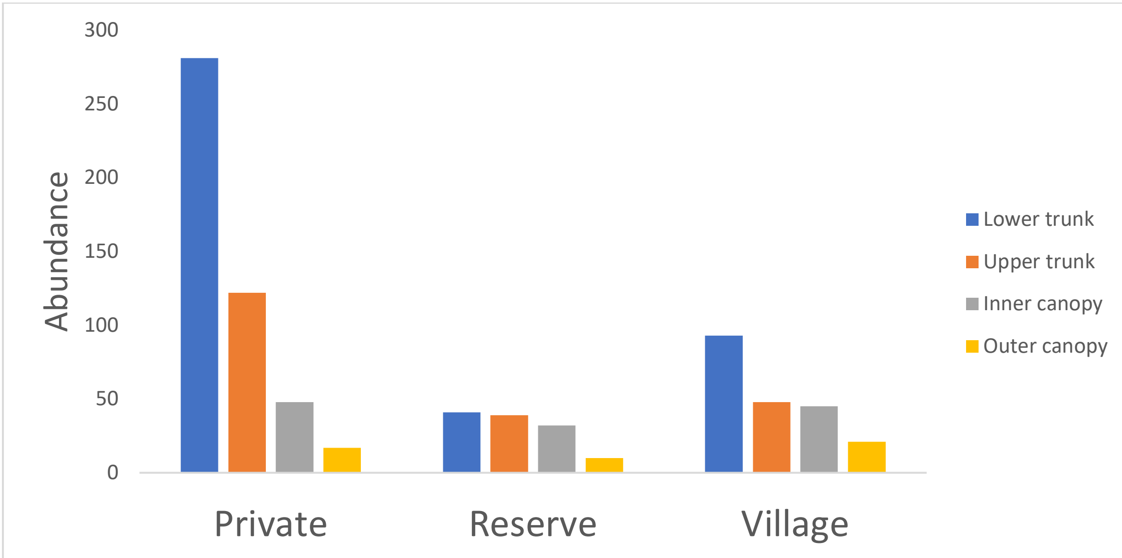


Figure 1.22: Abundance of hemi-epiphytes and holo-epiphytes in different zones across habitat types.

5.8. Unique epiphytic groups across habitat types

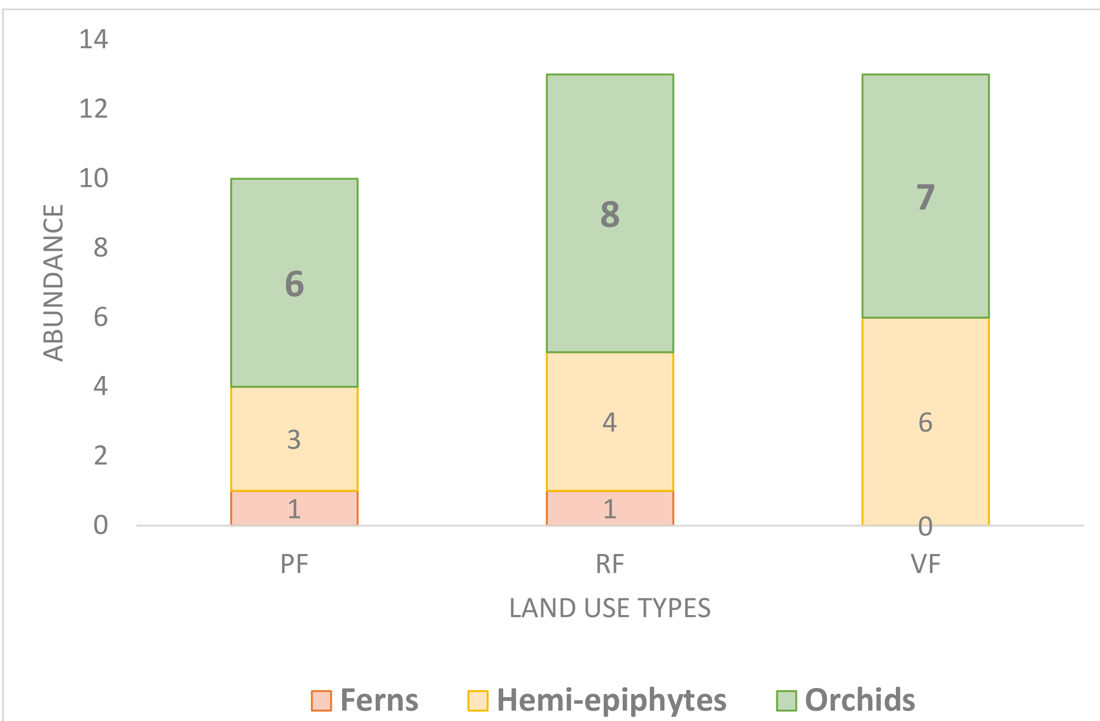


Figure 1.23: Unique species of epiphytic groups across habitat types.

Figure 1.23, shows that a unique species of ferns are not present in the village forest, hemi-epiphytes are more unique in the village forest and eight orchids are unique to only reserve forest.

