



Institute of Biodiversity and Environmental Conservation

**Comparison of Epiphyte Diversity Between Forest Trees and Oil Palm
Within the Forest-Oil Palm Plantation Boundary in SALCRA Plantation
Areas, Bau, Sarawak**

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Master of Science

2024

Comparison of Epiphyte Diversity Between Forest Trees and Oil Palm Within
the Forest-Oil Palm Plantation Boundary in SALCRA Plantation Areas, Bau,
Sarawak

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A thesis submitted

In fulfilment of the requirements for the degree of Master of Science

(Tropical Biodiversity)

Institute of Biodiversity and Environmental Conservation
UNIVERSITI MALAYSIA SARAWAK

2024

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgement has been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.



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Date: 8 August, 2024

ACKNOWLEDGEMENT

I would like to express my deepest gratitude and appreciation to all the people who have guided and help me in completing this thesis. First and foremost, I would like to express my greatest gratitude to my supervisors, Prof Dr Gabriel Tonga Noweg and Prof Dr Andrew Alek Tuen for their guidance, suggestions, encouragement, and constructive criticism in helping me throughout completing my thesis. Other than that, I would also like to extend my appreciation to the Malaysian Palm Oil Board (MPOB) for partly funding theresearch and to Sarawak Land Consolidation and Rehabilitation Authority (SALCRA), and oil palm farmers from Kampung Serasot, Bau for allowing me to do my fieldwork in their plantations.

Next, I would like to thank my field assistants and IBEC staffs, Mr. Mohamad Hasri Al-Hafiz Bin Haba and Miss Rahah binti Mohamad Yakup for their help during my fieldwork and in the institute's herbarium. Also for the fieldwork assistant from Kampung Serasot, the late Mr. Ginot Anak Tasan, for assisting me in the field and with plant species identification. I would also like to thank my friends, Julia Nelson, Alfred Keleman, Olga Ingan, Stephanie Judi, Vivien Patrick, Bobo Teo, Selvana Eyra, Julius William, Sara Dalton, and Ernadia Elsie for giving me the strength, advice, and motivation for me to complete my thesis.

Last but not least, my heartfelt thanks to my beloved father, Mr. Philip Anak Thomas Jali, my mother, Mdm. Ruby Anak Erie and my grandmothers for their financial support and encouragement. My appreciation is also extended to my siblings, Beatrice Philip and Bernedette Philip for the strength and motivation. I am grateful for all the experience and skills that I have gained from this project and am thankful to those who gave me the strength and courage to complete my works.

ABSTRACT

Epiphytes depend on other plants or trees for physical support, nutrients, or light, and they are critical indicators of a healthy forest as they are sensitive to environmental changes. This study is conducted with the objectives of i) to determine the epiphyte species composition in oil palm and forest plots, ii) to compare and frequency of individual species and the diversity of epiphytes based on the age of forests and oil palms as well as the distance of oil palm sample plots and forest sample plots from the forest-oil palm common boundary respectively, and iii) to establish the relationship between the epiphyte species frequency and diversity in the oil palm and forest sample plots. This study was conducted in Bau district, mainly in the Jagoi area. A total of 17 forest plots and 17 oil palm plantation plots were sampled. The frequency of individual species of epiphytes and overall plot diversity are assessed based on two factors: the distance of the plots to the forest-oil palm boundary (10 m and 100 m) and age class. Three forest ages, i.e., i) < 25 years, ii) 25-40 years, and iii) > 40 years, and three age classes of oil palm were identified, i.e., i) < 5 years, ii) 5-10 years, and iii) > 15 years). A sample plot of 10 m x 10 m in the forest was established, and trees with $DBH \geq 5$ cm and height ≥ 2 m from the forest floor were enumerated. Five individual oil palms at 10 m and 100 m distances from the forest-oilpalm boundary were also enumerated. The number of epiphytes in all measured trees and oil palms were identified and counted. The abundance and diversity of epiphytes were calculated using the Shannon-Wiener diversity index and compared between different habitats. According to the findings, there is a significant difference between the number of species and the total count of epiphytes as a function of the age of the forest and oil palm. The number of species and the total count of epiphytes are not significantly affected by the distance of the plots from the forest-oil palm common boundary. The results also show that several epiphyte species

abundance correlates with the age of the oil palms and the forest, whereas there is little to no correlation between the frequency of abundance of epiphytes species and the distance of the plots from the forest-oil palm boundary. The study concludes that the forest and oil palm ages influenced epiphytes' diversity and abundance. Meanwhile, the distance to the forest-oil palm boundary is not a significant determinant of species abundance of the epiphytes.

Keywords: Diversity, epiphytes, forest, forest-oil palm boundary, oil palm

Pembandingan Kepelbagaian Epifit di Atas Pokok dan Kelapa Sawit di Sempadan Hutan – Ladang Kelapa Sawit di SALCRA, Bau, Sarawak

ABSTRAK

Epifit bergantung pada tumbuhan atau pokok lain untuk sokongan fizikal, nutrien, atau cahaya dan ia adalah penunjuk penting kerana ia sensitif terhadap perubahan persekitaran. Kajian ini dijalankan dengan objektif untuk i) untuk menentukan komposisi spesies epifit dalam plot kelapa sawit dan hutan, ii) untuk membandingkan kekerapan individu dan kepelbagaian epifit berdasarkan umur dan jarak dalam kelapa sawit dan hutan daripada sempadan bersama hutan-kelapa sawit, dan iii) untuk menentukan hubungan antara kepelbagaian dan kekerapan epifit dalam ladang kelapa sawit dan hutan berdekatan. Kajian ini dijalankan di Daerah Bau, tertumpu di kawasan Jagoi, Sejumlah 17 plot hutan dan 17 plot ladang kelapa sawit telah dikaji. Analisis kekerapan individu dan kepelbagaian epifit plot ditumpukan kepada dua faktor, iaitu jarak plot dari pinggir hutan (10 m dan 100 m) dan kelas umur. Tiga umur hutan iaitu, i) < 25 tahun, ii) 25-40 tahun, dan iii) >40 tahun dan tiga kelas umur kelapa sawit telah dikenalpasti iaitu, i) < 5 tahun, ii) 5-10 tahun, dan iii) > 15 tahun). Plot 10 m x 10 m di digunakan dan pokok berukuran pada paras dada (DBH) ≥ 5 cm, dan ketinggian ≥ 2 m dari lantai hutan diukur. Lima individu kelapa sawit berjarak dalam lingkungan 10 m dan 100 m dari pinggir hutan juga diukur. Bilangan epifit dalam semua pokok hutan yang diukur dan kelapa sawit telah dikenal pasti dan dikira. Kekerapan individu dikira dan kepelbagaian epifit dianggarkan menggunakan indeks kepelbagaian Shannon-Weiner dan dibandingkan antara habitat yang berbeza. Hasil kajian menunjukkan terdapat perbezaan yang signifikan antara bilangan atau kekerapan spesies epifit dengan umur hutan dan kelapa sawit. Sementara itu, jarak plot daripada pinggir hutan (sempadan hutan-kelapa sawit) tidak menunjukkan pengaruh yang signifikan terhadap

bilangan (kekerapan) dan kepelbagaian spesies epifit. Selain itu, dapatan menunjukkan terdapat korelasi antara kekerapan beberapa spesies epifit dengan umur hutan dan kelapa sawit, manakala terdapat sedikit atau tiada hubungan antara kekerapan epifit dan jarak plot dari pinggir hutan. Kajian merumuskan bahawa kekerapan individu dan kepelbagaian epifit dipengaruhi oleh umur (hutan dan kelapa sawit), manakala jarak plot sampel dari pinggir hutan tidak menunjukkan pengaruh yang signifikan kepada kekerapan epifit.

Kata kunci: *Epifit, hutan, kelapa sawit, kepelbagaian, sempadan hutan*

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
cm	Centimeter
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
H _A	Alternative Hypothesis
H ₀	Null Hypothesis
km	Kilometre
m	Meter
NF	Natural Forest
OP	Oil Palm
sp.	Species
SVERA	Sampling of Vascular Epiphyte Richness and Abundance
WUE	Water-use-efficiency

CHAPTER 1

INTRODUCTION

1.1 Study Background

Numerous plant species are epiphytes, including ferns, orchids, and bromeliads (Zhao et al., 2015). Epiphytes get their nutrients from the air, rain, and compost with the help of the rainforest's copious amounts of heat and moisture. While the canopy of the rainforest showcases the beauty of the dominant tree species as they perpetually grow upward to capture the most sunlight, epiphytes are most prevalent in the layer of trees below, sometimes referred to as the mid-canopy.

Epiphytes grow in rainforest niches where specific microclimates are favorable for their emergence (Zhao et al., 2015). Another critical factor in the development of epiphytes is the host tree. Due to their peeling barks, some tree species reject epiphytes, preventing the buildup of dead foliage on their canopies. However, some trees produce toxins in their bark to prevent the growth of epiphytes. The consistent weather in tropical rainforests including the temperature, humidity, light, and rainfall—is especially advantageous. An illustration would be epiphytic ferns.

Epiphytes grow on the tree for their own survival, such as for physical support, nutrients, or light. Plants are either beneficial or harmful or live in symbioses with their host tree. Epiphytes, or the 'air plant,' do not root in the soil. They depended on trees for their survival, primarily for physical support. It attaches itself to grow on other plants and does not extract nutrients from the host's vascular system (Zhao et al., 2015).

In contrast to parasitic plants, epiphyte does not depend on their host for nutrients

and, thus, are not harmful to the host tree. According to Begon et al. (2006), parasites feed off their hosts' nutrients and harm them but do not immediately kill them. The survival of parasitic plants is partially (hemiparasites) or entirely (holoparasites) dependent on their host trees. While holoparasites rely on the host tree for nutrients and water, hemiparasites only partially depend on a host plant and can still engage in photosynthesis (Kaiser et al., 2015). In other words, epiphytes have symbiotic interactions, while parasitic plants show parasitic interactions with the host trees.

The most diverse plants might be ferns and flowering plants. Malaysia is one of the countries with the highest biodiversity per unit area in the world, second only to Indonesia in Southeast Asia, despite making up only 0.2% of the global land mass, according to the World Development Indicators (Ministry of Natural Resources and Science, 2006).

1.2 Problem Statement

Forest diversity depends on the age and type of forests. All trees have epiphytes growing on them. Host trees are of various species, diameters, and canopy sizes. Epiphyte diversity depends on the forest vegetation structure, light conditions, humidity, and abundance of shaded area. Higher diversity of epiphytic plants on trees can be found in a secondary forest as it allows more exposure to light and results of the presence of many light-demanding species.

Different forest type has different forest diversity. Disturbance in the forest, such as oil palm planting, may influence epiphytes invasion and diversity. There might be fewer epiphytes on trees near the forest-oil palm boundary, while forests further away from open areas (e.g. farmlands) tend to have more epiphytes. The diversity of a forest has implications for the quality of the forest environment. Different types of plants grow on

different types of trees. Some trees may have more parasitic plants, which can be harmful. The diversity of plants may differ accordingly to the types and sizes of host trees. The more diverse a forest is, the more likely it is to be a healthy environment.

In the forest, whether parasitic or not, epiphytic plants play essential roles in maintaining the ecosystem's balance, cycling nutrients and water, and providing a habitat for other life forms such as insects. Epiphytes are among the most vulnerable plant species on earth. Due to their sensitivity to environmental changes, epiphytes serve as a forest indicators, making it essential to understand their distribution.

In past research more attention was given to research related to terrestrial plants compared to epiphytic plants. This study is conducted to see if epiphyte invasions are related to forest parameters, i.e., age, ground vegetation, and distance from the forest or plantation edges. It is essential to know the distribution and abundance of epiphytes, to allow for a management that favour conservation and a balanced ecosystem in the forest and higher quality forest environment.

The research questions of this project include the following:

- i. Do forest disturbances influence epiphytes invasion on host plants?
- ii. Are epiphyte invasions related to certain forest parameters such as age and distance from the forest-oil palm boundary?

1.3 Objectives

The study's primary goal is to assess how forest age may influence the variety of epiphytic plant species on host trees in the forest and the host palm trees inside the plantation. Epiphytic plants may survive in different conditions depending on the species characteristics and types. The forest and oil palm plantation age may be a factor that affect

the diversity of epiphytic plants. The distance from the forest-oil palm boundary may also influence the density and diversity of epiphytic plants on host oil palm trees in the plantation. Therefore, this study focuses on the density and diversity of epiphytes on host plants in different forest and oil palm plantation ages and sample plot distances away from the forest-plantation boundary.

The specific objectives of the study are:

1. To compare the composition, diversity, and frequency of epiphytes in forest and oil palm plantations of different ages,
2. To compare the composition, diversity, and frequency of epiphytes in forest and oil palm plantations based on distances from the forest-plantation boundary (forest edge).

1.4 Hypothesis

Two hypotheses are put forth, namely:

1. H_0 : There is no significant difference in the diversity of epiphytes in forests and oil palm plantation with different ages.

H_A : There is a significant difference in the diversity of epiphytes in forests and oil palm plantation with different ages.

2. H_0 : There is no significant difference between the diversity of epiphytes in forest and oil palm plantations at different distant from the forest-plantation (forest edge) boundary.

H_A : There is a significant difference between the diversity of epiphytes in forest and oil palm plantations at different distant from the forest-plantation (forest edge) boundary.

1.5 Significance of the Study

The majority of forest trees have epiphytes. Tropical regions comprise 52% of all forests worldwide and are the most significant in biodiversity (Djuikouo et al., 2010; Holdridge, 1967). This diversity reflects the degree of heterogeneity or stability of vegetation and serves as a marker for understanding the relationships between the richness and abundance of specific trees (Trichon, 1997). People who live in tropical countries may be familiar with epiphytes; however, more research and understanding are required. Epiphytes have received insufficient research attention, particularly in tropical regions like Sarawak.

Due to its rapid expansion, particularly in Sarawak, Malaysia, oil palm plantation biodiversity enhancement plays a significant role in the state's overall biodiversity health. However, there has not been much research on the density and diversity of other plants in plantations. Furthermore, the effects of standard plantation vegetation management practices on plant communities have not been taken into account. The effects of epiphytes on the health and performances of oil palms, as an agricultural crop, have not been extensively studied.

Malaysia was even listed as one of the top 12 mega-diversity nations in The Global Diversity Outlook 2001 (Ministry of Natural Resources and Science, 2006). Given Malaysia's high biological diversity, it is not surprising that many parasitic plants and epiphytes are found here. Forest managers need to know the distribution and the abundance of epiphytes and parasitic plants that would be useful for the conservation and maintenance of water catchment areas, soil, and biodiversity conservation, as well as for a balanced ecosystem in the forest.

Changing forests to monoculture involves clear cutting the forest structure, which may cause a loss in epiphyte biodiversity (Böhnert et al., 2016). In addition, as the plantation

matures, the individual plant will be colonized by epiphytes as the seeds of colonizing species reach the plantation from the epiphytes population in the nearby primary forest or neighbouring older plantation.

Additionally, converting forests into monoculture changes the ecological conditions along the forest edge. Firstly, there are distinct differences in light and moisture availability between the forest edge and interior (Hauck et al., 2014). The forest edge also experiences higher wind speeds, radiation, and dust deposition than the forest interior. Therefore, to study the edge effect on the organism, it is ideal to assess the diversity of epiphytes as they are susceptible to small environmental changes (Aragón et al., 2015). In addition, as epiphytes diversity plays an essential role in the forest water cycle and nutrient cycling, its occurrence represents a healthy forest or area (Ellis, 2012).

1.6 Limitations of the Study

This study has possible limitations due to several reasons. First, the appropriate sample size was hard to determine as very few similar recent studies were found. As such there may be some element of underestimation which can result in poor data. There were some limitations related to the location of the study sites. Some sites are not accessible for revisit due to road damage, especially in the plantation areas. Weather played a big role in the timing of data collection and the ability to access the study sites. Third, the sampling technique does not involve tree climbing, and thus the estimation of frequency of individual species may have been affected in terms of accuracy.

1.7 Chapter Summary

Presented in Chapter One are the introductory notes on the subject of study and the presentation of the study goals and objectives. Two major hypotheses are put forth that reflect the primary focus of the study, as projected earlier in the problem statement. A brief account of the study importance and study limitations is also included.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The following discussions focus on various aspects of the forest environment and the occurrence of epiphytes in tropical rainforests. It also discusses previous research and studies on the element of the diversity of epiphytes and non-epiphytes on trees in different forests. Many elements of epiphytes will be described further. The literature review in this chapter does not just look at local Malaysian studies but also attempts to include studies outside Malaysian forest environments, especially in Southeast Asia. Although the central focus is on past studies on epiphytes, other related aspects of forest ecology are also included.

2.2 Species Richness and Land Use

Epiphytes make up about ten percent of all vascular plant species and are almost entirely found in tropical forests. As a result, they can make up to 25% of all vascular plant species (Nieder et al., 2001). According to Kress (1986) and Zotz (2013), epiphytes represent at least 24,000 species of vascular plants and contribute a significant portion (possibly 10%) of the world's plant diversity.

Land-use practices were different in every country. It primarily concerned the products and activities done in a particular area. The land use in Malaysia is generally for plantation and agriculture, such as oil palm plantations or rubber estates. Proper management of land use was critical for socio-economic development as well as for maintaining the environment. Unless they are given perpetual protection status, logged-over tropical forests have always faced intense pressure to be converted to other, more lucrative land uses

(Laurance, 2007). The large companies acquired large areas of forest land to be converted into mainly plantation or agriculture areas. Developers included areas or forests cleared for development purposes, such as residential or commercial areas.

Four land-use types including lowland rainforest, jungle rubber agroforests as well as rubber and oil palm plantations were compared in a study by Böhnert et al. (2016) in Jambi, Indonesia. The characteristics of each land-use system were analyzed, including species richness, abundance, and composition of the vascular epiphytes. The findings demonstrate that the jungle rubber agroforest, regarded as a significant refuge for epiphyte diversity, had the highest epiphyte richness. Due to the high rubber densities and presence of large, long-lived trees, the jungle rubber agroforest was found to have the highest epiphyte diversity through stand structure analysis. Compared to younger forests, forests with older trees, such as primary forests, may have a higher density of epiphytes.

2.3 Tropical Rainforests and the Threat

Tropical rainforests have been transformed, fragmented, and degraded due to anthropogenic activities like timber extraction, shifting cultivation, and the establishment of commercial plantations. Because of variations in the type of disturbance, the environment, the length of time since the disturbance, and the original vegetation type, different types of degraded forests persist after such degradation. Three types of forest degradation exist: logged over forest after commercial logging, early successional secondary forest, and grassland just after burning (Kenzo et al., 2007). In contrast to forest that was not degraded, this impacted the forest ecosystem's carbon storage, timber production, and soil quality.

Deforestation cause deterioration in environmental conditions by increasing

highlight intensity and causing severe soil mineral erosion. Therefore, the biodiversity of Malaysian forests and the ecological services they provide are in danger due to habitat loss and overuse (Sodhi & Brook, 2006).

Forest cover decreased from 51% to 49% in 2000 and is expected to decrease to 46% in 2020 (FAO, 2011). Due to pressures from agricultural conversion and the gradual expansion of permanent forest reserves, Malaysia's forest cover decreased from 22.4 Mha in 1990 to 20.5 Mha in 2010, and it is anticipated that it will decrease even further to 20.0 Mha in 2020 (FAO, 2011). Whereas in cases where protected areas already exist, most of them are inadequately funded and protected (Corlett & Primack, 2008). Due to ongoing encroachment and a lack of resources, many of the current protected areas are fragmented and may not have promising futures (Tisen & Bennett, 2002; Curran et al., 2004).

