GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Diversity of vascular epiphytes in jungle rubber along a distance gradient to Bukit Duabelas National Park in Sumatra (Indonesia)

Diversität vaskulärer Epiphyten in Kautschuk Agroforstsystemen entlang eines Distanzgradienten zum Bukit-Duabelas Nationalpark in Sumatra (Indonesien)

Masterarbeit an der Fakultät für Forstwissenschaften und Waldökologie der Georg-August-Universität Göttingen

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Contents

1 Abstract

Vascular Epiphytes represent an important part of the tropical forests biodiversity. Considering the change of almost all lowland rainforests of Sumatra into rubber and oil palm plantations and the related loss of biodiversity, this thesis wants to provide arguments for the assessment of the value of jungle rubber (*Hevea brasiliensis* agroforests) for Sumatra's biodiversity conservation. To provide data about abundance, species richness and ecology of vascular epiphytes, within jungle rubber 30 native trees were studied by climbing and 30 corresponding rubber trees were studied groundbased, additionally 12 rubber trees were studied groundbased in the plantations. The plots with an area of 400 m² each were placed along a distance gradient (20 km) to the border of the lowland rainforest in Bukit Duabelas National Park (BDNP). In jungle rubber 1950 vascular epiphyte individuals of 48 species were recorded, which were dominated by Ferns and Orchids, whereas other angiosperms were underrepresented. In the rubber plantations 194 epiphytes of 13 species were recorded, which were dominated by ferns. Almost all epiphytes recorded in the plantations were recorded in jungle rubber as well. Ecological characterization of the recorded species showed, that the plantations were dominated by frequent and abundant fern species, which were classified as generalists, whereas in jungle rubber additionally specialist species were found, mostly represented by orchids and other angiosperms. Regression analysis showed, that epiphyte density and species richness were firstly positive related with the basal area of the phorophyte and secondly negative related with the distance to the rainforest of BDNP. The distribution of the epiphyte species in the landscape indicated the rainforest as source for species. Beside the basal area of the phorophytes as additional influencing factor of the determined differences between jungle rubber and the plantations, as well as for the determined changes along the distance gradient to the forest border, jungle rubber showed a higher heterogeneity than rubber plantations. It is assumed, that jungle rubber harbors epiphyte species of the rubber plantations and of the rainforest, due to its diverse structure with remnant forest trees, the change of open and closed conditions and a more diversified microclimate.

Zusammenfassung

Vaskuläre Epiphyten haben einen bedeutenden Anteil an der Biodiversität tropischer Wälder. Im Hinblick auf die fast vollständige Umwandlung der Tieflandregenwälder Sumatras in Palmöl und Kautschuk Plantagen und dem damit verbundenen Verlust von Biodiversität, soll die vorliegende Arbeit Argumente für die Bewertung des Schutzwertes von Kautschuk Agroforstsystemen für die Biodiversität Sumatras liefern. Um Daten über Artenreichtum, Individuendichte und Ökologie der vorkommenden vaskulären Epiphyten zu erfassen, wurden in den Kautschuk Agroforstsystemen 30 Bäume beklettert und 30 Kautschuk Bäume vom Boden aus untersucht, des Weiteren wurden 12 Kautschuk-Bäume in den Plantagen vom Boden aus untersucht. Sekundäre Hemiepiphyten und zufällige Epiphyten wurden nicht berücksichtigt. Die Plots mit jeweils 400 m^2 Fläche wurden entlang eines 20 km langen Distanzgradienten zur Grenze des Tieflandregenwaldes im Bukit Duabelas Nationalpark (BDNP) platziert. In den Kautschuk Agroforsten wurden 1950 vasculäre Epiphyten aus 48 Spezies gezählt, Farne und Orchideen dominierten, während andere Angiospermen unterrepräsentiert waren. In den Kautschuk Plantagen wurden insgesamt 194 Epiphyten aus 13 Spezies gezählt, welche von Farnen dominiert wurden. Fast alle Epiphyten Arten der Plantagen wurden auch in den Agroforsten gefunden. Eine ökologische Charakterisierung der gefundenen Arten zeigte, dass auf den Plantagen überwiegend abundante und häufig vorkommende Farnarten zu finden waren, während in den Kautschuk Agroforsten zusätzlich auch Spezialisten vorkamen (überwiegend Orchideen und andere Angiospermen). Regressionsanalysen zeigten, dass Individuendichte und Artenreichtum vaskulärer Epiphyten erstens positiv mit der Stammgrundfläche des Phorophyten und zweitens negativ mit der Distanz zur Regenwaldgrenze im BDNP korrelieren. Zudem deutet die landschaftliche Verteilung der Arten darauf hin, dass der Regenwald als Artenquelle fungiert. Neben der Grundfläche des Phorophyten als ein weiterer erklärender Faktor für die Unterschiede zwischen den beiden Landnutzungssystemen und den Veränderungen mit steigender Distanz zum Regenwald, zeigten Kautschuk Agroforste eine höhere strukturelle Heterogenität als die Plantagen. Es wird angenommen, dass Kautschuk Agroforste durch die heterogene Struktur, mit noch vorhandenen großen Regenwaldbäumen, offenen und geschlossenen Strukturen sowie einem diverseren Microclima, sowohl Epiphyten Arten der Plantagen als auch des Regenwaldes beherbergen.

2 Introduction

2.1 Background of the thesis

This Master thesis is realized within Collaborative Research Centre (CRC) 990 "*Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems in Sumatra, Indonesia*" (EFForTS), a collaborative research project funded by the *Deutsche Forschungsgemeinschaft* (DFG). In this project German and Indonesian counterparts are joined together in close cooperation. Members of EFForTS are the University of Göttingen, University of Jambi Sumatra (UNJA), Bogor Agricultural University Java (IPB) and Tadulako University Palu Sulawesi (UNTAD).

The aim of the EFForTS project is to provide science based knowledge to protect and enhance the ecological functions of tropical lowland rainforest and forest transformation systems on landscape scale while improving human welfare (CRC 990). Furthermore, EFForTS wants to provide information on how to connect ecological conservation issues with agricultural land use (CRC 990). The study area of this project is located in Sumatra - one of the regions with the highest forest conversion rates in Southeast Asia (Miettinen et al., 2011) - more precisely in the lowlands of Jambi Province Sumatra inside and around Bukit Duabelas National Park (BDNP). A second investigation region of EFForTS, not considered in this thesis, is located inside and around the Harapan Rainforest concession (harapanrainforest.org). BDNP and Harapan Rainforest concession are covered by lowland rainforest. These remnant tropical rainforest areas function as forest reference system to investigate the effects of the forest conversion to agricultural land-use systems - rubber plantations (*Hevea brasiliensis*) and oil palm plantations (*Elaeis guineensis*) - and to jungle rubber. Jungle rubber is an agroforestry system based on rubber (*Hevea brasiliensis*) and with the characteristics of secondary forest (Gouyon et al., 1993).

Within EFForTS, this thesis is part of the B06 project - "*Taxonomic, phylogenetic, and biogeographical diversity of vascular plants in rainforest transformation systems on Sumatra (Indonesia)*" led by Prof. Dr. Holger Kreft. The aim of B06 is to investigate the effects of rainforest transformation on plant diversity and ecosystem functions on taxonomic, phylogenetic, functional and biogeographical levels and how plant diversity is partitioned at different spatial scales (CRC 990 - B06).

About a possible relation between the changes of vascular epiphyte diversity with the distance to natural forests only very little is known. An older study carried out in the Neotropics identified a negative relation between epiphyte numbers on isolated forest trees with the distance to the forest border (Hietz-Seifert et al., 1996). A recent study within the B06 project found indications for decreasing epiphyte richness in rubber plantations with increasing distance to the rainforest in BDNP (Böhnert, 2013). The present thesis takes this up and investigates the change of vascular epiphyte diversity in jungle rubber along a distance gradient to lowland rainforest in BDNP. Fieldwork and data collection was carried out in close cooperation with Arne Wenzel, a fellow student working on a closely linked master thesis.

2.2 Tropical rainforests, jungle rubber and epiphytes

Tropical rainforests belong to the most species-rich and diverse terrestrial ecosystems and harbor the main part of the global biological diversity (Barthlott et al., 2005; Kier et al., 2009; Mackinnon, 1997). Tropical rainforests are also important sources for timber and non-timber forest products - for example medicinal plants or food - and are therefore essential for the daily life and wellbeing of many people (Arnold & Perez, 2001; Balick et al., 1996). Furthermore, tropical rainforests play an important role as carbon sinks (Malhi & Grace, 2000). Tropical rainforest can accumulate large amounts of carbon - counting for 33 % of the terrestrial primary biomass production and storing about 25 % of the worlds terrestrial carbon - (Bonan, 2008). The largest tropical rainforests areas can be found in Central and tropical South America, mainly in the Amazonian basin. The second highest concentration of tropical rainforests exist in the Congo basin followed by Asia (FAO, 2010b). Indonesia represents 2.3 % of the global (FAO, 2010a) and 39 % of Southeast Asia’s forest area (Achard et al., 2002), and the country is listed on place eight of the most forest-rich countries worldwide (FAO, 2010a) and is ranked third of the most forest-rich countries in the tropics, after Brazil and the Democratic Republic of the Congo (FAO, 2010b).

Despite Indonesia’s rank as one of the most forest-rich countries, its tropical rainforests are highly threatened. Growing population results in increasing population density and higher demands on land and other natural resources which correlates with higher forest loss (Sodhi et al., 2010; Wright & Muller-landau, 2006). For example, commercial logging is responsible for huge losses of natural rainforests, even within protected areas (Asner et al., 2005). Currently, the forests of Southeast Asia have the highest rates of forest loss (Laurance, 2007; Margono et al., 2014; Sodhi et al., 2004). Especially affected are the lowland rainforests (Laumonier et al., 2010), which represent the main part of southeast Asian forests (Whitmore, 1990). Indonesia shows the second highest deforestation rates worldwide (Margono et al., 2014). An even more alarming trend in

Indonesia - before logging - is the conversion of forest into agricultural areas such as rubber, oil palm and paper pulp plantations. The conversion of rainforest into oil palm plantations has been identified as one of the major threats for biodiversity in Southeast Asia and especially in Indonesia (Giam et al., 2010; Laumonier et al., 2010; Wilcove et al., 2013; Wilcove & Koh, 2010).

In Sumatra primary lowland rainforest has almost completely disappeared and was initially converted into jungle rubber agroforestry systems since the early 20th century and later into large monoculture rubber and oil palm plantations (Beukema et al., 2007; Lambert & Collar, 2002). Large scale logging of lowland rainforest took place mainly in the 1970s and 1980s leaving only few areas of primary rainforest which are today mainly located inside of national parks (Gaveau et al., 2007; Laumonier et al., 2010). However, even within protected areas illegal logging and transformation into oil palm plantations has been reported frequently (Buckland, 2005; Curran et al., 2004). In the past 30 years Sumatra lost more than 50 % of its forest area (Figure 1), while the area of monocultural plantations increased enormous (Ekadinata & Vincent, 2011).

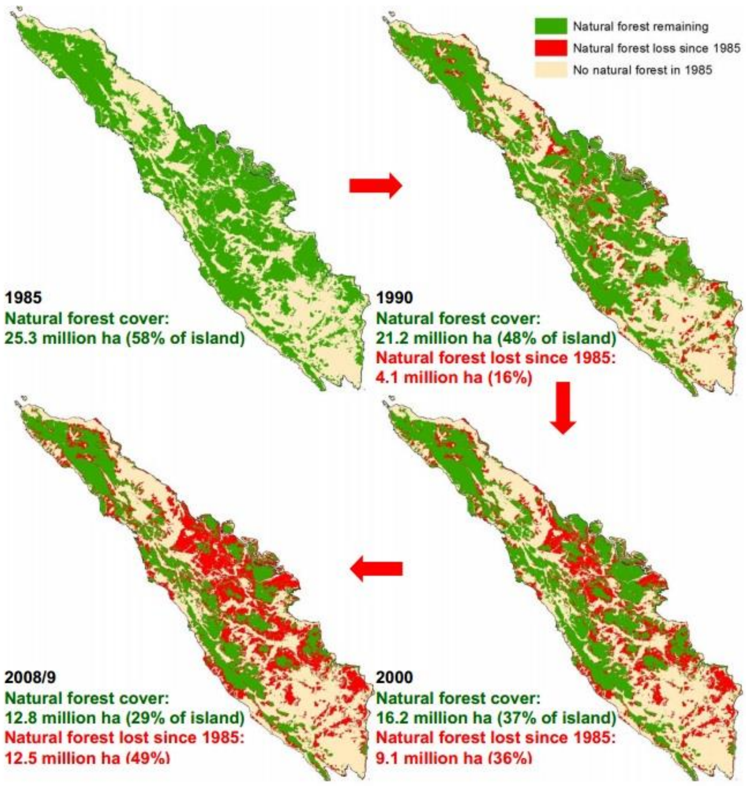

Figure 1: Loss of natural forest in Sumatra. Natural forest in Sumatra in 1985, 1990, 2000 and 2008/9 (green) and loss since 1985 (red) (Uryu et al., 2010).

Jungle rubber

Jungle rubber is a smallholder farming system common in Indonesia and especially in the Sumatran lowlands to produce rubber from *Hevea brasiliensis.* Jungle rubber exists since the beginning of the 20th century, when rubber was introduced in Sumatra (Beukema et al., 2007; Gouyon et al., 1993). Jungle rubber can be established by two ways. The first starts from cleared secondary or primary forest areas, usually by slash and burn. After this first clearing the rubber saplings are planted together with fruit trees and crops, for example upland rice and vegetables. This first phase lasts as long as the soil is fertile enough to grow crops and the rubber saplings are tall enough to resist competing weeds without weeding. In a second phase wild colonizing species are allowed to grow together with the rubber and a complex forest-like vegetation occurs (Gouyon et al., 1993). The second way to establish jungle rubber is by gap planting, also called Sisipan. In this system rubber saplings are planted in gaps of primary forest, secondary forest and also in mature jungle rubber for rejuvenation (Joshi et al., 2002). Jungle rubber established by this system harbors remnant trees and vegetation of the former system. The first latex can be tapped approximately 4 - 10 years after planting. The tapping period of these rubber agroforests lasts ca. 40 years, but can also reach ages up to 80 years. In addition to the rubber harvest, jungle rubber also provides firewood and timber. This makes jungle rubber a diversified agroforestry system which allocates the farmers' income (Gouyon et al., 1993; Joshi et al., 2002).

Old grown jungle rubber in Jambi can reach heights between 20 and 40 meters compared to forest heights up to 60 meters in primary lowland rainforests (Beukema et al., 2007). The structure of old jungle rubber resembles secondary forest with the rubber tree representing the ecological niche of native pioneer tree species like *Macaranga* spp. (Gouyon et al., 1993). In mature jungle rubber the percentage of rubber trees is on average 40 – 50 % and decreases with age (Hardiwinoto et al., 1999). Besides the age as important factor influencing species composition and structure of jungle rubber, several other influencing factors are important. The surrounding vegetation, the existing seed-bank, remnant rootstocks and trees also play an important. In addition to these factors, the vegetation's development process in jungle rubber is strongly influenced by the individual management of the landowner. The high variability and the differing sizes of jungle rubber areas varying from less than one to several hectares make standardized research in this land-use system difficult (Beukema, 2013).

Some authors assume that jungle rubber can maintain about 50 % of the biodiversity found in primary forests and that jungle rubber can be of high value for the conservation of primary rainforest species, particularly in the context of the fast disappearing lowland rainforest areas in Sumatra (Beukema & Van Noordwijk, 2004; Joshi et al., 2002). Besides that, jungle rubber itself is under pressure, intensification of agriculture land-use leads to a high conversion rate of jungle rubber into monocultural oil palm or rubber plantation (Joshi et al., 2002). Ekadinata & Vincent (2011) discovered, that the area of monocultural rubber plantations in the Bungo district (Jambi, Sumatra) increased from 3 % (1973) to 40 % (2005), while the area of jungle rubber decreased from 15 % to 11 % in the same period. Furthermore, they identified that the jungle rubber areas present in 1973 were almost all replaced by more intensive agricultural land-use systems in 2005. It can be expected, that the area of jungle rubber will decrease further in the future.

Epiphytes

Epiphytes are plants that germinate and grow non-parasitic on other plants, mainly shrubs and trees (Benzing, 1990; Zotz, 2013). Because many of them grow high up in the tree's canopy - out of reach and sight - epiphytes are often overlooked (Cardelús et al., 2006). In the Sumatran lowland rainforest vascular epiphytes are common (Whitten et al., 2000), but only little is known about their diversity and ecology and this group of species can be considered as understudied in tropical Southeast Asia (Corlett, 2014). In some Neotropical forests epiphytes can make up to 30 – 50 % of the total plant species richness (Gentry & Dodson, 1987; Kelly et al., 1994). In tropical rainforests epiphytes also play an important role in water and nutrient cycles (Coxson & Nadkarni, 1995). Additionally, epiphytes are an important habitat, shelter and food source for various arboreal vertebrates and invertebrates (Nadkarni & Matelson, 1989; Stuntz et al., 2002).

Vascular epiphytes can roughly be divided into two types: holoepiphytes and hemiepiphytes. In holoepiphytes, the entire lifecycle from germination to reproduction takes place on the host tree (phorophyte); for this reason they are also called true epiphytes. The lifecycle of hemiepiphytes in turn only partially takes place on the host tree. They can be subdivided into two subgroups, primary and secondary hemiepiphytes. The lifecycle of primary hemiepiphytes starts with germination on the host tree, but later their roots get in contact with the ground. Many *Ficus* species belong to this type of hemiepiphytes. In case of secondary hemiepiphytes it is the other way around; their lifecycle begins with germination on the ground, after growing up into the tree they lose contact to the ground and appear as epiphytes. Another group of epiphytes comprise accidental epiphytes, which are terrestrial plants that might occasionally germinate in an epiphytic habitat and possess no special adaption to life in canopy (Benzing, 1990). Secondary hemiepiphytes and accidental epiphytes were excluded from this study in accordance to Köster et al. (2013) and Zotz (2013).

Epiphytes have to deal with harsh growing conditions for instance low nutrient and water supply due to the lack of contact to soil and seasonal changes between wet and dry (Janzen, 1975). The most important limiting factor for the epiphytic mode of life is considered to be water (Laube & Zotz, 2003; Zotz & Hietz, 2001). Epiphytes have to deal with different environmental conditions along a vertical gradient, from shaded and moist in the understory to bright and dry in the canopy (Petter et al., 2015). For example, to deal with the dry and sunny conditions in the canopy epiphytes evolved several adaptations to minimize water loss, such as: poikilohydry, leaf, stem and root succulence, shootlessness and drought-deciduousness (Benzing et al., 1983; Benzing, 1990; Ng & Hew, 2000). The absent soil contact leads to a shortage of nutrients as the second important limiting grow factor of the epiphytic mode of life (Zotz & Hietz, 2001). Nutrient sources are mainly atmospheric depositions from dust, mist, rain and accumulated leaf litter (Benzing, 1981; 1990). In order to deal with this nutrient shortage epiphytes developed different strategies. Nutrient saving strategies are for example: a prolonged juvenile stage, reduced sizes of the vegetative parts and long lasting. Other strategies are the exploitation of additional nutrient sources, some epiphytes. For example, some epiphytes have evolved special roots or leaves that function as litter-impounding pools to accumulate nutrients (Benzing, 1990). Another nutrient source is organic debris accumulated by associated animals, for example ants (Davidson & Epstein, 1989; Stuntz et al., 2002; Treseder et al., 1995).