5.9. Species Composition across habitat types

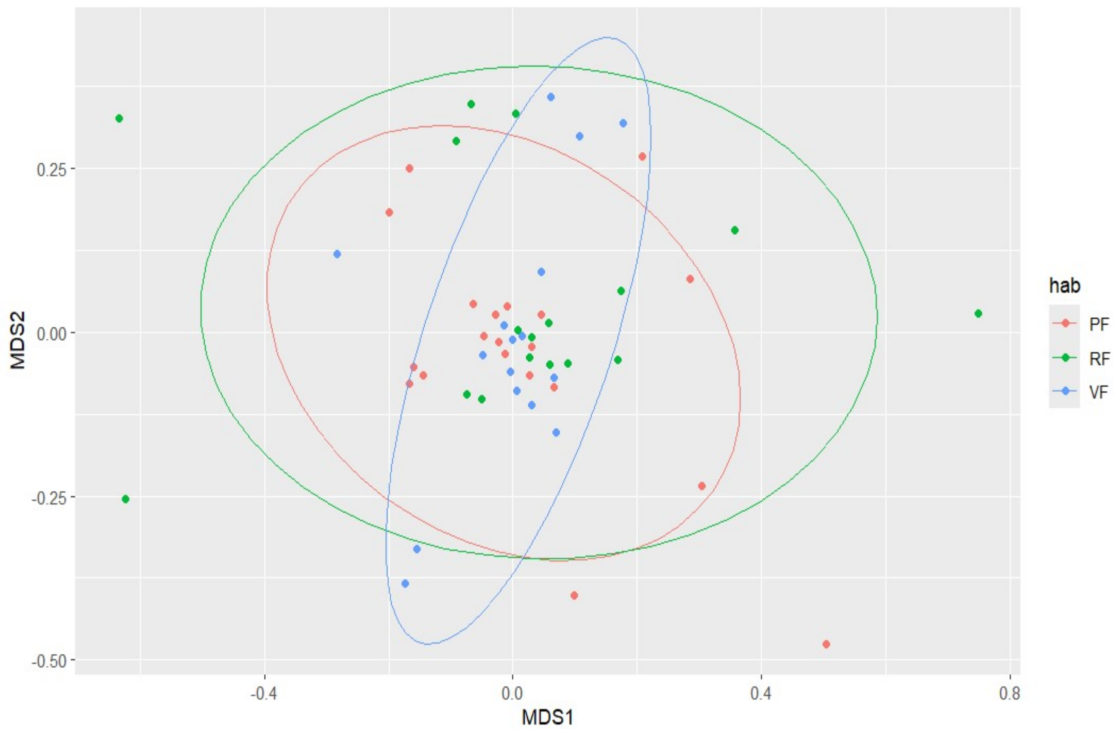


Figure 1.24: NMDS showing the species composition across habitat types.

NMDS shows that the green ellipse which is a reserve forest shows how the data is varied because it holds many species that occur only once and twice or species that are unique only to certain plots. Private forest (red ellipse) and village forest (blue ellipse) are a subset of reserve forest, which means that the species are similar, therefore species composition shows similarity across habitat types (**Figure 1.24**).

5.10 Disturbance variables that underline the variation in species composition.

5.10.1 Extent of lopping

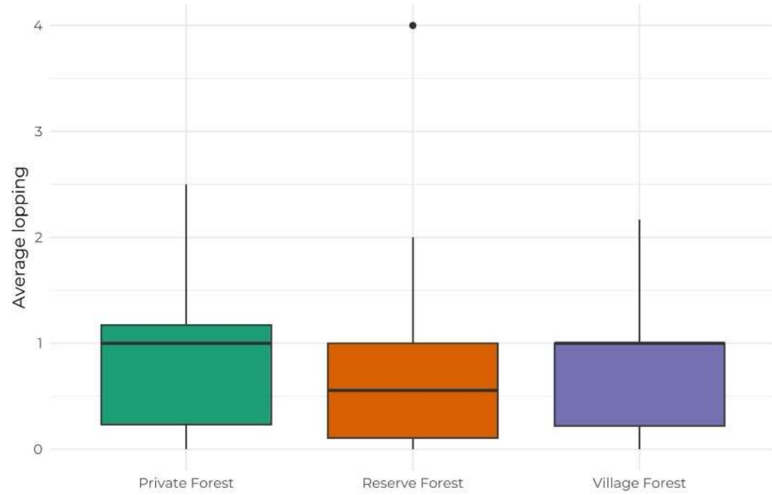


Figure 1.25: Box plot showing the extent of lopping across habitat types.

It was observed that the lopping frequency is more in the private forests compared to reserve forests and village forests (**Figure 1.25**).

5.10.2 Sum of GBH

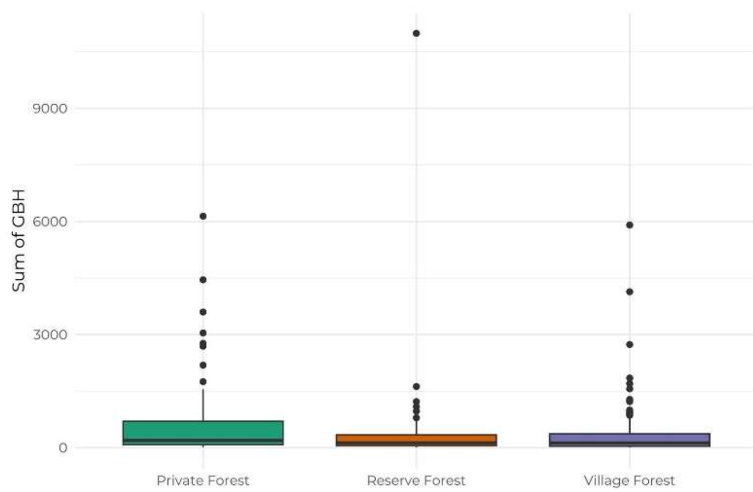


Figure 1.26: Box plot showing the sum of GBH across habitat types.

Figure 1.26 shows that GBH was more in private forests compared to reserve forests and village forests.

5.10.3 Average height

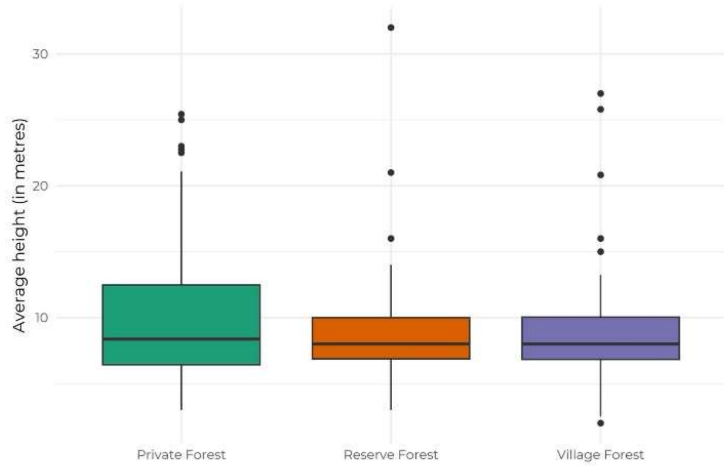


Figure 1.27: Box plot showing the average height across habitat types.