The conversion of the woodland into a residential or commercial area also involved developers. In Sarawak, some land has been cleared for business or residential sectors. This excludes unlicensed timber concessions that illegally cut forest land to harvest timber. As a result, the illegal loggers could continue searching for more timber, causing either temporary or permanent harm to the property. The land area that has been logged was around 124,449.51 square kilometers, practically the size of Peninsula Malaysia (Colchester et al., 2007). Strict measures need to be taken to stop large-scale land clearing that may cause more damage to the environment.

The world's most endangered types of forests are tropical rainforests, and over the past few decades, between one-third and half of these forests have already been converted to other forms of land-use systems (Primack & Corlett, 2005). The Indo-Malayan rainforest is the second-largest rainforest region in the world, located in tropical Asia (Whitmore,

1998). It used to cover the majority of the Malay Peninsula and extend across the Malay Archipelago from Sumatra in the west to New Guinea in the east. The area is one of the most biologically diverse and distinctive in the world regarding species richness and endemism, making it one of the planet's biodiversity hotspots (Mittermeier et al., 1999; Myers et al., 2000).

2.4 Environmental Factors and Epiphyte Diversity

Environmental elements like soil types, climate, and landforms impacted epiphyte diversity. Epiphytes receive more light from the canopy than from the dark understory (Lüttge et al., 1986), but several physiological constraints are relevant. For instance, the relative lack of nutrients caused by the canopy's lower concentration of suspended soil than the forest floor (though this does not necessarily mean lower relative nutrient content); the instability of the substrate; and, most importantly, the effects of water stress (Lüttge, 1989). This explains why vascular epiphytes are mainly found in subtropical and tropical regions.

Vascular epiphytes are killed by frost and dryness in temperate areas. Numerous genera within the canopy exhibit various ecological needs. For instance, different niches are frequently occupied by *Clusia* sp. and *Ficus* sp. (Prosperi, 1998). Some of the ecological variations among hemi-epiphyte genera can be explained by physiological and morphological adaptations like xeromorphic leaves, thick cuticula, depressed stomates, and water accumulation in the hypoderm (Putz & Holbrook, 1986).

As was observed in Venezuela and Costa Rica with numerous fig species, where water and nutrients retained in leaves during the epiphytic stage decreased after the aerial roots had reached the ground, these adaptations may even change as the organism develops (Putz & Holbrook, 1989; Holbrook & Putz, 1996). According to Prosperi (1998), different

growth forms are also responsible for the ecological differences between *Clusia* and *Ficus* in Amazonia, where *Clusia* is more able to adapt to sites with shady canopy than *Ficus*. These variations also have an impact on population size.

2.5 The Forest Environment

For plants that depend on hosts to survive, trees play crucial roles. A forest's diversity impacts the quality of the forest environment. Unfortunately, determining the health of the forest depends on the diversity of these species. Epiphyte plants, primarily ferns, and parasitic plants, primarily orchids, are some significant plants that inhabit trees. Different families of plants in the plant kingdom have independently evolved parasitic plants (Kuijt, 1969).

Despite being a prominent feature of many forests, epiphytes are less well-understood than terrestrial plants (Taylor et al., 2015). This indicates that compared to terrestrial plants, epiphytes, and parasitic plants that live on trees received less attention. Trees and plants cohabit in our forest, and biological interactions occur between the host trees and the plants. However, because they may occur on numerous levels and in various currencies, the costs, and benefits of symbiosis for a host organism are not always evident or easily quantified. (Cushman & Beattie, 1991). The literature review will highlight the biological interaction between the host trees and the plants that live on them. It mainly highlighted the epiphytes, non-harming plants to the host trees, and parasitic plants, which are harmful to the host trees. Therefore, in the review, the scope of the research will be listed, and an insight relationship related to the research will be highlighted.

2.6 Epiphytes and Their Roles in Rainforest Ecosystem

Barkman (1958) states that epiphytes grow on plants without consuming nutrients

or water from their hosts' living tissues. A plant known as an epiphyte does not require soil to develop; it lives on other trees. Most epiphytes get their nutrients and moisture from rain or the air. Epiphytes are particularly numerous and diverse in pristine wet mountain forests (Gentry & Dodson, 1987; Benzing, 1990), most likely due to high annual rainfall combined with slight seasonal variation (Kreft et al., 2004). Most epiphytes are flowering plants like orchids, ferns, mosses, and algae.

2.6.1 Roles of Epiphytes

Epiphytes offer animals abundant resources such as sustenance, hydration, materials for nesting, and a place to live (Gotsch et al., 2016); they also regulate mineral (Pike, 1978) and nutrient cycling (Diaz et al., 2010); and they are a significant contributor to the biomass and the diversity of a forest (Hsu et al., 2002). In addition, epiphytes provide food and habitat for various animals, including vertebrates, invertebrates, and microbes, as well as for the water in the forest (Nadkarni & Matelson, 1992).

A study by Nadkarni and Matelson (1989) showed that epiphytes are responsible for providing a significant amount of food to bird species, as evidenced by the fact that 60 percent of the birds in an area used them for foraging. That is just how vital the epiphytes are to the forest ecosystem. In addition to serving as food sources, epiphytes serve as homes for various forest creatures, including beetles, ants, spiders, and wasps. The insects thrive while living in the epiphytes in the rainforest canopy, but after they died, they provide the epiphytes with nutrients and minerals (Yanoviak et al., 2003). One of the essential elements of tropical biodiversity and distinguishing features of tropical forests is their diversity (Flores-Palacios & García-Franco, 2001; Gradstein et al., 2003).

Vascular epiphytes can make up one-third and half of the total vascular flora in some

tropical forests (Gentry & Dodson, 1987), making epiphytes a distinctive characteristic of tropical forests and setting them apart from most temperate forests (Gradstein et al., 2003).

2.6.2 Types of Epiphytes

Ten percent of the world's vascular flora depends on other plants, usually trees, without parasitism (Benzing, 1990). Since it is not parasitic, the trees are not harmed. To obtain sunlight, it primarily grows on trees as a source of energy without endangering the host trees. Most often, it grows on tree trunks or the bases of trees. There are four different types of epiphytes, namely:

1. Holo-epiphytes: Epiphytes that grow from seed to flower without touching the ground (Benzing, 1990).
2. Hemi-epiphytes: A portion of the life cycle of epiphytes is spent on land.
3. Primary-hemi: Strangler figs are an example of an epiphyte that starts as an epiphyte and eventually sends its roots down to the ground, whereas secondary hemi-epiphyte seedlings grow from terrestrial germination to secondary epiphyte status when their rooting shoots decompose (e.g., aroids).
4. Facultative epiphytes: Species where some individuals live on the ground.

2.6.3 Biology of Epiphytic Plants and Example

There are several species and families of epiphytes. On the tree bark, liverworts, mosses, and algae typically develop. The organic debris that builds up after they die will be perfect for developing ferns and orchids (Chin, 1992). Examples are the Bird's Nest Fern (*Asplenium nidus*) growing on the Rain Tree and the Dragon's Scales (*Pyrrosia piloselloides*) (Figure 2.1 and Figure 2.2).



Figure 2.1: *Asplenium nidus*



Figure 2.2: *Pyrrossia piloselloides*

In order to survive, plants are built with the ability to adapt to their environment. The host trees provided the epiphytic plants with support and sunshine. Some plants can store water and adapt to their environment. Water conservation becomes even more crucial for maintaining optimal stomatal control in extreme environments like the forest canopy, where plants such as epiphytes are entirely disconnected from the water source on the ground. As a result, plants have evolved various adaptations, including orchids' pseudo-bulbs, bromeliads' water-holding tanks (Benzing, 1990; Males, 2016; Zotz, 2016). Epiphytes may have high water-use-efficiency (WUE), but their ability to respond to sudden changes in their surroundings is more limited (Zhang et al., 2009).

2.7 Host Trees Characteristics

The properties of the trees significantly influence the diversity and abundance of epiphyte and parasitic plants. The bark of hosts is crucial because plants rely on their capacity to establish their roots in the non-soil medium. Despite studies showing that seedlings growing on rough, porous, and/or water-retaining bark have stronger drought resilience than

those growing on smooth bark, which cannot retain enough surface moisture, Reyes-Garcia et al. (2008) state that water shortage still poses a threat to mature epiphytes. On trees with rough bark, small vines that use tendrils to cling to crevasses thrive (Forsyth & Miyata, 1984), but heavier epiphytes tend to dislodge flaky bark (Kim et al., 1997).

These have demonstrated that tree features significantly influence the diversity and abundance of epiphytes. Epiphytes do not require much room to grow into a diverse population, so the more surface area they have to grow on, the more species there are on that particular host tree. Therefore, there is a potential that a region with older forests will have trees that are taller and bigger. A higher diversity is shown by host trees that are taller and have larger DBHs. Some plant species have an aerial root form known as velamen radicum that contains an epidermis. These root systems have many dead and empty cells, which act as sponges to store water when it rains. These plants would quickly dry out on their rock-face habitat without a structure like this.

The number of forks, altitude, aspect, canopy cover, DBH, and forest management methods all affected the species composition of the orchid and fern. The study by Yagya et al. (2017) demonstrates that host traits and host types influence the diversity of orchid and fern epiphytes. The presence of old or tall trees is the essential precondition for high epiphyte biodiversity, regardless of the current protection status.

Any change in vegetation to one without trees will inevitably result in a complete loss of epiphytes in the affected area because epiphytes depend on their host plants, which are typically trees (Figure 2.3). The range of locations on individual trees and over the forest canopy contributes to the diversity of epiphytes found in old-growth forests. Depending on which species are used to the most humid and shady stem bases, exposed twigs, thick or

decaying branches, or exposed stem bases, there is more or less obvious zonation within the tree.

Additionally, tree and branch fall create a level of disturbance that prevents a few species from monopolizing the available resources, allowing numerous species to coexist. Not all types of trees make good epiphyte hosts. Even while epiphytes do not seem to have much host specificity, some tree species are typically better hosts than others (Heitz, 1999).

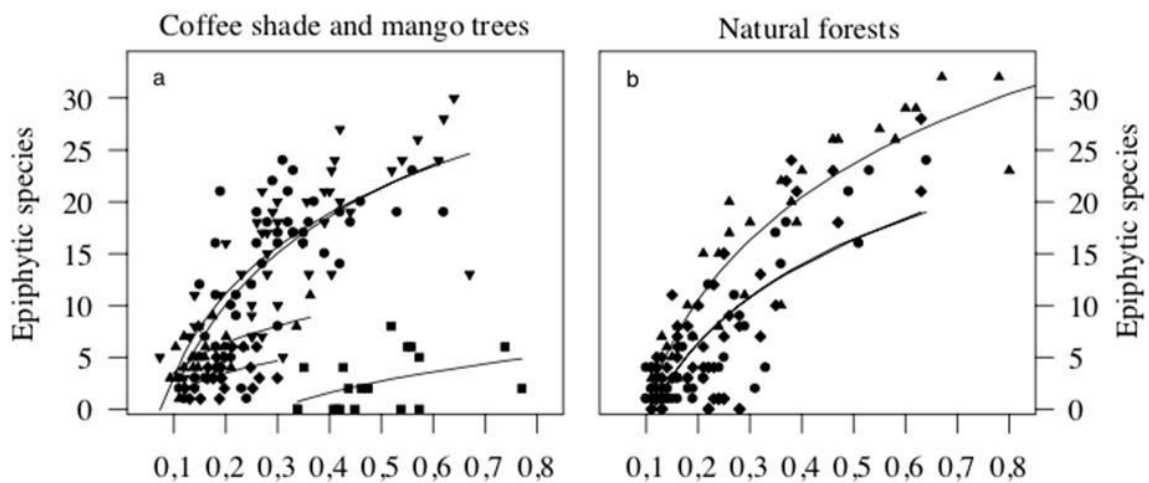


Figure 2.3: Comparison of Epiphyte Species in Different Vegetations
Source: Hietz (1999)

Based on study by Heitz (1999), trees with rough bark frequently make better hosts. Fewer epiphytes grew on mango trees compared to the shade plants that were investigated. The highly dense foliage focused on the outer crown, which allows for insufficient light to reach the branches where epiphytes could grow, seems to be one factor. Furthermore, mango bark contains a high concentration of tannins and phenolic chemicals, which may prevent germination.

2.8 Distribution of Ferns and Orchids

Ferns are widely dispersed since their primary method of dispersal is through their spores. Due to the spore's lightweight nature, which makes it simpler to be dispersed in the

presence of the wind, plants that sprout from spores are readily dispersed. Therefore, ferns can be found in environments where it is difficult for other plants to survive, such as forests, swamps, and mountains. However, it primarily develops in tropical regions with damp environments.

However, some fern species are endemic to certain areas. For example, *Sphaerostephanos capitata* and *Selliguea murudensis* are endemic to Sarawak and Sabah; meanwhile, *Alsophilia havilandii* and *Odontosoria veitchii* which are endemic to Mount Kinabalu and Borneo (Beaman, 2007).

According to the Hanbury-Tenison and Jeremy, (1979), there are perhaps 10,000 species of ferns in the whole world. According to data provided by the Sarawak Forest Department (2023), 757 species of ferns from 136 genera and 35 families have been discovered in Sarawak. Most ferns, including *Stenochlaena palustris* (paku midin), a popular meal among the Sarawak people, are edible. The favorable environment in Malaysia is the reason for the abundance of fern species found here.

Epiphytic plants exhibit complex patterns of distribution. Their species is usually confined to a particular climatic zone and forest type and favors specific microhabitats. In addition, the local distribution of epiphytes depends on the host tree species, their position, age, and condition, and the presence or absence of other epiphytes. These complex factors make it difficult to interpret their distribution pattern.

2.9 Epiphytes Diversity in Tropical Country

Barkman (1958) states that epiphytes can be found in many plant orders. Geographically, it is widely distributed among non-vascular plants such as lichens, mosses, and algae. On the other hand, vascular epiphytes like pteridophytes and phanerogams can

primarily only grow in tropical environments. They significantly contribute to the flora, especially in tropical rainforests, and their presence and abundance are frequently used to characterize these forests (Schimper, 1903; Richards, 1952). Many plant species can survive as epiphytes in humid environments for varying periods, such as some coastal and high mountain locations, despite lacking particular adaptations to such a life (Sharp, 1957).

Around 10% of all plants on Earth are epiphytes, and in tropical areas specifically, they account for about 25% of all vascular plant species (Wolf & Flamenco-S, 2003). This exemplifies the diversity of epiphytes and how well they can adapt to various habitats, including plantations, mangroves, and tropical and temperate forests. It is interesting to note that neither plant families nor epiphytic groupings exhibit epiphytes equally. The fern, angiosperm, and gymnosperm families and orders make up 20% of the 20, 000–25 000 species of vascular epiphytes, according to Benzing (1990). Monocotyledons make up the remaining 80% of these species. In addition, the major vascular plant families, such as Asteraceae, Fabaceae, and Poaceae, exhibit little epiphytic lifestyle (Benzing, 2004). Wolf (1993) argued that non-vascular epiphytes would significantly contribute to the epiphytic diversity and, in some cases, outnumber vascular epiphytes in abundance and diversity in any given sample plot, even though vascular and non-vascular epiphytes are two diverse groups (Gentry & Dodson, 1987).

Although epiphytes primarily rely on their hosts for physical support, their physical and geographic isolation from terrestrial resources forces them to develop a more dependent way of life. The bark texture, substrate instability, nutrients in the suspended soil, atmospheric nutrients, litter fall, leaching, branch shape, and aspect can all significantly impact a plant's diversity, abundance, and distribution (O'Malley, 2009; Marmor et al., 2010). Additionally, it is now understood that some epiphytes' biomass, species richness,

and composition vary with height in the canopy (Johansson, 1974; Gauslaa et al., 2008; Fritz, 2009). The epiphytic distribution on a single tree can vary significantly over time and space, according to Wolf (2005).

Epiphytes are numerous and an essential part of tropical forests, but they are susceptible to deforestation because they are mechanically dependent on their host trees. In general, older plantations are more complex architecturally than younger plantations and support more diverse assemblages of forest species from various ecological groups. However, as Kanowski (2017) notes, this effect correlates inversely with managerial intensity.

The horizontal and vertical distribution patterns of both are compared to some of their ecological requirements, with a focus on the distinctions between "holo-epiphytes," or non-parasitic plants, which use other plants, typically trees, as growing sites throughout their life cycles, and "hemi-epiphytes," or "half" epiphytes, which only spend part of their lives as epiphytes until their aerial roots become connected to the ground. In addition, vertical biological gradients like insolation and humidity changes from the forest floor to the canopy surface impact the holo epiphytic vegetation's composition.

Even though there are significant ecological differences between different forest ecosystems, the structure of the individual host trees matters more for hemi-epiphytes than the canopy structure. The scale-dependence of epiphyte diversity evaluation is primarily due to the striking differences in plant sizes and the corresponding mechanical and physiological requirements, as shown by the relatively small study areas for holo epiphytes and the extensive study areas for hemi-epiphytes (Nieder et al., 2018).

2.10 Variability in Epiphytic Species Across Different Forest Types and Ages

Due to the wide variety of habitats, Sarawak's natural forests offer a rich array of plants. There are over 3,000 recognized trees, and 40% of Sarawak's plant life is unique to Borneo (Forest Department of Sarawak, 2023). The types of epiphytes, the host trees, and environmental conditions all affected the variety of epiphytes on trees. Some epiphytes might only flourish on particular trees that serve as their hosts for them. For some epiphytes, the type of forest is also a significant consideration. Examples include the varieties of soil—peat, and non-peat—and the several kinds of forests, including kerangas, primary, dipterocarp, and more.

Some epiphytes can only be found in forests with peat soil and are absent from other soil types. The others include Hill Mixed Dipterocarp Forest (7.35 million ha), Peat Swamp Forest (0.33 million ha), and Mangrove Forest (0.07 million ha). Most of the trees in this kind of forest are Dipterocarps, which produce valuable logs due to their large size, cylindrical shape, and superior timber qualities. Mixed Dipterocarp Forest is currently the most critical forest type from an economic perspective due to its size and make-up (Forest Department Sarawak, 2023).

Sarawak's most prevalent and complex forest type is the hill mixed dipterocarp forest. It extends from the interior lower limit of the Montane Forest (about 1,500 m above sea level) to the inland limit of the coastal peat swamps, and a high diversity of species and life forms distinguishes it. There are trees, shrubs, climbers, and herbs (at about 45m) between the forest floor and the main canopy.

Schneider et al. (2022) assert that the requirement for agricultural intensification in the land-saving strategy has been linked to a decline in biodiversity in agricultural

ecosystems. Removal of plant species that compete with crops for nutrients, light, and water is a common step in intensification. This directly impacts plant diversity, but it can also negatively impact animal species richness and abundance by removing food sources, simplifying habitats, and using pesticides, which further decrease animal populations. In addition, important ecosystem services and activities like nutrient recycling or insect predation may suffer if a species goes extinct (Tschardt et al., 2012).

In addition to make it harder for many species to survive in agricultural settings, intensification restricts species' ability to spread within the agricultural system, exacerbating habitat fragmentation (Kupfer et al., 2006).

2.11 Factors Stimulating Epiphyte Infestation on Tree

A variety of factors can cause epiphyte infections on trees. The majority of epiphytes are small and self-pollinate by producing pollen. The type of host tree affects epiphyte infection on trees as well. A study on the interactions between two species of vascular epiphytes and ten host tree species in a coastal plain forest in the south-eastern United States found that the growth of epiphytes was significantly higher on host tree species that naturally bore high epiphyte loads than on host species with few or no epiphytes. These species-specific correlations were closely related to the host tree's bark's capacity to hold water (Callaway et al., 2002).