With 27,614 species in 913 genera and 73 families, vascular epiphytes (holo- and primary hemi-epiphytes) represent approximately 9% of the existing vascular plant diversity. The largest family of epiphytes, including approximately 68% of all epiphytes, is the family Orchidaceae with almost 19,000 species in 643 genera. Within the Orchidaceae family 69% of all species are epiphytes. Ferns and fern-allies represent the second most important group of epiphytes with about 2,700 species in 121 genera. Within ferns, the Polypodiaceae family is the most important family representing about 50% of all epiphytic fern species. Another important group of epiphytes occurring almost exclusively in the Neotropics are the bromeliads with almost 1,800 epiphytic species. Almost 60% of the species within the Bromeliaceae family appear as epiphytes. (Zotz, 2013)

Because of their specific adaptations to the harsh growing conditions, epiphytes react very sensitive to changes in their environment (Benzing, 1990). Due to the tree-dependent life of epiphytes, deforestation, land-use changes and changes of the microclimatic conditions can dramatically affect epiphyte diversity and can lead to high species losses (Hietz et al., 2006; Sala et al., 2000). Epiphyte species with small geographical distributions and narrow ecological tolerances are especially endangered due to their lower plasticity towards changes in their habitat (Köster et al., 2013). This makes epiphytes highly useful as model group for diversity research to investigate the effects of deforestation and land-use conversions.

2.3 Aims of the study/ Hypothesis

The main goal of this study is to investigate the change of vascular epiphyte diversity in jungle rubber agroforestry systems and rubber plantations along a distance gradient to primary lowland rainforest in Bukit Duabelas National Park. In this thesis the definition for epiphyte diversity will be restricted to epiphyte abundance and epiphyte species richness. Beside the effect of the distance to the forest on epiphyte richness and density, also the influence of spill-over effects by neighbouring phorophytes (host trees) and plots on epiphyte richness and density shall be investigated. A second focus is on differences between epiphyte communities in jungle rubber and rubber plantations and within jungle rubber between native and rubber phorophytes. Finally the value of jungle rubber for the conservation of vascular epiphyte diversity will be assessed.

The following hypotheses are tested in this study:

1) The abundance and species richness of vascular epiphytes decreases along a distance gradient to the national park.
2) The abundance and species richness of vascular epiphytes in jungle rubber is higher than in monocultural rubber plantations.
3) There are less specialized vascular epiphyte species and higher rates of common generalist species in monocultural rubber plantations than in jungle rubber.
4) Rubber plantations next to epiphyte species rich jungle rubber show higher numbers of epiphyte species.
5) Rubber trees next to epiphyte species rich native trees show higher numbers of epiphyte species.

3 Methods

3.1 Study area

The study area is located in Sumatra, the most western island of the Indonesian archipelago. With an area of 473,606 km², Sumatra is after Borneo the second largest island of the Indonesian archipelago and the sixth largest island of the world. It is located beneath the equator and reaches 1,760 km from northwest to southeast and up to 400 km from southwest to northeast (Barber et al., 2005). The western coast is shaped by the Barisan mountain range with its main peaks rising up to more than 2000 meters above sea level overtopped by Mt. Kerinci with 3805 meters above sea level. Many of the peaks are recent or active volcanoes, including Mt. Kerinci. The formation of the Barisan Mountains and the volcanic activity is caused by the collision and the movement of the Indian plate under the Asian plate which began 70 million years ago. The eastern part of the island is slightly undulating or flat with a few ranges of hills. Towards the eastern coast Sumatra is dominated by broad lowland areas with extended swamplands (Whitten et al., 2000).

The Barisan Mountains have a strong influence on the Sumatran climate and act as a barrier, blocking clouds and moist winds from the west. This results in high precipitation rates on the western side of the Barisan Mountains with rainfall up to 6000 mm/a and with less than 1500 mm/a in some areas on the eastern side (Whitten et al., 2000). The distribution of the rain in Sumatra during the year is mainly effected by the north-eastern monsoon between December and March and the south-western monsoon from May to September (Whitten et al., 2000). In Jambi the main precipitations fall from October to January, associated with the north-eastern monsoon (Laumonier, 1997). During the transition period of the north-eastern and the south-western monsoon in April, a second short rainy period occurs. Driest period in Jambi is between May and September (Whitten et al., 2000). The annual rainfall in the lowlands of Jambi is about 3000 mm (Beukema et al., 2007; Laumonier, 1997). With seven to eight wet months and no month with rainfall less than 100 mm a pronounced dry or rainy season does not exist (Beukema et al., 2007). Due to the location beneath the equator the annual fluctuation of the temperature in Sumatra is low and is mainly influenced by the altitude (Whitten et al., 2000). The yearly average minimum and maximum temperatures are 22.5°C and 31.4°C (Beukema et al., 2007).

The study area is located within the EFForTS project area (Figure 2), between Bukit Duabelas National Park and the Batang Asai River, a tributary of Sumatra’s longest stream the Batanghari. Bukit Duabelas National Park (BDNP) is located in Jambi Province in the centre of Sumatra and belongs to three administrative regencies: Sarolangun Bangko, Bungo Tebo, and Batanghari (MoFEC, 2015). The natural vegetation of BDNP is Dipterocarp dominated tropical lowland rainforest (Laumonier, 1997). The parks name, Bukit Duabelas means “The twelve hills”, due to the topography varying from flat to slightly hilly with a small range of outstanding hills in the south. The elevation of BDNP ranges from 50 m asl to heights up to 438 m asl (MoFEC, 2015). BDNP was founded in 2000 and covers an area of 60,500 ha with the following geographic coordinates: 102°29' – 102°49' E; 1°44' – 1°58' S (MoFEC, 2015). Inside BDNP average day temperatures range from 24 °C to 29 °C and the relative humidity varies between 71 % and 100 % (Kusuma & Hendrian, 2011). The soils are dominated by mainly well drained acidic red or yellow oxisols and ultisols, both low in nutrients (Laumonier, 1997; Whitten et al., 2000). In some areas also peat soils can be found, especially south of the national park. BDNP is an important water catchment area for the Batanghari watershed (MoFEC, 2015).

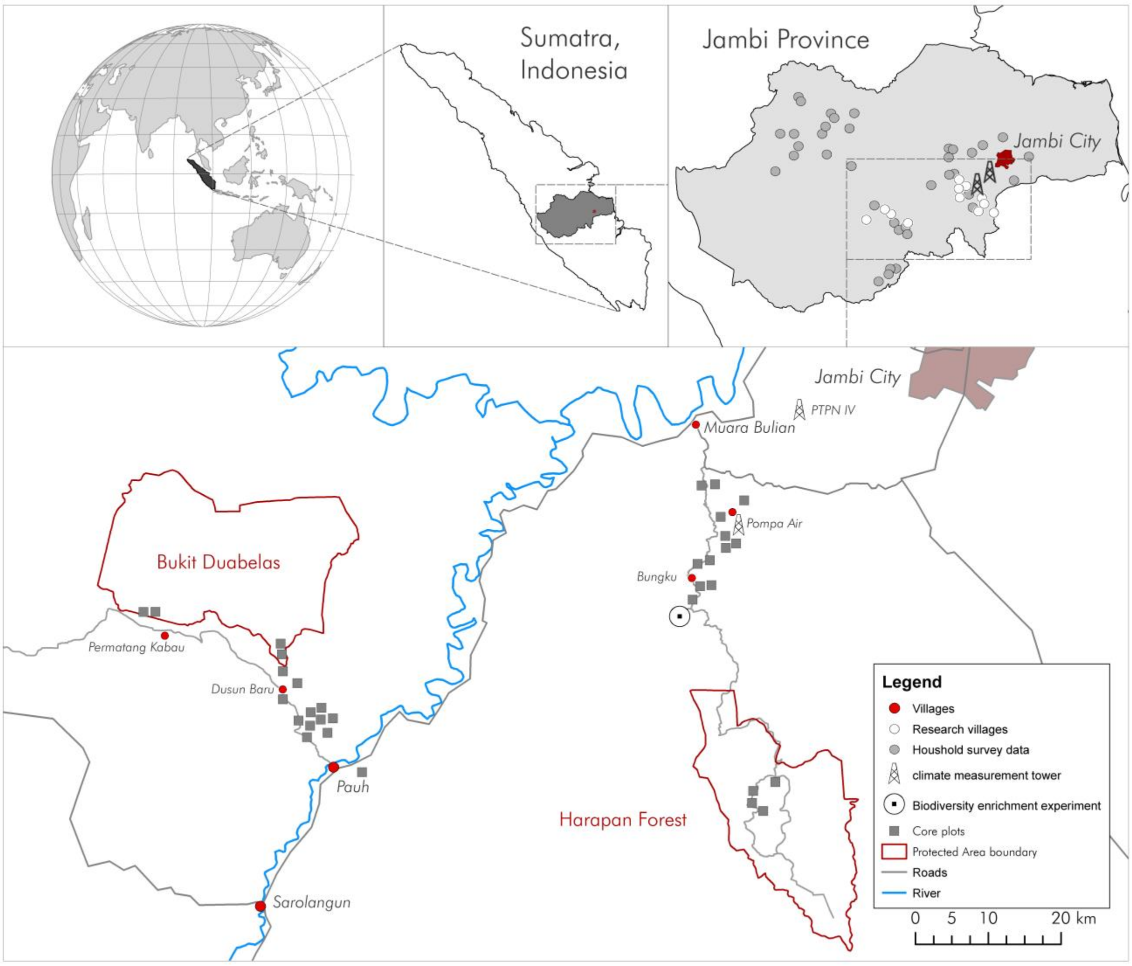

Figure 2: Location of the EFForTS project region in Jambi Province, Sumatra. (Source: Arne Erpenbach, 2015)

The area inside and around Bukit Duabelas National Park is homeland for the Orang Rimba (“people of the forest”) - a semi-nomadic indigenous group of people. Inside the forest, the Orang Rimba live from hunting, collecting plants and from swidden farming with crops like cassava or upland rice. Additionally they sell rubber from native rubber trees and produced on small rubber plantations inside the forest, resins collected from forest trees and other forest products such as Jenkol (*Archidendron pauciflorum*). Nowadays BDNP is living space for 1,300 Orang Rimba. The history of the park started in 1984 shortly after the first large scale logging activities in the region. In that time 30,000 ha were declared as protected living space for the Orang Rimba. To maintain their way of life the Orang Rimba are dependent on sufficient large areas of lowland rainforest (Steinebach, 2008).

3.2 Plot establishment and design

A total of 42 epiphyte plots were established in jungle rubber and rubber plantations along a distance gradient from Bukit Duabelas National Park to a jungle rubber area east of the Batang Asai River (Figure 3). The established plots were situated at elevations between 35 m asl and 90 m asl. The 30 jungle rubber plots were established in distances of 18 - 19 km (6 plots), 10 km (2 plots), 8 km (4 plots), 2.5 – 3.5 km (9 plots) and 0.2 - 1 km (9 plots) to BDNP. Additionally, it was attempted to establish one paired plot with every jungle rubber plot in a neighboring rubber plantation. Due to lack of neighboring rubber plantations, only a total of 12 paired rubber plots could be established.

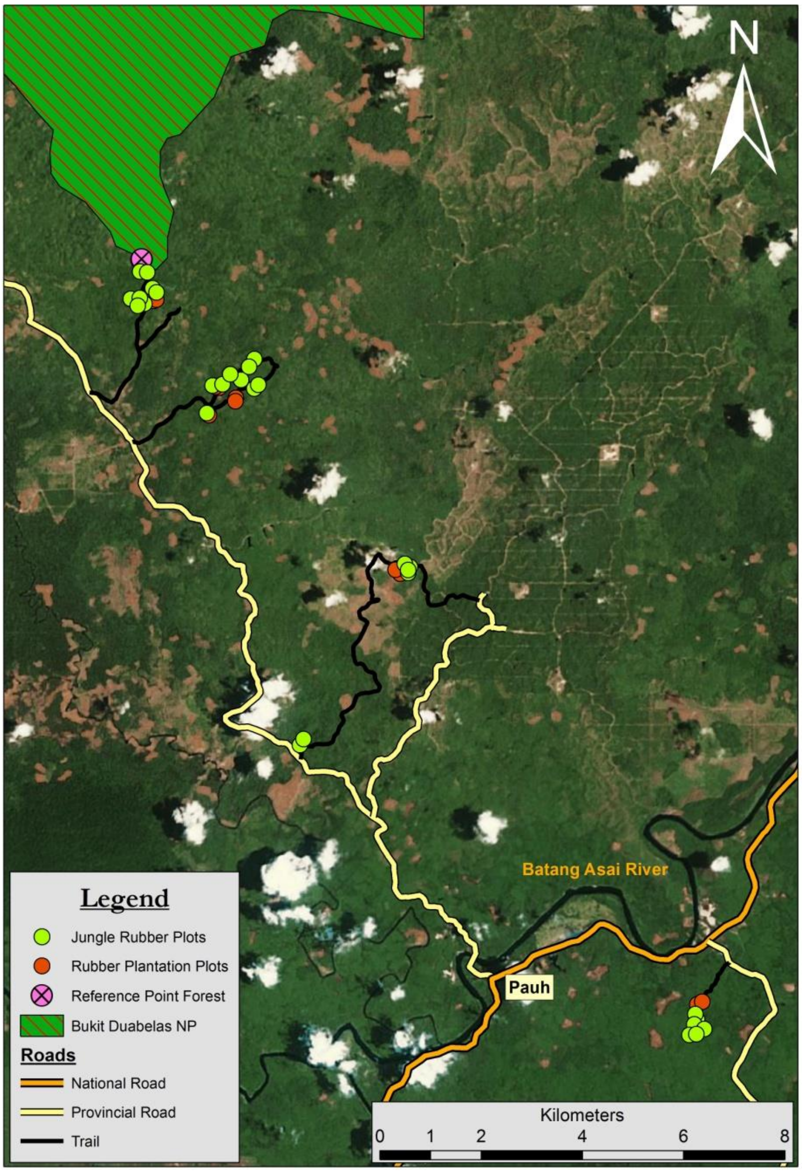

Figure 3: Map of the research area south-east of Bukit Duabelas National Park showing the positions of the established jungle rubber and rubber plantation plots and the access roads and trails.

The plots were established following the methods described by (Gradstein et al., 2003). Each plot measured 20 x 20 m (400 m^2) with one large host tree (phorophyte) in the centre (Figure 4). The jungle rubber plots were established around one native phorophyte and the closest rubber tree was chosen as a paired rubber phorophyte (Figure 4 A). Both, native and rubber phorophyte were examined for presence and abundance of vascular epiphytes. The native phorophytes were randomly chosen by two criteria: the first criterion was a minimum DBH (diameter at breast height at 1.30 m) of 40 cm for each phorophyte to ensure sufficient tree stability for climbing; the second criterion was a minimum distance of 60 m to the next plot. The 12 rubber plots were selected randomly with a maximum distance of 590 m to the paired jungle rubber plot and a minimum distance of 100 m to the next rubber plot. Here, one rubber phorophyte in the centre of each plot was examined for presence and abundance of vascular epiphytes (Figure 4B).

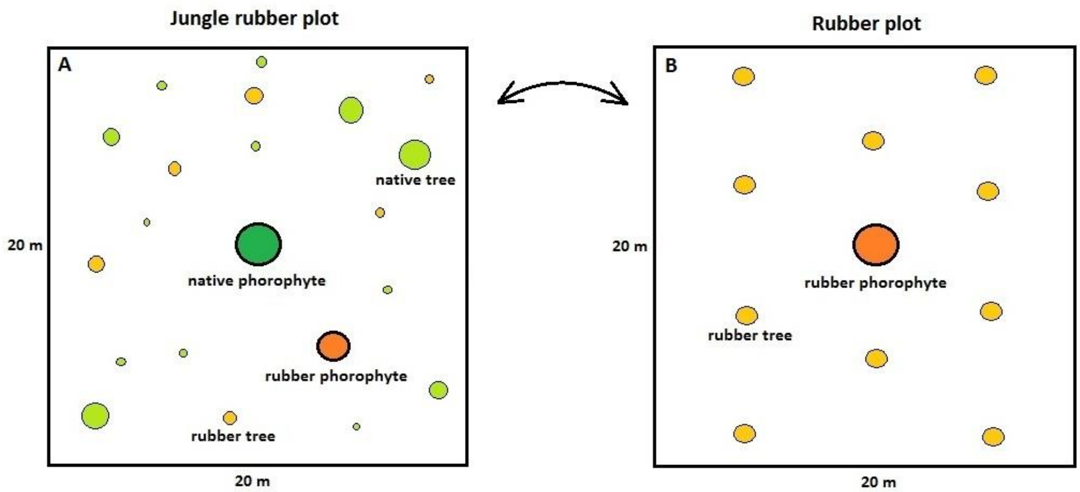

Figure 4: Design of the 20 x 20 meter jungle rubber (A) and rubber plantation (B) plots. Native trees are colored green, rubber trees orange. Phorophytes are characterized by black edging and darker color.

For each phorophyte the following data were collected: GPS coordinates, DBH, height, bark roughness and the height of canopy base (lowest branch). To mark the coordinates a *Garmin 62s* GPS device and for the height measurement a *Haglof Vertex IV* Hypsometer were used. Herbarium samples were collected from each phorophyte for later identification. Within the jungle rubber plots height of canopy base, tree height and DBH were recorded for all rubber and native trees above 10 cm DBH.

For every native and rubber phorophyte a complete inventory of all vascular epiphytes was created. Secondary hemiepiphytes and accidental epiphytes were excluded from this study in accordance to Köster et al. (2013) and Zotz (2013). To reach epiphytes growing in the upper tree crown, the phorophytes had to be climbed. Climbing was performed using the single rope climbing technique after Perry & Williams (1995) and Stoehr (2010). The following material was used for climbing the trees: throwing-bags (200 - 300 g), shooting-line (100 m), sling shot (*Bigshot*), climbing rope (50 m), climbing harness (*Petzl Avao Bod*), ascender (*Petzl*), belay device (*Petzl ID*) and several carabiners.

Because rubber phorophytes were mainly small sized these were investigated from the ground by using a binocular (*Nikon Monarch 10x42 DCF*). Each phorophyte was divided into five Johansson zones (JZ1 – JZ5) as shown in Figure 5 (Johansson, 1974). To compensate the relative small surface of JZ 1 compared to JZ 2 – JZ 5 all epiphytes occurring in JZ 1 on plot trees with a minimum DBH of 10 cm were recorded as well (S. R. Gradstein et al., 2003). For each detected epiphyte individual (morph-)species, growth height, leaf size and the Johansson zone were documented.

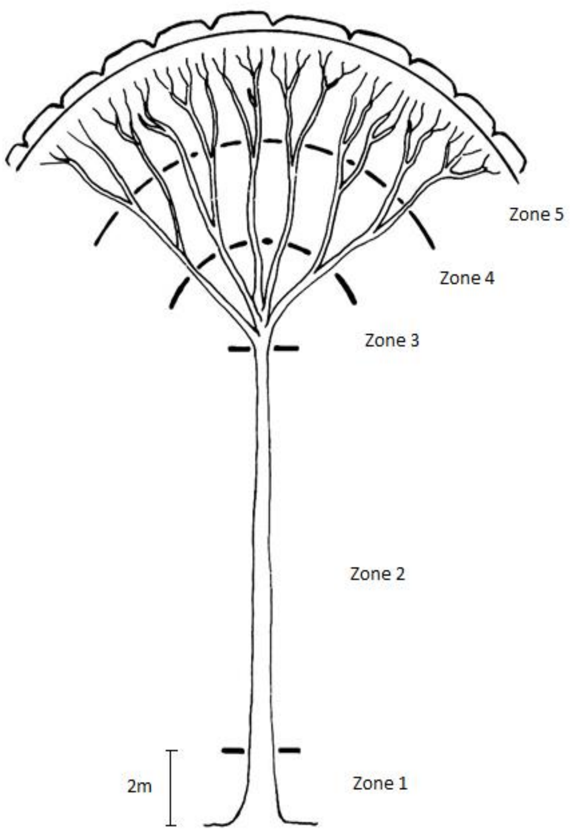

Figure 5: Classification of the phorophyte in five Johansson zones (JZ) (Johansson, 1974).