The average height was more in private forests compared to reserve forests and village forests (**Figure 1.27**).

5.10.4 Average slope

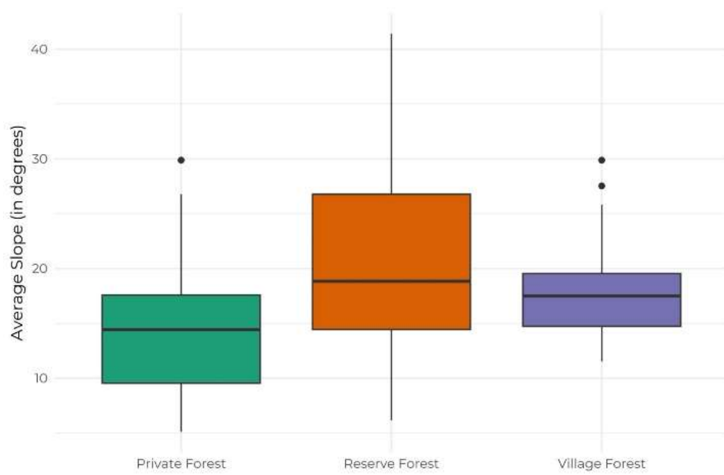


Figure 1.28: Box plot showing the average slope across habitat types.

The average slope across habitat was observed more in reserve forest, followed by village forest, and private forest (**Figure 1.28**). This is due to the topography of the study area, where soil retention is less. Another reason is that most of the sites are inaccessible by locals these habitats are usually comparatively undisturbed and could have more species of epiphytes that are adapted to fewer areas with higher slopes.

5.10.5 Average canopy cover

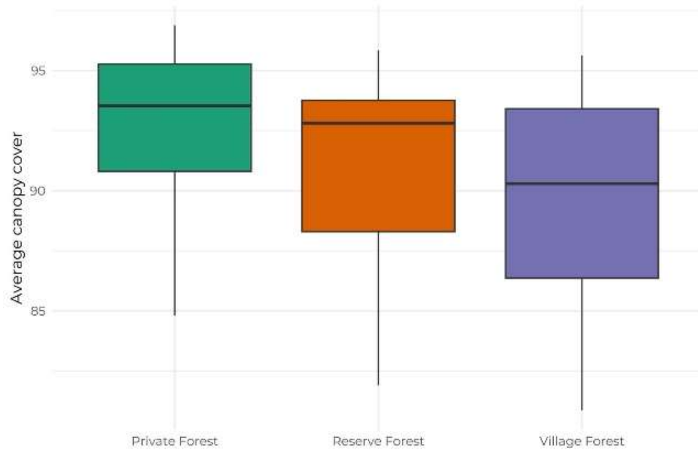


Figure 1.29: Box plot showing the average canopy cover across habitat types.

The average canopy was more in private forests compared to reserve forests and village forests (**Figure 1.29**).

5.10.6 Average elevation

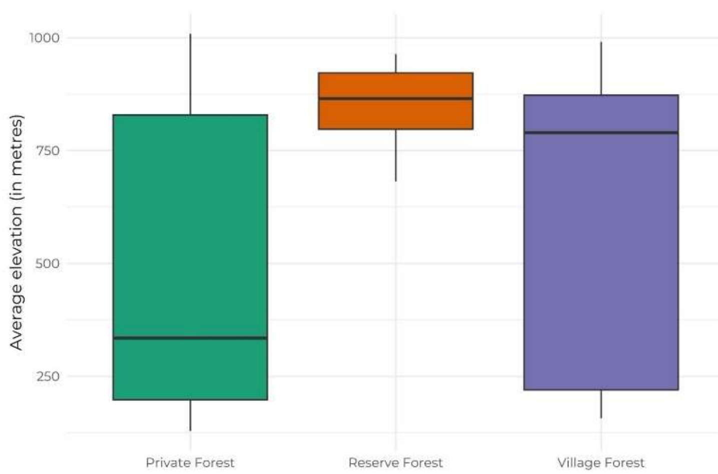


Figure 1.30: Box plot showing the average elevation cover across habitat types.

The average height was more in reserve forests compared to private forests and village forests (**Figure 1.30**).

The present study suggest that each habitat has its distinct species richness though they may not vary greatly but have their significant importance, briefly recapitulating the abundance and species richness of epiphytes across habitats.

Species richness and abundance

Sample-based rarefaction curve and Chao1 estimator suggest higher epiphytic richness in reserve forests as compared to private forests and village forests. It could be attributed due to diverse habitat type that play a crucial role in supporting epiphytic population. The rank abundance curves of the Reserve Forest (**Figure 1.18)**, show a uniform trend, and high species evenness as compared to other habitat types.

Individuals of *Michelia champaca* supported high abundance of epiphytes compared to other trees such as *Bauhinia purpurea* which comparatively has a greater number of individuals, and hence showed less epiphytic abundance across habitat types.

Why do certain epiphyte species dominate certain zones of occurrence?