According to Spicer and Woods (2022), tropical epiphytes that have survived evolved from terrestrial forms that flourished in gloomy, humid woods. Another excellent epiphyte in the tropical forest is the orchid. The fact that orchids produce tiny seeds (measured in microns), numbering in the hundreds of thousands, is a crucial factor in their success in the forest. Due to their small size and the balloon-like seedcoat, orchid seeds are

easily transported by wind currents over large areas. Insects are another method used by orchids to disperse pollen. It is truly unique how orchids can survive in the canopy. Their roots' large surface area makes it possible for them to absorb nutrients and water quickly. In addition, the plant's ability to store water in its secondary stems allows it to withstand drying periods.

2.12 Epiphytes and its Impacts on Oil Palm

Elaeis guineensis, or oil palm, is a critical component of Sarawak's economic growth. It has been widely and extensively grown throughout Malaysia, quickly becoming one of the most important crops for producing oil and generating money for private industries and individuals. Epiphytes that grow or climb on oil palm trees' trunks are common.

However, it is unknown whether epiphytes that grow on oil palm trees are affected by the epiphytes from a nearby forest. The types and number of epiphytes on oil palms may be affected by the trunk's height and DBH. The species may also depend on the type of soil or the environmental factors such as the area's light intensity, temperature or air humidity. The diversity of epiphytes may also vary depending on the plantation management. The plantation management may include removing the epiphytes on the palm trees (Prescott et al., 2015).

Oil palm plantations have proliferated in recent years, significantly impacting biodiversity and tropical habitats. However, oil palm forms a much more varied and structurally complex habitat than many other crops due to its long lifespan (25–30 years). Both epiphytes on palm trunks and an abundance of understory vegetation can be examples of this. Unfortunately, little research has been done on the diversity of this plantation vegetation, and little consideration has been given to how typical plantation vegetation

management practices affect various plant communities (Dunnett, 2004)

Agriculture is rapidly growing and intensifying to keep up with rising consumption and a growing global population. The tropics, where there are still areas of natural habitat available for conversion and socioeconomic conditions are encouraging rapid development, are where such change is occurring the fastest.

Oil palm (*Elaeis guineensis*), a perennial crop used to make palm oil, is planted on ever-larger tracts of land in Southeast Asia. In the ten years leading up to 2010, the area of oil palm plantations in Southeast Asia increased by 87%, and Indonesia and Malaysia are the two countries that produce the most palm oil, accounting for almost 85% of global production (FAO, 2019). With its high yields compared to other oil crops, palm oil is a very versatile vegetable oil that can be used for cooking, processed foods, cosmetics, and biofuels (Wahid et al., 2005).

Despite its effectiveness, the industry has had a significant negative impact on the environment, mainly because most of the oil palm expansion has come at the expense of forest loss. With an average annual forest loss of 1.4% between the 1990s and 2000s, Southeast Asia experienced one of the highest deforestation rates in any tropical region. By 2010, Malaysia, Sumatra, and Java had lost almost 70% of their forests (Wilcove et al., 2013).

Oil palm plantations are structurally more streamlined and highly disturbed than tropical forests. The establishment of plantations can expose soil to compaction, erosion, and leaching (as is the land case immediately after logging) (Clarke & Walsh, 2006). When exposed, peat soils exhibit high levels of subsidence and peat oxidation (Hooijer et al., 2012;

Manning et al., 2019). Additionally, chemical pesticides and fertilizers are frequently used when cultivating plants (Corley & Tinker, 2003). In monocultures and single-age stands, oil palm trees are typically planted. Plantations with young palm trees have an open canopy, which causes temperatures up to 6.5°C hotter and significantly drier than in old-growth forests (Hardwick et al., 2015).

Various types of epiphytes grow on oil palms. Depending on the type, epiphytes can be beneficial, harmful, or neutral to the oil palm tree. Epiphytes can benefit biodiversity through house insects such as ants, beetles, bees, and many more. However, it is harmful if the epiphytes take space, food, or water and limit the growth of the oil palm tree. Some epiphytes do not affect the oil palm tree. Most plantation includes epiphyte management, which includes trimming or removing any epiphytes on the oil palm trunk. This ensures that the epiphytes do not affect oil palm production.

The amount of production in an oil palm plantation may vary depending on epiphytes, but there could be other factors affecting the plantations, such as the quality of seeds, the temperature, weather, and sunlight exposure may affect the production. In addition, the impact of the surrounding environment may also impact the epiphyte on oil palm trees. One type of plant that plays a significant role in the ecosystems of oil palm plantations is epiphytes. Epiphytes, which grow on tree stems, are a vital source of energy and a home for various organisms, including arthropods.

2.13 Past Research Methods

Over the years, various research techniques have been used to estimate epiphytes' density, including cranes, canopy walkways, ladders, rope access techniques, and hot air balloons. Since developing more sophisticated techniques, epiphytic distribution patterns

on specific trees have received more focus. For example, the mountaineering climbing techniques (Perry, 1978) were used in the study by Engwald et al. (2000) for epiphytes in the rainforest in Venezuela-diversity and dynamics of a biocenosis. This was accomplished by installing a permanent rope system that connected three emerging host trees. A crane served as both a working tool and an observation platform. To ascertain the epiphyte diversity, spatial distribution, and dynamic processes of the vascular epiphytic vegetation between various forest types, the epiphytes were sampled around the crane plot. Plots were created for the plantation area, primary forest, secondary forest, and disturbed vegetation.

In addition to mountaineering climbing methods, Wolf et al. (2009) estimated the abundance and recorded the number of plant components in a designated area to study the richness and abundance of vascular epiphytes. Trees with (DBH > 5cm) were sampled and identified to species level. The forest plot was randomly sampled to analyze the forest structure within a 30m x 30m plot. Based on the presence of epiphytes on each tree, epiphytes were sampled. This study's primary goal is to compare the relationships between epiphyte richness, abundance, and host tree size. The host tree type was further divided into trunk or branch segments. In this study, the SVERA protocol was used, and epiphyte- poor trees like ant trees and trees with sloughing bark were excluded because they may affect the relationship between tree size and species richness or biomass.

Based on Yagya et al. (2017) research, epiphyte species and host plants (*Schima wallichii* and *Quercus lanata*) have a relationship. Data were gathered in Shivapuri Nagarjun National Park's national forest (NF) and the community forest (CF) of Naudhara. Both univariate and multivariate tests were used to analyze the data. He totalled 41 different types of epiphytes (33 orchids and eight fern species). Compared to NF, the abundance of orchid species is significantly higher in CF.

2.14 Epiphytic Propagation and Seed Colonization

Probably the most well-known method for any plant is seed propagation. To plant the seed, use a substrate that drains well, such as pure vermiculite or a sand-and-peat mixture. Next, sprinkle a thin layer of sand on top of the seeds after evenly moistening the substrate.

Despite being fundamentally important for understanding species distribution, abundance, population dynamics, and life-history variation, seed dispersal is one of the least understood stages in plant life cycles. Nevertheless, dispersal may be essential for the regional persistence of species that live in fragmented habitats.

The main goal was to create an easy method to evaluate a plant's capacity for dispersal and colonization. The processes of seed production, seed transport, and seedling recruitment were considered when dispersal and colonization were studied. Using supported assumptions about

- i. a trade-off between seed production and seed size,
- ii. a relatively low predictive power of seed transport for species' actual dispersal and colonization,
- iii. a positive effect of seed size on recruitment, and a general prevalence of recruitment limitations by seed availability, a prediction is made that species with intermediate seed sizes will have the best ability to disperse and colonize in a given community.
- iv. Field data support this prediction. A classification system with four fundamental plant categories is proposed based on estimates of the ability of local populations to persist and disperse and colonize new areas. Finally, some suggestions are made for the conservation of plants in each of these four categories on a landscape scale (Ove, 2000).

CHAPTER 3

METHODOLOGY

3.1 Study Site Background

3.1.1 Study Area

Bau town is located 45 km away and approximately 50 minutes from central Kuching. Bau is located in northern Sarawak, inside the island of Borneo. It is a gold mining town with limestone cliff formations supporting much endemic flora, including the rare pitcher plant *Nepenthes northiana*. Most Bau residents are of the Bidayuh ethnics, followed by the Chinese, the Malay, the Iban, and many more. Bau is also located near the Sarawak Borneo-Kalimantan Indonesia border. The district encompasses 104 villages, as reported by the Bau District Office (2022), and has a total land area of 884.4 square kilometers, according to the State Planning Unit (2012).

There are several villages around the Jagoi area, and some of them are close to oil palms plantation. Part of the residents in Bau are farmers who cultivate rice and grow oil palms and peppers. They also collect some plants from the forest, community fruit forests and active farming areas, for consumption or sale. Most youths work in the main city of Kuching or had out migrated to other towns or cities in Malaysia.

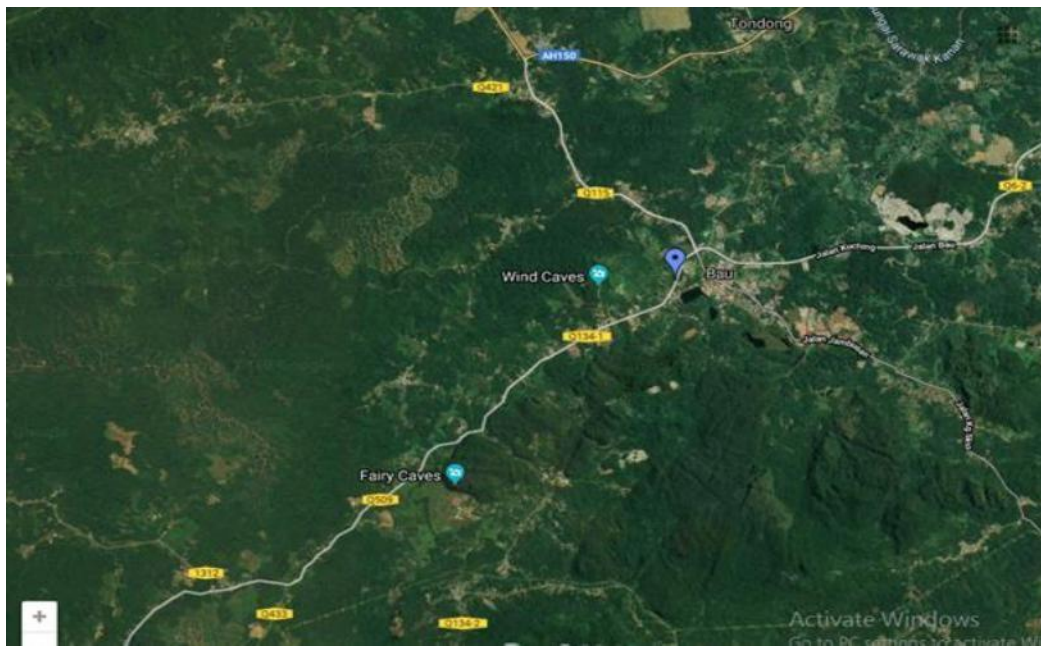


Figure 3.1: Map of Study Area
Source: Google Earth Pro (2022)

3.1.2 Forest in Bau

For their limestone forest, the Bau is renowned. According to Pour et al. (2013), around 40% of the forest in this district is covered by the primary rainforest, which is mainly situated on unproductive limestone hills and elevated mountains. The remaining forests in Bau are mostly secondary forests. Some 1,230 ha of humid primary forest were lost in Bau between 2002 and 2020, accounting for 7.9% of Malaysia overall tree cover loss. During this time, the total area of Bau's humid primary forest shrunk by 6.5%.

The young and mature secondary forests are forests that are former hill rice plots, left to regenerate naturally. The average tree diameter ranges from about 8cm to 20 cm. On good soils with thick top-soil (A-horizon) layer, these forests are usually dominated by pioneer tree species such as benua (*Macaranga* spp.), leban (*Vitex pubescens*), semupa (*Adinandra domusa*), and mupuot (*Vernonia arborea*). On poorer soils, however, the most common pioneer species are likely to be somah (*Ploiarium alternifolium*), kiriep (*Cratoxylum flexiosum*), ngiliwat (*Vitex* sp.), badad (*Macaranga gigantea*), and atap (*Nauclea racemosa*).

In general, this type of forest does not host significant epiphytes and parasitic plants, probably due to its relatively young age.

The old forests in this study include former shifting cultivation areas which may be more than 70 years old, agroforestry areas (old fruit forests or *dusun*), and remnants of primary forests (in scattered patches). Trees are generally larger, with an average diameter of between 35 to 50cm, depending on site productivity. The species of trees are normally consisting of those that are categorized as being climax species. These trees include dipterocarps (e.g. *Shorea macrophylla*, *Shorea ovata*, *Drobalanops* sp., *Cotylelobium* sp., *Vatic* sp.) and non-dipterocarps (e.g. *Myristica* sp., *Dipsyros* sp., *Koompassia palembanica*, *Syzygium* sp., *Knema* sp., *Alsaedaphne* sp. and so on). In the old agroforestry category, common species include fruit trees such as durian (*Durio zibethanus*), moran (*Alangium* sp.), bowang (*Mangifera pajang*), motan (*Mangifera torquenda*) and non-fruit trees (e.g. nyatoh (*Palaquium gutta*), tapang (*Koompassia excelsa*). These forest trees are tall with parasites and epiphytes established on the lower parts of the stem and lower branches.

3.1.3 Oil Palm Plantation in Bau

Bau town is also known for its significant oil palm plantation estate. Five estates cover 12,701 Ha of land converted into oil palm plantations throughout the Bau-Lundu region (SALCRA, 2021). It is managed by the Sarawak Land Consolidation and Rehabilitation Authority (SALCRA). Bau region's four oil palm estates are Jagoi, Bratak, Undan, and Stenggang. With 10,100 ha and 11% of the total land area in Bau, oil palm plantations are the largest by type of plantation.

The study site is located mainly in the Jagoi part of Bau. This study focused on the Jagoi SALCRA and Bratak SALCRA oil palm plantations. Both areas are mostly planted with oil palm with few patches of forest in the plantation. For each selected oil palm estate

or farm, both the host trees in the forests and the plantation areas are assessed for epiphyte contents.

3.2 Forest and Oil Palm Sampling

For each study site, two forest plots and two plantation plots were established. There were 17 forest plots with different ages (below 25 years, between 25 and 40 years, and over 40 years). For this study, the forest areas which were less than 25 years old categorized as “young forest” while those which were between 25 and 40 years old were categorized as “matured secondary forests”. Forests tracts which older than 40 years were categorized as “old forest”. Every tree meeting the specification along the 10m x 10m specified plots will be sampled. Specifications for trees that were surveyed include trees with ($DBH \geq 5$ cm, and height ≥ 3 m) from the forest floor. For oil palm plantations, there were 17 oil palm plots with different ages (below 10 years, between 10 and 15 years, and over 15 years). The oil palm which was less than 10 years old categorized as “young plantation”, meanwhile those which were between 10 and 15 years old were categorized as “mature plantation” and those over the age of 15 years were categorized as “old plantation”. For oil palm plots, five individual oil palms at 10 m and 100 m distances from the forest edge were also enumerated. Voucher specimens were taken for laboratory identification and records. All epiphytic plants found on trees and palms with diameter greater than 5 cm and height greater than 3 m were enumerated.

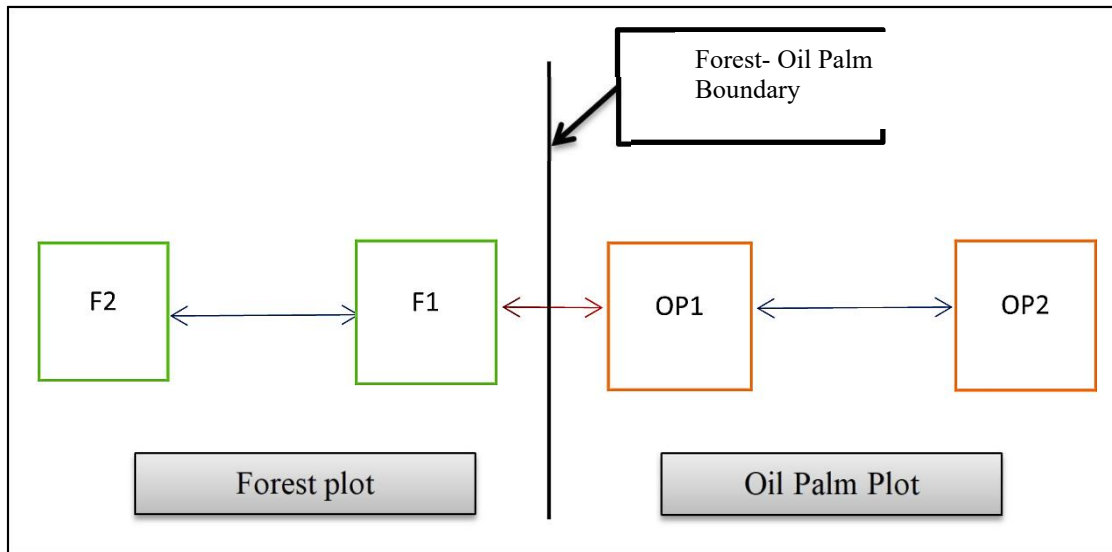


Figure 3.2: Sampling Plots

Where, F2 (Forest 2), 100m from F1 (Forest1)

OP2 (Oil palm 2), 100m from OP1 (Oil palm 1)

Distance from F1 and OP1 is 20m and black line indicates forest-oil palm boundary.

3.3 Sample Identification

Identification of trees and plants on trees were made with the help of IBEC and the Faculty of Resource Science research assistants. First, the trees were marked for easier identification. The trees were immediately tagged to avoid misidentification and to facilitate re-visit afterwards. In some cases, aluminum tags were used. Samples of unidentified epiphytes or tree species were brought to the Sarawak Forest Department herbarium for comparison and identification purposes, as shown in Figure 3.3. After identification, the sample was sewn onto mounting paper, labeled for documentation, and kept in the herbarium for future reference.



Specimen collected (Left),
Herbarium specimen
(Right)

Specimen collected (Left),
Herbarium specimen
(Right)

Figure 3.3: Plant Samples are Compared with Samples from Forest Department Herbarium

3.4 Data Analysis

3.4.1 Descriptive Analysis

Descriptive analysis helps to accurately describe, present, or summarized data points so that patterns that fully meet the needs of the data can emerge. It is a fundamental statistical analysis that includes scatter plots, contingency tables, frequency, dispersion, position, and central tendency measures. In addition, descriptive analysis can help transform raw data into a format that is simple to interpret and presentable, such as data rearrangement, order, and data manipulation. In this study, the total number of species, frequency (total count) of

individuals of each species is calculated. Basic frequency tables are compiled by forest and oil palm samples according to ages and distance from the forest-plantation boundary.

3.4.2 Epiphyte Diversity

One of the objectives of the study is to estimate and compare the diversity of epiphytes in the forest and oil palm environments. The Shannon-Weiner diversity Index is used. The Shannon-Weiner index is described as follows:

In the Shannon index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), $\ln$ is the natural log, Σ is the sum of the calculations, and s is the number of species.

The Shannon-Wiener index is defined as the natural logarithm of the total number of species. A value for evenness approaching zero reflects large differences in abundance of species, whereas an evenness of one means all species are equally abundant:

$$\text{Shannon Index (H)} = -\sum_{i=1}^s p_i \ln p_i$$

The Shannon-Weiner index is an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled.

3.4.3 Comparison of Epiphyte Diversity

Comparison between epiphyte diversity is performed for forest plots of different ages and different sample plots distances from the forest edge. Another comparison is made for diversities of epiphytes in palms of different ages and distances of sample plots from the forest edge in the plantation environment.