Figure 6: A) With epiphytes covered branch in a durian tree. B) Forest at the border of Bukit Duabelas National Park. C) The Author climbing a phorophyte. D) Tapped rubber tree in jungle rubber. E) Biggest studied rubber phorophyte in jungle rubber. F) Preparing the collected epiphyte samples. G) Photo documentation, flower of *Acriopsis liliifolia.* Photos: Arne Wenzel (C, E), Lukas Beeretz (A, B, D, F, G)

Of each recorded epiphyte species three herbarium specimens were collected. For a small number of epiphyte species, collecting samples was not possible because these plants grew out of reach in the upper tree canopy. These specimens were documented by taking photos with a *Canon EOS 550D DSLR* with a *Canon EF 70–300mm f/4–5.6* zoom lens.

Detailed close up photos were taken of the collected samples with a *Canon EF-S 60mm f/2.8* macro objective. To ensure sufficient exposure a *Canon MR-14EX* ring flash was used. Additional tools for photographing were a black cloth as background, a tripod for stable positioning and a millimeter scale (Figure 6 G). To preserve the specimen samples these were placed between newspaper sheets and stored in a simple herbar field-press.

After finishing the field work, the recorded species had to be identified at least on genus level and wherever possible on species level. For this matter the collected plant samples were shipped to SEAMEO BIOTROP Bogor (Java). Most of the identification work was accomplished with help from staff at SEAMEO BIOTROP Bogor and staff at the Orchid house in the Botanical Garden Bogor. Used literature and websites were:

- Ferns of Thailand, Laos and Cambodia. (Lindsay & Middleton, 2012)
- Kew garden (The Herbarium Catalogue)
- Orchids of Sumatra (Comber, 2001)
- Ferns of Malaysia in colour (Piggott, 1988)
- Ferns of the tropics (Wee, 1998)

In Bogor the herbarium samples were also prepared for long term storage at the Herbarium Bogoriense (LIPI) and the herbarium of SEAMEO BIOTROP. The taxonomic classification used in this thesis is in accordance with The Plant List (2013; http://www.theplantlist.org/).

The collected data were all transferred to a *Microsoft Access* database to create suitable tables for further statistical analyses with *R* (version 3.1.2). Graphical visualization was performed using *Microsoft Excel* and *R*. The observed species were divided into three taxonomic groups: Orchids (Orchidaceae), Ferns (all Pteridophytes) and other Angiosperms (all other flowering plants beside the orchids).

Figure 7: A) Jungle rubber next to the forest with closed canopy. B) Homogeneous jungle rubber, probably established by slash and burn. C) *Grammatophyllum speciosum* on rubber tree in jungle rubber. D) Logged remnant forest tree in jungle rubber near the village Pauh. E) *Cymbidium* sp. on rubber tree in jungle rubber. F) Remnant forest tree next to rubber tree. G) *Dendrobium pachyphyllum* on rubber tree in jungle rubber. Photos: Lukas Beeretz

3.3 Analysis of epiphyte density and richness

In a first step epiphyte density and richness were compared directly. This was performed for the two land-use systems jungle rubber and rubber plantations and additionally for native and rubber phorophytes within jungle rubber plots. The aim was to figure out the differences between:

- the two land-use systems jungle rubber and rubber plantations
- rubber and native trees within jungle rubber
- rubber trees in plantation and in jungle rubber environment

To interpret the differences the Kruskal-Wallis H-test was applied. This non parametric rank sum significance test was used because the jungle rubber data were not normally distributed. To test normal distribution Shapiro-Wilk and Kolmogorov-Smirnov normality test were applied, the later required the *R* package *nortest*. The results were displayed in boxplots. Additionally, the relation of species density with epiphyte species richness was tested with regression analysis. Regression analysis was performed using the function *lm()* in *R*.

3.4 Analysis of the vertical epiphyte distribution

To analyse the differences in the vertical distribution of epiphyte density and richness between the two landuse systems and also between native and rubber phorophytes within jungle rubber the data were divided into five Johansson zones. Overall, the same procedure as described before was applied here, with the exception, that the boxplots were created with *ggplot2* (version 1.0.0) in this case. This *R* package provides several possibilities to manipulate the plot design and the function *facet wrap* gives a good option to show multiple plots in one figure. Furthermore, the differences of epiphyte individual and species numbers between the five Johansson zones each were tested by pairwise multiple comparison (post-hoc test). This was performed using the function *posthoc.kruskal.nemenyi.test()* of the *R* package *PMCMR* (Pohlert, 2014). Post-hoc test was applied for jungle rubber, rubber plantation and within jungle rubber for native and rubber phorophytes.

To show differences of the ecology of the recorded species, the vertical distribution of the most abundant species with more than 20 individuals was visualized. For this purpose, for each selected species (16 spp.), the individual numbers with the corresponding Johansson zone were plotted each. Visualization was performed with the *R* package *ggplot2*. Because of high differences of the individual numbers between the Johansson zones and between the species, the scale for the individual numbers was logarithmic transformed. Finally, the selected epiphyte species were categorized into five JZ-groups depending on their vertical distribution.

3.5 Analysis of relation between distance to the forest border and epiphyte density and richness

To analyze the influence of distance to the forest border on epiphyte density and richness the distance to the forest border had to be determined for each plot. This was carried out with *QuantumGIS* (*QGIS* Version 1.8.0 Lisboa, 2013), a free available open source geographic information system software (GIS). To acquire the distance data, first the recorded coordinates of each plot were transferred from the GPS device to *QGIS* and a distance matrix was created. As reference a point on the south eastern edge of Bukit Duabelas National Park was defined. The coordinates of the reference point are: longitude, 102.752954 and latitude, -2.008108. As coordinate reference system DGN95/ UTM zone 48S was used. This UTM zone (Universal Transverse Mercator) is up to date and suitable for distance calculations. The acquired distance data were transferred to *Microsoft Excel* (Version 2007) via csv table and prepared for further treatment with the other recorded plot data in *R*.

To describe the relation between epiphyte richness and distance to the forest border, linear, logarithmic transformed and non linear regression models with single and multiple prediction variables were applied (cf. Packard, 2013). R functions for this procedure are *lm()* and *nls().* To identify the best fitting model R^2 was calculated and *Akaike's Information Criterion* was applied (cf. Rossiter, 2009; Spiess & Neumeyer, 2010). This was performed in *R* with the function *AIC().* To identify other explanatory variables for species richness and diversity the applied correlation and regression analysis was repeated for all recorded possible prediction variables. After identifying the variables correlating with species richness, the data were displayed in scatter plots, in case of significance together with the selected regressions. Visualization was performed in *R* with the package *ggplot2*. This procedure was applied on the two landuse systems jungle rubber and rubber plantation and within jungle rubber for native and rubber phorophytes.

In addition to the correlation and regression analysis of epiphyte density and richness with the related data, the distribution and abundance of each recorded epiphyte species along the distance gradient was visualized to identify differences in the distribution patterns on landscape level across the different recorded epiphyte species and taxonomic groups. To make these differences between species recognizable, the distance gradient was divided into 5 segments and for every segment the species' average abundance per phorophyte was calculated. All studied phorophytes were included in the calculation. Argument for categorization of the distance segments was clustering of the 30 jungle rubber and 12 rubber plantation plots in five zoned groups. The observed species were divided into three categories: orchids (Orchidaceae), ferns (all Pteridophytes) and other Angiosperms (all other flowering plants). Visualization was performed as a table chart with the package *ggplot2* in *R*. In dependence on their occurrence and abundance the epiphyte species were categorized into four abundance groups:

1. High abundance and widely distributed (>20 individuals, occurrence in 3 to 5 distance segments)
2. High abundance and not widely distributed (>20 individuals, occurrence in 1 to 2 distance segments)
3. Low abundance and widely distributed (≤ 20 individuals, occurrence in 3 to 5 distance segments)
4. Low abundance and not widely distributed (≤ 20 individuals, occurrence in 1 to 2 distance segments)

3.6 Analysis epiphyte communities

To show the differences of the epiphyte communities between both land-use systems, rank frequency and rank abundance plots were created. For the rank frequency plot, the recorded epiphyte species were ranked in accordance with their occurrence frequency in the studied plots of each land-use system. The determined ranks were displayed on the x-axis and the occurrence frequency on the y-axis. To compare both land-use systems, the occurrence frequencies were plotted as relative values. For the rank abundance plots the same procedure was applied, with the abundance of the species instead of the occurrence frequency. For better comparability the abundance values were shown as relative values on a logarithmic scale.

To discuss hypothesis 3 some of the recorded epiphyte species were characterized in accordance to their possible ecological amplitudes. Due to sparse specific information about the ecological amplitudes of the recorded species and the absence of characterizing data of the different epiphytic habitats, within the limits of this thesis only a rough ecological characterization of species could be performed. Species occurring frequently and widely distributed (abundance-group 1 and 3) in both land-use systems were defined as generalist species. Conversely, species occurring in only one land-use system with low frequency and not widely distributed (abundance-group 2 and 4) were defined as specialist species. As an indication for the ecological amplitude, the vertical distribution of the 16 most abundant epiphyte species was included in the characterization. The results of the characterization will only be discussed (chapter 5.3).

3.7 Analysis paired plots and phorophytes

Additionally to the influence of distance to the forest border on epiphyte density and richness, a possible influence of epiphyte density and richness of neighboring plots and phorophytes was examined. This was done between jungle rubber plots and neighboring rubber plantation plots, between rubber phorophytes in jungle rubber and rubber plantations and between native and rubber phorophytes within jungle rubber plot. To recognize influences caused by vicinity, suitable plot and phorophyte combinations had to be identified. In case of corresponding plots of the two land-use systems – jungle rubber and rubber plantations – it was not realizable to establish a paired rubber plantation plot for each jungle rubber plot. Because of the heterogeneous structure of the area - consisting of jungle rubber, secondary forest, oil palm plantations and rubber plantations - only few neighboring rubber plantations could be located. As a result, 12 rubber plantation plots with a maximum distance to the next jungle rubber plot of approximately 590 meter were established. In the surroundings of every EFForTS jungle rubber core plot, each three rubber plantation plots were established. To create enough pairs for each rubber plot, the two closest jungle rubber plots were identified by generating a distance matrix in *Qgis*. This led to 24 plot combinations on which correlation and regression analysis was applied. Visualization was accomplished using ggplot2 in *R*.

4 Results

4.1 Total numbers of recorded epiphyte individuals and species

In the 30 jungle rubber and 12 rubber plantation plots studied, an overall number of 2144 individuals of 49 species and 11 families of vascular epiphytes were recorded. Of these, 1950 individuals (91 %) of 48 species and 10 families were found in jungle rubber and 194 individuals (9 %) of 13 species and 8 families were found in rubber plantations. Hence 12 species of 7 families occurred in both of the two systems. Most of the recorded species were identified as holoepiphytes, only 4 species with each two of the families Moraceae and Melastomaceae were categorized as primary hemiepiphytes.

Ferns dominated the recorded vascular epiphytes in jungle rubber with 1417 individuals (72.6 %), followed by orchids with 526 individuals (27 %) and other angiosperms with 7 individuals (0.4 %) (Figure 8 a). Ferns also dominated the rubber plantations with 188 individuals (97 %), followed by orchids with 4 individuals (2 %) and other angiosperms with 2 individuals (1 %). Ferns and orchids occurred in jungle rubber with each 22 species (each 45.8 %), whereas ferns dominate the orchids in the rubber system with 10 fern (77 %) and 2 orchid species (15 %) (Figure 8 b). Other angiosperms occurred in both systems in only small numbers, 4 in jungle rubber (8.3 %; two *Ficus* spp. and two Melastomaceae spp.) and 1 in rubber (7.7 %; *Dischidia* cf. *imbricata*). The major part of the fern species (11 spp.) belongs to the Polypodiaceae, followed by Davalliaceae with 4 species and Vittariaceae with 3 species. Aspleniaceae, Lycopodiaceae, Nephrolepidaceae and Pteridaceae were represented by species each. The complete species list is provided in Appendix 1.

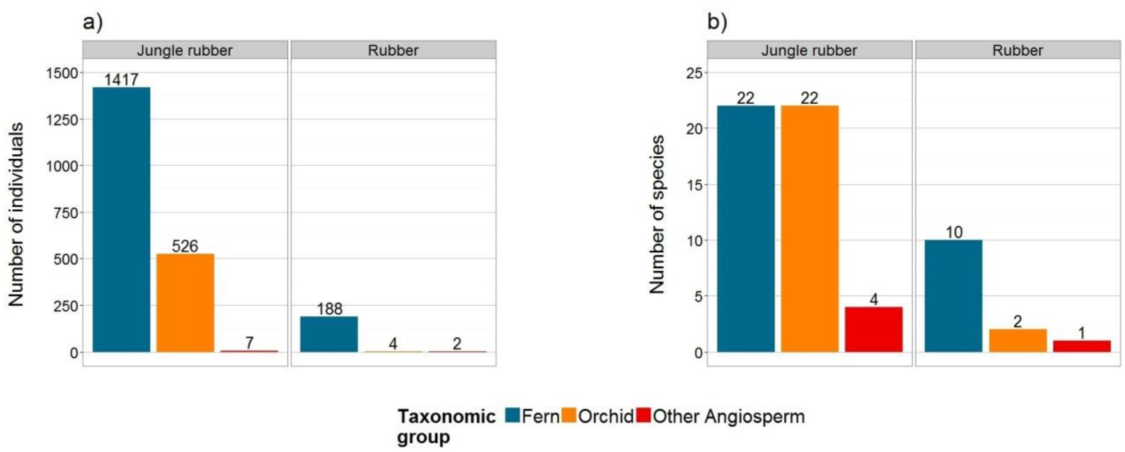

Figure 8: Total number of recorded epiphyte individuals **a)** and species **b)** for the two land-use-systems jungle rubber and rubber plantation across three taxonomic groups. Results based on 30 jungle rubber and 12 rubber plantation plots.

Within the 30 jungle rubber plots, 31 of the 48 recorded species were found on native phorophytes only, 6 species were found on rubber phorophytes only and 11 species were found on both, native and rubber phorophytes. Native and rubber phorophytes differed in their number of epiphyte individuals - the majority of individuals was recorded on native phorophytes (1754 individuals, 90 %). On rubber phorophytes in total 196 epiphyte individuals were recorded. The taxonomic distribution of the epiphyte individuals between native and rubber phorophytes was similar to that of the two land-use systems shown in Figure 8 a (Figure 9 a). The same was true for the distribution of epiphytic fern and other angiosperm species (Figure 9 b). A notable difference between rubber phorophytes in jungle rubber and rubber plantations was that the former harbored more orchid species (6 spp.; Figure 9 b) than rubber plantations (2 orchid spp.; Figure 8 b).

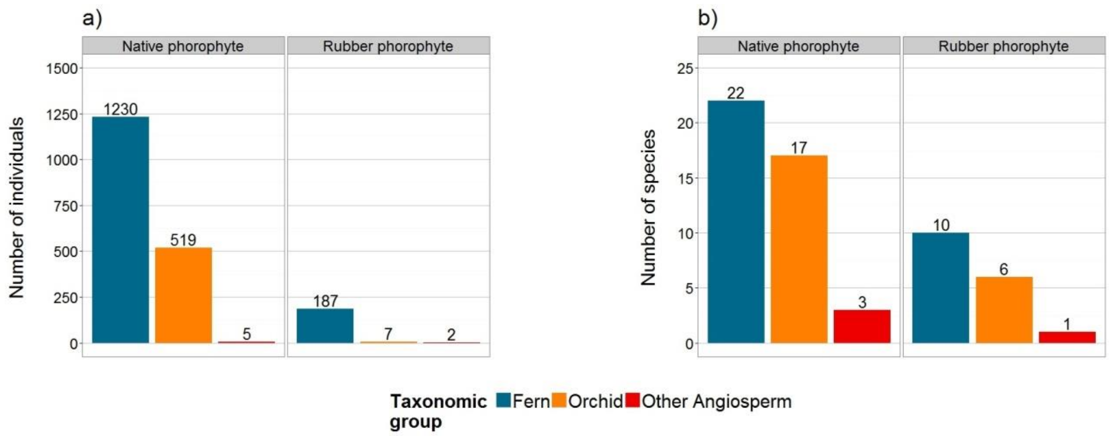

Figure 9: Total number of recorded epiphyte individuals **a)** and species **b)** within jungle rubber for native and rubber phorophytes across three taxonomic groups. Results based on 30 jungle rubber plots.

The 30 native phorophytes studied belonged to 25 different species in 13 families, with *Durio ziberthinus* (durian tree) occurring four times and *Artocarpus elasticus, Endospermum diademum, Koompassia malaccensis* each occurring twice. For a complete phorophyte lists see Appendix 2 – 4.

4.2 Epiphyte density and richness

Jungle rubber had significantly more epiphyte individuals than rubber plantations ($p < 0.05$; Kruskal-Wallis test; Figure 10 a). With an average of 65 individuals per jungle rubber plot and 16.2 individuals per rubber plantation plot, epiphyte density is on average four times higher in jungle rubber than in rubber plantations. Rubber phorophytes within jungle rubber had more than twice as many epiphyte individuals (mean 16.2) than rubber phorophytes within jungle rubber (mean 6.53), but the difference was not significant (Figure 10 b). Comparing epiphyte density between native and rubber phorophytes in jungle rubber (Figure 10 c), it is notable, that beyond some exceptions, the main part of the individuals in jungle rubber were found on native phorophytes. Epiphyte density on native phorophyte (mean 58.47 individuals) was on average nine times higher than on rubber phorophytes (6.53 individuals). The Kruskal-Wallis test showed that this difference is highly significant ($p < 0.001$).

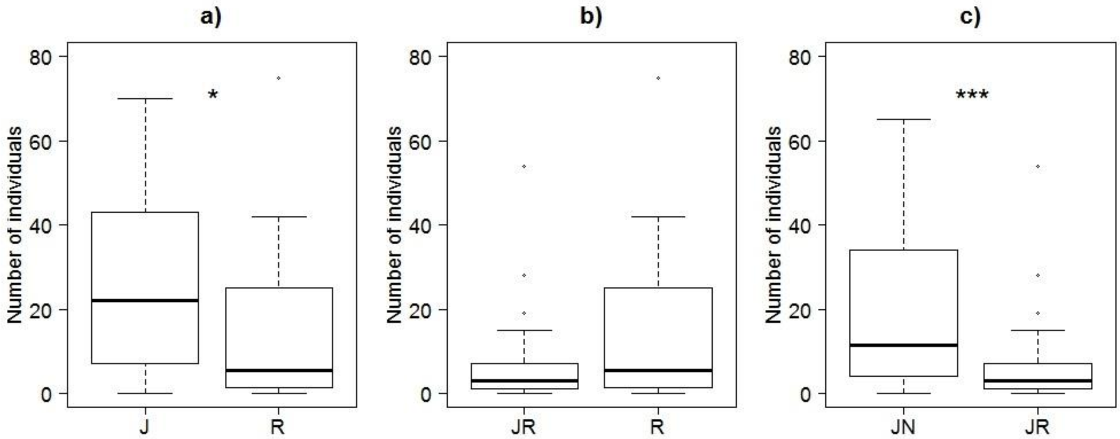

Figure 10: Epiphyte density per plot **a)** in jungle rubber (J) and rubber plantations (R) - **b)** on rubber phorophytes in jungle rubber (JR) and rubber plantations (R) - **c)** in jungle rubber on native phorophytes (JN) and on rubber phorophytes (JR). Six outliers for J with 115, 151, 152, 164, 368 and 531 and six outliers for JN with 98, 115, 148, 164, 364 and 528 individuals are not shown for clarity. Results based on 30 jungle rubber plots and 12 rubber plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05 based on Kruskal-Wallis tests (p-values: a: 0.042 – b: 0.27 – c: 0.00089).

Epiphyte species richness was significantly higher on jungle rubber than on rubber plots ($p < 0.05$; Kruskal-Wallis test; Figure 11 a). Epiphyte species richness was on average two times higher in jungle rubber (mean 5.63 spp.) than in rubber plantations (mean 3 spp.). The comparison of rubber phorophytes within jungle rubber and rubber plantations showed no significant difference (Figure 11 b). Between native phorophytes and rubber phorophytes within jungle rubber epiphyte species richness differed significant ($p < 0.01$; Kruskal-Wallis test; Figure 11 c). Epiphyte species richness was slightly more than two times higher on native phorophytes (mean 4.47 spp.) than on rubber phorophytes (mean 2.2 spp.).