In private forests, the zones of occurrence of species are high in the lower trunks which could be due to forest clearing, a form of human interaction through interference and disturbance as also observed by Hirzel & Le Lay (2008). Species such as *Piper longum*, which grows naturally are protected because of their commercial value and medicinal value (Gajurel et al., 2021). On the other hand, species like *Pothos chinensis,* and *Rhaphidophora* sp. which can occupy the same zone on tree trunks and might compete for space are unutilized by locals and hence are frequently cleared or removed manually from *Areca catechu* plantations. Another reason could be due to suitable niche for their survival as indicated by Gleson (1926), Peterson et al. (1999), Peterson & Vieglais (2001), Martínez-Meyer et al., 2004 and Hirzel & Le Lay (2008) which observed in greater abundance in the upper trunks in the reserve forest.

The abundance of species in the upper trunk of the reserve forest could be that the understorey has more cover therefore more moisture is retained which can function as a water conservator in mosses on the bark of the host when it rains, this serves as a good refuge for many species of ferns that requires such condition. Certain species, such as *Lepisorus sp.* and *Davallodes hymenophylloides*, are known to be associated with moss, which provides a suitable niche for those ferns, as also observed by Zotz (2016).

As orchid requires mild to full sun light for their growth and development and this could be achieved from these filtered canopies that are lopped by villages for fuel wood collection. Consequently, lopping could have a positive and also negative impact on the orchid abundance.

What are the factors for species composition?

Several factors might contribute to epiphyte composition resulted due to diverse niches available for epiphyte colonization and increased availability of suitable substrates, such as older trees, tree size, and rough bark or it could be due to microclimatic conditions. In Figure 1.23, unique species are found only in one particular habitat because of the site factors. Figure 1.24, Private Forest (red ellipse) and village forest (blue ellipse) are a subset of reserve forest, which means that the species are similar, therefore species composition shows similarity across habitat types because of soil differences and geographical features across habitat types (Valencia (2004). Figure 1.25 shows that because the harvest of species like *Cinnamomum tamala* and *Areca catechu* is happening inside the private forest, these species are commercially valued more.

Girth at Breast Height (GBH)

The sum of GBH shows that the reason is that most private forests have larger trees or primary trees with a Girth above 200m because of when we look at the life history traits of the locals when the challan market was open at the border between Meghalaya and Bangladesh, they used to challan wood from Meghalaya to Bangladesh, therefore, people are more conservative towards the trees growing in their land as it has higher timber value when they are sold to the Bangladeshi, thus the remaining trees are the remnants of trees left in the private forest. Another reason is also that since there are plantations inside these forests many stems of Areca catechu are conserved for years for a good harvest. this suggests even in private forests disturbance is more, while mature forests harbour good numbers of epiphytes. The sum of GBH in reserve forests and village forests could be due to which these forests are recent forests or coppice forests which have less stem density. Species that adapt in such forests are early successional epiphytes that can survive such environments (Figure 1.26).

Height

The reason that private forest has plantations have more heights is that they are comparatively less disturbed, and another reason is that there are many matured old trees in such habitats, therefore they have time to grow suggesting stability (Figure 1.27).

Slope

The slope is also one of the factors that results in species composition due to the topography of the study area, where soil retention is less. Another reason is that most of the sites are inaccessible by locals and these habitats are comparatively undisturbed and could have more species of epiphytes that are adapted to fewer areas with higher slopes (Figure 1.28).

Canopy cover

Private forests with plantations had more canopy cover, but do not have understorey because of plantation cleaning by locals for better management during harvesting, therefore, these habitats usually have an extreme temperature which can create stress to many epiphytes.

Moreover, other reasons could be due to forest characteristics such as canopy structure could serve as a suitable habitat for epiphytes (Nascimbene et al (2013).

Elevation

Elevation plays an important role in defining species composition. In Figure 1.30, one of the reasons to understand differences in species composition could be the land use history of the area. The village forests and the private forests had altered habitats due to agriculture and human habitations established mostly in flatter lands by locals. Another reason is that higher elevations have cooler temperatures which can harbour different species of epiphytes, moreover will have more precipitation which is caused by the orographic uplift which can hold more humidity perfect microhabitats for mosses and fern. Rahbek (1995); and Kumar et al (2022) found that biodiversity increases with elevation up to a certain point, after which it tends to decline, likely due to decreasing temperature and productivity.

REFERENCES

- Adhikari, Y. P., Fischer, A., & Fischer, H. S. (2012). Micro-site conditions of epiphytic orchids in a human impact gradient in Kathmandu valley, Nepal. *Journal of mountain Science*, *9*, 331-342.
- Archibold O. W. (1995). *Ecology of world vegetation*. Chapman & Hall, London.
- Barthlott, W., Schmit-Neuerburg, V., Nieder, J., & Engwald, S. (2001). Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. *Plant ecology*, *152*, 145-156.
- Benzing, D. H. (1990). Vascular Epiphytes. General biology and related biota. Cambridge University Press. *New York, NY*, *147*.
- Benzing, D. H. (1998). Vulnerabilities of tropical forests to climate change: the significance of resident epiphytes. *Climatic change*, *39*(2), 519-540.
- Benzing, D. H. (2008). *Vascular epiphytes: general biology and related biota*. Cambridge University Press.
- Benzing, H. D. (1995). Vascular Epiphytes. In: Lowman, M.D., Nadkarni, N.M. (Eds.), Forest Canopies. Academic Press, New York, pp. 225–251.
- Champion, H. G., & Seth, S. K. (1968). *A revised survey of the forest types of India*. Manager of publications, Govt. of India.
- Chandrakanth, M. G., Bhat, M. G., & Accavva, M. S. (2004). Socio-economic changes and sacred groves in South India: protecting a community-based resource management institution. In *Natural Resources Forum* (Vol. 28, No. 2, pp. 102-111). Oxford, UK: Blackwell Publishing Ltd.
- Chao, A. (1984). Nonparametric estimation of the number of classes in a population. *Scandinavian Journal of statistics*, 265-270.
- Chao, A., Gotelli, N. J., Hsieh, T. C., Sander, E. L., Ma, K. H., Colwell, R. K., & Ellison, A. M. (2014). Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. *Ecological monographs*, *84*(1), 45-67.
- Currie DJ, Mittelbach G, Cornell HV, Field R, Gue´gan J, Hawkins BA, Kaufman DM, Kerr JT, Oberdorff T, O’Brien EM, Turner JRG (2004). *Ecol Lett* 7:1121–1134.