The Kruskal-Wallis H test is a rank-based non-parametric test that can determine whether there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. It is also referred to as

the "one-way ANOVA on ranks." It can be considered as an extension of the Mann-Whitney U test that enables comparing more than two independent groups, it is regarded as the non-parametric alternative to the one-way ANOVA.

The test determines whether there is a difference between the medians of two or more groups. As with most statistical tests, test statistics can be calculated and contrasted to a cut-off distribution point. The H statistic is the test statistic applied in this test. The test's hypotheses are as follows:

H0: population medians are equal.

H1: population medians are not equal.

If there is a significant difference between groups, it can be calculated using the Kruskal-Wallis test. However, it does not specify which groups are unique. It can be done using Post Hoc.

3.4.4 Relationship between Epiphyte and Forest Characteristics

A statistical measure of the strength of a relationship between paired data is Spearman's correlation analysis. The strength and direction of the relationship between the two variables are determined by the Spearman's correlation value, which ranges from -1 to +1. A 95-percent confidence level for two-tail analysis is the significance level for this study, which is set at 0.05.

Unlike Pearson's correlation, normality is unnecessary since it is a nonparametric statistic. The Spearman rank correlation is calculated using the following formula:

$$p = 1 - \frac{6 \sum_i^2 d}{n(n^2 - 1)}$$

ρ = Spearman rank correlation

d_i = the difference between the ranks of corresponding variables
 n = number of observations

The assumptions of Spearman correlation require that the scores on one measure be monotonically related to the other variable and that the data be at least ordinal. Table 3.1 shows the strength of the association between the variables, as predicted by Miller (1991).

Table 3.1: Interpretation of the Spearman's Correlation Value

Correlation coefficient r (+/ -) value	Relationship between variables
- 0.20	Little or no relationship
0.20- 0.40	Some slight relationship
0.40- 0.60	Substantial relationship
0.60- 0.80	Strong relationship
0.80- 1.00	High relationship

Source: Miller (1991)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Overview of Results and Discussion Chapter

A study on epiphyte diversity that examines the correlation between age and distance as a factor can provide valuable insights into the dynamics of epiphyte communities. By analyzing the relationship, the study can uncover the patterns in the establishment and growth of the epiphyte population over time. The Kruskal-Wallis test and Spearman's correlation analysis demonstrate that age is a significant determinant of epiphyte diversity. Young oil palm plantations have noticeable difference in epiphyte diversity between plots of different age, but in older, and matured oil palm plantations there appear to be somewhat higher frequency of individuals in each epiphyte species.

Distance as a factor can also provide information on how epiphyte is affected by environmental conditions. However, correlation analysis and the Kruskal-Wallis test show no relationship in epiphytic diversity with the distance of sample plots from the forest-oil palm boundary. This finding may be related to the limitation in the study methodology where the distance of the first sample plot was only 10 meters and second plot was 90 meters from the forest edge. This distance (between the forest edge plot and the second plot) may be insufficient in detecting the difference in the establishment potential of epiphytic plants. In some instances, on the contrary, the mean rank analysis performed indicates a higher diversity of epiphyte in the sample plots further from the forest edge. This may be due to the influence with other factors such as general wind direction, influence of animals and birds as dispersal agents of seeds and spores. Overall, this study better explains the ecological processes that shape the epiphyte communities and informs the conservation management

strategies for epiphyte-rich ecosystems.

4.2 Epiphyte Species Composition in Forest and Oil Palm Plots

4.2.1 Species of Epiphytes by Family on Tree in The Forest

There were 1416 epiphytes individuals identified, comprising 91 species, 60 genera, and originating from 39 different families, as listed in Table 4.1. Among them, the highest group of epiphytes belong to the family Blechnaceae with 220 individuals of *Stenochlaena palustris* species (13.4 %), followed by Fabaceae and Similacaceae with 175 individuals (10.7%) and 172 individuals (10.5%) respectively. Aspleniaceae, which dominantly consists of the ‘Birds nest fern,’ is also recorded as having more than 100 species with 144 individuals (8.8%). Meanwhile, 16 families appeared to be the most frequent, with more than 20 epiphytes individuals in each family. The remaining 23 families seemed less frequent, with fewer than 20 individuals in each family.

Seven epiphytes were recorded over 50 individuals. In addition, there is *Asplenium nidus* (127 individuals), *Stenochlaena palustris* (220 individuals), *Smilax hypoleuca* (88 individuals), *Spatholobus ferrugineus* (62 individuals), *Smilax odoratissima* (57 individuals), *Spatholobus sp.* (55 individuals), and *Morinda umbellata* (52 individuals).

Based on the table below, the most individual epiphytes species were recorded in the mature forest (25-40 years old), followed by young and old forests with 364 and 318 individuals, respectively. Based on distance, forests nearer to the forest edges (10m) have slightly higher epiphyte individuals, with 762 individuals, compared to the forest with a 100m distance from forest edges, with 654 individual epiphyte species. Mature forests have more trees without epiphytes (101 trees), followed by old forests (89 trees) and young forests (36 trees). Based on the distance, 122 trees recorded no epiphytes for plots nearer to forest edges, and 104 trees recorded no epiphytes for plots further from the forest edges.

Table 4.1: Species and Number of Epiphytes on Tree Based on Forest Age and Distance from Forest-Oil Palm Boundary

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<25	25-40	>40	10m	100m	
Apocynaceae	<i>Dischidia</i> sp.	0	2	3	2	3	28 (1.7)
	<i>Hoya coronaria</i>	0	0	1	0	1	
	<i>Hoya</i> spp.	0	0	1	1	0	
	<i>Willughbeia angustifolia</i>	2	15	4	6	15	
Araceae	<i>Alocasia macrorrhizos</i>	0	15	0	15	0	27 (1.6)
	<i>Scindapsus pictus</i>	1	2	1	1	3	
	<i>Scindapsus</i> sp.	0	0	2	1	1	
	<i>Scindapsus treubii</i>	1	3	2	1	5	
Arecaceae	<i>Calamus manan</i>	0	2	2	2	2	28 (1.7)
	<i>Calamus scipionum</i>	0	4	3	0	7	
	<i>Calamus</i> sp.2	1	4	2	5	2	
	<i>Calamus</i> sp.1	0	2	2	0	4	
	<i>Calamus</i> sp.3	0	1	3	1	3	
	<i>Ceratolobus concolor</i>	0	2	0	1	1	
Aspleniaceae	<i>Asplenium nidus</i>	26	75	26	89	38	144 (8.8)
	<i>Asplenium phyllitidis</i>	2	8	2	5	7	
	<i>Asplenium</i> sp.	0	1	4	1	4	
Athyriaceae	<i>Diplazium esculentum</i>	0	7	3	2	8	10 (0.6)
Blechnaceae	<i>Stenochlaena palustris</i>	76	116	28	125	95	220 (13.4)
Connaraceae	<i>Agelaea macrophylla</i>	0	0	1	0	1	47 (2.9)
	<i>Rourea mimosoides</i>	9	17	20	25	21	
Convolvulaceae	<i>Merremia umbellata</i>	22	8	11	23	18	41 (2.5)
Davalliaceae	<i>Davalia denticulata</i>	3	6	0	5	4	9 (0.5)
Dilleniaceae	<i>Tetracera akara</i>	7	13	4	11	13	24 (1.5)

Table 4.1 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<25	25-40	>40	10m	100m	
Dipteridaceae	<i>Dipteris conjugata</i>	2	1	0	1	2	3 (0.2)
Euphorbiaceae	<i>Pimelodendron</i> sp.	0	0	3	2	1	3 (0.2)
Fabaceae	<i>Bauhinia crudiantha</i>	0	1	4	0	5	175 (10.7)
	<i>Bauhinia purpurea</i>	3	4	6	8	5	
	<i>Caesalpinia</i> sp.	5	3	5	4	9	
	<i>Callerya nieuwenhuisii</i>	0	4	2	2	4	
	<i>Centrosema pubescens</i>	0	7	0	0	7	
	<i>Derris trifoliata</i>	8	5	1	8	6	
	<i>Spatholobus ferrugineus</i>	17	24	21	35	27	
	<i>Spatholobus</i> sp.	4	44	7	47	8	
	Flagellariaceae	<i>Flagellaria indica</i>	7	3	0	10	
Gleichenaceae	<i>Dicranopteris linearis</i>	1	12	0	2	11	13 (0.8)
Lamiaceae	<i>Premna cordifolia</i>	1	2	0	2	1	3 (0.2)
Leguminosae	<i>Entada spiralis</i>	2	25	14	28	13	41 (2.5)
Loganiaceae	<i>Strychnos borneensis</i>	0	19	0	12	7	19 (1.2)
Lygodiaceae	<i>Lygodium flexousum</i>	5	0	4	5	4	42 (2.6)
	<i>Lygodium microphyllum</i>	0	4	0	4	0	
	<i>Lygodium</i> sp.	16	12	1	14	15	
Melastomataceae	<i>Clidemia hirta</i>	0	1	0	0	1	13 (0.8)
	<i>Medinilla latericia</i>	2	4	0	4	2	
	<i>Medinilla magnifica</i>	0	0	1	0	1	
	<i>Medinilla</i> sp.1	0	1	2	0	3	
	<i>Medinilla</i> sp.2	0	2	0	1	1	
Menispermaceae	<i>Fibraurea tinctoria</i>	5	3	0	1	7	8 (0.5)

Table 4.1 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<25	25-40	>40	10m	100m	
Moraceae	<i>Ficus benjamina</i>	4	2	1	2	5	36 (2.2)
	<i>Ficus korthalsii</i>	0	3	2	3	2	
	<i>Ficus microcarpa</i>	2	5	0	2	5	
	<i>Ficus</i> sp.1	6	2	0	6	2	
	<i>Ficus</i> sp.2	0	2	0	0	2	
	<i>Ficus tinctoria</i>	1	1	5	5	2	
Myrsinaceae	<i>Embelia</i> spp.	2	15	3	9	11	20 (1.2)
Myrtaceae	<i>Syzygium</i> sp.	0	0	1	1	0	1 (0.1)
Nepenthaceae	<i>Nepenthes ampullaria</i>	3	0	0	2	1	18 (1.1)
	<i>Nepenthes gracilis</i>	10	1	4	11	4	
Nephrolepidaceae	<i>Nephrolepis biserrata</i>	0	0	1	0	1	1 (0.1)
Ochnaceae	<i>Euthemis minor</i>	0	1	0	0	1	1 (0.1)
Ophioglossaceae	<i>Ophioglossum pendulum</i>	0	12	0	8	4	12 (0.7)
Orchidiaceae	<i>Bulbophyllum</i> spp.	1	1	6	1	7	12 (0.7)
	<i>Dendrobium</i> sp.	0	3	1	1	3	
Passifloraceae	<i>Adenia clementis</i>	3	4	3	3	7	17 (1.0)
	<i>Passiflora foetida</i>	0	5	2	3	4	
Piperaceae	<i>Piper betle</i>	0	1	0	1	0	57 (3.5)
	<i>Piper caninum</i>	0	7	0	2	5	
	<i>Piper muricatum</i>	0	3	0	3	0	
	<i>Piper porphyrophyllum</i>	3	26	12	17	24	
	<i>Piper vestitum</i>	0	4	1	4	1	

Table 4.1 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<25	25-40	>40	10m	100m	
Polypodiaceae	<i>Drynaria quercifolia</i>	1	9	5	6	9	41 (2.5)
	<i>Goniophlebium percussum</i>	2	1	0	2	1	
	<i>Microsorium punctatum</i>	1	2	0	2	1	
	<i>Platycterium coronarium</i>	0	6	0	3	3	
	<i>Platycterium wallichii</i>	0	3	2	3	2	
	<i>Pyrossia longifolia</i>	0	5	0	3	2	
	<i>Pyrossia piloselloides</i>	0	1	3	1	3	
Pteridaceae	<i>Vittaria elongata</i>	1	1	0	1	1	5 (0.3)
	<i>Vittaria ensiformis</i>	0	3	0	1	2	
Rhamnaceae	<i>Ziziphus kunstleri</i>	0	0	1	0	1	1 (0.1)
Rubiaceae	<i>Chilocarpus torulus</i>	19	15	2	16	20	97 (5.9)
	<i>Morinda umbellata</i>	0	26	26	24	28	
	<i>Paederia foetida</i>	0	8	0	7	1	
	<i>Uncaria</i> sp.	0	1	0	0	1	
Smilacaceae	<i>Smilax hypoleuca</i>	24	42	22	51	37	172 (10.5)
	<i>Smilax odoratissima</i>	32	8	17	28	29	
	<i>Smilax</i> sp.	14	12	1	9	18	
Thelypteridaceae	<i>Christella parasitica</i>	3	6	0	9	0	10 (0.6)
	<i>Pronephrium asperum</i>	0	0	1	0	1	
Urticaceae	<i>Poikilospermum suaveolens</i>	0	2	0	0	2	2 (0.1)
Vitaceae	<i>Cissus repens</i>	4	1	0	0	5	5 (0.3)
	Total	364	734	318	762	654	1416 (100)
	None	36	101	89	122	104	

4.2.2 Epiphyte Species Composition in Oil Palm Plantation

There were 1365 epiphytes individuals, comprising of 102 species and 72 genera of epiphytes from 50 families, as listed in Table 4.2. Among them, the highest group of epiphytes belong to the family Polypodiaceae (24.6%), Davalliaceae (9.2%), and Arecaceae (8.8%). In addition, five families recorded more than 50 individuals, namely; Acanthaceae, Aspleniaceae, Blechnaceae, Melastomataceae, and Nephrolepidaceae. Meanwhile, the other 42 families recorded less than 50 individuals of epiphytes.

Species with the highest recorded individuals are *Davallia denticulata* (121 individuals), *Elaeis guineensis* (119 individuals), *Pyrossia longifolia* (104 individuals), *Goniophlebium percussum* (104 species), *Nephrolepis radicans* (71 individuals), *Nephrolepis biserrata* (60 individuals), *Asytasia intrusa* (57 individuals), *Stenochlaena palustris* (52 individuals), and *Clidemia hirta* (50 individuals).

With 682 recorded individuals, old palm trees (15 years and older) have the highest concentration of epiphytes. Mature oil palm plantations (10–15 years old) and young oil palm plantations (10 years old) follow with 451 and 232 individuals, respectively.

As for the distance of the oil palm from the forest edges, the number of individuals of epiphytes is similar, with 681 epiphytes individuals in the oil palm nearer to the forest edges (10m) compared to 684 epiphytes individuals further from the forest edges (100m).

Table 4.2: Species and Number of Epiphytes on Oil Palm Trees Based on Age and Distance from Forest-Oil Palm Boundary

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<10	10-15	>15	10m	100m	
Acanthaceae	<i>Asystasia intrusa</i>	11	18	28	23	34	57 (4.2)
Anacardiaceae	<i>Camgnosperma coriacea</i>	0	1	3	1	3	4 (0.3)
Apocynaceae	<i>Chilocarpus torulus</i>	0	0	1	0	1	3 (0.2)
	<i>Hoya coronaria</i>	2	0	0	2	0	
Aquifoliaceae	<i>Ilex cymosa</i>	1	0	0	0	1	5 (0.4)
	<i>Ilex</i> sp.	0	0	4	1	3	
Araceae	<i>Scindapsus treubii</i>	0	1	0	0	1	1 (0.1)
Arecaceae	<i>Calamus</i> sp.	1	0	1	1	1	120 (8.8)
	<i>Elaeis guineensis</i>	25	41	52	57	61	
Asphodelaceae	<i>Dianella ensifolia</i>	2	0	2	1	3	4 (0.3)
Aspleniaceae	<i>Asplenium adiantoides</i>	0	0	4	1	3	74 (5.4)
	<i>Asplenium longissimum</i>	0	1	2	1	2	
	<i>Asplenium nidus</i>	3	25	38	35	31	
	<i>Asplenium</i> sp.	0	1	0	1	0	
Asteraceae	<i>Ageratum conyzoides</i>	6	1	2	3	6	13 (1.0)
	<i>Erechtities Valerianifolia</i>	0	0	1	0	1	
	<i>Mikania micrantha</i>	0	0	3	1	2	
Athyriaceae	<i>Diplazium esculentum</i>	0	3	3	1	5	6 (0.4)
Blechnaceae	<i>Stenochlaena palustris</i>	0	27	25	27	25	52 (3.8)
Calophyllaceae	<i>Calophyllum</i> sp.	1	0	0	1	0	1 (0.1)
Cannabaceae	<i>Trema occidentalis</i>	0	0	2	0	2	2 (0.1)
Costaceae	<i>Costus speciosus</i>	2	0	4	3	3	6 (0.4)
Cucurbitaceae	<i>Momordica charantia</i>	0	0	1	0	1	1 (0.1)

Table 4.2 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<10	10-15	>15	10m	100m	
Davalliaceae	<i>Davallia denticulata</i>	14	41	66	57	64	126 (9.2)
	<i>Davallia heterophylla</i>	0	1	2	1	2	
	<i>Davallia repens</i>	0	1	0	0	1	
	<i>Davallia</i> sp.	1	0	0	1	0	
Dilleniaceae	<i>Dillenia suffruticosa</i>	0	0	13	8	5	13 (1.0)
Dioscoreaceae	<i>Dioscorea hispida</i>	0	1	2	2	1	3 (0.2)
Ebenaceae	<i>Diospyros foxworthyi</i>	0	1	0	0	1	1 (0.1)
Euphorbiaceae	<i>Endospermum diadenum</i>	2	3	1	3	3	26 (1.9)
	<i>Hevea brasiliensis</i>	2	3	3	6	2	
	<i>Macaranga pruinosa</i>	3	2	3	4	4	
	<i>Macaranga</i> sp.	0	0	2	2	0	
	<i>Mallotus paniculatus</i>	0	1	0	1	0	
	<i>Mallotus repandus</i>	1	0	0	0	1	
Fabaceae	<i>Centrosema pubescens</i>	0	7	0	5	2	13 (1.0)
	<i>Derris trifoliata</i>	0	1	2	3	0	
	<i>Ixora</i> sp.	0	1	2	1	2	
Hypericaceae	<i>Cratoxylum arborescens</i>	0	0	1	1	0	2 (0.1)
	<i>Cratoxylum formosum</i>	0	0	1	0	1	
Hypoxidaceae	<i>Curculigo orchoides</i>	0	1	0	1	0	1 (1.0)
Lamiaceae	<i>Calicarpa longifolia</i>	0	1	1	0	2	10 (0.7)
	<i>Premna</i> sp.	1	0	0	1	0	
	<i>Vitex pubescens</i>	2	1	4	2	5	
Lauraceae	<i>Alseodaphne</i> sp.	1	0	0	1	0	7 (0.5)
	<i>Litsea</i> sp.	2	0	4	5	1	

Table 4.2 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<10	10-15	>15	10m	100m	
Lindsaeaceae	<i>Odontosoria chinensis</i>	0	4	5	4	5	9 (0.7)
Loganiaceae	<i>Norrisia maior</i>	2	2	1	2	3	5 (0.4)
Lygodiaceae	<i>Lygodium scandens</i>	6	0	8	9	5	15 (1.1)
	<i>Lygodium</i> sp.	0	1	0	1	0	
Melastomataceae	<i>Clidemia hirta</i>	5	18	27	21	29	79 (5.8)
	<i>Melastoma malabathricum</i>	8	9	12	12	17	
Menispermaceae	<i>Fibraurea tinctoria</i>	0	1	0	1	0	1 (0.1)
Moraceae	<i>Ficus aurata</i>	3	1	3	4	3	47 (3.4)
	<i>Ficus benjamina</i>	2	1	1	1	3	
	<i>Ficus gecharis</i>	0	0	1	1	0	
	<i>Ficus microcarpa</i>	0	0	1	1	0	
	<i>Ficus</i> sp.	0	0	1	0	1	
	<i>Ficus subulata</i>	0	7	0	3	4	
	<i>Ficus tinctoria</i>	6	2	6	7	7	
	<i>Ficus villosa</i>	0	5	7	5	7	
Myrsinaceae	<i>Embelia</i> spp.	1	3	0	2	2	4 (0.3)
Myrtaceae	<i>Syzygium acuminatissima</i>	0	1	0	1	0	6 (0.4)
	<i>Syzygium kunstleri</i>	0	0	1	0	1	
	<i>Syzygium</i> sp.1	1	0	1	1	1	
	<i>Syzygium</i> sp.2	0	0	2	1	1	
Nephrolepidaceae	<i>Nephrolepis biserrata</i>	17	24	19	28	32	119 (8.7)
	<i>Nephrolepis exaltata</i>	0	5	1	2	4	
	<i>Nephrolepis radicans</i>	14	11	46	37	34	
	<i>Nephrolepis</i> sp.	2	0	2	4	0	