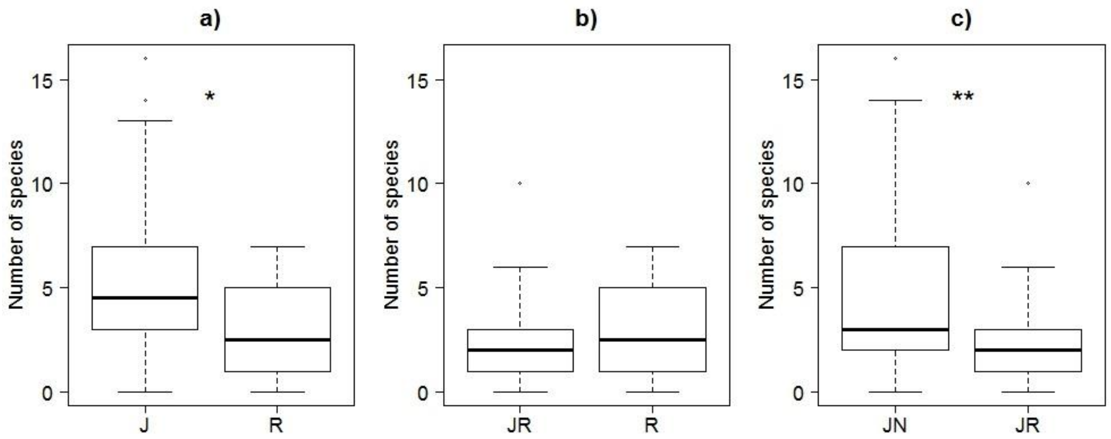

Figure 11: Epiphyte species richness per plot **a)** in jungle rubber (J) and rubber plantations (R) - **b)** on rubber phorophytes in jungle rubber (JR) and rubber plantations (R) - **c)** in jungle rubber on native phorophytes (JN) and on rubber phorophytes (JR). Results based on 30 jungle rubber plots and 12 rubber plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05 based on Kruskal-Wallis tests (p-values: a: 0.034 – b: 0.28 – c: 0.0067).

Vascular epiphyte individual numbers were strongly positive related with epiphyte species numbers in jungle rubber ($p < 0.05$), in rubber plantations ($p < 0.01$) and within jungle rubber on native phorophytes ($p < 0.01$) and rubber phorophytes ($p < 0.001$) (Figure 12).

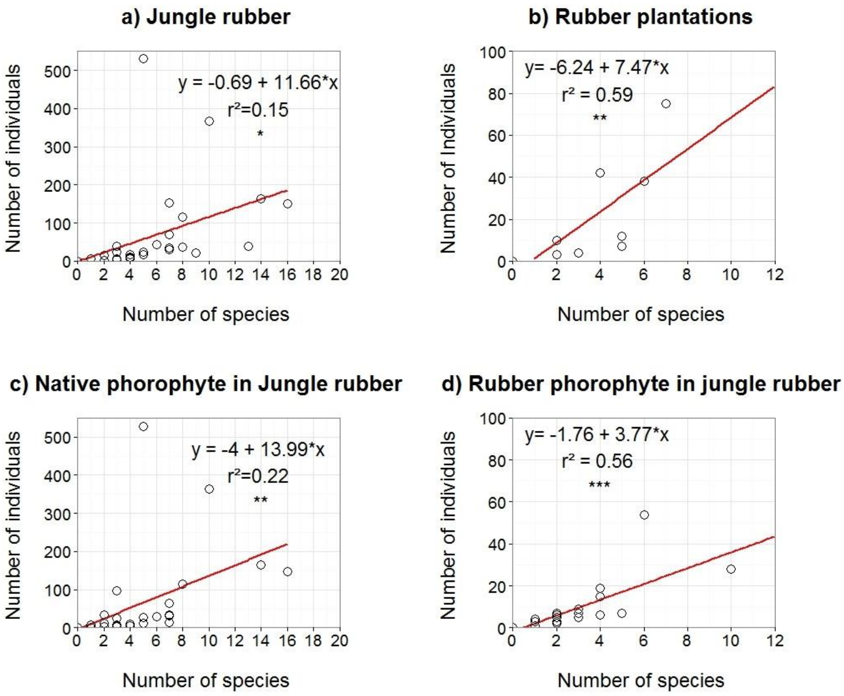

Figure 12: Number of vascular epiphyte individuals with number of vascular epiphyte species for jungle rubber (**a**), rubber plantations (**b**) and within jungle rubber for native phorophytes (**c**) and rubber phoro-

phytes (**d**). Results based on 30 jungle rubber plots and 12 rubber plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05 based on regression analysis.

4.3 Vertical epiphyte distribution

In jungle rubber highest epiphyte individual numbers were found in JZ1 (mean 27.7) followed by JZ3 (mean 21.13), to JZ4 and JZ5 epiphyte individual numbers decreased. The differences between the JZ zones were only partial significant in jungle rubber (Appendix 6). In the rubber plantations epiphyte individual numbers were highest in JZ1 (15.58), but decreased strongly to JZ2 (mean 0.58) and to zero in the upper JZ zones. Differences between the JZ zones were mainly significant in the rubber plantations. Jungle rubber had in JZ1 on average twice as more epiphyte individuals (mean 27.7) than rubber plantations (mean 15.58), but the difference was not significant (Figure 13 A). With a significant difference between both land-use systems in JZ2 ($p < 0.05$), in this zone jungle rubber had on average 20 times more epiphytes individuals (mean 12.03), than rubber plantations (mean 0.58). In rubber plantations no epiphytes were recorded in JZ3 to JZ5, whereas in jungle rubber epiphyte individual numbers increased from JZ2 to JZ3 (mean 21.13) and decreased to JZ4 (mean 3.6) and JZ5 (mean 0.53). The differences between jungle rubber and rubber plantations for epiphyte individual numbers were significant in JZ3 ($p < 0.01$) and JZ4 ($p < 0.05$), but not in JZ5.

In jungle rubber epiphyte species numbers were highest in JZ1 (mean 2.67), followed by JZ3 (mean 2.5) and decreasing to JZ5, but the differences were mainly not significant (Appendix 6). In the rubber plantations epiphyte species numbers were highest in JZ1 and decreased strongly to JZ2 (mean 0.5). In the upper JZ zones (JZ3 – JZ5) no epiphytes were found in rubber plantations. In the rubber plantations JZ1 differed mainly significant from the other JZ zones. Differences of epiphyte species numbers in JZ1 between jungle rubber (mean 2.97) and rubber plantations (mean 2.67) could not be identified (Figure 13 B). In JZ2 jungle rubber showed almost four times more epiphyte species (mean 1.87), than rubber plantations (mean 0.5), but the difference was just not significant ($0.05 < p < 0.1$). In JZ3, JZ4 and JZ5 no species were found in rubber plantations, while jungle rubber showed the second highest epiphyte species number in JZ3 (mean 2.5) and differs significantly from rubber plantations in this zone ($p < 0.01$). In JZ4 of jungle rubber, epiphyte species numbers (mean 1.13) differ significantly from rubber plantations ($p < 0.05$). In JZ5 the differences of epiphyte species numbers between jungle rubber (mean 0.16) and rubber plantations (0) were not significant.

The detailed results of the pairwise multiple comparisons of the five Johansson zones (epiphyte density and richness) of jungle rubber and rubber plantations are shown in Appendix 6.

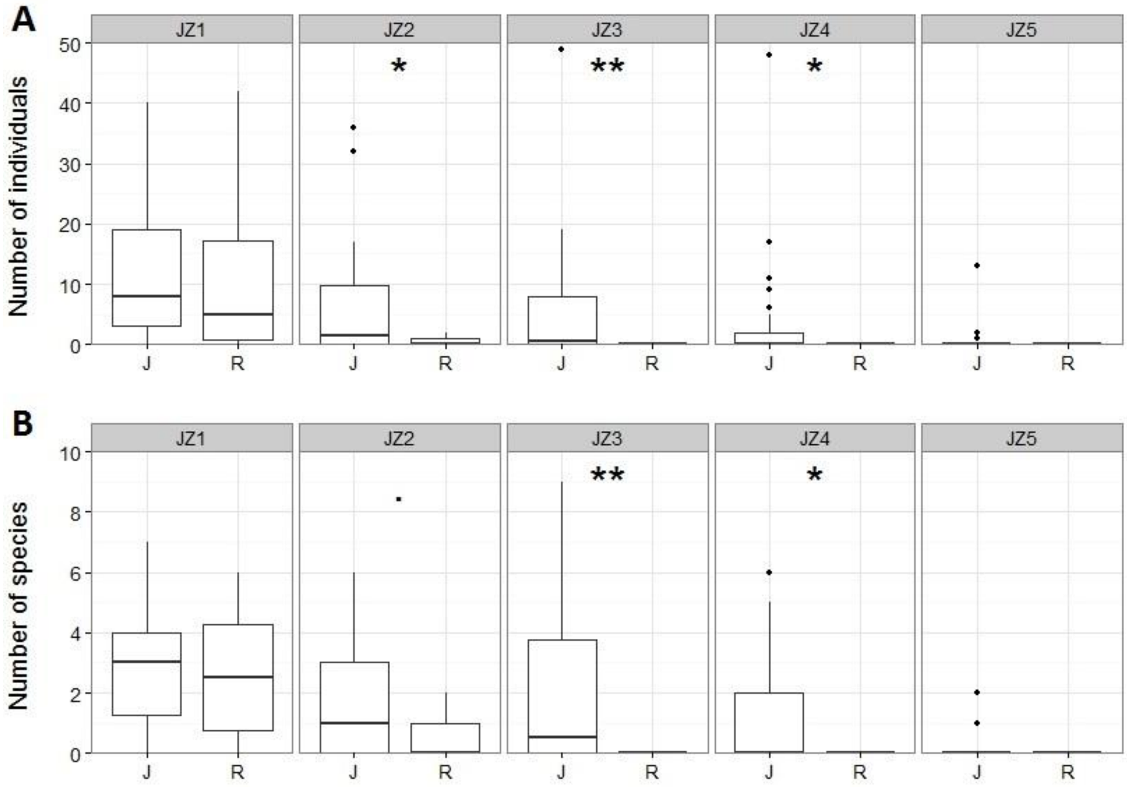

Figure 13: Number of epiphyte individuals (**A**) and number of epiphyte species (**B**) in jungle rubber (J) and rubber plantation (R) divided into five Johansson Zones (JZ1 to JZ5). For clarity, in A ten outliers are not shown in this figure, for JZ1 four in J with 55, 57, 89 and 380 individuals and one in R with 74 individuals, for JZ2 two in J with 61 and 150 individuals and for JZ3 three in J with 100, 107 and 307 individuals. In B two outliers are not shown, both in J for JZ3 with 13 and 14 individuals. Kruskal-Wallis p-values for **A:** JZ1: 0.39; JZ2: 0.04; JZ3: 0.003; JZ4: 0.01; JZ5: 0.26 and **B**: JZ1: 0.75; JZ2: 0.05; JZ3: 0.003; JZ4: 0.01; JZ5: 0.26. Results based on 30 jungle rubber and 12 rubber plantation plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1.

Within jungle rubber native phorophytes showed the highest epiphyte individual numbers in JZ1 (mean 21.73) and JZ3 (mean 21.1), but the differences between the JZ zones were mainly not significant (Appendix 6). On rubber phorophytes within jungle rubber highest epiphyte individual numbers were found in JZ1 (mean 5.97), this zone mainly differed significantly from the other JZ zones. On average native phorophytes showed four times higher epiphyte individual numbers in JZ1 (mean 21.73) than rubber phorophytes (mean 5.97), but the difference was not significant (Figure 14 A). With a highly significant difference ($p < 0.001$) native phorophytes showed in JZ2 more than 20 times higher epiphyte individual numbers (mean 11.6) than rubber phorophytes (mean 0.43). In JZ3 native phorophytes had almost identical epiphyte individual numbers (mean 21.1) than in JZ1, whereas individual numbers on rubber phorophytes in this zone decreased to almost zero (mean 0.03). The difference between both phorophytes was highly significant in JZ3 ($p < 0.001$). On native phorophytes epiphyte individual numbers decreased in JZ4 (mean 3.5) and JZ5 (mean 0.53). Rubber phorophytes had almost zero epiphyte individuals in JZ4 (mean 0.1) and no individuals in JZ5. The difference between the two phorophytes was significant in JZ4 ($p < 0.01$), but not significant in JZ5.

Highest epiphyte species numbers on native phorophytes within jungle rubber were found in JZ3 (mean 2.46), followed by JZ2 (mean 1.63) and JZ1 (mean 1.6), but the differences were not significant (Appendix 6). On rubber phorophytes within jungle rubber epiphyte species numbers were significantly highest in JZ1 (mean 1.93; $p < 0.001$), while the other zones showed almost no epiphytes species. Between native and rubber phorophytes no differences could be identified for epiphyte species numbers in JZ1 (Figure 14 B). Epiphyte species numbers on native phorophytes differed significantly in JZ2 (mean 1.6), JZ3 (mean 2.46) and JZ4 (mean 2.46) from the corresponding zones on rubber phorophytes (JZ2: mean 0.3, $p < 0.01$; JZ3: mean 0.03, $p < 0.001$; JZ4: mean 0.01, $p < 0.01$). In JZ5 epiphyte species numbers showed no significant difference between native phorophytes (mean 0.17) and rubber phorophytes with no epiphytes species in this zone.

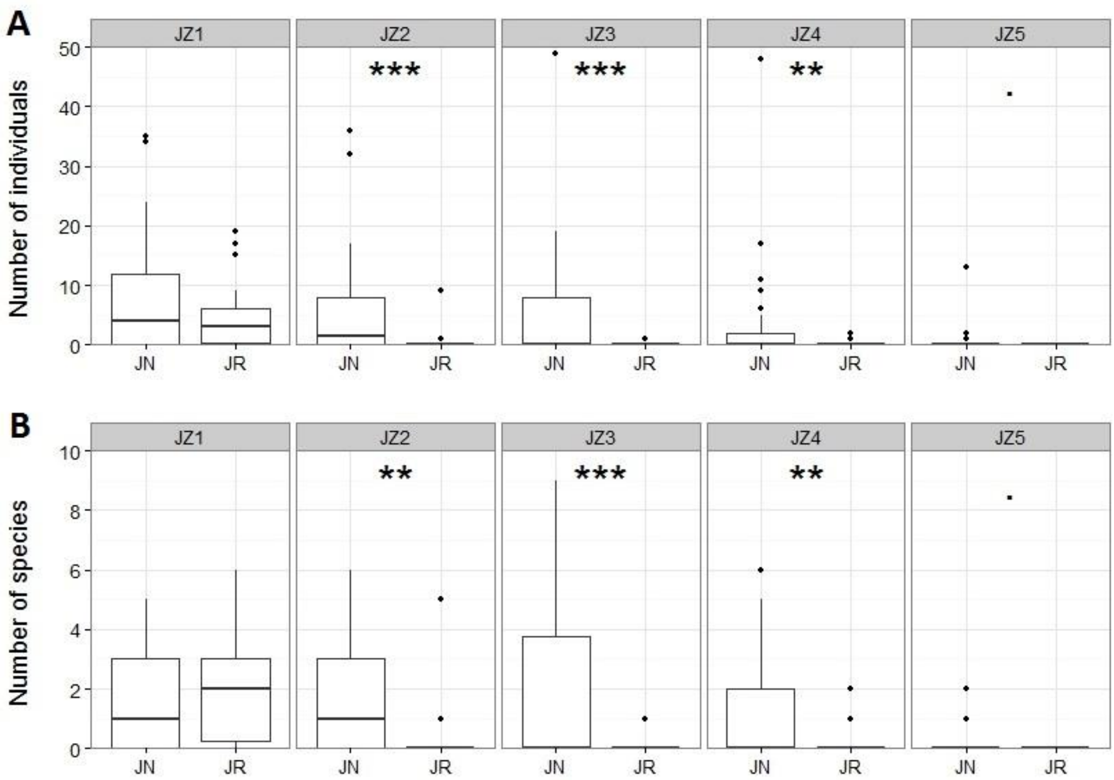

Figure 14: Number of epiphyte individuals (**A**) and number of epiphyte species (**B**) in jungle rubber on native phorophytes (JN) and rubber phorophytes (JR) divided into five Johansson Zones (JZ1 to JZ5). For clarity, nine outliers are not shown in this figure **A**, for JZ1 three in JN with 51, 52 and 377 individuals and one in JR with 54 individuals, for JZ2 two in JN with 61 and 150 individuals and for JZ3 three in JN with 100, 107, and 307 individuals. For **B** two outliers are not shown in this figure, both in JN with 13 and 14 individuals for JZ3. Kruskal-Wallis p-values for **A**: JZ1: 0.67; JZ2: 0.0008; JZ3: 0.00009; JZ4: 0.007; JZ5: 0.08 and **B:** JZ1: 0.53; JZ2: 0.001; JZ3: 0.00009; JZ4: 0.007; JZ5: 0.08. Results based on 30 jungle rubber plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1.

To allow deeper insights in the ecology of some species the vertical distribution of the 16 most abundant species across five Johansson zones is visualized (Figure 15). Because of some species with very low or high individual numbers, the individual numbers are logarithmic transformed. Noticeable is, that most of the species show peaks in Johansson zone 1 or 3, some species even in both. Depending on the vertical distribution patterns across the Johansson zones, the selected species were roughly divided into five JZ-groups:

I. Species found almost only in Johansson zone 1 and 2 (*Antrophyum callifolium* and *Microsorum punctatum*). Observations during fieldwork showed that these species were mainly found in the understory at moist and highly shaded parts of the phorophyte.
II. Species with peaks in Johansson zone 1 and 3 (*Nephrolepsis acutifolia* and *Vittaria elongata*). Observations during fieldwork showed that these species were

mainly found at parts of the phorophyte rich in moist and accumulated humus, for example branch forks and hollows.

III. Species with the peak in Johansson zone 4 (*Bulbophyllum sp. II* and *Pyrrosia pilloselloides*). Observations during fieldwork showed, that these species were mainly found at sunlight exposed big to thin branches in the upper canopy of the phorophyte.

IV. Species with the peak in Johansson zone 3 (*Acriopsis densiflora, Bulbophyllum sp. V, Cleisostoma subulatum, Dendrobium leonis* and *Huperzia sp. I*). The first three of these species were mainly found in the centre of the phorophyte in partial shaded parts. *Dendrobium leonis* was mainly found on big horizontal sunlight exposed branches in the canopy. *Hupezia sp. I* was only found on the bottom side of big sunlight exposed branches.

V. Species with characteristics of two or more of the described distribution patterns (I - IV). To this group the remaining three highly abundant fern species, *Asplenium nidus, Davallia denticulata* and *Drynaria quercifolia* can be assigned. During fieldwork *Asplenium nidus* individuals have been found as medium to large sized plants growing in almost all Johansson zones at partial shaded stable parts of the phorophyte mainly near the stem. Extreme large numbers of this fern in very small juvenile stages have been found in the lower two Johansson zones. *Davallia denticulata* have been found in large numbers in juvenile stage at lower parts and in adult stage at partial shaded to sunlight exposed parts in all Johansson zones, but mainly at places richer in accumulated humus. *Drynaria quercifolia* has been found at parts rich in accumulated humus all over the phorophyte. Large numbers of this species in juvenile stage have been found at lower parts of the phorophytes.