- Das, P. T., & Sudhakar, S. (2014). Land suitability analysis for orange & pineapple: A multi criteria decision making approach using geo spatial technology. *Journal of Geographic Information System*, *2014*.
- Dawson, J. W., & Sneddon, B. (1969). The New Zealand rain forest: A comparison with tropical rain forest. Pacific Science, 23, 131–147.
- D'Cunha, J. P., & Gowda, P. V. (2013). Epiphyte diversity on avenue trees of national and state highways of Udupi district, Karnataka, India. *Int Res J Biol Sc*, *2*(5), 30-39.
- Deb, C. R., & Paul, A. (Eds.). (2021). *Bioresources and Sustainable Livelihood of Rural India*. Mittal Publications.
- Dikshit, K.R. and Dikshit, J.K. (2014). North-East India: Land, People and Economy. Advances in Asian Human-Environmental Research, Springer Dordrecht Heidelberg New York London, pp. 800.
- Efron, B. (1981). Nonparametric estimates of standard error: the jackknife, the bootstrap and other methods. *Biometrika*, *68*(3), 589-599.
- Einzmann, H. J., Weichgrebe, L., & Zotz, G. (2021). Long-term community dynamics in vascular epiphytes on Annona glabra along the shoreline of Barro Colorado Island, Panama. *Journal of Ecology*, *109*(4), 1931-1946.
- Flores-Argüelles, A., Espejo-Serna, A., López-Ferrari, A. R., & Krömer, T. (2022). Diversity and vertical distribution of epiphytic angiosperms, in natural and disturbed forest on the Northern Coast of Jalisco, Mexico. *Frontiers in Forests and Global Change*, *5*, 828851.
- Flores-Palacios, A., Garcı´a-Franco J.G. (2006). The relationship between tree size and epiphyte species richness: testing four different hypotheses. *J Biogeogr* 33:323–330
- Gajurel, P. R., Kashung, S., Nopi, S., Panmei, R., & Singh, B. (2021). Can the Ayurvedic pippali plant (Piper longum L.) be a good option for livelihood and socio-economic development for Indian farmers? *Current Science* (00113891): 120(10).
- Gentry, A. H., & Dodson, C. H. (1987). Diversity and biogeography of neotropical vascular epiphytes. *Annals of the Missouri Botanical Garden*, *74*(2), 205-233.
- Givnish TJ, Spalink D, Ames M, Lyon SP, Hunter SJ, Zuluaga A, Doucette A, Giraldo G, McDaniel J, Clements MA, Arroyo MTK, Endara L, Kriebel R, Williams NH, Cameron KM. 2016. Orchid historical biogeography, diversification, Antarctica and the paradox of orchid dispersal. Journal of Biogeography 43(10): 1905-1916.

- Gómez González, D. C., Rodríguez Quiel, C., Zotz, G., & Bader, M. Y. (2017). Species richness and biomass of epiphytic vegetation in a tropical montane forest in western Panama. *Tropical Conservation Science*, *10*, 1940082917698468.
- Gotelli NJ, Entsminger GL (2001) Ecosim: null models' software for ecology, version 7.0. Acquired Intelligence Inc, & Kesey-Bear, Jericho
- Gradstein, S. R., Nadkarni, N. M., Krömer, T., Holz, I., & Nöske, N. (2003). A protocol for rapid and representative sampling of vascular and non-vascular epiphyte diversity of tropical rain forests. *Selbyana*, 105-111.
- Gustafsson ALS, Verola CF, Antonelli A. 2010. Reassessing the temporal evolution of orchids with new fossils and a Bayesian relaxed clock, with implications for the diversification of the rare South American genus Hoffmannseggella (Orchidaceae: Epidendroideae). BMC Evolutionary Biology 10(1): 1-13.
- Haridasan, K. & R.R. Rao (1985–1987). Forest Flora of Meghalaya. Vol. I & II. Bishen Singh Mahendra Pal Singh, Dehra Dun, India, 937pp.
- Hietz, P., 1999. Diversity and Conservation of Epiphytes in a Changing Environment. Proceedings of the International Conference on Biodiversity and Bioresources: Conservation and Utilization, International Union of Pure and Applied Chemistry. 23–27p.
- Hietz, P., Buchberger, G., & Winkler, M. (2006). Effect of forest disturbance on abundance and distribution of epiphytic bromeliads and orchids. Ecotropica, 12(2), 103-112.
- Hirzel, A. H., & Le Lay, G. (2008). Habitat suitability modelling and niche theory. *Journal of Applied Ecology*, 45(5), 1372-1381.
- Hsieh, T. C., Ma, K. H., & Chao, A. (2016). iNEXT: an R package for rarefaction and extrapolation of species diversity (H ill numbers). *Methods in Ecology and Evolution*, *7*(12), 1451-1456.
- Hurlbert, S. H. (1971). The nonconcert of species diversity: a critique and alternative parameters. *Ecology*, *52*(4), 577-586.
- ISFR (2019). India State of Forest Report. Forest Survey of India, Dehradun.
- Johansson D (1974). Ecology of vascular epiphytes in West African rain forest. Acta Phytogeogr Suec 59:1–136.
- Kreft, H., & Jetz, W. (2007). Global patterns and determinants of vascular plant diversity. *Proceedings of the National Academy of Sciences*, 104(14), 5925-5930.