Table 4.2 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<10	10-15	>15	10m	100m	
Ophioglossaceae	<i>Ophioglossum pendulum</i>	15	8	13	21	15	36 (2.6)
Orchidaceae	<i>Vanilla pilifera</i>	0	0	1	0	1	1 (0.1)
Phyllanthaceae	<i>Phyllanthus</i> sp.	4	0	0	0	4	4 (0.3)
Piperaceae	<i>Peperomia pellucida</i>	9	5	0	7	7	20 (1.5)
	<i>Piper nigrum</i>	3	0	3	2	4	
Polypodiaceae	<i>Drynaria quercifolia</i>	0	2	0	2	0	336 (24.6)
	<i>Goniophlebium percussum</i>	9	36	59	56	48	
	<i>Microsorium punctatum</i>	6	5	6	9	8	
	<i>Microsorium scolopendria</i>	0	0	2	2	0	
	<i>Phymatocorus scolopendria</i>	3	2	0	5	0	
	<i>Polypodium</i> sp.	0	0	5	4	1	
	<i>Pyrrosia longifolia</i>	11	31	62	55	49	
	<i>Pyrrosia piloselloides</i>	0	2	1	0	3	
	<i>Pyrrosia</i> sp.	0	1	1	2	0	
	Pteridaceae	<i>Adiantum latifolium</i>	2	2	1	3	
<i>Taenitis</i> sp.		2	1	0	0	3	
Rosaceae	<i>Rubus</i> sp.	2	8	0	7	3	10 (0.7)
Rubiaceae	<i>Morinda umbellata</i>	3	0	0	0	3	15 (1.1)
	<i>Paederia foetida</i>	1	1	2	3	1	
	<i>Timonius lasianthoides</i>	0	4	4	5	3	
Saurauiaceae	<i>Saurauia</i> sp.	0	0	1	0	1	1 (0.1)
Smilacaceae	<i>Smilax blumeii</i>	0	2	2	4	0	8 (0.6)
	<i>Smilax myosotiflora</i>	0	0	4	4	0	
Solanaceae	<i>Physalis minima</i>	0	0	1	0	1	1 (0.1)

Table 4.2 Continued

Families	Epiphytes species	Categories					Frequencies (Percentage [%])
		Age			Distance		
		<10	10-15	>15	10m	100m	
Tectariaceae	<i>Tectaria crenata</i>	0	6	3	3	6	11 (0.8)
	<i>Tectaria</i> sp.	2	36	56	48	46	
Theaceae	<i>Eurya acuminata</i>	0	0	1	0	1	1 (0.1)
Urticaceae	<i>Poikilospermum suaveolens</i>	0	0	4	0	4	4 (0.3)
Vitaceae	<i>Leea indica</i>	5	9	9	8	15	23 (1.7)
Vittariaceae	<i>Vittaria elongata</i>	0	8	8	8	8	16 (1.2)
	<i>Vittaria ensiformis</i>	5	2	5	10	2	
	Total	232	451	682	681	684	1365

4.2.3 Discussion of Epiphyte Frequency Based on Forest Characteristics

Based on the current findings, more lianas (climber or woody vines) and hemiepiphytes (*Ficus* or figs) were found on the host trees. Lianas and hemiepiphytes were reported to represent up to 20 to 25 % of the vascular flora (Gentry & Dodson, 1987). Surprisingly, their abundance is quite vast, where up to 85 % of forest trees could support lianas (Putz, 1984; Clark & Clark, 1990; Perez –Salicrup, 1998); while 20 % of forest trees were found to be colonized by hemiepiphytes (Prosperi, 1998).

This is in agreement with the findings by Croat (1978), reporting that 22 % of the forest trees account for lianas, and in the same forest, Todzia (1986) discovered that hemiepiphytes colonized almost 10 % of the forest trees. Following that, *Centrosema pubescens*, commonly known as butterfly pea, is also one of the highest-growing epiphytes in the forest. They are a perennial herb species in Fabaceae family and are best known as climbers (Meijaard et al., 2018).

Next, *Davalia denticulata*, or ‘Rabbit’s foot fern,’ is a widespread species often observed as epiphytes in various forest types (Tsutsumi & Kato, 2008), showing a significant total count of individual epiphytes in the oil palm plots (n=121). Other than that, *Hoya coronaria*, also seemed to grow widely on forest trees and oil palms. They belong to a group of largely epiphytic flowering plants native to Southeast Malaysia and increasingly popular as ornamental plants globally.

A finding by Rahayu et al. (2018) highlighted that *Hoya coronaria* appeared to be the most contributing biomass in the heath forest compared to other *Hoya* species. Likewise, the *Ophioglossum pendulum*, also known as Adder’s tongue Fern or ‘Daun Rambut,’ is a ribbon-like epiphytic fern that grows on damp primary trees throughout tropical Asia

(Zamora & Co, 1986). The remaining species, including the epiphytic pepper plants, flowering plants, rhizomes, ferns, shrubs, and vines, were found within the range of 1 to 3 distributed among the forest trees.

Given the variety of epiphyte species examined in this study, epiphytes are essential sources of biological diversity because they can sprout and grow on host plants to provide structural support and anchorage (Benzing, 1990; Laube & Zotz, 2006). Almost 84 families of vascular plants, or at least 876 genera, have at least one epiphytic species, according to Kress (1989) estimation. There are 29,000 species of epiphytes, accounting for 10% of all vascular plant species worldwide (Gentry & Dodson, 1987).

Holoepiphytes, which spend their entire life cycle in the canopy, and hemiepiphytes, which tend to spend a portion of their lives rooted in terrestrial soil, are two common classifications for epiphytes. Primary hemiepiphytes begin their lives in the canopy and send roots to the ground, whereas secondary hemiepiphytes begin on the ground, grow to the canopy, and lose terrestrial connections (Benzing, 2004). Additionally, epiphytes maintain the interactions and processes that make up the forest ecosystem, which helps to increase species diversity (Cummings et al., 2006; Burns & Zotz, 2010).

Additionally, compared to trees with epiphytes that have been removed, trees with epiphytes tend to have a greater variety and abundance of invertebrate species (Diaz et al., 2012). Tree species significantly impact the distribution of epiphytes, stand age, and dispersal restrictions (Woods, 2013). A host tree species may contain a variety of epiphytes that are distinct from those found in other host tree species (Laube & Zotz, 2006).

These findings imply that the variety of microhabitats found within each host tree may be related to epiphyte diversity (Cardelus & Chazdon, 2005). Indeed, a variety of physical and chemical host characteristics as well as environmental factors, may have an

impact on the epiphyte growth on specific trees (Vanderpoorten et al., 2004). Numerous studies were conducted to determine which epiphyte species preferred each host tree species (Male & Roberts, 2005; Laube & Zotz, 2006).

For example, a total of 126 morphospecies grew epiphytically on a single mature host tree (phorophyte) in Costa Rica, according to a study by Schuettpehlz and Trapnell (2006). Like this, French Guiana recorded 77 species from three phorophyte tree species. Additionally, numerous studies that examined the distribution of epiphytic flora on a single host species and included numerous epiphytic flowering plants from the genera *Smilax*, *Dendrobium*, *Entada*, *Morinda*, *Flagellaria*, and *Derris* concurred with this study (Affeld, 2008; Werner & Gradstein, 2009; Larrea & Werner, 2010).

4.2.3.1 Forest Age

Forest age is one of the prominent factors contributing to the variation in epiphytes density and species richness. Furthermore, the variation in forest structure between young and old forests, including large, old-growth trees, seemed to influence epiphyte community composition (Barthlott et al., 2001). As such, this current study has evaluated the epiphytes species frequency in three different forest ages, including young forest (< 25 years), mature forest (25-40 years), and old forest (> 40 years). As demonstrated in the result, the epiphyte total count was significantly higher in the mature forest ($n = 734$) compared to the young ($n = 364$) and old forest ($n = 318$).

This result was at odds with several studies (Hietz, 1998; Barthlott et al., 2001; Krömer & Gradstein, 2003; Benavides et al., 2006; Cascante-Marin et al., 2006) that reported greater epiphyte density and species richness in “old forest.” Old forest, also referred to as primary forest, has distinctive ecological characteristics and reached a great age (White & Llyod, 1994). Large dead trees still standing, multi-layered canopies, and coarse woody

debris on the forest floor are common features of old-growth forests (Wirth et al., 2009).

However, larger trees are expected to have a greater variety of epiphytes than smaller trees. The majority of the trees in this forest may also be older because it is older than 40 years old (Hilmo & Sastad, 2001; Hyvarinen et al., 1992; Kuusinen, 1996; Johansson et al., 2007). This is another factor contributing to the diversity of epiphytic organisms. For instance, a study by Flores-Palacios and Garcia-Franco (2006) found that the tree's age correlated with an increase in lichen species (epiphytes). Woods (2013) emphasized the influence of stand age and tree species composition on the distribution of epiphytes.

Although old-growth forests contribute to species diversity and richness, there are a few possible reasons for the lower epiphyte density found in the old forest compared to the mature and young forests in this study. First of all, trees tend to grow larger as they age, and their growth usually decreases as they reach maturity, which could have limited the epiphyte growth and density (Thomas, 1996; Koch & Sillet, 2004). In a study by Luskin & Potts (2011) in an oil palm plantation that has reached maturity, a four times significant reduction in the density of ferns and palms was observed, while grasses exhibited a noticeable increase in abundance.

Then, there is a high likelihood that the physical and chemical characteristics of the trees will change over time. These changes may impact the substrate the epiphytes use to grow, reducing density (Lie et al., 2009). This is justified by numerous studies that detail how certain epiphytes favor a particular host species depending on their substrate, chemical makeup, or physical characteristics (Laube & Zotz, 2006).

Also, the old forest could be denser with large trees with reduced gaps, thus limiting the light penetration onto the smaller trees underneath the canopy, which may highly influence the epiphyte growth. For instance, *Ficus* in South-East Asia dipterocarp forests

require high light conditions for their successful establishment (Laman, 1995). Therefore, there is a high likelihood of decreased *Ficus* spp. in the old forest due to the scarcity of light intensity.

According to Turner et al. (1994), 62 % of epiphytes loss was encountered due to massive deforestation in Singapore. Most large trees would be removed during logging operations, affecting the epiphytes requiring larger branches to root. For example, figs (*Ficus* spp.) found abundantly in this study could be declined over several logging cycles towards the larger trees they grow on (Lambert & Marshall, 1991).

Meanwhile, young and mature forests are a simple ecosystem with uniformed aged trees and confined undergrowth. Most young and mature forests are the regeneration product of clear-cut logging practices where some trees are planted. The higher light intensity in both the young and mature forests may be resulting in better epiphyte density and frequency due to the even-aged trees and bigger gaps through the canopy.

Furthermore, young and mature forests were found to contain the most drought tolerant species due to the hotter and drier conditions compared to the damp and shady old forests (Krömer & Gradstein, 2003). In addition, the study's young forest is under 25 years old, meaning that over time, the stems' substratum qualities may become more suited to a broader range of species (Fritz et al., 2008). A slow-growing tree has a more stable bark that could support a variety of epiphytic species, which justifies the higher epiphyte frequency and density in the outcome.

Mixed trees and increased diversity often characterize mature forests. They contain mainly coniferous trees and can reach up to 60 years old. Mostly, mature forests are second-generation forests due to logging and external disturbances such as wind, fire, or disease.

4.2.3.2 Distance of Forest Edges

Apart from the forest age, the distance of forest edges from the oil palm plantation was also evaluated since the study site at Jagoi area is situated near to oil palm plantation. The distance of the forest is categorized as near the forest edge and far (100 m from the forest edge). Most trees around the forest edge coexisted next to the oil palm trees.

Higher epiphytes frequencies in the forest plots were found in trees near to forest- oil palm boundary ($n = 762$) compared to the forest far from the forest edge ($n = 654$). There seemed to exhibit a slight drop in epiphyte frequency on the trees located further from the forest-oil palm boundary compared to near the forest edge. This is because the trees near the forest edge are also closer to oil palm plantations.

However, the significant increase in oil palm cultivation over the previous 20 years through logging and forest conversion resulted in a decrease in forest area (Nomura et al., 2019), which in turn caused a decline in biodiversity and ecosystem services (Barnes et al., 2014; Brühl & Eltz, 2010). Besides, oil palm plantations are also rich in vascular epiphytes, mostly weeds (Ginting et al., 2004)

These weeds are a vital resource and habitat for numerous creatures and microorganisms, which later proved to be a pest for oil palm trees (Cruz-Angón et al., 2009). According to Franklin et al. (2021), the findings indicate that greater amounts of solar radiation and wind velocity can promote seed scattering towards the boundary between the forest and oil palm areas, potentially leading to a rise in the number of species present in that boundary region. This could explain why trees near to the forest-oil palm plantation boundary have a higher epiphyte frequency than the plots further from the forest edge.

As for the oil palm plantation plots, the result shows that the epiphytes frequency in plots further from the forest-oil palm boundary is slightly higher ($n = 684$) compared to the

plots near to the forest edge ($n = 681$) . The results shown not much of a difference between the frequency of the epiphytes on oil palm plantations, both on plot near and further from the forest-oil palm boundary. When considered as a whole, oil palm

4.3.1 Comparison of Epiphyte Diversity and Frequency Based on Age and Distance in Forest and Oil Palm Plantation

The Kruskal-Wallis test was used to compare the medians of two or more groups for the number and frequency of epiphytes in oil palm plantations and forest edges according to age and distance factors. It is frequently used when the group variance is uneven, or the data is not normally distributed.

But regardless of the underlying distribution of the data, the Kruskal-Wallis test was employed in this study to determine whether there is a significant difference in the median diversity of epiphytes between age and distance. The test is also resistant to outliers, which are frequent in ecological data (Benhadi-Marin, 2018).

4.3.2 Comparison of Epiphyte Diversity and Total Count of Epiphytes Based on Age

The diversity of the epiphytes is compared for plots of different ages for both the forest and oil palm plantation. The Kruskal-Wallis test indicate there is a statistically significant relationship between the two variables. Table 4.3 shows that at a p-value of 0.05, the number of species and total counts of epiphytes at the forest and oil palm plantation are statistically significant with age. The diversity of epiphytes in oil palm plantation plots is also significantly different with age ($p = 0.046$). As a result, the null hypothesis—according to which there is no association between the two variables—is rejected.

Table 4.3: The Kruskal-Wallis's Test Result Between Epiphyte Diversity and Density(Total Count) Against Age in The Forest and Oil Palm Plantation

Variables		Age	
Diversity	Forest	Chi-square	1.227
		df	2
		Sig (p-value)	0.541
	Oil palm plantation	Chi-square	6.165
		df	2
		Sig (p-value)	0.046
Number of species	Forest	Chi-square	15.82
		df	2
		Sig (p-value)	0.000
	Oil palm plantation	Chi-square	11.60
		df	2
		Sig (p-value)	0.003
Total count of epiphytes	Forest	Chi-square	26.82
		df	2
		Sig (p-value)	0.000
	Oil palm plantation	Chi-square	12.05
		df	2
		Sig (p-value)	0.002

*Correlation is significant at p-value < 0.05

According to Table 4.4, the mean rank for forest age is highest for young forest age less than 25 years old for the number of species and total count of epiphytes. The mean for the number of species is 479.18, and for the total count of epiphytes is 485.15.

Table 4.4: The Mean Rank Value Between Epiphyte Diversity and Total Count of Epiphytes Based on Age in Forest and Oil Palm Plantation

Categories		Diversity				Number of species				Total count of epiphytes			
		Forest		Oil palm plantation		Forest		Oil palm plantation		Forest		Oil palm plantation	
		N	Mean rank	N	Mean rank	N	Meanrank	N	Mean rank	N	Meanrank	N	Meanrank
Age*	Young	10	14.60	6	23.50	197	479.18	30	58.80	197	485.15	30	72.83
	Mature	16	18.94	10	20.95	417	443.98	50	86.08	417	451.67	50	105.34
	Old	8	18.25	18	13.58	257	389.95	90	94.08	257	372.90	90	78.70

*For forest age - Young (<25 years old), Mature (25-40 years old), Old (>40 years old)

For oil palm plantation age - Young (<10 years old), Mature (10-15 years old), Old (>15 years old)

The older oil palm plantation, which is older than 15 years, has the highest mean rank (mean rank = 94.08) for the number of species. The next one is the total count of epiphytes in an oil palm plantation, where the mature plantation with oil palms aged between 10 and 15 years has the highest mean rank (mean rank = 105.34).

4.3.3 Comparison of Epiphyte Diversity and Total Count of Epiphytes Based on Distance

Epiphyte diversity and total count of epiphytes are also compared for plots with different distances from the forest edge.

Table 4.5: The Kruskal-Wallis's Test Result Between Epiphyte Diversity and Density (Total Count) Against Distance of The Forest and Oil Palm Plantation to The Forest-Oil Palm Boundaries

Variables			Distance
Diversity	Forest	Chi-square	0.578
		df	1
		Sig (p-value)	0.447
	Oil palm plantation	Chi-square	0.050
		df	1
		Sig (p-value)	0.823
Number of species	Forest	Chi-square	0.495
		df	1
		Sig (p-value)	0.482
	Oil palm plantation	Chi-square	0.074
		df	1
		Sig (p-value)	0.786
Total count of epiphytes	Forest	Chi-square	0.059
		df	1
		Sig (p-value)	0.808
	Oil palm plantation	Chi-square	0.172
		df	1
		Sig (p-value)	0.678

*Correlation is significant at p-value < 0.05

The outcome of the Kruskal-Wallis' tests demonstrate no statistically significant ($p > 0.05$) relationship between the diversity, number of species and total count of epiphytes in forest and oil palm plantation with the distance from the forest-oil palm boundary. Therefore, the null hypothesis that says there is no significant relationship between the diversity of the forest and oil palm with the distance is accepted. This result thus seems to

suggest that the occurrence of epiphytes is similar throughout the whole plantation regardless of the distance of host plants from the forest-oil palm plantation boundary.

Although the Kruskal-Wallis test shows no significant relationship between the diversity, number of species and total count of epiphytes in forest and oil palm plantations with the distance of host plants from the forest-oil palm plantation boundary, the mean rank value analysis is still carried out as in Table 4.6.

Table 4.6: The Mean Rank Value Between Epiphyte Diversity and Total Count of Epiphytes Based on Distance of Host Plants from The Forest-Oil Palm Plantation Boundary

		Diversity				Number of species				Total count of epiphytes			
		Forest		Oil palm plantation		Forest		Oil palm plantation		Forest		Oil palm plantation	
		N	Mean rank	N	Mean rank	N	Mean rank	N	Mean rank	N	Mean rank	N	Mean rank
Distance	10 m	17	18.88	17	17.88	465	430.57	85	84.48	465	437.88	85	83.95
	100 m	17	16.12	17	17.12	406	442.22	85	86.52	406	433.85	85	87.05

According to Table 4.6, the mean number of epiphyte species on the forest edge is higher when it is further from the forest edge, which is 100 meters into the forest because the forest interior plots are often more stable and less disturbed than the plots near to the forest- oil palm boundary. The forest plots closer to the forest edge (forest-plantation boundary) which are subjected to physical disturbances, are more open and less humid rendering it relatively unfavorable for epiphyte colonization.