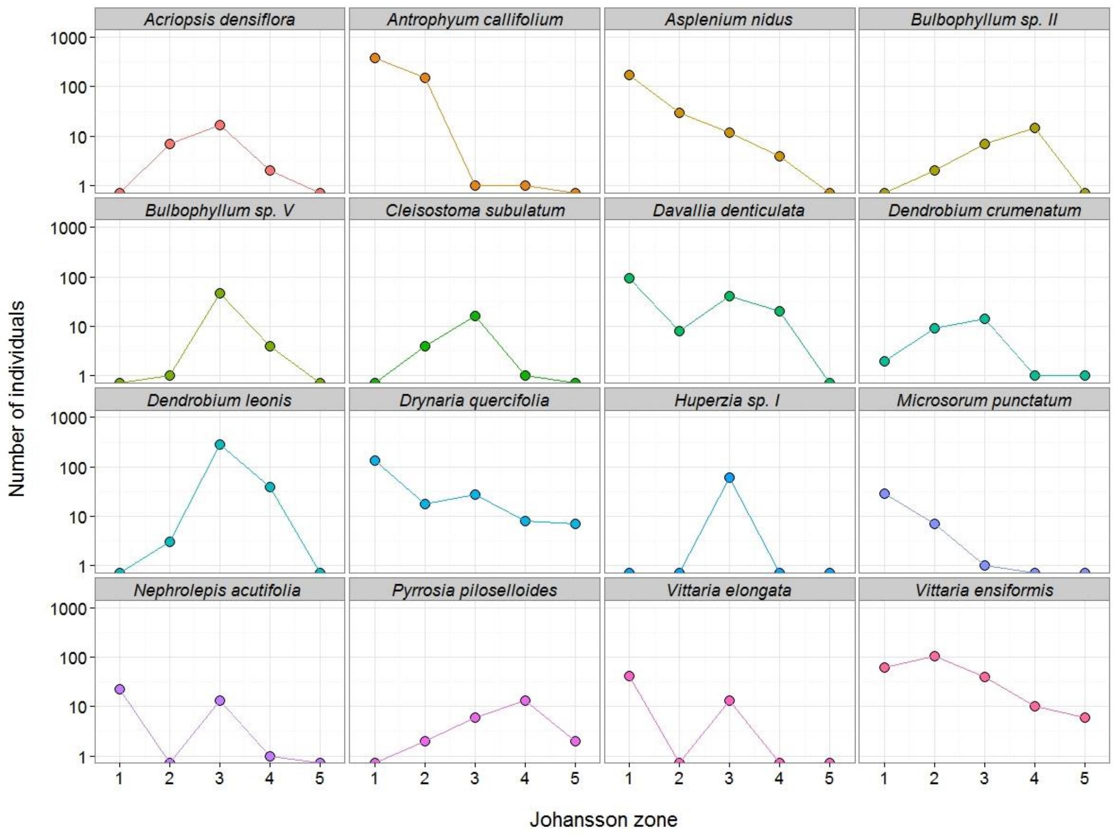

Figure 15: Vertical distribution of the 16 most abundant epiphyte species with more than 20 recorded individuals each across five Johansson zones. Number of individuals (y-axis) is logarithmic transformed.

4.4 Distance to forest border

The density of vascular epiphytes per plot was negatively related to the distance to the forest border for: jungle rubber ($p < 0.01$), rubber plantations ($p < 0.001$ and within jungle rubber for native phorophytes ($p < 0.01$) (Figure 16 a, b, c). For rubber phorophytes within jungle rubber a relation of epiphyte density with the distance to the forest border could not be identified (Figure 16 d). The calculated regressions explain the decreasing epiphyte density with the increasing distance to the forest border mainly for rubber plantations (r^2 0.8) and partial for jungle rubber (r^2 0.27) and native phorophytes within jungle rubber (r^2 0.23). The characteristics of the drawn regression lines differ between both land-use systems. The regression curves for jungle rubber and the native phorophyte within it are flatter and decline slowly with increasing distance to the forest, in contrast to that is the regression line for the rubber plantations steep and declines quickly with increasing distance the forest.

High values and outliers for epiphyte density show mostly also high values for basal area, visualized with a color gradient. The results of the correlation analysis between epiphyte density and basal area of the phorophyte are shown in Figure 19.

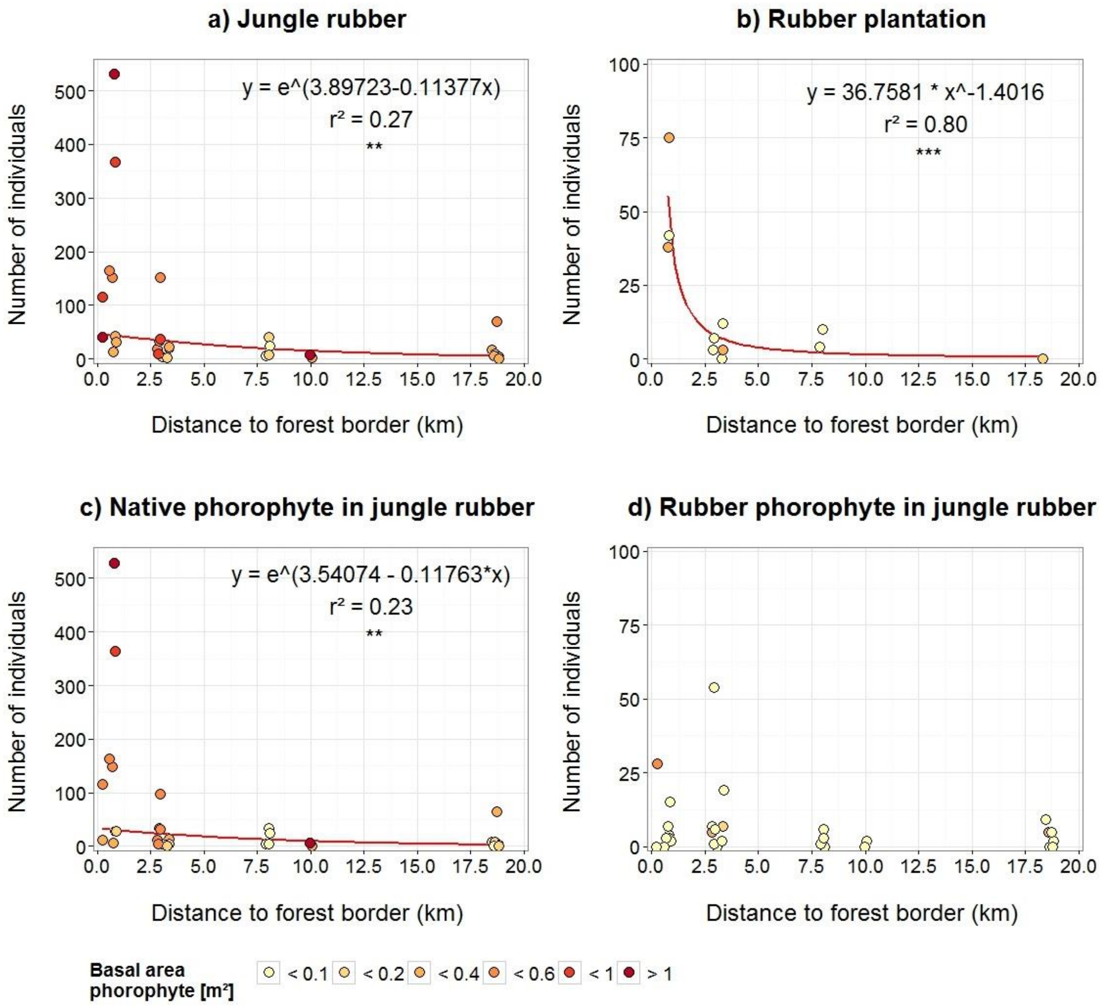

Figure 16: Epiphyte density with increasing distance from the forest for jungle rubber **a)**, rubber plantations **b)** and in jungle rubber on native phorophytes **c)** and rubber phorophytes **d)**. Color is showing basal area of the phorophyte. Results based on 30 jungle rubber and 12 rubber plantation plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1, based on non-linear and log-transformed regression analysis.

Vascular epiphyte species richness per plot is negatively related with the distance to the forest border for: jungle rubber ($p < 0.001$), rubber plantations ($p < 0.01$) and within jungle rubber for native phorophytes ($p < 0.01$) (Figure 17 a, b, c). Rubber phorophytes within jungle rubber show no relation between epiphyte species richness and the distance to the forest border (Figure 17 d). The calculated regressions explain decreasing epiphyte species richness with the increasing distance to the forest border partial for jungle rubber (r^2 0.43), rubber plantations (r^2 0.58) and for native phorophytes within jungle rubber (r² 03). All drawn regression curves show the same characteristic, but on different levels.

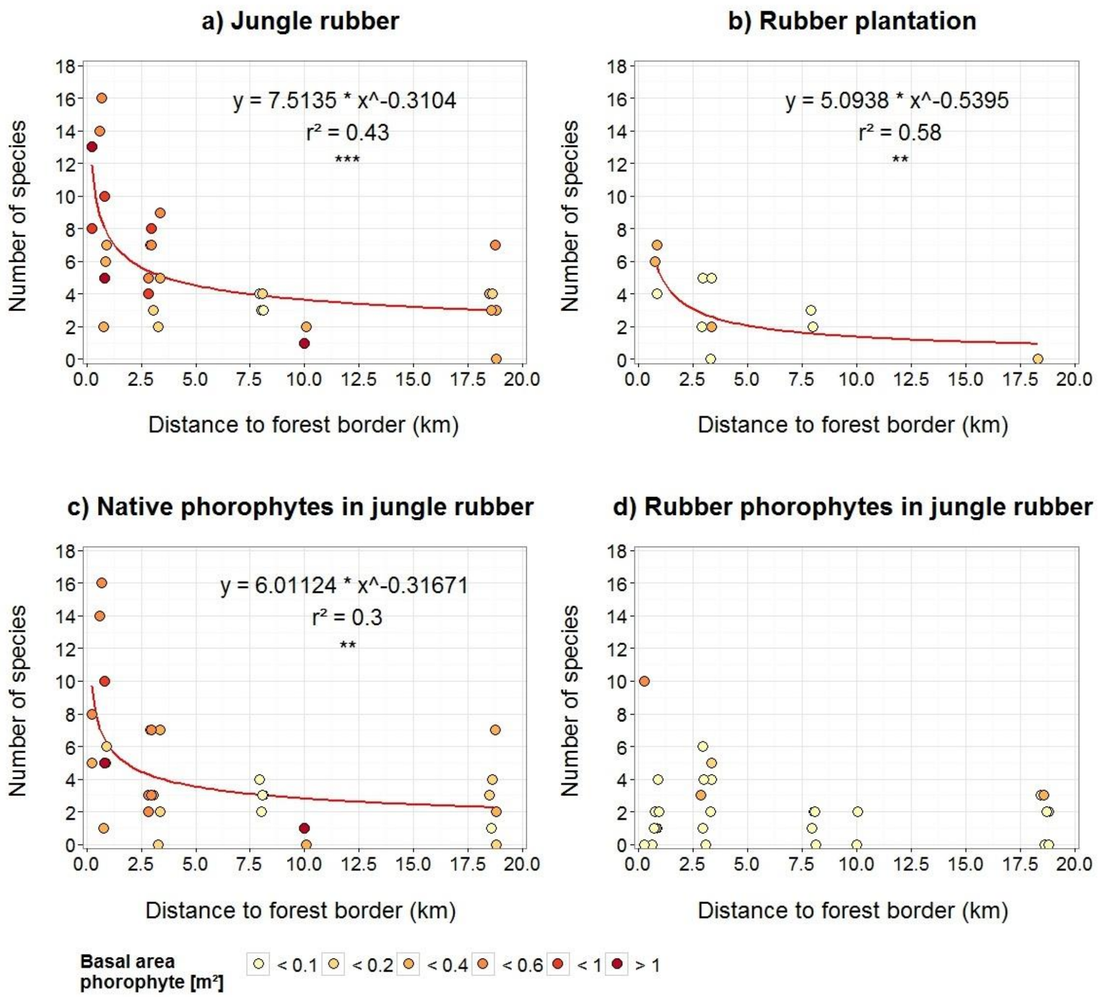

Figure 17: Epiphyte species numbers with increasing distance from the forest for jungle rubber **a)**, rubber plantations **b)** and in jungle rubber on native phorophytes **c)** and rubber phorophytes **d)**. Color is showing basal area of the phorophyte. Results based on 30 jungle rubber and 12 rubber plantation plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1, based on non-linear regression analysis.

The recorded vascular epiphyte species showed different distributions and abundances along the distance gradient to the forest (Figure 18). Most species were found next to the forest (distance 0.2 – 3.5 km) and also the abundances of most species were higher next to the forest (distance 0.2 – 1 km). All other angiosperms and almost all orchids were found next to the forest (distance 0.2 – 3.5 km). Ferns were found along the complete distance gradient, but with highest species richness and abundances next to the forest. In dependence on their abundance and distribution along the distance gradient, the recorded epiphyte species can be roughly divided into four abundance-groups:

1) High abundance and widely distributed, represented only by ferns for example: *Antrophyum callifolium, Asplenium nidus, Davallia denticulata, Drynaria quercifolia* and *Vittaria ensiformis*.
2) High abundance and not widely distributed, for example *Dendrobium leonis* (orchid) and *Huperzia* sp*. I,* part of the Lycopodiaceae family and classified into the taxonomic group of the ferns.
3) Relative low abundance and widely distributed, for example *Monagramma* sp. (fern) - this group is the smallest.
4) Low abundance and not widely distributed, represented by ca. 65 % of all recorded species including most of the orchid species and all other angiosperms.

For the complete list of the abundance groups see Appendix 5.

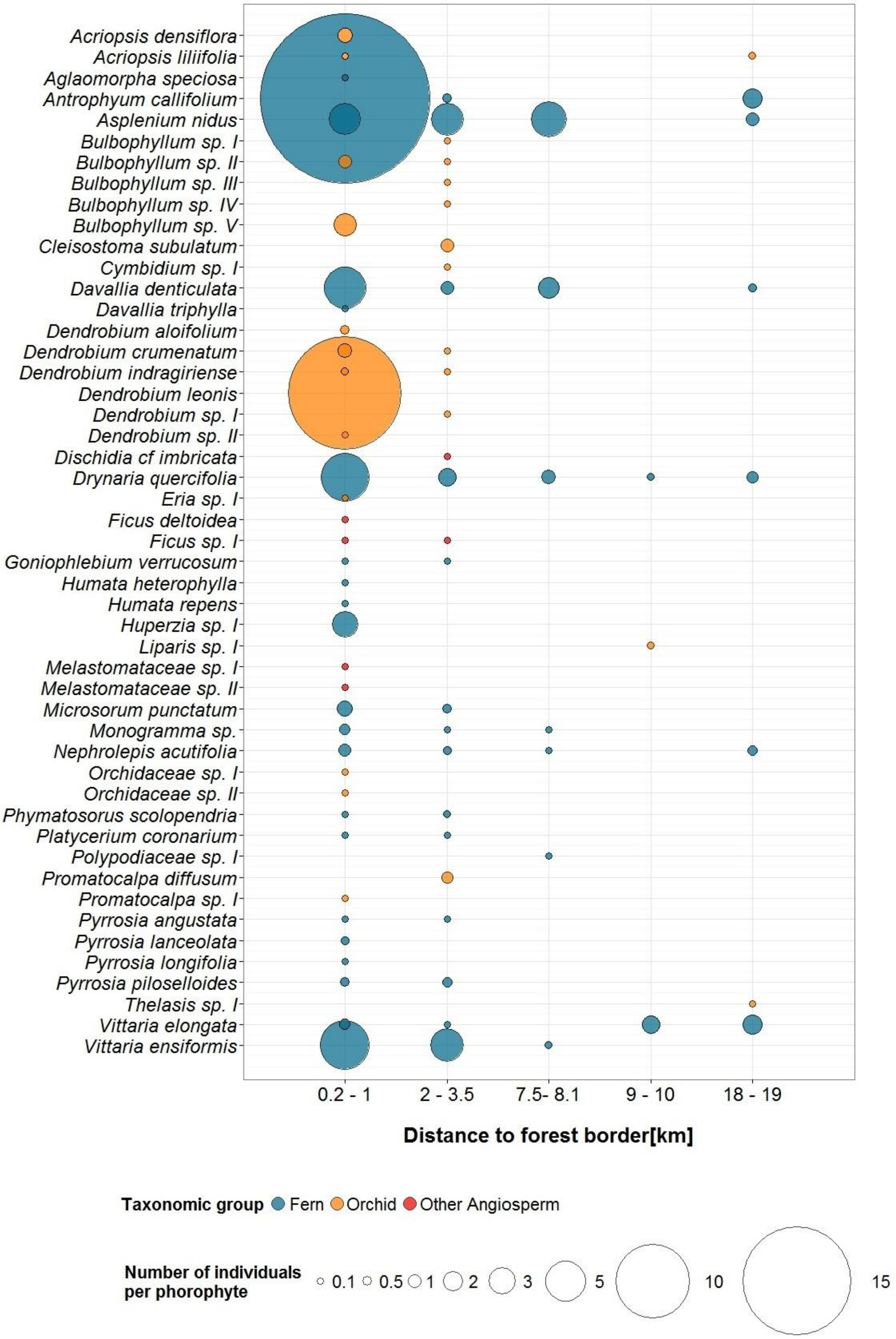

Figure 18: Average abundance per phorophyte (rubber plantations and jungle rubber) of all recorded epiphyte species along a distance gradient from the forest border. The distance gradient is categorized into five segments representing aggregated groups of plots at five distance levels. Epiphyte species are divided across three taxonomic groups represented by the colors. Results based on 30 jungle rubber and 12 rubber plantation plots.

Basal area of the phorophyte

Correlation and regression analysis showed that beside distance to the forest border also the phorophytes' basal area influences epiphyte density and species richness (Figure 19). The average basal area of the phorophytes was approximately three times higher for native trees within jungle rubber (0.33 m²), than for rubber trees within jungle rubber (0.09 m²) and in rubber plantations (0.1 m²). Vascular epiphyte density correlated positively with the basal area of the phorophyte for jungle rubber ($p < 0.001$), rubber plantations ($p < 0.05$) and within jungle rubber for native phorophytes ($p < 0.001$) and rubber phorophytes ($p < 0.05$) (Figure 19). The basal area of the phorophyte explained epiphyte density partially for jungle rubber (r^2 0.33), rubber plantations (r^2 0.37) and within jungle rubber for native phorophytes (r^2 0.43) and rubber phorophytes (r^2 0.19).

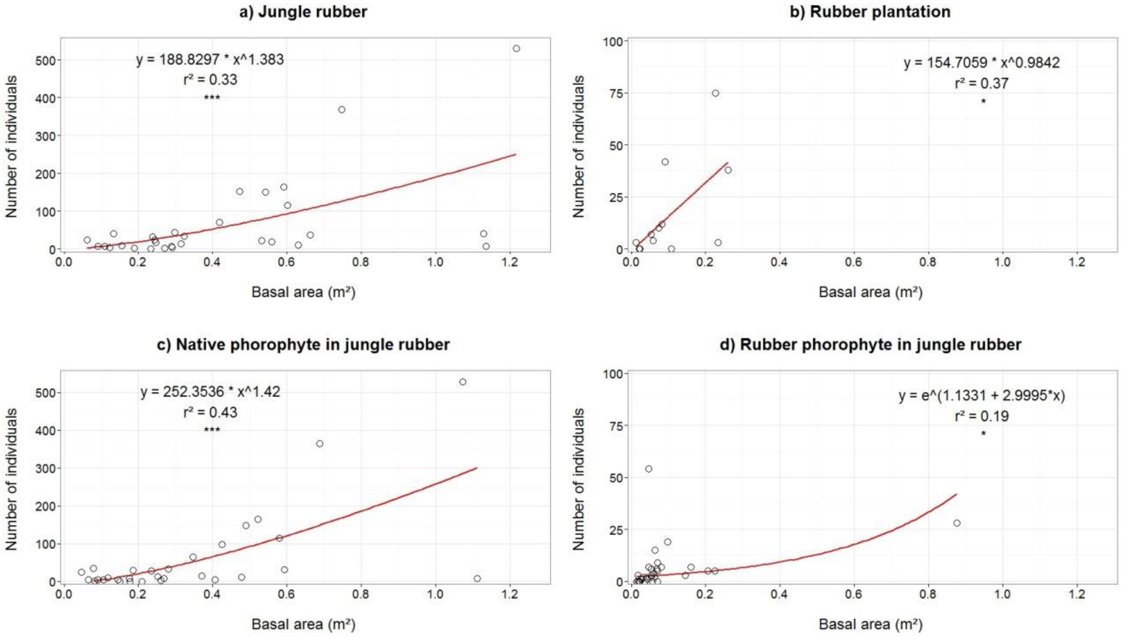

Figure 19: Correlation of epiphyte density and basal area of the phorophyte for jungle rubber **a)**, rubber plantations **b)** and in jungle rubber for native phorophytes **c)** and rubber phorophytes **d)**. Results based on 30 jungle rubber and 12 rubber plantation plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1, based on non-linear and log-transformed regression analysis.