- Kumar, R., Prajapati, U., & Koli, V. K. (2022). Factors driving the tree species richness in sacred groves in Indian subcontinent: a review. Biodiversity and Conservation, 31(12), 2927-2943.
- Lovejoy, T. E. (2006). Climate change and biodiversity.
- Lowman, M. D. *Life in the Treetops.* New Haven, CT: Yale University Press, 1999.
- Lugo, A. E., & Scatena, F. N. (1992). Epiphytes and climate change research in the Caribbean: a proposal. *Selbyana*, 123-130.
- Lyngdoh, A. W., Kumara, H. N., Babu, S., & Karunakaran, P. V. (2023). Community Reserves: Their significance for the conservation of mammals in a mosaic of community-managed lands in Meghalaya, Northeast India. *Plos one*, *18*(1), e0280994.
- Lynser, M. B., Nongbri, B., & Makdoh, K. (2020). Firewood consumption and extraction from community forests in East Khasi Hills District, Meghalaya: its impact on woody species diversity and population structure. Tropical Plant Research 7(3): 669–677
- Madison, M. (1977). Vascular epiphytes: their systematic occurrence and salient features. *Selbyana*, *2*(1), 1-13.
- Mani, M.S. (1974). *Ecology and Biogeography in India*. Dr. W. Junk b.v., Publishers, The Hague, 773 pp.
- Mao, A. A., Sinha, B. K., Verma, D., & Sarma, N. (2016). *Check-list of Flora of Meghalaya*. Meghalaya Biodiversity Board, Shillong.
- Martínez-Meyer, E., Townsend Peterson, A. & Hargrove, W. W. (2004). Ecological niches as stable distributional constraints on mammal species, with implications for Pleistocene extinctions and climate change projections for biodiversity. *Global Ecology and Biogeography*, 13(4), 305–314.
- Meghalaya Biodiversity Board (2019). Meghalaya Biodiversity Strategy & Action Plan (MBSAP): 2017-2030. Wildlife Institute of India, Dehradun pp.
- Mir, A. H., Borah, R., Kharbuli, N. V., Lasushe, K. U., Deori, C., Chaudhury, G., ... & Choudhury, H. (2023). Orchid Diversity in Community Managed Subtropical Forests in Khasi Hills of Meghalaya, Northeast India. *Journal of Plant Science Research*, *39*(1).
- Mir, A. H., Upadhaya, K., Roy, D. K., Deori, C., & Singh, B. (2019). A comprehensive checklist of endemic flora of Meghalaya, India. Journal of Threatened Taxa, 11(12), 14527-14561.

- Mishra, B. P., Tripathi, O. P., Tripathi, R. S., & Pandey, H. N. (2004). Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. *Biodiversity & Conservation*, *13*, 421-436.
- Nascimbene, J., Thor, G., & Nimis, P. L. (2013). Effects of forest management on epiphytic lichens in temperate deciduous forests of Europe–A review. Forest ecology and management, 298, 27-38.
- Ormsby, A. (2013). Analysis of local attitudes toward the sacred groves of Meghalaya and Karnataka, India. *Conservation and Society*, *11*(2), 187-197.
- Padmawathe, R., Qureshi, Q., & Rawat, G. S. (2004). Effects of selective logging on vascular epiphyte diversity in a moist lowland forest of Eastern Himalaya, India. *Biological Conservation*, *119*(1), 81-92.
- Page, N. V., Qureshi, Q., Rawat, G. S., & Kushalappa, C. G. (2010). Plant diversity in sacred forest fragments of Western Ghats: A comparative study of four life forms. *Plant Ecology*, *206*, 237-250.
- Perez-Escobar, O. A., Bogarín, D., Przelomska, N. A., Ackerman, J. D., Balbuena, J. A., Bellot, S., ... & Antonelli, A. (2023). The origin and speciation of orchids. *bioRxiv*, 2023-09.
- Peterson, A. T. & Vieglais, D. A. (2001). Predicting species invasions using ecological niche modeling: new approaches from bioinformatics attack a pressing problem. *BioScience*, 51(5), 363–371.
- Peterson, A. T., Soberon, J. & Sanchez-Cordero, V. (1999). Conservatism of ecological niches in evolutionary time. *Science*, 285 (5431), 1265–1267.
- Pinho, B. X., Peres, C. A., Leal, I. R., & Tabarelli, M. (2020). Critical role and collapse of tropical mega-trees: A key global resource. In *Advances in Ecological Research* (Vol. 62, pp. 253-294). Academic Press.
- Putz, F. E., & Holbrook, N. M. (1986). Notes on the natural history of hemiepiphytes. *Selbyana*, 61-69.
- Quenouille, M. H. (1956). Notes on bias in estimation. *Biometrika*, *43*(3/4), 353-360.
- Rahbek, C. (1995). The elevational gradient of species richness: a uniform pattern?. Ecography, 18(2), 200-205.
- Ramírez S. R., Gravendeel B, Singer R. B, Marshall C. R, Pierce N. E. 2007. Dating the origin of the Orchidaceae from a fossil orchid with its pollinator. *Nature*, 448: 1042–1045.