Additionally, the forest interior has a much more diverse range of host plants for epiphytes to grow and a more complex structure with different canopy layers providing a more comprehensive range of microclimates and resources of epiphytes. Crown structural complexity promotes the development of vascular epiphytes with sufficient moisture availability (Sillett et al., 2022). This could lead to higher species diversity of epiphytes inside the forest than near the forest-oil palm boundary.

However, the mean rank total count of epiphytes is higher in the forest interior than in the plot near the forest-oil palm boundary. The species frequency is higher at the forest-oil palm boundary than at the forest interior plots because the forest-oil palm boundary is a transition zone between the forest and the surrounding habitat. Therefore, it often has more light and less shade than the forest interior.

This increased light can benefit some epiphyte species, allowing them to establish and reproduce more efficiently. This is similar to a study by Williams-Linera (1990) in which she found that floristic composition was unchanged along transects from the forest boundaries to the interior of forests, and light-demanding species are not abundant in the forest interior compared to the plot near the forest-oil palm boundary. In addition, tree density and basal area were twice as high at the forest-oil palm boundary compared to the forest interior, where the boundaries were created five to twelve years earlier. For the oil

palm plantation, the mean rank is highest in the plot 100 meters into the oil palm plantation for both the number of species and total count of epiphytes. This is because the further the site into the oil palm plantation, the more complex its structure and microhabitat. An oil palm plantation is a monoculture, less disturbed and more stable inside the plantation, allowing for better epiphytes' survival and reproduction.

4.3.4 Discussion of Epiphyte Diversity and Total Count of Epiphytes on Forest Characteristics

Because the older forest age has a more consistent microclimate than the younger forest age, the significant relationship between the variables can be explained (Davies- Colley et al., 2000). In addition, the older forest age provides a habitable area for epiphytes (Renhorn et al., 1996). For example, established forest canopies can provide more shade and a stable microclimate resulting in diverse epiphyte communities than younger ones.

This is due to the strong reduction in wind and direct sunlight below canopies, which dampens variations in temperature and humidity (De Frenne et al., 2021). The substrate availability, which is the mature trees at the edge of an old forest, is another factor in addition to the one already mentioned. This is because lichens' dispersed seeds, spores, and soredia need a suitable substrate to grow and colonize (Bartels & Chen, 2012).

A few different variables influence this relationship. According to Böhnert et al. (2016), the low epiphyte diversity in young plantations may be caused by farm workers occasionally removing epiphytes because they typically believe that epiphytes lower yields by parasitizing the trees. However, unless the epiphyte cover gets so dense that it competes with trees for light, the risk of epiphytes damaging trees is minimal. The microclimate influence is another factor cited by the same study; it is well-known that young plantations have hotter and less humid climates, which may lessen the diversity of epiphytes.

The high mean number of species and total count of epiphytes in the young forest

age is due to the increased light penetration, higher humidity, and lower wind exposure in this area (Löbel et al., 2012). In addition, because of the young area, there is less competition from other plants, allowing epiphytes to establish and thrive (Magrach et al., 2014). According to Köster et al. (2009), it is possible that young forest ages are less disturbed, allowing for greater epiphyte diversity. At the same time, mature and old forest ages may have been subjected to more human activities, such as logging or development, disrupting the habitat's microclimate and decreasing the epiphyte diversity.

Böhnert et al., 2016 explained that epiphyte diversity increases with the oil palm age. This is because epiphytes had more time to colonize and develop diverse communities in the older plantation. However, oil palms have higher epiphyte diversity than other monocultures like rubberwood (Rembold et al., 2017). This is due to the peculiar surface of oil palm stems and the fact that cut oil palm leaves typically remain affixed to the trunk or are left on the ground for slow decomposition. As a result, an environment is created rich in organic material, supplies nutrients, and holds water. These encourage the growth of dense epiphytic vegetation, made up of a few dominant epiphytic fern species and weeds that accidentally become epiphytes on land.

Mature oil palm plantations have had more time to establish themselves than young oil palm plantations, allowing more epiphyte species to colonize the area. In addition, epiphytes are slow-growing organisms (Schmidt & Zotz, 2002). Besides that, mature oil palm trees have grown to reach their full potential and are the most productive at this age, and the epiphyte that grows surrounding the oil palm plant is no longer removed. Additionally, as it is stable and less disturbed, it allows for better survival and reproduction of epiphytes. They have more complex structures with a greater variety of microhabitats. This complexity provides epiphytes with more space, light, and nutrients (Matelson et al.,

1993).

While for the older oil palm plantation, the mean total count of epiphytes decrease may be because of the dead or dying trees at a later age, causing a disturbance and leading to a less stable environment for epiphytes (Esseen et al., 1997). In addition, the yield of oil palm increases with age for seven or eight years and then decreases (McMorrow, 2001). As the yield decreased, the oil palm trees started to get removed for new plant cycles. Therefore, there is a low frequency of epiphyte in older oil palm plantations above 15 years of age.

This may be because the distance between the two plots for the forest-oil palm boundary and forest interior is only 90 meters apart. Therefore, the methodology needed to be more adequate to detect a significant relationship between distance and epiphyte diversity.

4.4 Relationship of Epiphyte Diversity and Frequency with Age and Distance in Forest and Oil Palm Plantation

4.4.1 Correlation of Epiphyte Diversity and Total Count of Epiphytes with Age

According to Table 4.7, the sample size for the forest is 871 and for oil palm plantation is 170. This shows that the forest is more diverse in terms of epiphytes occurrence.

Table 4.7: The Correlation Between Epiphyte Diversity and Frequency Based on Age in Forest and Oil Palm Plantation

Variables			Age
Diversity	Forest	Correlation efficient	0.148
		Sig (p-value)	0.403
		N	34
	Oil palm plantation	Correlation efficient	-0.430
		Sig (p-value)	0.011*
		N	34
Number of species	Forest	Correlation efficient	-0.08
		Sig (p-value)	0.01*
		N	871
	Oil palm plantation	Correlation efficient	0.22
		Sig (p-value)	0.00*
		N	170
Total count of epiphytes	Forest	Correlation efficient	-0.14
		Sig (p-value)	0.00*
		N	871
	Oil palm plantation	Correlation efficient	-0.04
		Sig (p-value)	0.57
		N	170
*Correlation is significant at p-value < 0.05			

The diversity of the epiphytes is significantly correlated with the age of the oil palm plantation with p-value of 0.01. The number of species and total count of epiphyte are significantly correlated with age in the forest, with p-values of 0.01 and 0.00, respectively. This is because species diversity and richness usually increase with age and are identical to epiphytes.

For the correlation coefficient, the number of species has low or no correlation with age, with a negative correlation of -0.08. This means that when the age of the forest increases, the number of species decreases. Furthermore, the correlation coefficient for the total count of epiphytes and the age of the forest shows the same trend of low or no correlation with the value of -0.14. This indicates that as the age of the forest increases, species frequency decreases.

Only the number of species significantly correlates with age for the oil palm

plantation site, with a correlation value of $r(170) = 0.22$, $p = 0.00$. On the other hand, the number of species has a correlation coefficient of 0.22 in the oil palm plantation site with the age factor, which denotes a tenuous relationship. This indicates that as a site gets older, more species appear. However, the total count of epiphytes is -0.04 regarding age, which shows little or no relationship.

4.4.2 Correlation of Epiphyte Diversity and Total Count of Epiphytes with Distance

Additionally, a correlation analysis was done to determine how far an oil palm plantation and the distance to the forest-oil palm boundary affected the number of species and total count of epiphytes. Table 4.8 contains the information needed for the analysis.

Table 4.8: The Correlation Between Epiphyte Diversity and Frequency Based on Distance in Forest and Oil Palm Plantation

Variables			Distance
Diversity	Forest	Correlation efficient Sig (p-value) N	-0.141 0.427 34
	Oil palm plantation	Correlation efficient Sig (p-value) N	-0.039 0.827 34
Number of species	Forest	Correlation efficient Sig (p-value) N	0.02 0.48 871
	Oil palm plantation	Correlation efficient Sig (p-value) N	0.02 0.79 170
Total count of epiphytes	Forest	Correlation efficient Sig (p-value) N	-0.00 0.81 871
	Oil palm plantation	Correlation efficient Sig (p-value) N	0.03 0.68 170

*Correlation is significant at $p\text{-value} < 0.05$

No relationship between the quantity and total count of epiphytes from the forest and distance is shown in Table 4.8. There is also no relationship between the diversity of the epiphytes with the forest and oil palm plantation distance. The result of the correlation coefficient, for the forest, there is little or no correlation between the number of species and the distance, with a value of 0.02. While for species frequency, the correlation coefficient is -0.00, meaning little negative or no correlation. This means that the number of species increases when the distance increases, but their frequency is reduced.

In contrast, the correlation coefficient for the oil palm plantation is 0.02 for the number of species and 0.03 for the total count of epiphytes with distance. This can be interpreted as the number of species and total count of epiphytes having little or no correlation with distance. However, as the distance increase, the number of species and total count of epiphytes increase by a tad.

4.4.3 Discussion of Epiphyte Diversity and Total Count of Epiphytes Relationship with Age and Distance

This study investigated two factors affecting the epiphyte distribution: age and distance. The correlation between the two factors is monitored with the number of species and total count of epiphytes in two locations: forest and oil palm plantation. The correlation analysis between epiphyte diversity and age and distance can provide insights into the relationship between epiphyte diversity and environmental factors that affect their growth. Furthermore, by understanding the correlation between them, scientists can better understand the ecological processes that shape epiphyte communities and how they respond to different environmental factors.

Additionally, this analysis can help identify key growth factors essential for promoting epiphyte diversity and can help with conservation and management strategies to protect and produce epiphyte-rich ecosystems. Table 4.7 displays the relationship between age-based epiphyte frequency and diversity in oil palm plantations and forests. Table 4.7 shows no correlation between the number of species and the total count of epiphytes from the forest with the distance.

This is similar to a study by Aragón et al. (2015), which found no significant differences in distance to the forest-oil palm boundary. However, they found that the case is higher when there is no forest continuity as the surrounding matrix. In addition, there are significant differences in epiphytic composition between three distances (south-pine, north-shrub, and south-shrub). In the current study, however, the distance between the plots is not far from each other. Thus, there is no significant correlation between distance, and number of species and total count of epiphytes.

There is also no correlation between the distance, number of species and total count of epiphytes the same in the oil palm plantation. This is similar to a study by Madison (1979) which found that 25 species of epiphytes were present in the plot. However, they were randomly distributed throughout the area. Some species like *Myrmecodia tuberculosa* Jack have significantly contagious distribution, but species like Asclepiadaceae have clumped distribution in the rubberwood plantation.

Regarding the correlation coefficient, for the forest, there is little or no correlation between the number of species and the distance, with a value of 0.02. While for species frequency, the correlation coefficient is -0.00, meaning little negative or no correlation. This means that the number of species increases when the distance increases, but their frequency is reduced. Esseen (2006) also found that species are dramatically reduced in the forest

adjoining open wetlands. At the same time, Aragón et al. (2015) suggest that irradiance strongly modulates epiphytic response. The total count of epiphytes is high near the forest because of the high growth of light-demanding species. However, as the distance increase toward the forest interior, their frequency decrease, and they have been replaced with shaded species. That is why the number of species increases as the distance increase.

While for the oil palm plantation, the correlation coefficient between the numbers of species with distance is 0.02 and between the total count of epiphytes and distance is 0.03. This can be interpreted as the number of species and total count of epiphytes having little or no correlation with distance. However, as the distance increase, the number of species and total count of epiphytes increase by a tad. In a study by Madison (1979), she explains that the colonization of rubber trees by an epiphyte species is significantly dependent on colonization by other species. Therefore, a tree with an epiphyte species is much more likely to be colonized by additional epiphyte species than unoccupied trees. Therefore, the epiphytes grow from one species to another regardless of distance.

Franklin et al. (2021) explain that the results show that higher levels of solar radiation and wind speed, which may encourage seed dispersal to the forest-oil palm boundary, may cause increased species diversity at the forest-oil palm boundary. The epiphytes that can grow on the edge of the forest are also typically present inside the forest.

While for the oil palm plantation, the sample size is smaller because of the monoculture of the site, thus decreasing the epiphytes diversity. This is similar to a study by Boelter et al. (2011), which discovered that even mature plantation sites had low epiphyte richness due to low phorophyte diversity and size heterogeneity in *Araucaria* forests. Moreover, less than one-third of epiphyte species in the forest can be found in *Araucaria* forest.

Woods and Dewalt (2013) found that a 115-year-old secondary forest is 49 percent similar in epiphytes in old-growth forests, which is similar to the current result of a significant correlation for the forest between the number of species and total count of epiphytes with age. However, with a much lower occurrence of epiphytes, this value is higher than another secondary forest area that is 35 years old.

Dittrich et al. (2013) also discovered a weak or nonexistent relationship between species diversity and age, concluding that the diversity and cover of epiphytes on living and dead trees are not at their lowest during the initial stages of forest development or regeneration. This is because there are abundant standing dead trees during the regeneration stage, which can be the habitat for the epiphyte. While during the second stage, known as the initial stage, most standing dead trees are collapsed and thus no longer provide habitat for the epiphytes. It is the same during the climax stage, where most collapsed dead trunks are now mostly decomposed, thus further decreasing the epiphytes' diversity.

One possible explanation for these circumstances is that converting forests into plantations dramatically changes the area's microclimate. Therefore, it takes time for the region to recover its microclimate and for the epiphyte species to grow. In addition, epiphytes are well known for their slow growth, and it may take up to a decade for the first reproduction of epiphytes after deforestation (Köster et al., 2009; Einzmann & Zotz, 2016).

Growth rates and habitat suitability determine the process of epiphyte establishment. Establishment limitation is the inability of epiphytes to colonize or establish a new stand. Biotic factors like competition and specificity may be responsible for establishing limitations (Bartels & Chen, 2012).

Luskin and Potts (2011) found that the older plantation had a disproportionately higher number of buffered microclimates than the younger plantation. This is desirable for

the growth of epiphytes and as more epiphyte species grow in the old plantation. However, it takes time for them to reproduce and increase their frequency. Therefore, the frequency of epiphytes is not significant with age.

According to a study by Luskin and Potts (2011), who discovered that total epiphytes abundance is significantly higher in older plantations due to significantly greater trunk surface area, the correlation between the coefficient in the oil palm plantation site with the age factor in this study was similar to that finding.

Luskin and Potts (2011) also discovered that there was either little or no correlation between the frequency of a species and age. They discovered that while grasses are abundant, the density of ferns and palms has decreased by a factor of four. At the same time, there were no differences between young and old plantations in leafy or climbing epiphytes. In a subsequent study by Koh (2008), understories from a Borneo plantation demonstrated a similar declining trend for epiphyte density with plantation age, with 1.29% less epiphyte cover annually.

Additionally, because of changes in canopy cover, radiation, temperature, and humidity brought on by the clear-cutting of forests make way for plantations. According to Böhnert et al. (2016), there is no correlation between the frequencies of epiphytes in different ages of oil palm plantations.

Epiphytes are highly vulnerable to deforestation, and it takes up to a decade for the first reproduction of epiphytes because they are slow-growing (Köster et al., 2009; Einzmann & Zotz, 2016). Therefore, it takes longer for the epiphytes to recover after an area is cleared for plantation, and since oil palm plantations are roughly the same age, there is no correlation between the two factors.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Overview of Conclusion and Recommendations Chapter

This chapter concludes the results based on the objectives and the hypothesis stated in the study. Suggestions for continuing research on this topic in the future are also included.

5.2 Conclusions

Overall, a total of 1416 epiphytes individuals from 39 families from 17 forest plots and a total of 1365 epiphytes individuals from 51 families on 17 oil palm plots around the Jagoi area was documented. The most dominant epiphytes families on the tree belong to Blechnaceae, Fabaceae, and Similacaceae. Meanwhile, the dominant epiphytes families on oil palm belong to Polypodiaceae, Davalliaceae, and Arecaceae.

As shown by the results for forest age, the young forest had an average epiphyte density that was substantially greater than the mature and old forests. As for the distance of the tree from the forest-oil palm boundary, the epiphyte density rose considerably from the young forest closer to the forest boundary than those positioned further in the center of the forest. In contrast, the mature and old trees appeared to have a little lower density of epiphytes when they were farther from the forest boundary than when they were closer. In comparison to nearby trees, trees located farther from the forest boundary contained more species of epiphytes.

Additionally, the findings indicated a significant correlation between age and the number of species and the total count of epiphytes in oil palm. The null hypothesis of no correlation between age and the quantity and frequency of epiphyte species in oil palm plantations, is then rejected. For the number of species and total count of epiphytes, young

forestage (< 25 years old) have the highest mean rank. The old oil palm plantation, which is older than 15 years, has the highest mean rank for the variety of species.

The outcome demonstrates that there is no statistically significant variation in the frequency and variety of epiphyte species in forest. The null hypothesis, therefore, asserts that there is no valid correlation between the two variables. For the forest, there is a considerable relationship between the number of species and the total count of epiphytes and age. For the correlation coefficient, the number of species has little to no association with age. Additionally, the correlation coefficient for species frequency and forest age exhibits a similar trend of little or no association. This indicates that as the age of the forest increases, species frequency decreases.

Only the number of species is substantially correlated with age for the oil palm plantation site. The number of species in the oil palm plantation correlates with the site with the age factor, which denotes a weak association. This indicates that as oil palm age gets older, more species appear. There is no relationship between distance and the number of species and the total count of epiphytes along the forest border. The correlation coefficient for the forest shows that there is little to no association between the variety of species and the distance. In contrast, the correlation coefficient for species indicates a negligibly small or nonexistent correlation. This translates to an increase in species number but a decrease in frequency as distance increases.

In comparison, the correlation coefficient for the oil palm plantation indicates that there is little to no link between species diversity and geographic distance. The number of species and total count of epiphytes do, however, slightly increase with increasing distance. Both epiphytes on trees and oil palms show a variety of species and families. Epiphytes such as *Asplenium nidus*, *Stenochlaena palustris*, and *Ophioglossum pendulum* show a

significant number on both the forest trees and oil palm trees. These epiphytes show high adaptability abilities as they can thrive both under the forest and oil palm canopy cover.

As Malaysia is a mega biodiversity country, it is important to do a study focusing on the forest and oil palm ecosystem, not only on trees but on other components of the forest such as epiphytes can be done. As epiphytes are part of the ecosystem, it contributes to species richness and diversity in an area and is important for a balanced ecological community.

5.3 Recommendations

There is not much research that studies epiphytes. A limited study is available, while epiphytes comprise 10% of the flora. Epiphytes are an essential indicator of a healthy forest, this means more studies should be done on epiphytes.

In this study, the data were analyzed using the Kruskal-Wallis and correlations coefficient, and further research is needed, including using regression to analyze and prove the data's accuracy. Since the study was done around Bau, mainly the Jagoi area, the subsequent research can be expanded throughout Sarawak with a bigger plot size. Given the prospects, epiphyte diversity can be assessed by comparing the soil type, such as the epiphytes on oil palms in both peat and mineral soil. The diversity of epiphytes can also be compared between the types of forest, such as mixed dipterocarp, kerangas, and peat swamp.