The regression analysis of vascular epiphyte species richness with basal area of the phorophyte showed positive relations for jungle rubber ($p < 0.01$) and within jungle rubber for native phorophytes ($p < 0.01$) and rubber phorophytes ($p < 0.001$) (Figure 20 a, c, d). In rubber plantations this positive relation between epiphyte species richness and basal area of the phorophyte is only weak ($0.05 < p < 0.1$) (Figure 20 b). The basal area of the phorophyte explained epiphyte species richness partially for jungle rubber

(r^2 0.34), rubber plantations (r^2 0.33) and within jungle rubber for native phorophytes (r^2 0.35) and rubber phorophytes (r^2 0.58).

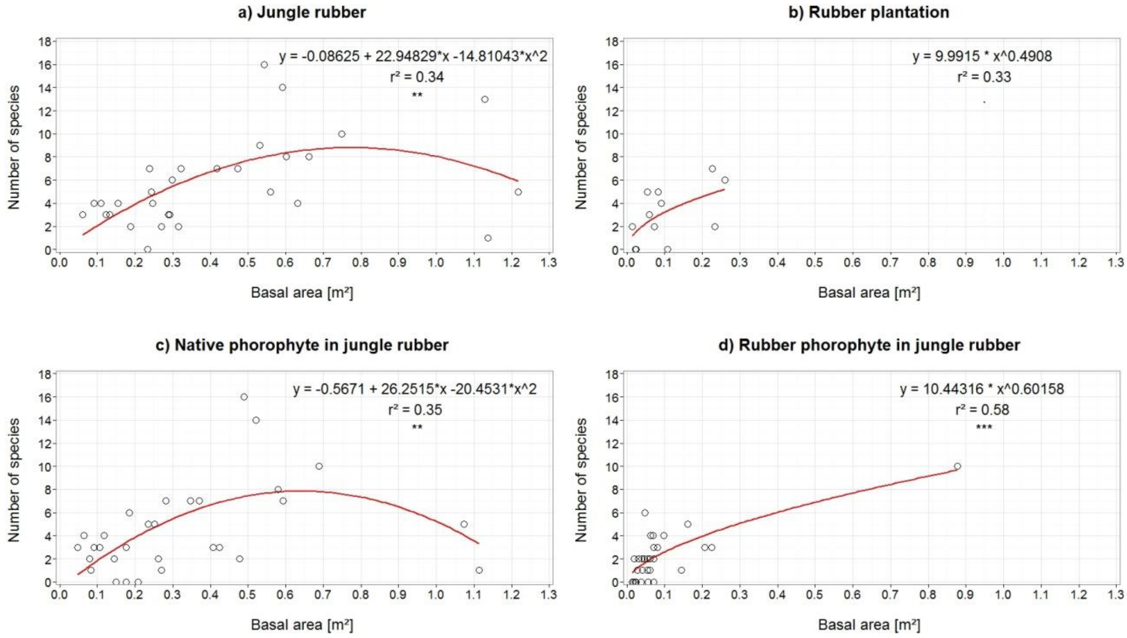

Figure 20: Correlation of species numbers and basal area of the phorophyte for jungle rubber **a)**, rubber plantations **b)** and in jungle rubber for native phorophytes **c)** and rubber phorophytes **d)**. Results based on 30 jungle rubber and 12 rubber plantation plots. Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1, based on non-linear regression analysis.

Basal area as sum of the native and the rubber phorophyte showed a negative relation with the distance to the forest border ($p < 0.05$; Figure 21 a). Basal area of the rubber trees in rubber plantations showed no relation with the distance to the forest (Figure 21 b). Within jungle rubber the negative relation of basal area of the native phorophytes with the distance to the forest is on the border of significance ($0.05 < p < 0.1$; Figure 21 c) and basal area of the rubber phorophytes within jungle rubber showed no relation with the distance to the forest border (Figure 21 d). Summarized basal area of all trees with a DBH above 10 cm was significantly negative related with the distance to the forest border ($p < 0.05$; Figure 21 e).

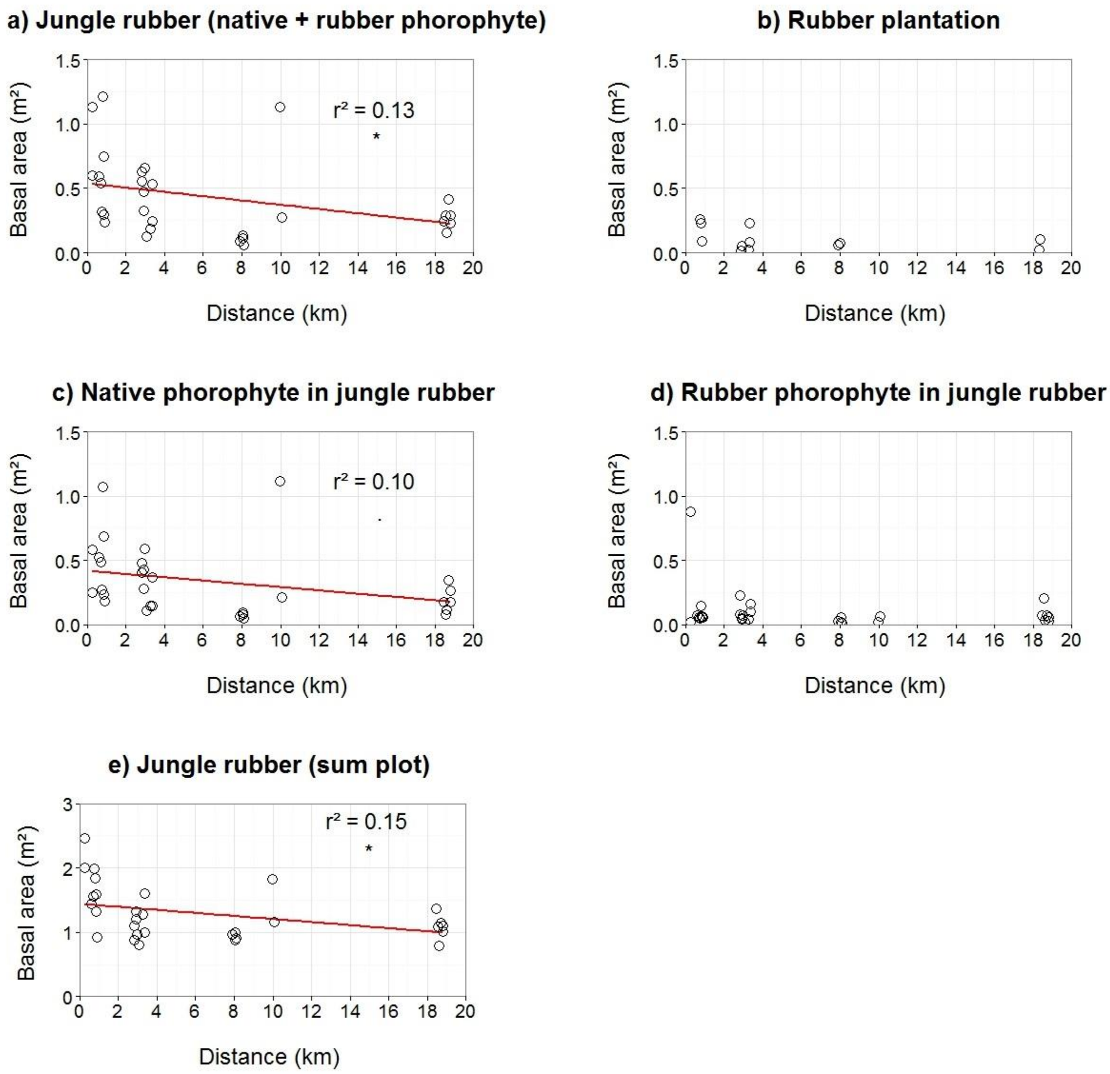

Figure 21: Basal area of jungle rubber (sum of native and rubber phorophyte) (**a**), rubber plantations (**b**), native phorophytes within jungle rubber (**c**), rubber phorophytes within jungle rubber (**d**) and summarized for all trees above 10 cm DBH in jungle rubber (**e**) with the distance to the forest border. Results based on 30 jungle rubber plots and 12 rubber plantation plots. Significance codes: (*) < 0.05, (.) < 0.1 based on linear regression analysis.

4.5 Vascular epiphyte communities

To show the different characteristics between the two land-use systems for the occurrence frequency and the abundance of vascular epiphyte species, rank frequency and rank abundance curves were created (Figure 22). The horizontal scales rank the species from most to least frequent (Figure 22 a, b) and from most to least abundant (Figure 22 c, d). For a better comparability of the two land-use systems frequency and abundance are shown as relative values. Because of the short range of the relative abundance values and the concentration of extremely low values close to zero the scale for relative abundance is logarithmic transformed. Additionally, the species are divided into three taxonomic groups: orchids, ferns and other angiosperms

The rank frequency plots show for jungle rubber a long curve with a steep drop and a long tail (Figure 22 a), while the curve for the rubber plantations is short, steep and with shorter tail (Figure 22 b). Few fern species occurred with high frequencies in both systems (*Drynaria quercifolia, Asplenium nidus, Davallia denticulata,* and *Nephrolepis acutifolia*). Two additional fern species occurred frequently in jungle rubber, which were absent in rubber plantations (*Vittaria ensiformis* and *Vittaria elongata*). With one exception (*Dendrobium crumenatum*) orchids and other angiosperms occurred with very low frequency in both land-use systems.

The rank abundance plot shows for jungle rubber a long slowly descending curve with tail (Figure 22 c), while the curve for the rubber plantations shows a short and steep course (Figure 22 d). In the rubber plantations the most frequent four fern species were also the most abundant species (*Drynaria quercifolia, Davallia denticulata, Asplenium nidus* and *Nephrolepis acutifolia).* In jungle rubber, one fern and one orchid with both low occurrence frequencies were the most abundant species (*Antrophyum callifolium* and *Dendrobium leonis*). The in jungle rubber already as highly frequent identified fern species (Figure 22 a), were also highly abundant (Figure 22 c).

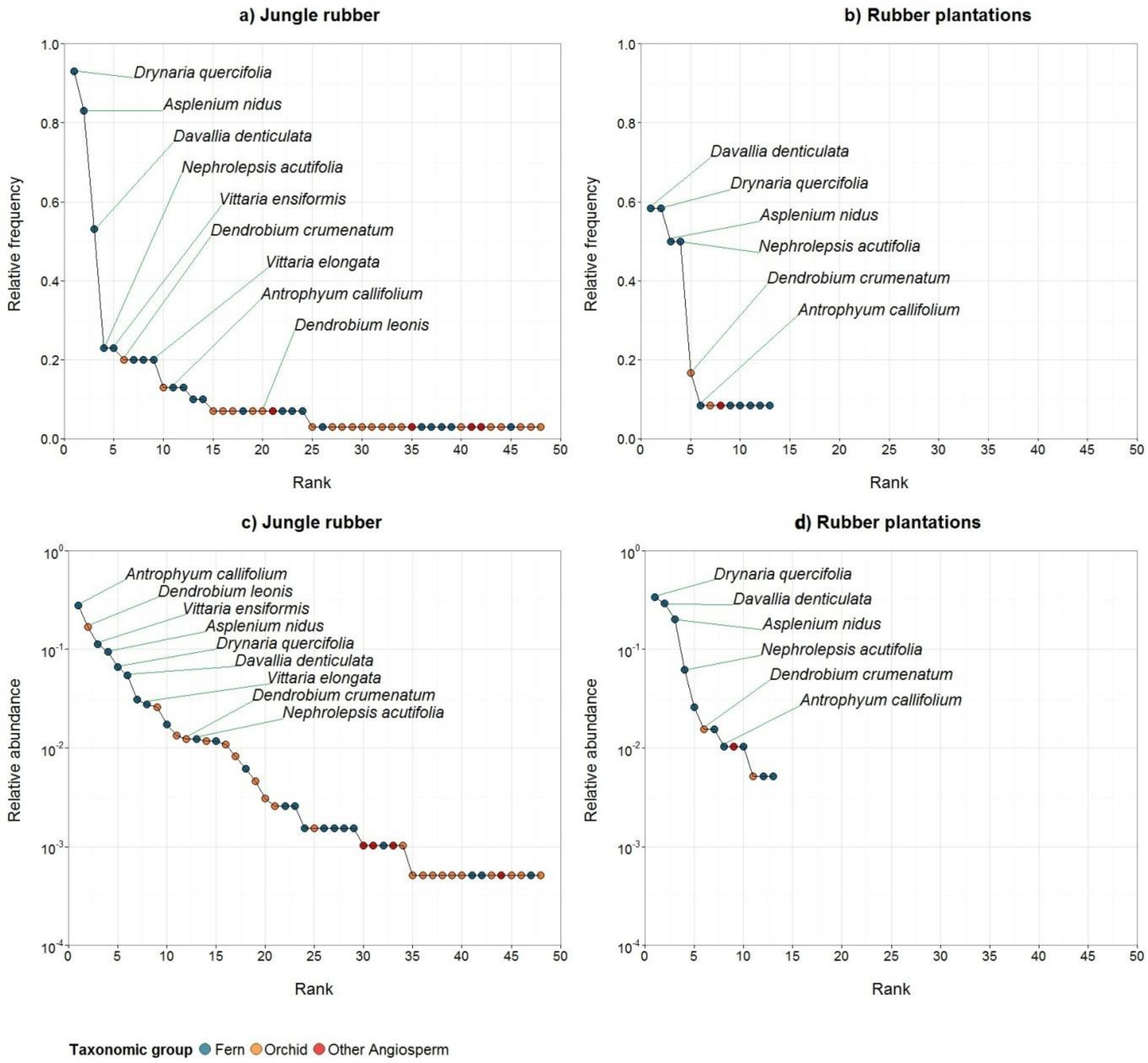

Figure 22: Rank frequency curves for jungle rubber (**a**) and rubber plantations (**b**); and rank abundance curves for jungle rubber (**c**) and rubber plantations (**d**). Horizontal scales rank the species from most to least frequent (**a, b**) and from most to least abundant (**c, d**). Scale for relative abundance (**b, c**) is logarithmic transformed. Colors show the taxonomic group of each species. Results based on 30 jungle rubber and 12 rubber plantation plots.

4.6 Paired plots and phorophytes

Beside the distance to the forest border and basal area of the phorophyte as influencing factors on epiphyte density and richness (chapter 3.4), a possible relation of epiphyte density and epiphyte species richness between neighboring plots and phorophytes was analyzed. The analysis was based on 24 plot combinations of 12 rubber plantation plots with the two nearest jungle rubber plots. In total 12 jungle rubber plots were identified as neighbors, each was combined one to four times with the 12 rubber plantation plots to create the plot pairs. The distance between the 24 plot pairs ranged from 56 to 590 meter with an average of 234 meter distance between the plots.

The results of the regression analysis show, that vascular epiphyte density and species richness each correlate strongly positive between rubber plantation and near jungle rubber plots (both $p < 0.001$) (Figure 23 a, d). The calculated regressions describe the relation between the two land-use systems mainly for epiphyte density (r^2 0.7) and partial for species richness (r^2 0.44). Epiphyte density and species richness each showed no relation between rubber plantations and the nearest rubber phorophytes within jungle rubber (Figure 23 b, e) and also between the corresponding rubber and native phorophytes within jungle rubber, correlations for epiphyte density and species richness each could not be identified (Figure 23 c, f).

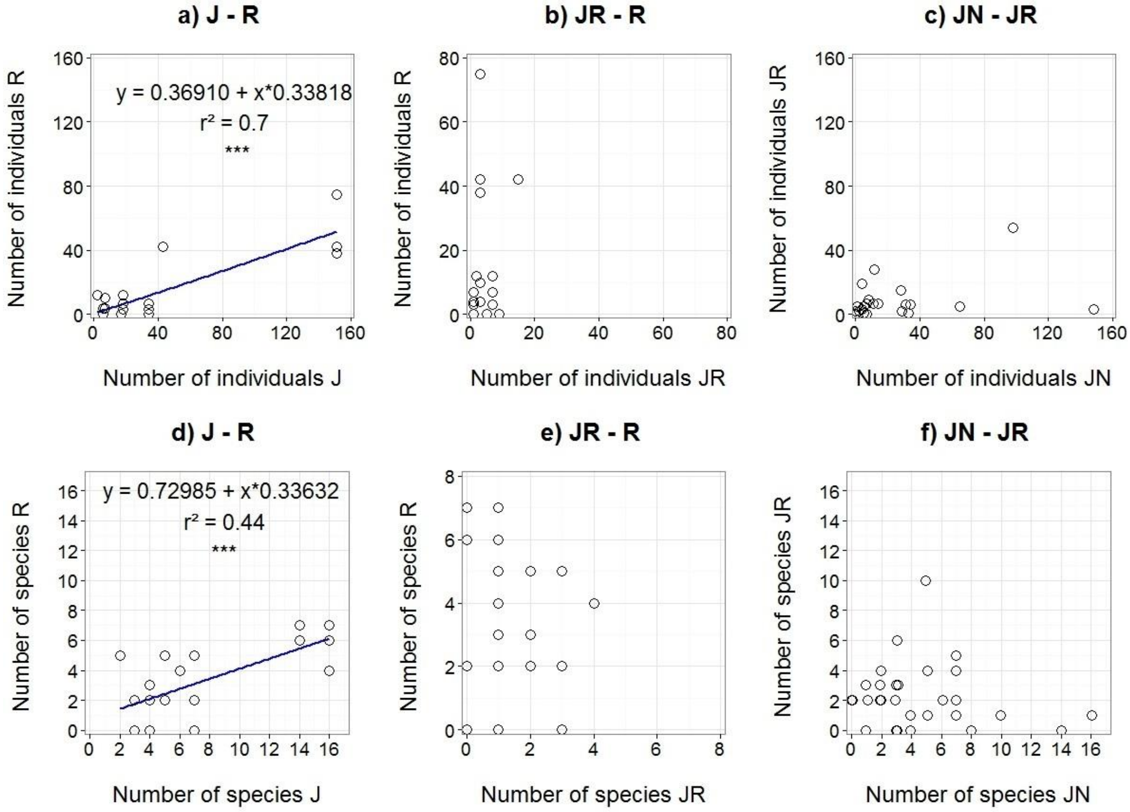

Figure 23: **a)** Number of individuals in rubber plantations (R) with number of individuals of neighboring jungle rubber plots (J) and **b)** with number of individuals of the neighboring rubber phorophyte within jungle rubber (JR) - **c)** Number of individuals on rubber phorophytes (JR) with number of individuals on the native phorophytes (JN) within each jungle rubber plot. - **d)** Number of species in rubber plantations (R) with number of species of the neighboring jungle rubber plot (J) and **e)** with number of species of the neighboring rubber phorophyte within jungle rubber (JR) - **f)** Number of species on rubber phorophyte (JR) with number of species on the native phorophyte (JN) within each jungle rubber plot. Results based on regression analysis of 24 plot pairs in rubber plantations and jungle rubber (**a**, **b**, **c**, **d)** and each 30 corresponding native and rubber phorophytes within jungle rubber (**e**, **f**) Significance codes: (***) < 0.001, (**) < 0.01, (*) < 0.05, (.) < 0.1, based on linear regression analysis.