- Rodgers, W. A., Panwar, H.S. and Mathur, V.B. (2000). Wildlife Protected Area Network in India: A review (Executive summary). Wildlife Institute of India, Dehra Dun. 44 pp.
- Sarat, M. (2007). *Orchids of India - a glimpse*. Bishen Singh Mahendra Pal Singh, Dehradun 248001, India.
- Singhvi, A. K., & Krishnan, R. (2014). Past and the present climate of India. *Landscapes and landforms of India*, 15-23.
- Solomon, S. et al. (eds) (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
- Sylvester, S. P., Sylvester, M. D., & Kessler, M. (2014). The world's highest vascular epiphytes found in the Peruvian Andes. *Alpine Botany*, *124*, 179-185.
- Tandon, S. K., Chakraborty, P. P. And Singh, V. 2014. Geological and tectonic framework of India: Providing context to geomorphologic development. Pp. 3–14 in Kale, V. S. (ed.). Landscapes and Landforms of India. Springer Netherlands, Dordrecht.
- Taylor, A., Zotz, G., Weigelt, P., Cai, L., Karger, D. N., König, C., & Kreft, H. (2022). Vascular epiphytes contribute disproportionately to global centres of plant diversity. *Global Ecology and Biogeography*, *31*(1), 62-74.
- Tiwari, B. K., Tynsong, H., & Lynser, M. B. (2010). Forest management practices of the tribal people of Meghalaya, North-East India. *Journal of Tropical Forest Science*, 329-342.
- Todzia, C. (1986). Growth habits, host tree species, and density of hemiepiphytes on Barro Colorado Island, Panama. *Biotropica*, 22-27.
- Tripathi, S.K., Roy, A., Kushwaha, D., Lalnunmawia, F., Lalnundanga, et al. (2016). Perspectives of Forest Biodiversity Conservation in Northeast India. *J. Biodivers. Biopros. Dev.,* 3: 157.
- Valencia, R., Foster, R. B., Villa, G., Condit, R., Svenning, J. C., Hernández, C., ... & Balslev, H. (2004). Tree species distributions and local habitat variation in the Amazon: large forest plot in eastern Ecuador. Journal of ecology, 92(2), 214-229.
- Wagner, K., Mendieta-Leiva, G., & Zotz, G. (2015). Host specificity in vascular epiphytes: a review of methodology, empirical evidence and potential mechanisms. *AoB plants*, *7*, plu092.

- Woods, C. L., Cardelús, C. L., & DeWalt, S. J. (2015). Microhabitat associations of vascular epiphytes in a wet tropical forest canopy. *Journal of Ecology*, *103*(2), 421-430.
- Zotz, G. (1997). Substrate use of three epiphytic bromeliads. *Ecography*, *20*(3), 264-270.
- Zotz, G. (2005). Vascular epiphytes in the temperate zones–a review. *Plant Ecology*, *176*, 173-183.
- Zotz, G. (2016). *Plants on plants-the biology of vascular epiphytes* (Vol. 15, p. 282). Berlin: Springer.
- Zotz, G. et al., (2009). *Epiphytic plants in a changing world-global: change effects on vascular and non-vascular epiphytes*. Springer-Verlag Berlin Heidelberg 2009, DOI:10.1007/978-3-540-68421-3
- Zotz, G., & Bader, M. Y. (2011). Sampling vascular epiphyte diversity–species richness and community structure. *Ecotropica*, 17, 103-112.
- Zotz, G., & Schultz, S. (2008). The vascular epiphytes of a lowland forest in Panama-species composition and spatial structure. *Plant Ecology*, *195*, 131-141.
- Zotz, G., & Zotz, G. (2016). Interactions with other organisms. Plants on Plants–The Biology of Vascular Epiphytes, 203-227.

Appendix 1. Checklist of Tree species recorded.

Tree code	Scientific name	Habit
T1	*Knema erratica* (Hook.f. & Thomson) J.Sinclair	Tree
T2	*Brassaiopsis glomerulata* (Blume) Regel	Tree
T3	*Premna bengalensis* C.B.Clarke	Tree
T4	*Dasymaschalon longiflorum* (Roxb.) Finet & Gagnep.	Small Tree
T5	*Ficus tinctoria G.Forst.*	Tree
T6	*Garcinia pedunculata* Roxb. ex Buch.-Ham.	Tree
T8	*Viburnum foetidum* Wall.	Shrub
T10	*Albizia odoratissima* (L.f.) Benth.	Tree
T13	*Helixanthera ligustrina* (Wall.) Danser	Parasitic shrub
T16	*Firmiana colorata* (Roxb.) R.Br.	Tree
T18	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	Tree
T25	*Monoon simiarum* (Buch.-Ham. ex Hook.f. & Thomson) B.Xue & R.M.K.Saunders	Tree
T26	*Hydnocarpus kurzii* (King) Warb.	Shrubs/Trees
T28	*Elaeocarpus floribundus* Blume	Tree
T32	*Berberis napaulensis* (DC.) Spreng. var. napaulensis	Shrub
T39	*Sumbaviopsis albicans* (Blume) J.J.Sm.	Tree
T40	*Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill	Tree
T42	*Lepisanthes erecta* (Thwaites) Leenh.	Shrub

T46	*Diospyros kaki* Thunb.	Tree
T49	*Cordia dichotoma* G.Forst.	Tree
T50	*Saraca asoca* (Roxb.) W.J.de Wilde	Tree
T85	*Styrax serrulatus* Roxb.	Tree
T86	*Itea chinensis* Hook. & Arn.	Tree
T111	*Archidendron clypearia* (Jack) I.C.Nielsen	Tree
T112	*Areca catechu* L.	Tree
T113	*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery	Tree
T114	*Artocarpus heterophyllus* Lam.	Tree
T115	*Baccaurea ramiflora* Lour.	Tree
T117	*Bauhinia purpurea* L.	Tree
T118	*Bauhinia variegata* L.	Tree
T119	*Betula alnoides* Buch.-Ham. ex D.Don	Tree
T120	*Bombax ceiba* L.	Tree
T122	*Caryota urens* L.	Tree
T123	*Castanopsis armata* (Roxb.) Spach	Tree
T124	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Tree
T125	*Castanopsis lanceifolia* (Oerst.) Hickel & A.Camus	Tree
T126	*Castanopsis tribuloides* (Sm.) A.DC.	Tree
T127	*Castanopsis wattii* (King ex Hook.f.) A.Camus	Tree
T128	*Cinnamomum bejolghota* (Buch.-Ham.) Sweet	Tree
T129	*Cinnamomum curvifolium* (Lour.) Nees	Tree