Based on this study, a comparison of epiphytes on trees and oil palms was made. However, it is necessary to examine other indicators, which include changing the types of the plantation, such as studying the epiphytes diversity in rubber plantations and comparing them to the epiphytes in the forest. Furthermore, since the focus of this study is on the age of the forest and the distance of the plot from its edges, it is necessary to look at other parameters, with a particular emphasis on the differences in epiphyte diversity based on the

diameter at breast height (DBH) with the height of the trees or oil palms. Instead of the diversity of epiphytes in this study, the subsequent research can be more specific than the general epiphytes. The species should be more specific such as orchids and lianas. The diversity of the epiphytes can also be compared by comparing the diversity of epiphytes based on the species. Therefore, it is hoped that information from this study will be used in future institutional or informal research and development.

Together, this study's findings demonstrated the significant differences between the habitat preferences of epiphytes in an oil palm plantation and a rain forest. As a result of the canopy's extreme complexity, the tropical rainforest is characterized by higher species diversity, including some rare species, in contrast to oil palm plantations, which seem to limit species to specific viable niches within their diverse epiphyte habits. Furthermore, the diversity of epiphytes associated with forest age and distance from an oil palm setting had never been surveyed in Sarawak before this study.

However, this study is restricted to several plots of the forest, which could limit the generalization of this investigation. Hence, more comprehensive documentation of epiphyte diversity on host trees within natural ranges is required to understand how the epiphyte/ host interactions in forest and oil palm landscapes are established and preserved. Also, an in-depth investigation could be imposed on the microclimate conditions of the forest that could influence the epiphytes' diversity and the management of oil palm plantations to avoid loss of epiphytes unless they are interfering with production.

REFERENCES

- Abella, S. R. (2010). Disturbance and plant succession in the Mojave and Sonoran Deserts of the American Southwest. *International Journal of Environmental Research and Public Health*, 7(4), 1248-1284. <https://doi.org/10.3390/ijerph7041248>
- Affeld, K. (2008). *Spatial complexity and microclimatic responses of epiphyte communities and their invertebrate fauna in the canopy of northern rata (Metrosideros robusta A. Cunn.: Myrtaceae) on the West Coast of the South Island, New Zealand* (Doctoral dissertation, Lincoln University).
- Aragón, G., Abuja, L., Belinchón, R., & Martínez, I. (2015). Edge type determines the intensity of forest edge effect on epiphytic communities. *European Journal of Forest Research*, 134(3), 443-451.
- Barkman, J. J. (1958). Phytosociology and ecology of cryptogamic epiphytes. Assen, Netherlands van Gorcum Co N.
- Barnes, A. D., Jochum, M., Mumme, S., Haneda, N. F., Farajallah, A., Widarto, T. H., & Brose, U. (2014). Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning. *Nature Communications*, 5(1), 5351. <https://doi.org/10.1038/ncomms6351>
- Bartels, S. F., & Chen, H. Y. H. (2012). *Mechanisms Regulating Epiphytic Plant Diversity. Critical Reviews in Plant Sciences*, 31(5), 391-400. doi:10.1080/07352689.2012.680349
- 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. <https://doi.org/10.1023/A:1011483901452>

- Bau District Office. (2022). List of villages and village chiefs for Bau District year 2022 (Senarai kampung dan ketua kaum bagi daerah Bau Tahun 2022). Bau, Sarawak, Malaysia.
- Beaman, J. H. (2007). *Ferns of Kinabalu: an introduction*. Kota Kinabalu: Natural History Publications (Borneo), 2007.
- Begon, M., Townsend, C. R., Harper, J. L. (2006) Ecology “from individuals to ecosystems”. 4th ed. Malden (MA): Blackwell, p. 738.
- Benavides, A. M., Wolf, J. H., & Duivenvoorden, J. F. (2006). Recovery and succession of epiphytes in upper Amazonian fallows. *Journal of Tropical Ecology*, 22(6), 705-717. <https://doi.org/10.1017/S0266467406003580>
- Benhadi-Marín, J. (2018). A conceptual framework to deal with outliers in ecology. *Biodiversity and Conservation*, 27(12), 3295-3300.
- Benzing, D. H. (1990). Vascular epiphytes. Cambridge, Cambridge University Press.
- Benzing D.H. (2004). Vascular epiphytes. In: Lowman MD, Rinker HB eds. Forest canopies. 2nd edition. London, Elsevier Academic Press. Pp. 175–211
- Boelter, C. R., Zartman, C. E., & Fonseca, C. R. (2011). Exotic tree monocultures play a limited role in conserving Atlantic Forest epiphytes. *Biodiversity and Conservation*, 20(6), 1255-1272.
- Böhnert, T., Wenzel, A., Altenhövel, C., Beeretz, L., Tjitrosoedirdjo, S. S., Meijide, A., ... & Kreft, H. (2016). Effects of land-use change on vascular epiphyte diversity in Sumatra (Indonesia). *Biological Conservation*, 202, 20-29.
- Brühl, C. A., & Eltz, T. (2010). Fuelling the biodiversity crisis: Species loss of ground-dwelling forest ants in oil palm plantations in Sabah, Malaysia (Borneo). *Biodiversity and Conservation*, 19, 519-529. <https://doi.org/10.1007/s10531-009-9596-4>

- Burns, K. C., & Zotz, G. (2010). A hierarchical framework for investigating epiphyte assemblages: networks, meta-communities, and scale. *Ecology*, 91(2), 377-385. <https://doi.org/10.1890/08-2004.1>
- Callaway, R. M., Reinhart, K. O., Moore, G. W., Moore, D. J., & Pennings, S. C. (2002). Epiphyte host preferences and host traits: Mechanisms for species-specific interactions. *Oecologia*, 132, 221-230. <https://doi.org/10.1007/s00442-002-0943-3>
- Cardelus, C. L., and Chazdon, R. L. (2005). Inner-crown microenvironments of two emergent tree species in a lowland wet forest. *Biotropica* 37: 238–244.
- Cascante-Marín, A., Wolf, J. H., Oostermeijer, J. G. B., Den Nijs, J. C. M., Sanahuja, O., & Durán-Apuy, A. (2006). Epiphytic bromeliad communities in secondary and mature forest in a tropical premontane area. *Basic and Applied Ecology*, 7(6), 520- 532. <https://doi.org/10.1016/j.baae.2005.10.005>
- Chin, W. Y. (1992). A guide to ferns of Singapore. 3rd edition. Singapore Science Centre.
- Clark, D. B., & Clark, D. A. (1990). Distribution and effects on tree growth of lianas and woody hemiepiphytes in a Costa Rican tropical wet forest. *Journal of Tropical Ecology*, 6(3), 321-331. <https://doi.org/10.1017/S0266467400004570>
- Clarke, M. A., & Walsh, R. P. D. (2006). Long-term erosion and surface roughness change of rain-forest terrain following selective logging, Danum Valley, Sabah, Malaysia. *Catena*, 68(2-3), 109-123. <https://doi.org/10.1016/j.catena.2006.04.002>
- Colchester, M., Pang, W., Wong, M. C., & Jalong, T. (2007). Land is Life Land Rights and Oil Palm Development in Sarawak.
- Corlett, R. T., & Primack, R. B. (2008). Tropical rainforest conservation: a global perspective. *Tropical forest community ecology*, 442-457.
- Corley, R., & Tinker, P. (2003). Site selection and land preparation. *The Oil Palm*, 4th Edn.

(Oxford: Blackwell Science Ltd.), 234-269.

Croat, T. B. (1978). *Flora of barro colorado island*. Stanford University Press.

Cruz-Angón, A., Baena, M. L., & Greenberg, R. (2009). The contribution of epiphytes to the abundance and species richness of canopy insects in a Mexican coffee plantation. *Journal of Tropical Ecology*, 25(5), 453-463.

<https://doi.org/10.1017/S02664674039990125>

Cummings, J., Martin, M., & Rogers, A. (2006). Quantifying the abundance of four large epiphytic fern species in remnant complex notophyll vine forest on the Atherton Tableland, north Queensland, Australia. *Cunninghamia*, 9, 521-527.

Curran, L. M., Trigg, S. N., McDonald, A. K., Astiani, D., Hardiono, Y. M., Siregar, P., ... & Kasischke, E. (2004). Lowland forest loss in protected areas of Indonesian Borneo. *Science*, 303(5660), 1000-1003. 10.1126/science.1091714

Cushman, J. H., & Beattie, A. J. (1991). Mutualisms: assessing the benefits to hosts and visitors. *Trends in Ecology & Evolution*, 6(6), 193-195. [https://doi.org/10.1016/0169-5347\(91\)90213-H](https://doi.org/10.1016/0169-5347(91)90213-H)

Davies-Colley, R. J., Payne, G. W., & Van Elswijk, M. (2000). Microclimate gradients across a forest edge. *New Zealand Journal of Ecology*, 24, 111-121.

De Frenne, P., Lenoir, J., Luoto, M., Scheffers, B. R., Zellweger, F., Aalto, J., ... & Hylander, K. (2021). Forest microclimates and climate change: Importance, drivers and future research agenda. *Global Change Biology*, 27(11), 2279-2297

Díaz, I.A., Sieving, K.E., Peña-Foxon, M.E., Larraín, J. & Armesto, J.J. (2010). Epiphyte diversity and biomass loads of canopy emergent trees in Chilean temperate rain forests: a neglected functional component. *For. Ecol. Manage.* 259, 1490–1501

Díaz, I. A., Sieving, K. E., Peña-Foxon, M., & Armesto, J. J. (2012). A field experiment

- links forest structure and biodiversity: Epiphytes enhance canopy invertebrates in Chilean forests. *Ecosphere*, 3(1), 1-17. <https://doi.org/10.1890/ES11-00168.1>
- Dittrich, S., Hauck, M., Jacob, M., Rommerskirchen, A., & Leuschner, C. (2013). Response of ground vegetation and epiphyte diversity to natural age dynamics in a Central European mountain spruce forest. *Journal of Vegetation Science*, 24(4), 675-687.
- Djuikouo, M. N. K., Doucet, J. L., Nguembou, C. K., Lewis, S. L., & Sonké, B. (2010). Diversity and aboveground biomass in three tropical forest types in the Biosphere Reserve, Cameroon. *African Journal of Ecology*, 48(4), 1053-1063. <https://doi.org/10.1111/j.1365-2028.2010.01212.x>
- Dunnett, N. (2004). The dynamic nature of plant communities—pattern and process in designed plant communities. In *The Dynamic Landscape: Design, Ecology and Management of Naturalistic Urban Planting* (pp. 127-149).
- Einzmann, H. J. R., & Zotz, G. (2016). How diverse are epiphyte assemblages in plantations and secondary forests in tropical lowlands? *Tropical Conservation Science*, 9(2), 629-647.
- Ellis, C. J. (2012). Lichen epiphyte diversity: a species, community and trait-based review. *Perspectives in Plant Ecology, Evolution and Systematics*, 14(2), 131-152.
- Engwald, S., Schmit-Neuerburg, V., & Barthlott, W. (2000). Epiphytes in rain forests of Venezuela-diversity and dynamics of a biocenosis. In *Results of worldwide ecological studies. Proceedings of the first symposium by the AFW Foundation. Günter Heimbach, Hoheneim, Holland* (pp. 425-434).
- Esseen, P. A., Ehnström, B., Ericson, L., & Sjöberg, K. (1997). Boreal forest. *Ecological bulletins*, 16-47.
- Esseen, P. A. (2006). Edge influence on the old-growth forest indicator lichen *Alectoria*

- sarmentosa in natural ecotones. *Journal of Vegetation Science*, 17(2), 185-194.
- FAO (Food and Agriculture Organization). (2011). Southeast Asian Forests and Forestry to 2020: Subregional Report of the Second Asia-Pacific Forestry Sector Outlook Study. Food and Agricultural Organization of the United Nations
- FAO (Food and Agricultural Organization). (2019). *Crops*. FAOSTAT statistical database, Rome, updated March 4, 2020. <http://www.fao.org/faostat/en/#data/QC>
- Fisher, R. F. (1995). Amelioration of degraded rain forest soils by plantations of native trees. *Soil Science Society of America Journal*, 59(2), 544-549. <https://doi.org/10.2136/sssaj1995.03615995005900020039x>
- Flores-Palacios, A., & García-Franco, J. G. (2001). Sampling Methods for Vascular Epiphytes: Their Effectiveness in Recording Species Richness and Frequency. *Selbyana*, 22(2), 181–191. <http://www.jstor.org/stable/41760095>
- Flores-Palacios, A., & García-Franco, J. G. (2006). The relationship between tree size and epiphyte species richness: Testing four different hypotheses. *Journal of Biogeography*, 33(2) 323-330. <https://doi.org/10.1111/j.1365-2699.2005.01382.x>
- Forest Department Sarawak. (n.d.). *Ferns*. February 2023. <https://forestry.sarawak.gov.my/page-0-0-684-Ferns.html>
- Forest Department Sarawak (2021). *Types and Categories of Sarawak's Forests*. <https://forestry.sarawak.gov.my/page-0-160-593-Types-and-Categories-of-Sarawak-s-Forests.html>
- Forsyth, A., & Miyata, K. (1984). Tropical Nature. Charles Scribner's Sons.
- Franklin, C. M., Harper, K. A., & Clarke, M. J. (2021). Trends in studies of edge influence on vegetation at human-created and natural forest edges across time and space. *Canadian Journal of Forest Research*, 51(2), 274-282.

- Fritz, Ö., Gustafsson, L., & Larsson, K. (2008). Does forest continuity matter in conservation?—A study of epiphytic lichens and bryophytes in beech forests of southern Sweden. *Biological Conservation*, 141(3), 655-668.
<https://doi.org/10.1016/j.biocon.2007.12.006>
- Fritz, Ö. (2009). Vertical distribution of epiphytic bryophytes and lichens emphasizes the importance of old beeches in conservation. *Biodiversity and Conservation*, 18, 289-304. <https://doi.org/10.1007/s10531-008-9483-4>
- Gauslaa, Y., Marit, L. I. E., & Ohlson, M. (2008). Epiphytic lichen biomass in a boreal Norway spruce forest. *The Lichenologist*, 40(3), 257-266
- Gentry, A. H., & Dodson, C. H. (1987). Diversity and biogeography of neotropical vascular epiphytes. *Annals of the Missouri Botanical Garden*, 74(2), 205-233.
<https://doi.org/10.2307/2399395>
- Ginting, K., Sutarta, E. S., & Purba, R. Y. (2004). Pengendalian Gulma Epifit Pada Kelapa Sawit. *Warta PPKS*, 12(2-3), 23-27.
- Gotsch, S., Nadkarni, N., & Amici, A. (2016). The functional roles of epiphytes and arboreal soils in tropical montane cloud forests. *Journal of Tropical Ecology*, 32(5), 455-468.
doi:10.1017/S026646741600033X
- 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. <https://www.jstor.org/stable/41750962>
- Hanbury-Tenison, A.R. & Jeremy, A.C., (1979) 'The RGS Expedition to Gunung Mulu 1977/78,' *Geographical Journal*, Vol. 14, pp. 175-191. (PR Mulu 2.088)
- Hardwick, S. R., Toumi, R., Pfeifer, M., Turner, E. C., Nilus, R., & Ewers, R. M. (2015). The relationship between leaf area index and microclimate in tropical forest and oil

- palm plantation: Forest disturbance drives changes in microclimate. *Agricultural and Forest Meteorology*, 201, 187-195. <https://doi.org/10.1016/j.agrformet.2014.11.010>
- Hauck, M., de Bruyn, U., Javkhlan, S., & Lkhagvadorj, D. (2014). Forest edge–interior differentiation in the epiphytic lichen diversity of the forest steppe in the Khangai Mountains, Mongolia. *Journal of Plant Ecology*, 7(3), 287-297.
- Hietz, P. (1998). Diversity and conservation of epiphytes in a changing environment. *International Union of Pure and Applied Chemistry (IUPAC)*, 70, 11.
- Hietz, P. (1999). Diversity and conservation of epiphytes in a changing environment. *Pure Appl Chem* 70(2):1–11
- Hilmo, O., & Sæstad, S. M. (2001). Colonization of old-forest lichens in a young and an old boreal *Picea abies* forest: An experimental approach. *Biological Conservation*, 102(3), 251-259. [https://doi.org/10.1016/S0006-3207\(01\)00100-8](https://doi.org/10.1016/S0006-3207(01)00100-8)
- Holbrook, N. M., & Putz, F. E. (1996). Physiology of tropical vines and hemiepiphytes: plants that climb up and plants that climb down. *Tropical forest plant ecophysiology*, 363-394.
- Holdridge, L. R., & Tosi Jr, J. A. (1967). Tropical Science Center: San Jose, Costa Rica. *Life Zone Ecology; Tropical Science Center: San Jose, Costa Rica*.
- Hooijer, A., Page, S., Jauhiainen, J., Lee, W. A., Lu, X. X., Idris, A., & Anshari, G. (2012). Subsidence and carbon loss in drained tropical peatlands: reducing uncertainty and implications for CO₂ emission reduction options. *Biogeosciences Discussions*, 8(5). 10.5194/bgd-8-9311-2011
- Hsu, C. C., Horng, F. W., & Kuo, C. M. (2002). Epiphyte biomass and nutrient capital of a moist subtropical forest in north-eastern Taiwan. *Journal of Tropical Ecology*, 18(5), 659-670.