5 Discussion

5.1 Epiphyte density and richness in jungle rubber and in rubber plantations

Between the two examined land-use systems - jungle rubber and rubber plantations - remarkable differences could be identified. For example the overall epiphyte individual numbers, of 2144 recorded individuals, 1950 (91 %) were recorded in jungle rubber; only 194 epiphyte individuals were found in rubber plantations. Even considering that only 12 rubber plantations plots were examined - compared to 30 jungle rubber plots - this difference is still obvious. Also the overall vascular epiphyte species numbers differ clearly, in jungle rubber 48 species were recorded, approximately four times more species than in the rubber plantations, with only 13 epiphyte species. Just one species was exclusively found in rubber plantations. Compared to studies carried out in the Neotropics the overall species numbers seem to be low (Barthlott et al., 2001; Flores-Palacios & García-Franco, 2008; Köster et al., 2009). Data evaluated by Böhnert (2013) and Altenhövel (2013) in the same area had similar results for rubber plantations (11 species) and lowland rainforest (44 species) in Bukit Duabelas National Park (BDNP). Their results were based on 30 plots each. Extrapolation performed by them identified a maximum of 72.6 vascular epiphyte species in the rainforest (Altenhövel, 2013; Böhnert, 2013). Extrapolation performed by Wenzel (2015) on the same data as this thesis identified a maximum of 72.5 epiphyte species in jungle rubber, which is almost identical compared to the rainforest. It should be expected that the primary rainforest - as natural and mainly undisturbed system - harbors more epiphyte species than the jungle rubber agroforestry system. One reason for the estimations of equal values for vascular epiphyte species could be seen in an underestimation of the species number for the rainforest. A possible reason for this can be seen in the clustered positions of the 30 forest plots at two relative small areas in the BDNP (Altenhövel, 2013; Böhnert, 2013). In contrast to that the plots studied in the present thesis were placed along a distance gradient (20 km) covering a wider area of the landscape, which may probably include a wider range of potential epiphyte habitats.

On plot level jungle rubber showed a four times higher average epiphyte density per plot and an almost two times higher average epiphyte species richness per plot than rubber plantations (Figure 10, 11). Considering the vertical epiphyte distribution across the five Johansson zones, it is apparent that epiphyte density and richness in jungle rubber and rubber plantations differed significantly (Figure 13, 14). In JZ1 both systems were quite similar, but in rubber plantations epiphyte density and species richness were almost only represented by this zone and were significantly highest in JZ1. For comparison, in jungle rubber also the upper JZs had remarkable values for epiphyte density and richness and the differences between the JZs were mainly not significant. These results indicate that the phorophytes in rubber plantations were more homogeneous than in jungle rubber. Comparing jungle rubber with the rainforest, the vertical epiphyte distribution pattern in the rainforest is shifted upwards. Here epiphyte density and richness is lowest in JZ1 and highest in the upper Johansson zones – JZ3 to JZ5 (Altenhövel, 2013). This leads to the assumption, that the vertical distribution pattern of vascular epiphytes in jungle rubber can be seen as a combination of patterns found in the rainforest and the plantations.

In terms of epiphyte individual numbers ferns dominate both land-use systems, while in jungle rubber also orchids had an important part, in jungle rubber almost only ferns were counted (97 %). The taxonomic distribution of the individual numbers roughly fits with the taxonomic distribution of the recorded species in rubber plantations (10 fern spp.; 2 orchid spp.; 1 other angiosperm), but this does not apply for jungle rubber. Jungle rubber was dominated by ferns and orchids (each 22 spp.), while only other angiosperms were underrepresented (4 spp.). For comparison, Altenhövel (2013) and Böhnert (2013) recorded less ferns (13 spp.) and orchids (17 spp.), but more other angiosperms (14 spp.) in the rainforest of BDNP. Beukema and Van Noordwijk (2004) recorded more fern species in 11 rainforest plots (24 spp.) and in 17 rubber plantation plots (16 spp.), but less in 23 jungle rubber plots (18 spp.). Differences in plot size and plot numbers must be considered comparing these results. The taxonomic distribution pattern in jungle rubber can be seen as a combination of patterns found in forests and the plantations.

The heterogeneous structure of jungle rubber, with big sized remnant forest trees, young secondary vegetation and the change between light and shaded conditions, indicates that jungle rubber provides a wider range of potential epiphyte habitats compared to rubber plantations. Beukema and Van Noordwijk (2004) identified jungle rubber as habitat for forest and plantation species and explained this with the heterogenic structure of jungle rubber showing characteristics of rainforests and rubber plantations. Furthermore, in jungle rubber a more diversified microclimate was identified, resembling more the microclimatic conditions of the rainforest, with lower temperatures and higher humidity, especially in the understory (Böhnert, 2013; Wenzel, 2015). The importance of the climatic conditions for epiphyte diversity will be discussed more closely later in relation with the distance to the forest (chapter 4.2). Furthermore, the native phorophytes in jungle rubber showed a three times higher basal area (0.33 m^2) than the studied rubber phorophytes in rubber plantations (0.1 m^2) and basal area was identified as an important factor influencing epiphyte density and richness (Figure 19, 20). The basal area of the phorophyte was already identified in other studies as a crucial factor for epiphyte density and richness (Flores-Palacios & García-Franco, 2006; Hietz-Seifert et al., 1996; Wolf, 2005) and will also be discussed later in relation with the distance to the forest (chapter 4.2). A possible factor influencing epiphyte density and species richness in rubber plantations reported by Böhnert (2013) is the selective removing of epiphytes from the rubber trees by plantation workers. Due to a lack of reliable information this factor shall be not further discussed at this point, but may be of importance in rubber plantations, the more intensive land-use system (Joshi et al., 2002).

In a next step a closer look on the differences of native and rubber trees as potential epiphyte host trees will be taken. The different epiphyte density and species richness between the two land-use systems is clearly and might be explainable by several factors related to differences between both land-use systems. But taking a look on the native and rubber phorophytes within jungle rubber significant differences could be identified (Figure 10, 11). On native phorophytes the average epiphyte density was approximately nine times higher and epiphyte species richness was two times higher than on rubber phorophytes. These differences are comparable to the differences between the two land-use systems. Furthermore, rubber phorophytes in jungle rubber showed no significant differences to rubber phorophytes in the plantations for epiphyte density (Figure 10), epiphyte species richness (Figure 11) and basal area. Additionally the vertical distribution between both was similar (Figure 13, 14). Only the taxonomic distribution of the recorded epiphytes differed between rubber phorophytes in plantations and in jungle rubber, with clearly more orchids (6 spp.) on rubber within jungle rubber than in the plantations (2 orchid spp.). A possible reason for the accumulation of epiphytes in JZ1 and the lack of epiphytes in the higher zones can be seen in the structure of the rubber trees. Rubber itself has a relatively smooth bark, but due to injuries of the bark - caused by rubber tapping - the bark evolves a rough and structured surface, often with accumulated humus and moist in small hollows (Figure 6 D). Compared to untapped trunks parts the diameter of the tapped trunk parts seemed to be swollen up, reminding the shape of a flask or cone. Almost all recorded epiphytes on rubber phorophytes within jungle rubber and in plantations were found on this lower part of the trunk. This can be explained by the preference of some species for rough bark (Gradstein & Culmsee, 2010; Hietz, 1998), by better germination conditions for epiphyte seeds on humus and moist capturing parts of the phorophyte (Benzing, 1990) and also chemical properties of the bark may have a influence on epiphyte development (Frei & Dodson, 1972). Remarkable is the almost total absence of epiphytes at upper trunk parts and in the canopy of rubber phorophytes, which could be observed also for native phorophytes with small trunk diameter (DBH) or basal area. The basal area of rubber phorophytes within jungle rubber was identified to be positive related with epiphyte density and species richness (Figure 19, 20).Thus, basal area can assumed to be the main reason for the differences between native phorophytes (mean 0.33 m²) and rubber phorophytes within jungle rubber (mean 0.09 m²). An additional indication for this assumption is the existence of an outstanding big sized rubber phorophyte, which was found in jungle rubber. This rubber tree showed a relative high epiphyte density and harbored 10 epiphyte species (Appendix 3) with some of them recorded exclusively on this tree. Also noticeable for this phorophyte was the recording of some epiphytes in the upper Johansson zones (JZ3 – JZ4). This outstanding rubber phorophyte and the overall small size of all other rubber phorophytes, lead to the assumption, that rubber phorophytes can harbor high epiphyte diversity when they have the chance to get mature. At this point shall be mentioned, that beside the species recorded on the plots additional epiphyte species could be observed during fieldwork on rubber trees within jungle rubber. These observed species were mainly eye-catching flowering or big sized orchids (Figure 7).

In relation with the discussion about the suitability of different tree species as epiphyte host trees, differences between the studied native phorophytes within jungle rubber shall also be discussed. As mentioned the majority of epiphyte individuals and species was found on the native phorophytes and also the average values for epiphyte density and species richness were highest for native phorophytes (Figure 10, 11), but simultaneously these group was very heterogeneous (appendix 2):

- The native phorophytes were of 25 different tree species.
- The basal area differed highly (0.05 m² - 1.1 m²).
- The recorded epiphyte individual numbers ranged from 0 to 528.
- The species numbers differed highly with a minimum of 0 and a maximum of 16 recorded species.

A relation of the phorophytes' bark structure with epiphyte individual and species numbers could not be identified (results not shown). As for the rubber phorophytes, basal area of the native phorophytes showed positive relation with epiphyte individual and species numbers (Figure 19, 20). Remarkable because of high epiphyte individual and species numbers were some studied durian trees (*Durio ziberthinus*). During fieldwork durian trees could be observed as big sized and always epiphyte rich trees within and around the villages and sometimes even within oil palm plantations. Other native phorophytes species had almost no species although they had a high basal area, for example the biggest studied tree (*Koompassia malaccensis;* appendix 2*).* Possible explanations for differences between tree species and their suitability as epiphyte host trees can be seen, for example, in different water holding capacities of the bark (Callaway et al., 2002) or periodical peeling of the bark (ter Steege & Cornelissen, 1989).

Finally hypothesis 2 can be confirmed; the abundance and species richness of vascular epiphytes in jungle rubber is higher than in monocultural rubber plantations. It is assumed that the heterogenic structure and the higher basal area of jungle rubber are the main explanations for the differences between both land-use systems. The microclimatic conditions may also have an influence on the differences between both systems. Additionally it is assumed, that rubber trees are potential epiphyte species rich phorophytes, when they can mature.

5.2 Distance gradient to the forest border

The results show, that in jungle rubber and rubber plantations vascular epiphyte density and species richness decrease significantly with increasing distance to the rainforest in Bukit Duabelas National Park. Additionally it could be observed that only a few highly abundant fern species were found along the complete distance gradient to the forest; orchids and other angiosperms were mainly found next to the forest (Figure 18).

One possible explanation for decreasing epiphyte density and species richness could be colonization of jungle rubber by vascular epiphytes originating from the forest. Remnant rainforest fragments can be seen as seeds for recolonisation of degraded areas (Turner & Corlett, 1996). Orchids for example have extreme small seeds which are dispersed by wind and can spread over long distances (Arditti & Ghani, 2000), the same applies to ferns with their small spores (Dassler & Farrar, 2001). Of epiphytic angiosperms, which orchids belong to, 84 % of the species have anemochorous seed dispersal (Mondragón et al., 2015). Beside available seeds and spores also suitable substrates and habitats for germination and growth are important for epiphyte colonization (Benzing, 1990; Mondragón et al., 2015). Orchid seeds for example are dependent on mycorrhizal fungi for germination and these fungi themselves are also dependent on certain conditions (Dearnaley, 2007). Based on differences and similarities between epiphyte communities along a distance gradient in the highlands of Chiapas (Mexico), Wolf (2005) found indications that dispersal of epiphytes over 10 km is rare. The distribution and abundance of the recorded vascular epiphyte species along the distance gradient of the present thesis gives the impression of a similar relation, the epiphyte species number decreased strongly and beyond a distance of approximately 8 km to the forest only few additional species occurred, this especially notable for orchids and other angiosperms (Figure 18). The quick decreasing of the regression curve for epiphyte species numbers with increasing distance to the forest is another hint for a limited dispersion of species from the forest (Figure 17).

Microclimate

Another important and often discussed factor for epiphyte density and richness is the climate, species richness of epiphytes is positively related with moist climate and high annual precipitation (Kreft et al., 2004; Poltz & Zotz, 2011). Lower epiphyte species numbers and abundance, as well as changes in the epiphyte communities in disturbed habitats compared to natural forest, are explained by less diversified microclimatic conditions in the disturbed habitats (Barthlott et al., 2001; Hietz-Seifert et al., 1996). Jungle rubber as extensive land-use system and can be seen as a less disturbed system compared to the rubber plantations (Joshi et al., 2002). Nöske et al. (2008) identified that species richness of vascular epiphytes decreased from old-grown forest towards more open vegetation. Furthermore, beside the topographic exposure the microclimate is mainly influenced by the canopy cover (Ashcroft & Gollan, 2012). A recent study determined the microclimatic differences between primary forests, secondary forests and oil palm plantations in Borneo and found out, that primary forests are up to 2.5°C cooler than secondary forests and up to 6.5°C cooler than oil palm plantations. Besides that, the leaf area index (LAI; leaf area / ground area) was identified as an important influencing factor for the differences of humidity and temperature (Hardwick et al., 2015). The drier and hotter microclimate in degraded areas, such as plantations, leads to a change of the epiphyte communities, with less drought intolerant and more drought resilient species (Gradstein, 2008; Wolf, 2005). Furthermore, drier microclimatic conditions are assumed to result in lower epiphyte colonization rates (Werner et al., 2005). It is assumed, that the microclimate is an important factor to explain the differences between both land-use systems. For the change of epiphyte density and species richness along the distance gradient, the microclimate may also play a role, but specific data for the validation of the grade of its influence are not available.

Basal area

As mentioned above, the basal area of the phorophytes was identified as an important factor influencing vascular epiphyte density and species richness (Figure 19, 20). For jungle rubber and the native phorophyte within it, it is noticeable that the relation of basal area and epiphyte species numbers first increases with increasing basal area and later decreases with further increasing basal area (Figure 20). This does not fit with the expectation of a clearly positive relation between basal area and species numbers and can be explained by the relative small sample size and by overfitting of the non-linear regressions. It is assumed that an increasing sample size, with a higher amount of big sized trees would change the regression curve. Several other studies identified basal area and tree size in general as an highly important factor for epiphyte diversity (Beukema, 2013; Flores-Palacios & García-Franco, 2006; Hietz-Seifert et al., 1996; Wolf, 2005). Higher numbers of epiphyte individuals and species on big sized phorophytes can be explained by a larger surface and a more diversified tree structure compared to small phorophytes (Ayyappan & Parthasarathy, 2001; Barthlott et al., 2001). A more diversified phorophyte structure provides a higher variety of different epiphyte habitats, due to a wide range of different branch diameters and parts richer in accumulated humus and moist (Ayyappan & Parthasarathy, 2001). Furthermore, the already mentioned microclimate is more diversified at big sized trees, with sunlight exposed hot and dry parts in the outer canopy and more shaded, humid and cooler parts at lower trunk parts and in the center of the canopy (Petter et al., 2015). But also the age of the phorophytes is essential, as colonization by epiphytes is an ongoing process (Barthlott et al., 2001). Beside the identified positive relation of the phorophytes' basal area with epiphyte individual numbers and species numbers, additionally the basal area of jungle rubber and the native phorophyte within it showed a negative relation with the distance to the forest (Figure 21). Rubber plantations and the rubber phorophyte within jungle rubber showed no relation between basal area and the distance to the forest. This leads to the conclusion that basal area influences the change of epiphyte individual and species numbers along the distance gradient in jungle rubber and the native phorophytes within it, but not in rubber plantations and rubber phorophytes within jungle rubber.

Management

As discussed, the tree size is an important factor influencing epiphyte individual and species numbers. Along the distance gradient differences could be observed between the plots, which could be traced back partially to different kinds of management by the owner. As mentioned in the introduction, jungle rubber can be established by two different ways: by slash and burn and by gap planting (Sisipan). Most of the examined jungle rubber plots showed to be established by gap planting, due to the existence of big sized remnant forest trees. Four jungle rubber plots located at a distance to the forest of approximately 8 km (Figure 3) showed a completely different structure without remnant trees and more homogeneous compared to the other jungle rubber plots. Here the rubber trees were planted in uniform rows and the accompanied vegetation showed almost only pioneer trees of a similar age and small in diameter (Figure 21 c), such as *Macaranga* spp.. Additionally big sized and charred tree stumps - probably remnants of the former forest - together with charcoal in the soil could be observed. The observed differences lead to the conclusion, that the mentioned four plots were established by slash and burn. On these four plots almost only the highly frequent and abundant species of both land-use systems were recorded (*Asplenium nidus, Davallia denticulata, Drynaria quercifolia* and *Nephrolepis acutifolia*). Beside the establishment process also the further management influences the development of epiphytes strongly, for example, the selective logging of remnant old grown and big sized trees, which could be observed at the plots furthest away from the forest border (Figure 7). The importance of such remnant forest trees for epiphyte species richness can be seen at the studied durian phorophytes next to the forest, with their outstanding high epiphyte individual and species numbers. These trees were probably remnant forest trees. As mentioned above, old grown durian trees could be observed at many places in the study area, often as enormous trees and mostly completely covered with epiphytes. Wolf (2005) identified remnant forest trees as essential for epiphytes species richness and as epiphyte seed sources for recolonisation of the surroundings.

Finally it can be confirmed, that the abundance and species richness of vascular epiphytes decreases along a distance gradient to the national park (hypothesis 1). Böhnert's (2013) statement, that vascular epiphyte species richness in rubber plantations decreases with increasing distance to the forest in BNDP can be substantiated. Additionally it can be assumed that the change of epiphyte density and species richness along the distance gradient is influenced by several factors. Vicinity to the forest has a positive influence on species density and richness.

5.3 Vascular epiphyte communities

The floristic compositions in jungle rubber and rubber plantations showed high similarities. Except of one species (*Dischidia cf. Imbricata*) almost all species found in rubber plantations were also found in jungle rubber. Additionally both land-use systems were dominated by a few highly frequent and abundant fern species (*Drynaria quercifolia, Davallia denticulata, Asplenium nidus* and *Nephrolepis acutifolia*) (Figure 22), which were all identified as widely distributed and highly abundant (abundance-group 2; Figure 18). In accordance to the characterization arguments (chapter 3.6) these species are characterized as common generalists. Former studies already identified *Drynaria quercifolia, Davallia denticulata* and *Asplenium nidus* as highly abundant and common in rainforest, jungle rubber and rubber plantations of Jambi (Altenhövel, 2013; Beukema et al., 2007; Böhnert, 2013). Additionally, these fern species are known as common and widely distributed in the tropics of Asia (Ayyappan & Parthasarathy, 2001; Lindsay & Middleton, 2012; Zhang et al., 2009). Considering the vertical distribution (Figure 15) it is apparent, that these fern species show high abundances in most of the JZ zones, indicating possible wide ecological amplitudes. Furthermore *Nephrolepis acutifolia* and *Davallia denticulata* were identified as highly abundant in oil palm plantations (Altenhövel, 2013). But also some other species show attributes of generalist species, for example *Vittaria elongata* and *Vittaria ensiformis* (fern spp.), which were highly abundant in jungle rubber. Beukema et al. (2007) identified both *Vittaria* spp. as highly abundant in jungle rubber and rainforest and found the former also in rubber plantations. Altenhövel (2013) identified both species as abundant in oil palm plantations and found *Vittaria ensiformis* additionally in the rainforest. Furthermore, both species are widely distributed across the Indo-Pacific region (Lindsay & Middleton, 2012). Because *Vittaria elongata* occurs more or less abundant in four systems and *Vittaria ensiformis* shows a wide vertical distribution (Figure 15), both species will be also characterized as generalists. Additionally two other species will be characterized as generalist species - *Dendrobium crumenatum* (orchid) and *Pyrrosia pilloselloides* (fern), both species showed relative wide vertical distributions, with *Pyrrosia pilloselloides* tending to the upper and *Dendrobium crumenatum* tending to the lower JZ zones (Figure 15). During the fieldwork, these two species were observed in more or less highly abundance along the roads, in gardens, parks and cities all over Sumatra, Java and Singapore at low to medium elevations. *Pyrrosia pilloselloides* is known to be a rather common species with wide distribution (Lindsay & Middleton, 2012; Wee, 1998). *Dendrobium crumenatum* is known to grow from coastal areas to forests and even in urban habitats (Leong & Wee, 2013). From Hawaii this orchid is even reported to be neophytic (Ackerman, 2012) and it was one of the first orchids recolonizing Krakatau after its eruption in 1883 (Partomihardjo, 1992). It can be assumed that *Dendrobium crumenatum* and *Pyrrosia pilloselloides* both have wide ecological amplitudes.