T130	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & C.H.Eberm.	Tree
T132	*Drimycarpus* racemosus (Roxb.) Hook.f. ex Marchand	Tree
T133	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	Tree
T134	*Ehretia wallichiana* Hook.f. & Thomson ex C.B.Clarke	Tree
T135	*Elaeocarpus rugosus* Roxb. ex G.Don	Tree
T136	*Engelhardia spicata* Lechen ex Blume	Tree
T137	*Eurya acuminata* DC.	Tree
T138	*Eurya japonica* Thunb.	Shrub
T139	*Exbucklandia populnea* (R.Br. ex Griff.) R.W.Br.	Tree
T140	*Ficus simplicissima* Lour.	Tree
T141	Ficus *pyriformis* Hook. & Arn.	Shrub
T142	*Ficus semicordata* Buch.-Ham. ex Sm.	Tree
T143	*Ficus rumphii* Blume	Tree
T144	*Ficus simplicissima* Lour.	Tree
T145	*Glochidion lanceolarium* (Roxb.) Voigt	Tree
T146	*Glochidion thomsonii* (Müll.Arg.) Hook.f.	Shrubs ca. 3 m tall
T147	*Gynocardia odorata* R.Br.	Tree
T148	*Itea macrophylla* Wall.	Tree
T149	*Leea indica* (Burm.f.) Merr.	Shrub
T150	*Ligustrum robustum* (Roxb.) Blume	Shrub
T151	*Litsea monopetala* (Roxb.) Pers.	Tree
T152	*Macaranga indica* Wight	Tree

T153	*Mangifera indica* L.	Tree
T154	*Mesua ferrea* L	Tree
T155	*Magnolia champaca* (L.) Baill. ex Pierre	Tree
T157	*Olax acuminata* Wall. ex Benth.	Shrub/ Small tree
T158	*Pandanus odorifer* (Forssk.) Kuntze	Tree/shrub
T159	*Machilus kingii* Hook.f.	Tree
T161	*Pittosporum napaulense* (DC.) Rehder & E.H.Wilson	Shrub
T162	*Photinia integrifolia* Lindl.	Tree
T164	*Castanopsis* indica (Roxb. ex Lindl.) A.DC.	Tree
T165	*Schima wallichii* (DC.) Korth.	Tree
T166	*Schima khasiana* Dyer	Tree
T167	*Symplocos cochinchinensis* (Lour.) S.Moore	Tree/shrub
T168	*Symplocos pyrifolia* Wall. ex G.Don	Tree
T169	*Syzygium diospyrifolium* (Wall. ex Duthie) S.N.Mitra	Tree
T170	*Syzygium tetragonum* (Wight) Wall. ex Walp.	Tree
T171	*Syzygium cumini* (L.) Skeels	Tree
T172	*Wallichia oblongifolia* Griff.	Shrub
T173	*Monosis volkameriifolia* (DC.) H.Rob. & Skvarla	Tree
T174	*Wendlandia tinctoria* (Roxb.) DC.	Tree
T175	*Miliusa dioeca* (Roxb.) Chaowasku & Kessler	Shrub
T176	*Antidesma khasianum* Hook.f.	Tree

Appendix 2. Checklist of Hemi-epiphyte and holo-epiphytes recorded.

Hemi-epiphyte and holo-epiphytes Code	**Scientific Name**	**Habit**
B2	*Heptapleurum* Gaertn.	
B3	*Rhaphidophora decursiva* (Roxb.) Schott	Climber
B4	*Pothos chinensis* (Raf.) Merr.	Climber
B5	*Piper hymenophyllum* Miq.	Climber
B6	*Piper betle* L.	Climber
B7	*Hoya lanceolata* Wall. ex D.Don	Shrub
B9	*Rhaphidophora calophylla* Schott	Climber
B11	*Rhaphidophora* Hassk.	
B12	*Aeschynanthus* Jack	
B17	*Ficus rumphii* Blume	Tree
B18	*Hoya verticillata* (Vahl) G.Don var. *verticillata*	Climber
B19	*Piper peepuloides* Roxb.	Climber
B21	*Heptapleurum* Gaertn.	
B22	*Ficus sarmentosa* Buch.-Ham. ex Sm. var. sarmentosa	Climber
B23	*Scurrula parasitica* L.	Shrub
B24	*Ficus glaberrima* Blume	Tree
B25	*Agapetes variegata* (Roxb.) D.Don ex G.Don	Shrub

Appendix 3. Checklist of orchids recorded.

Orchid Code	**Scientific name**
Pholidota sp.1	*Coelogyne* Lindl.
Dendrobium transparens Wall. ex Lindl.	*Dendrobium transparens* Wall. ex Lindl.
Vanda	*Vanda* R.Br.
Dendrobium sp.3	*Dendrobium* Sw.
Gastrochilus sp.	*Gastrochilus* D.Don
Dendrobium aphyllum	*Dendrobium aphyllum* (Roxb.) C.E.C.Fisch.
Bulbophyllum sp1.	*Bulbophyllum* Thouars
Dendrobium sp.4	*Dendrobium* Sw.
Aerides	*Aerides* Lour.
Dendrobium densiflorum	*Dendrobium densiflorum* Lindl.
Bulbophyllum sp. 2	*Bulbophyllum* Thouars
Aerides sp.2	*Aerides* Lour.
Pholidota sp.2	*Coelogyne* Lindl.
Cymbidium aloifolium (L.) Sw.	*Cymbidium aloifolium* (L.) Sw.
Papilionanthe teres	*Papilionanthe teres* (Roxb.) Schltr.

Appendix 4. Checklist of ferns recorded.

Fern code	Accepted name
A1	*Microsorum* Link
A2	*Huperzia squarrosa* (G.Forst.) Trevis.
A3	*Lepisorus carnosus* (Hook.) C.F.Zhao, R.Wei & X.C.Zhang
A4	*Pyrrosia flocculosa* (D.Don) Ching
A6	*Selaginella willdenowii* (Desv.) Baker
A12	*Davallodes hymenophylloides* (Blume) M.Kato & Tsutsumi
A20	*Pyrrosia* Mirb.
A24	*Pyrrosia porosa* (C.Presl) Hovenkamp
A16	*Lepisorus* (J.Sm.) Ching