- Hyvärinen, M., Halonen, P., & Kauppi, M. (1992). Influence of stand age and structure on the epiphytic lichen vegetation in the middle-boreal forests of Finland. *The Lichenologist*, 24(2), 165-180. <https://doi.org/10.1017/S0024282900500073>
- Johansson, D. (1974). *Ecology of vascular epiphytes in West African rain forest* (Doctoral dissertation, Sv. växtgeografiska sällsk.)
- Johansson, P., Rydin, H., & Thor, G. (2007). Tree age relationships with epiphytic lichen diversity and lichen life history traits on ash in southern Sweden. *Ecoscience*, 14(1), 81-91. [10.2980/11956860\(2007\)14\[81:TARWEL\]2.0.CO;2](https://doi.org/10.2980/11956860(2007)14[81:TARWEL]2.0.CO;2)
- Kaiser, B., Vogg, G., Fürst, U. B., & Albert, M. (2015). Parasitic plants of the genus *Cuscuta* and their interaction with susceptible and resistant host plants. *Frontiers in plant science*, 6, 45. <https://doi.org/10.3389/fpls.2015.00045>
- Kenzo, T., Ichie, T., Ogawa, T., Kashimura, S., Hattori, D., Irino, K. O., ... & Ninomiya, I. (2007). Leaf physiological and morphological responses of seven dipterocarp seedlings to degraded forest environments in Sarawak, Malaysia: a case study of forest rehabilitation practice. *Tropics*, 17(1), 1-16. <https://doi.org/10.3759/tropics.17.1>
- Kim, G. M., Siegel, A. J. And Shandro, J. R. (1997). Holding on for dear life: The effects of bark substrate on epiphyte load and composition. *Dartmouth Studies in Tropical Ecology*. p. 43-50.
- Koch, G. W., & Sillett, S. C. (2004). Jennlngs GMet al. *The limits to tree height. Nature*, 428, 851-4.
- Koh, L. P. (2008). Can oil palm plantations be made more hospitable for forest butterflies and birds? *Journal of Applied Ecology*, 45(4), 1002-1009. <https://doi.org/10.1111/j.1365-2664.2008.01491.x>

- Köster, N., Friedrich, K., Nieder, J., & Barthlott, W. (2009). Conservation of epiphyte diversity in an Andean landscape transformed by human land use. *Conservation Biology*, 23(4), 911-919.
- Kanowski, P. J. (2017). Australia's forests: Contested past, tenure-driven present, uncertain future. *Forest Policy and Economics*, 77, 56-68.
<https://doi.org/10.1016/j.forpol.2015.06.001>
- Kreft, H., Köster, N., Küper, W., Nieder, J., & Barthlott, W. (2004). Diversity and biogeography of vascular epiphytes in Western Amazonia, Yasuní, Ecuador. *Journal of Biogeography*, 31(9), 1463-1476. <https://doi.org/10.1111/j.1365-2699.2004.01083.x>
- Kress, W. J. (1986). The systematic distribution of vascular epiphytes: an update. *Selbyana*, 2-22. <https://www.jstor.org/stable/41888782>
- Kress, W. J. (1989). The systematic distribution of vascular epiphytes, 234–261. *Vascular plants as epiphytes*. Springer-Verlag, Berlin.
- Krömer, T., & Gradstein, S. R. (2003). Species richness of vascular epiphytes in two primary forests and fallows in the Bolivian Andes. *Selbyana*, 190-195.
- Kuijt, J. (1969). The biology of parasitic flowering plants. University of California Press, Berkeley. *The biology of parasitic flowering plants*. University of California Press, Berkeley.
- Kupfer, J. A., Malanson, G. P., & Franklin, S. B. (2006). Not seeing the ocean for the islands: the mediating influence of matrix-based processes on forest fragmentation effects. *Global Ecology and Biogeography*, 15(1), 8-20.
<https://doi.org/10.1111/j.1466-822X.2006.00204.x>
- Kuusinen, M. (1996). Epiphyte flora and diversity on basal trunks of six old-growth forest

- tree species in southern and middle boreal Finland. *The Lichenologist*, 28(5), 443- 463.
<https://doi.org/10.1006/lich.1996.0043>
- Laman, T. G. (1995). *Ficus stupenda* germination and seedling establishment in a Bornean rain forest canopy. *Ecology*, 76(8), 2617-2626. <https://doi.org/10.2307/2265832>
- Lambert, F. R., & Marshall, A. G. (1991). Keystone characteristics of bird-dispersed *Ficus* in a Malaysian lowland rain forest. *The Journal of Ecology*, 793-809.
<https://doi.org/10.2307/2260668>
- Larrea, M. L., & Werner, F. A. (2010). Response of vascular epiphyte diversity to different land-use intensities in a neotropical montane wet forest. *Forest Ecology and Management*, 260(11), 1950-1955. <https://doi.org/10.1016/j.foreco.2010.08.029>
- Laube, S., & Zotz, G. (2006). Neither host-specific nor random: Vascular epiphytes on three tree species in a Panamanian lowland forest. *Annals of Botany*, 97(6), 1103- 1114.
<https://doi.org/10.1093/aob/mcl067>
- Laurance, W. F. (2007). Have we overstated the tropical biodiversity crisis? *Trends in Ecology & Evolution*, 22(2), 65-70. <https://doi.org/10.1016/j.tree.2006.09.014>
- Lie, M. H., Arup, U., Grytnes, J. A., & Ohlson, M. (2009). The importance of host tree age, size and growth rate as determinants of epiphytic lichen diversity in boreal spruce forests. *Biodiversity Conservation* 18, 3579–3596.
<https://doi.org/10.1007/s10531-009-9661-z>
- Löbel, S., Snäll, T., & Rydin, H. (2012). Epiphytic bryophytes near forest edges and on retention trees: reduced growth and reproduction especially in old-growth-forest indicator species. *Journal of applied ecology*, 49(6), 1334- 1343.
- Luskin, M. S., & Potts, M. D. (2011). Microclimate and habitat heterogeneity through the oil palm lifecycle. *Basic and Applied Ecology*, 12(6), 540-551.

- Lüttge, U., Ball, E., Kluge, M., & Ong, B. L. (1986). Photosynthetic light requirements of various tropical vascular epiphytes. *Physiologie vegetale*.
- Lüttge, U. (1989). [Ecological Studies] Vascular Plants as Epiphytes *Volume 76 || Vascular Epiphytes: Setting the Scene*. , 10.1007/978-3-642-74465-5(Chapter 1), 1– 14. doi:10.1007/978-3-642-74465-5_1
- Madison, M. (1979). Distribution of epiphytes in a rubber plantation in Sarawak. *Selbyana*, 5(2), 207-213.
- Magrach, A., Rodríguez-Pérez, J., Campbell, M., & Laurance, W. F. (2014). Edge effects shape the spatial distribution of lianas and epiphytic ferns in Australian tropical rain forest fragments. *Applied Vegetation Science*, 17(4), 754-764.
- Male, T. D., & Roberts, G. E. (2005). Host associations of the strangler fig *Ficus watkinsiana* in a subtropical Queensland rain forest. *Austral ecology*, 30(2), 229-236. <https://doi.org/10.1111/j.1442-9993.2005.01442.x>
- Males J. (2016). Think tank: water relations of Bromeliaceae in their evolutionary context. *Bot. J. Linn. Soc.* 181 415–440. 10.1111/boj.12423
- Manning, F. C., Kho, L. K., Hill, T. C., Cornulier, T., & Teh, Y. A. (2019). Carbon emissions from oil palm plantations on peat soil. *Frontiers in Forests and Global Change*, 37. <https://doi.org/10.3389/ffgc.2019.00037>
- Marmor, L., Törra, T., & Randlane, T. (2010). The vertical gradient of bark pH and epiphytic macrolichen biota in relation to alkaline air pollution. *Ecological Indicators*, 10(6), 1137-1143. <https://doi.org/10.1016/j.ecolind.2010.03.013>
- Matelson, T. J., Nadkarni, N. M., & Longino, J. T. (1993). Longevity of fallen epiphytes in a neotropical montane forest. *Ecology*, 74(1), 265-269
- McMorrow, J. (2001). Linear regression modelling for the estimation of oil palm age from

- Landsat TM. *International Journal of Remote Sensing*, 22(12), 2243-2264.
- Meijaard, E., Garcia-Ulloa, J., Sheil, D., Wich, S. A., Carlson, K. M., Juffe-Bignoli, D., & Brooks, T. M. (2018). Oil palm and biodiversity: A situation analysis by the IUCN Oil Palm Task Force.
- Miller, J. N. (1991). Basic statistical methods for analytical chemistry. Part 2. Calibration and regression methods. A review. *Analyst*, 116(1), 3-14.
- Ministry of Natural Resources and Environment. (2006). *Biodiversity in Malaysia*. <https://www.ketsa.gov.my/PustakaMedia/Penerbitan/Biodiversity%20in%20Malaysia.pdf>
- Mittermeier, R. A., Myers, N., Mittermeier, C. G., & Robles Gil, P. (1999). *Hotspots: Earth's biologically richest and most endangered terrestrial ecoregions*. CEMEX, SA, Agrupación Sierra Madre, SC.
- Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853-858. <https://doi.org/10.1038/35002501>
- Nadkarni, N. M., & Matelson, T. J. (1989). Bird use of epiphyte resources in neotropical trees. *The Condor*, 91(4), 891-907. <https://doi.org/10.2307/1368074>
- Nadkarni, N. M., & Matelson, T. J. (1992). Biomass and nutrient dynamics of epiphytic litterfall in a neotropical montane forest, Costa Rica. *Biotropica*, 24-30. <https://doi.org/10.2307/2388470>
- Nieder, J., Prosperí, J., & Michaloud, G. (2001). Epiphytes and their contribution to canopy diversity. In *Tropical Forest Canopies: Ecology and Management: Proceedings of ESF Conference, Oxford University, 12-16 December 1998*. pp. 51 -63. Springer Netherlands.

- Nieder, R., Benbi, D.K. & Reichl, F.X. (2018). Soil as a Transmitter of Human Pathogens. In: Soil Components and Human Health. Springer, Dordrecht. https://doi.org/10.1007/978-94-024-1222-2_13
- Nomura, K., Mitchard, E. T. A., Patentee, G., Bastide, J., Oswald, P., & Nwe, T. (2019). Oil palm concessions in southern Myanmar consist mostly of unconverted forest. *Scientific Reports*, 9(1), 11931–. doi:10.1038/s41598-019-48443-3
- Ove, E. (2000). Seed dispersal and colonization ability of plants — *Assessment and implications for conservation*. , 35(2), 115–123. doi:10.1007/bf02803091
- O'Malley, K. (2009). Patterns of abundance and diversity in epiphytic orchids on Parashorea malaanonan trees in Danum Valley, Sabah. The Plymouth StudentScientist 2 (2); 38-58.
- Perez-Salicrup, D. R. (1998). *Effects of liana cutting on trees and tree seedlings in a tropical forest in Bolivia*. University of Missouri-Saint Louis.
- Perry, D. R. (1978). A method of access into the crowns of emergent and canopy trees. *Biotropica*, 155-157. <https://doi.org/10.2307/2388019>
- Pike, L. H. (1978). The importance of epiphytic lichens in mineral cycling. *Bryologist*, 247-257. <https://doi.org/10.2307/3242186>
- Pour, A.B., Hashim, M., & Van, G. J. (2013) Detection of hydrothermal alteration zones in a tropical region using satellite remote sensing data: Bau goldfield, Sarawak, Malaysia. *Ore geology reviews*. Elsevier, Amsterdam
- Prescott, G. W., Edwards, D. P., & Foster, W. A. (2015). Retaining biodiversity in intensive farmland: epiphyte removal in oil palm plantations does not affect yield. *Ecology and Evolution*, 5(10), 1944–1954. doi:10.1002/ece3.1462
- Primack, R.B. and Corlett, R.T. (2005) Tropical Rain Forests: An Ecological and

Biogeographical Comparison. Blackwell Science, Oxford.

- Prosperi, J. (1998). *Biologie du développement des héli-épiphytes ligneux* (Doctoral dissertation, Montpellier 2).
- Putz, F. E. (1984). The natural history of lianas on Barro Colorado Island, Panama. *Ecology*, 65(6), 1713-1724. <https://doi.org/10.2307/1937767>
- Putz, F. E., & Holbrook, N. M. (1986). Notes on the natural history of hemiepiphytes. *Selbyana*, 61-69. <https://www.jstor.org/stable/41888786>
- Putz, F. E., & Holbrook, N. M. (1989). Strangler fig rooting habits and nutrient relations in the llanos of Venezuela. *American Journal of Botany*, 76(6), 781-788. <https://doi.org/10.1002/j.1537-2197.1989.tb15056.x>
- Rahayu, S., Fakhurrozi, Y., & Putra, H. F. (2018). Hoya species of Belitung Island, Indonesia, utilization, and conservation. *Biodiversitas Journal of Biological Diversity*, 19(2), 369-376. <https://doi.org/10.13057/biodiv/d190203>
- Rembold, K., Mangopo, H., Tjitrosoedirdjo, S. S., & Kreft, H. (2017). Plant diversity, forest dependency, and alien plant invasions in tropical agricultural landscapes. *Biological Conservation*, 213, 234-242.
- Renhorn, K. E., Esseen, P. A., Palmqvist, K., & Sundberg, B. (1996). Growth and vitality of epiphytic lichens: I. Responses to microclimate along a forest edge-interior gradient. *Oecologia*, 109, 1-9.
- Reyes-García, C., Griffiths, H., Rincón, E., & Huante, P. (2008). Niche differentiation in tank and atmospheric epiphytic bromeliads of a seasonally dry forest. *Biotropica*, 40(2), 168-175. <https://doi.org/10.1111/j.1744-7429.2007.00359.x>
- Richards, P. W. (1952). The tropical rainforest. Cambridge. *Recensent: S. H ejny*.
- Sarawak Land Consolidation and Rehabilitation Authority (SALCRA). 2021. Oil Palm.

<https://www.salcra.gov.my/en/development-project/oil-palm>

- Schimper, A. F. W. (1903). Plant-geography upon a physiological basis. Oxford: Oxford University Press.
- Schmidt, G., & Zotz, G. (2002). Inherently slow growth in two Caribbean epiphytic species: a demographic approach. *Journal of Vegetation Science*, 13(4), 527- 534.
- Schneider, J. M., Zabel, F., Schünemann, F., Delzeit, R., & Mauser, W. (2022). Global cropland could be almost halved: Assessment of land saving potentials under different strategies and implications for agricultural markets. *Plos one*, 17(2), e0263063. <https://doi.org/10.1371/journal.pone.0263063>
- Schuettelpelz, E., & Trapnell, D. W. (2006). Exceptional epiphyte diversity on a single tree in Costa Rica. *Selbyana*, 65-71.
- Sharp, A. J. (1957). Vascular epiphytes in the Great Smoky Mountains. *Ecology*, 38(4), 654-655.
- Sillett, S. C., Antoine, M. E., Carroll, A. L., Graham, M. E., Chin, A. R., & Van Pelt, R. (2022). Rangewide climatic sensitivities and non-timber values of tall *Sequoia sempervirens* forests. *Forest Ecology and Management*, 526, 120573.
- Sodhi, N. S., & Brook, B. W. (2006). *Southeast Asian biodiversity in crisis*. Cambridge University Press.
- Spicer, M. E., & Woods, C. L. (2022). A case for studying biotic interactions in epiphyte ecology and evolution. *Perspectives in Plant Ecology, Evolution and Systematics*, 54, 125658. <https://doi.org/10.1016/j.ppees.2021.125658>
- State Planning Unit. (2012). Sarawak: facts and figures 2012. Chief Minister's Department
- Taylor, A., Burns, K., & Bruun, H. H. (2015). Epiphyte community development throughout

- tree ontogeny: an island ontogeny framework. *Journal of Vegetation Science*, 26(5), 902-910. <https://doi.org/10.1111/jvs.12289>
- Thomas, S. C. (1996). Asymptotic height as a predictor of growth and allometric characteristics in Malaysian rain forest trees. *American journal of Botany*, 83(5), 556-566. <https://doi.org/10.1002/j.1537-2197.1996.tb12739.x>
- Tisen, O. & Bennett, E. (2002). Wildlife conservation as part of holistic planning for sustainable forest management. *The Malaysian Forester*, 65(2): 59-65.
- Todzia, C. (1986). Growth habits, host tree species, and density of hemiepiphytes on Barro Colorado Island, Panama. *Biotropica*, 22-27. <https://doi.org/10.2307/2388357>
- Trichon, V. (1997). Spatial heterogeneity of a tropical rain forest in Sumatra: effect of topography on floristic structure. *Annales des Sciences Forestie`res*, 54:431–446.
- Tscharntke, T., Tylianakis, J. M., Rand, T. A., Didham, R. K., Fahrig, L., Batáry, P., & Westphal, C. (2012). Landscape moderation of biodiversity patterns and processes-eight hypotheses. *Biological reviews*, 87(3), 661-685. <https://doi.org/10.1111/j.1469-185X.2011.00216.x>
- Tsutsumi, C., & Kato, M. (2008). Morphology and evolution of epiphytic Davalliaceae scales. *Botany*, 86(12), 1393-1403. <https://doi.org/10.1139/B08-098>
- Turner, I. M., Tan, H. T. W., Wee, Y. C., Ibrahim, A. B., Chew, P. T., & Corlett, R. T. (1994). A study of plant species extinction in Singapore: Lessons for the conservation of tropical biodiversity. *Conservation Biology*, 8(3), 705-712. <https://doi.org/10.1046/j.1523-1739.1994.08030705.x>
- Vanderpoorten, A., Engels, P., & Sotiaux, A. (2004). Trends in diversity and abundance of obligate epiphytic bryophytes in a highly managed landscape. *Ecography*, 27(5), 567-576. <https://doi.org/10.1111/j.0906-7590.2004.03890.x>

- Wahid, B., M., Abdullah, S. N. A., & Henson, I. E. (2005). Oil Palm-Achievements and Potential. *Plant Production Science*, 8(3), 288–297. doi:10.1626/pp.8.288
- Werner, F. A., & Gradstein, S. R. (2009). Diversity of dry forest epiphytes along a gradient of human disturbance in the tropical Andes. *Journal of vegetation science*, 20(1), 59-68. <https://doi.org/10.1111/j.1654-1103.2009.05286.x>
- White, D. L. & Lloyd, F. T. (1994). Defining Old Growth: Implications For Management. Paper presented at the *Eighth Biennial Southern Silvicultural Research Conference*, Auburn, AL, Nov. 1-3.
- Whitmore, T. C. (1988). Forest types and forest zonation. *Key Environments: Malaysia*, 20, 30
- Wilcove, D. S., Giam, X., Edwards, D. P., Fisher, B., & Koh, L. P. (2013). Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. *Trends in ecology & evolution*, 28(9), 531-540. <https://doi.org/10.1016/j.tree.2013.04.005>
- Williams-Linera, G. (1990). Vegetation structure and environmental conditions of forest edges in Panama. *The Journal of Ecology*, 356-373.
- Wirth, C., Gleixner, G., & Heimann, M. (2009). *Old-growth forests: Function, fate, and value—an overview* (pp. 3-10). Springer Berlin Heidelberg.
- Wolf, J. H. D. (1993). *Ecology of epiphytes and epiphyte communities in montane rain forests, Colombia* (No. 584.09861 W6).
- Wolf, J.H.D. & Flamenco-S, A. (2003) Patterns in species richness and distribution of vascular epiphytes in Chiapas, Mexico. *Journal of Biogeography*, 30, 1689–1707
- Wolf, J. H. (2005). The response of epiphytes to anthropogenic disturbance of pine-oak forests in the highlands of Chiapas, Mexico. *Forest ecology and management*, 212(1-3), 376-393. <https://doi.org/10.1016/j.foreco.2005.03.02>

- Wolf, J. H., Gradstein, S. R., & Nadkarni, N. M. (2009). A protocol for sampling vascular epiphyte richness and abundance. *Journal of Tropical Ecology*, 25(2), 107-121.
- Woods, C. L. (2013). *Factors influencing the distribution and structure of tropical vascular epiphyte communities at multiple scales* (Doctoral dissertation, Clemson University).
- Woods, C. L., & DeWalt, S. J. (2013). The conservation value of secondary forests for vascular epiphytes in Central Panama. *Biotropica*, 45(1), 119-127.
- Yagya P. A. , Fischer A., Fischer, H.S., Rokaya, M. B., Bhattarai, P. & Gruppe, A. (2017). Diversity, composition and host-species relationships of epiphytic orchids and ferns in two forests in Nepal. *Journal of Mountain Science*, 14(6), 1065–1075. doi:10.1007/s11629-016-4194-x
- Yanoviak, S. P., Kragh, G. & Nadkarni, N. M. (2003) Spider Assemblages in Costa Rican Cloud Forests: Effects of Forest Level and Forest Age, *Studies on Neotropical Fauna and Environment*, 38(2), 145-154, DOI: 10.1076/snfe.38.2.145.15922
- Zamora, P. M., & Co, L. (1986). *Guide to Philippine flora and fauna: Economic ferns, endemic ferns, gymnosperms*. Natural Resources Management Center, Ministry of Natural Resources and University of the Philippines.
- Zhang Q., Chen J.-W., Li B.-G., Cao K.-F. (2009). Epiphytes and hemiepiphytes have slower photosynthetic response to light flecks than terrestrial plants: evidence from ferns and figs. *Journal of Tropical Ecology* 25, 465–472. 10.1017/S026646740900618X
- Zhao, M., Geekiyanage, N., Xu, J., Khin, M. M., Nurdiana, D. R., Paudel, E., & Harrison, R. D. (2015). Structure of the epiphyte community in a tropical montane forest in SW China. *PloS one*, 10(4), e0122210. <https://doi.org/10.1371/journal.pone.0122210>

Zotz, G. (2013). The systematic distribution of vascular epiphytes - a critical update. *Botanical Journal of the Linnean Society*, 171(3), 453–481.
doi:10.1111/boj.12010

Zotz G. (2016). Plants on Plants – The Biology of Vascular Epiphytes. Switzerland: Springer International Publishing; 10.1007/978-3-319-39237-0