In accordance to the characterization arguments (chapter 3.6) almost all orchids and other angiosperms can be characterized as specialists. These species were mainly found in jungle rubber with low frequencies and low abundances (Figure 22). More than 30 % of the species recorded in jungle rubber were singletons (one recorded specimen) and about 10 % doubletons (two recorded specimen). But also some highly abundant species must be characterized as specialists (*Dendrobium leonis, Antrophyum callifolium* and *Huperzia sp. I). Dendrobium leonis* and *Huperzia sp. I* were found highly abundant on big sunlight exposed horizontal branches of remnant forest-trees (durian), but had both very low occurrence frequencies (Figure 22). The most abundant of all species, *Antrophyum callifolium* was found at shaded and moist bottom parts of big trunks, highly abundant in some jungle rubber plots and found with only few specimens in rubber plantations. Both described habitat types were limited and only found on few phorophytes and can be described as two specific habitats, with the first dry and bright and the second moist and shaded. Beside *Antrophyum callifolium,* in rubber plantations *Dischidia cf. Imbricata* was the only species characterized as specialist. This species was found on a relative big sized and highly sunlight exposed rubber tree and was also identified as relative abundant in the forest and as singleton in rubber plantations (Böhnert, 2013).

Beside the similarities of jungle rubber and rubber plantations, such as the domination by highly frequent and abundant fern species, it could be identified that jungle rubber harbors a higher number of epiphytic species which can be characterized as specialist species. Despite the limitations of this thesis it can be confirmed, that monocultural rubber plantations harbor less specialized vascular epiphytic species and higher rates of common generalist species than jungle rubber (hypothesis 3).

5.4 Paired plots and phorophytes

The results of the paired plot analysis showed a significant relation of epiphyte density and species richness between neighbored rubber plantations and jungle rubber. Nevertheless, these results should be viewed critically. From initially 30 wanted rubber plantation plots – each corresponding one of the 30 jungle rubber plots – in total only 12 plots could be realized due to a lack of rubber plantations next to jungle rubber. These 12 rubber plantation plots even were not really paired with corresponding jungle rubber plots, they were mainly located in small groups in the surrounding of a group of jungle rubber plots. This resulted in 24 plot combinations with the distance between the corresponding plots ranging from 56 to 590 meter, which is a wide range. In conclusion it can be said that epiphyte abundance and species richness in rubber plantations might be related with epiphyte abundance and species richness of neighboring jungle rubber (hypothesis 4). But to confirm this thesis for certain, further investigation has to be carried out with more uniform conditions, but such investigation is difficult to carry out in a landscape with a highly heterogenic distribution of different land-use systems. An explanation for the identified relations between neighbored plots of both land-use systems could be seen in similar climatic conditions, but due to lack of data this is speculation. Another explanation could be seen in the dispersal of epiphytes originating from nearby species rich jungle rubber or other epiphyte species-pools, but to confirm this assumption the species compositions have to be compared between the plots.

Moving the focus from plot level on phorophyte level no relation could be observed between the rubber phorophytes in jungle rubber and the rubber plantations. The same could be observed within jungle rubber between native and rubber phorophytes. This does not fit with the expectations described by hypothesis 5, that rubber phorophytes next to species rich native phorophytes show higher numbers of epiphyte species. A possible explanation for this lack of correlation can be seen in the small plot size. Big and old grown phorophytes correlate with high species numbers, but showed also big sized canopy. Such phorophytes probably strongly dominate the small plots of 400 m² with the shadow they cast. Thereby it can be assumed, that rubber trees growing next to big sized native trees provide only few types of epiphyte habitats, which would probably limit epiphyte richness. Additionally rubber phorophytes within jungle rubber showed no relation with the distance to the forest border (Figure 16, 17), which indicates that epiphyte abundance and species richness on rubber phorophytes in jungle rubber is influenced by other factors than the described fact in chapter 5.2. Finally hypothesis 5 cannot be confirmed.

6 Conclusions

Within the EFForTS subproject B06, this thesis investigated the change of vascular epiphyte abundance and species richness along a distance gradient to the rainforest in Bukit Duabelas National Park (BDNP). Vascular epiphytes are an essential part of the tropical biodiversity. The obtained results are an important component to assess the conservation value of jungle rubber for vascular epiphyte diversity.

The investigation showed that the abundance and species richness of vascular epiphytes is higher in jungle rubber than in rubber plantations. Compared to the rainforest of BDNP, vascular epiphyte species richness in jungle rubber is on a similar level. It is assumed that several factors have an influence on the differences of epiphyte diversity between jungle rubber and rubber plantations. Main difference between both systems is the highly heterogeneous structure of jungle rubber, which indicates that jungle rubber provides a wider range of different epiphyte habitats. The basal area of the phorophytes was identified as an important factor influencing the abundance and species richness of epiphytes. Based on the vertical distribution and the occurrence frequency of selected epiphyte species, it is assumed, that jungle rubber harbors higher rates of specialized vascular epiphyte species. Only few information exist about the specific ecology of the vascular epiphytes of Southeast Asia, further investigations would provide a better basis for the valuation of epiphyte communities in both land-use systems. Additionally, the results showed that epiphyte species richness and abundance in jungle rubber is related to epiphyte species richness and abundance in nearby rubber plantations. But due to an unstable basis, these results will be interpreted as hint for further investigation. Furthermore the results confirmed the main hypothesis of this study that the abundance and species richness of vascular epiphytes decreases along a distance gradient to the rainforest. Beside the changing structure of jungle rubber along the distance gradient, such as the decreasing basal area of the phorophytes and less big sized remnant forest trees, it is assumed that dispersal of epiphyte species originating from the forest has an effect on the change of epiphyte diversity along the distance gradient. To confirm this certainly, more information about the dispersal and distribution patterns of vascular epiphytes across the landscape is needed, especially about the less frequent species, but the present results can be seen as a first basis of information about the distribution of vascular epiphytes in jungle rubber agroforests of Jambi's lowlands.

The final conclusion of this thesis is that jungle rubber has a high value for the conservation of vascular epiphytes. The value of jungle rubber must be recognised, especially in the context of the disappearing lowland rainforests and the progressing intensification of the agricultural land-use systems. Beukema's and Van Noordwijk's (2004) statement, that “jungle rubber systems can play a role in conservation of part of the primary rain forest species, especially in areas where the primary forest has already disappeared” shall be followed. Additionally the value of remnant forest trees within and outside of jungle rubber for vascular epiphyte conservation shall be mentioned, especially as jungle rubber is threatened itself, due to agricultural intensification (Ekadinata & Vincent, 2011). In this context a study focusing on the value of durian trees for the local conservation of epiphyte diversity would be interesting. Especially, because it seems, that durian trees are mostly left untouched from the ongoing land-use changes. Other authors even suggest to focus on large native trees as refuges for epiphytes in disturbed landscapes (Kartzinel et al., 2013).

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8 Appendix

Table 1: List of all recorded vascular epiphyte species inclusive number of recorded individuals in jungle rubber and in rubber plantations.

no.	family	genus	species	author	jungle rubber	rubber plantation
1	*Apocynaceae*	*Dischidia*	*cf. imbricata*		-	2
2	*Aspleniaceae*	*Asplenium*	*nidus*	L.	184	39
3	*Davalliaceae*	*Davallia*	*denticulata*	(Burm. f.) Mett. ex Kuhn	106	57
4	*Davalliaceae*	*Davallia*	*triphylla*	Hook.	3	-
5	*Davalliaceae*	*Humata*	*heterophylla*	(Sm.) Desv.	1	-
6	*Davalliaceae*	*Humata*	*repens*	(L. f.) J. Small ex Diels	2	-
7	*Lycopodiaceae*	*Huperzia*	*sp. I*		60	-
8	*Melastomataceae*	*Melastomataceae*	*sp. I*		1	-
9	*Melastomataceae*	*Melastomataceae*	*sp. II*		2	-
10	*Moraceae*	*Ficus*	*deltoidea*	Jack	2	-
11	*Moraceae*	*Ficus*	*sp. I*		2	-
12	*Nephrolepidaceae*	*Nephrolepis*	*acutifolia*	(Desv.) Christ	24	12
13	*Orchidaceae*	*Acriopsis*	*densiflora*	Lindl.	26	-
14	*Orchidaceae*	*Acriopsis*	*liliifolia*	(J.Koenig) Seidenf.	6	-
15	*Orchidaceae*	*Bulbophyllum*	*sp. I*		1	-
16	*Orchidaceae*	*Bulbophyllum*	*sp. II*		23	1
17	*Orchidaceae*	*Bulbophyllum*	*sp. III*		3	-
18	*Orchidaceae*	*Bulbophyllum*	*sp. IV*		1	-
19	*Orchidaceae*	*Bulbophyllum*	*sp. V*		51	-
20	*Orchidaceae*	*Cleisostoma*	*subulatum*	Blume	21	-
21	*Orchidaceae*	*Cymbidium*	*sp. I*		1	-
22	*Orchidaceae*	*Dendrobium*	*aloifolium*	(Blume) Rchb.f.	9	-
23	*Orchidaceae*	*Dendrobium*	*crumenatum*	Sw.	24	3
24	*Orchidaceae*	*Dendrobium*	*indragiriense*	Schltr.	5	-
25	*Orchidaceae*	*Dendrobium*	*leonis*	(Lindl.) Rchb.f.	330	-
26	*Orchidaceae*	*Dendrobium*	*sp. I*		1	-
27	*Orchidaceae*	*Dendrobium*	*sp. II*		1	-
28	*Orchidaceae*	*Eria*	*sp. I*		1	-
29	*Orchidaceae*	*Liparis*	*sp. I*		1	-
30	*Orchidaceae*	*Orchidaceae*	*sp. I*		1	-
31	*Orchidaceae*	*Orchidaceae*	*sp. II*		1	-
32	*Orchidaceae*	*Pomatocalpa*	*diffusum*	Breda	16	-
33	*Orchidaceae*	*Pomatocalpa*	*sp. I*		2	-
34	*Orchidaceae*	*Thelasis*	*sp. I*		1	-
35	*Polypodiaceae*	*Aglaomorpha*	*speciosa*	(Blume) M.C. Roos	3	-
36	*Polypodiaceae*	*Drynaria*	*quercifolia*	(L.) J. Sm.	129	66
37	*Polypodiaceae*	*Goniophlebium*	*verrucosum*	J.Sm.in Hk.	1	1
38	*Polypodiaceae*	*Microsorum*	*punctatum*	(L.) Copel.	34	3
39	*Polypodiaceae*	*Phymatosorus*	*scolopendria*	(Burm. f.) Pic. Serm.	5	-
40	*Polypodiaceae*	*Platycerium*	*coronarium*	(Mull.) Desv.	3	-
41	*Polypodiaceae*	*Polypodiaceae*	*sp. I*		1	-
42	*Polypodiaceae*	*Pyrrosia*	*angustata*	(Sw.) Ching	3	1
43	*Polypodiaceae*	*Pyrrosia*	*lanceolata*	(L.) Farw.	5	2
44	*Polypodiaceae*	*Pyrrosia*	*longifolia*	(Burm. f.) C.V. Morton	3	-
45	*Polypodiaceae*	*Pyrrosia*	*piloselloides*	(L.) M.G. Price	23	-
46	*Pteridaceae*	*Antrophyum*	*callifolium*	Blume	541	2
47	*Vittariaceae*	*Monogramma*	*sp.*		12	5
48	*Vittariaceae*	*Vittaria*	*elongata*	Sw.	54	-
49	*Vittariaceae*	*Vittaria*	*ensiformis*	Sw.	220	-

Table 2: List of all studied native phorophytes within jungle rubber, with structure data, coordinates and number of recorded vascular epiphyte individuals and species. Sum basal area is the sum of basal area for all trees above 10 cm DBH within the plot.

plot-nr.	family	species	bark roughness	basal area phorophyte [cm²]	sum basal area plot [cm²]	hight [m]	start of canopy [m]	longitude	latitude	nr. epiphyte species	nr. epiphyte individuals
JR-01	*Euphorbiaceae*	*Macaranga cf sumatrana*	smooth	1758.66	13699.24	23.3	8.7	102.851384	-2.143024	3	8
JR-02	*Rosaceae*	*Prunus arborea*	medium	2354.22	15886.76	27.5	10	102.753676	-2.016026	5	28
JR-03	*Malvaceae*	*Durio ziberthinus*	medium	6878.36	13180.09	34	20	102.752914	-2.015719	10	364
JR-04	*Euphorbiaceae*	*Endospermum diademum*	smooth	795.77	8771.81	21	11.8	102.800803	-2.063084	2	34
JR-05	*Apocynaceae*	*Alstonia angustifolia*	smooth	471.81	9113.03	18	8	102.800443	-2.064144	3	24
JR-06	*Euphorbiaceae*	*Macaranga hosei*	smooth	644.58	9733.02	19	10	102.799859	-2.062524	4	5
JR-07	*Myristicaceae*	*Myristica sp. I*	medium	1184.43	7935.95	24.9	14.5	102.851157	-2.144847	4	9
JR-08	*Rubiaceae*	*Rubiaceae sp. I*	medium	2611.57	10993.24	23.4	10	102.852962	-2.145676	2	2
JR-09	*Euphorbiaceae*	*Endospermum diadenum*	smooth	911.08	10023.27	19	11.3	102.800484	-2.063628	3	4
JR-10	*Fabaceae*	*Koompassia malaccensis*	medium	827.92	10918.56	20.6	12.9	102.851672	-2.143965	1	1
JR-11	*Lauraceae*	*Neolitsea cf javanica*	heavy	3712.77	15979.88	20.8	10	102.773884	-2.030513	7	14
JR-12	*Malvaceae*	*Durio ziberthinus*	medium	1052.41	8070.34	21	10	102.770819	-2.029654	3	4
JR-13	*Fabaceae*	*Callerya atropurpurea*	smooth	1450.30	9959.44	25	12.5	102.773166	-2.031196	2	4
JR-14	*Euphorbiaceae*	*Macaranga cf conifera*	smooth	3477.06	11428.52	21	10.3	102.8503	-2.146706	7	65
JR-15	*Fabaceae*	*Parkia speciosa*	smooth	1766.70	10129.49	23.3	13.4	102.851525	-2.146601	0	0
JR-16	*Moraceae*	*Artocarpus elasticus*	medium	10727.04	18375.47	26	14.3	102.751254	-2.015146	5	528
JR-17	unidentified	unidentified tree species	smooth	2694.17	19824.75	24.2	16	102.752862	-2.015026	1	7
JR-18	*Lamiaceae*	*Teisjmanniodendron*	medium	1850.73	9192.5	17.6	11.9	102.752495	-2.016385	6	29
JR-19	*Combretaceae*	*Terminalia foetidissima*	medium	4776.64	8786.31	26.7	13.7	102.765779	-2.030625	2	11
JR-20	*Malvaceae*	*Durio ziberthinus*	medium	4894.33	15636.72	27.2	14.3	102.755802	-2.014005	16	148
JR-21	*Burseraceae*	*Dacryodes costata*	medium	5215.19	14451.59	26.6	10	102.755163	-2.013262	14	164
JR-22	*Malvaceae*	*Durio ziberthinus*	medium	5801.20	20054.16	30.8	19	102.752926	-2.010257	8	115
JR-23	*Moraceae*	*Artocarpus integer*	smooth	2521.81	24617.53	16.9	4	102.754189	-2.010423	5	12
JR-24	*Moraceae*	*Artocarpus sp.*	medium	2812.59	13294.51	28.4	16.3	102.767535	-2.030428	7	33
JR-25	*Moraceae*	*Artocarpus elasticus*	smooth	4064.50	10948.1	27.4	14.2	102.768888	-2.028619	3	5
JR-26	*Moraceae*	*Artocarpus anisophyllus*	smooth	4246.33	12085.12	19.1	5.2	102.773202	-2.0259	3	98
JR-27	*Moraceae*	*Prainea limpato*	smooth	5930.83	9608.9	21.8	4.4	102.772257	-2.027303	7	31
JR-28	*Fabaceae*	*Dialium indum*	medium	1493.59	12795.42	22.8	6.9	102.764757	-2.035557	0	0
JR-29	*Ixonanthaceae*	*Ixonanthes petiolaris*	smooth	2088.43	11584.41	22.6	16.7	102.781201	-2.094827	0	0
JR-30	*Fabaceae*	*Koompassia malaccensis*	smooth	11130.98	18210.02	37	17.1	102.781839	-2.0938	1	7

Table 3: List of all studied rubber phorophytes within jungle rubber, with structure data, coordinates and number of recorded vascular epiphyte individuals and species.

plot-nr.	family	species	bark roughness	basal area phorophyte [cm²]	hight [m]	start of canopy [m]	longitude	latitude	nr. epiphyte species	nr. epiphyte individuals
JR-01	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	703.15	19.50	7.20	102.85137	-2.143053	3	9
JR-02	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	630.33	11.80	6.50	102.75369	-2.016023	4	15
JR-03	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	602.32	18.40	9.80	102.75282	-2.015727	1	4
JR-04	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	535.08	14.60	4.00	102.80078	-2.063053	2	6
JR-05	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	140.37	11.60	8.10	102.80045	-2.064171	0	0
JR-06	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	267.70	14.50	7.70	102.79986	-2.062489	1	1
JR-07	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	367.97	13.20	8.50	102.85115	-2.144878	0	0
JR-08	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	305.90	13.90	7.50	102.85296	-2.145671	2	2
JR-09	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	183.35	14.00	5.90	102.80052	-2.063636	2	3
JR-10	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	2062.73	13.50	6.40	102.85171	-2.144032	3	5
JR-11	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	1604.60	17.20	7.00	102.77383	-2.030444	5	7
JR-12	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	175.79	16.20	6.10	102.77086	-2.029702	0	0
JR-13	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	980.47	12.00	8.00			4	19
JR-14	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	703.15	13.50	7.60	102.85042	-2.146764	2	5
JR-15	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	561.50	15.50	6.40	102.85152	-2.146575	0	0
JR-16	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	1450.30	20.00	10.00	102.75123	-2.015104	1	3
JR-17	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	459.64	15.00	10.00			2	7
JR-18	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	535.08	12.30	7.00			2	2
JR-19	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	811.77	15.60	6.10	102.76584	-2.030604	3	7
JR-20	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	535.08	12.20	8.10	102.75576	-2.014073	1	3
JR-21	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	703.15	13.50	8.00	102.75515	-2.013269	0	0
JR-22	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	215.18	8.60	6.00	102.75294	-2.010257	0	0
JR-23	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	8771.82	19.30	7.20	102.75427	-2.010363	10	28
JR-24	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	412.53	10.20	7.40			1	1
JR-25	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	2245.99	14.10	7.60	102.76876	-2.028632	3	5
JR-26	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	471.81	15.00	7.10			6	54
JR-27	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	688.27	18.90	8.50	102.77231	-2.027276	4	6
JR-28	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	389.93	14.70	7.00	102.76479	-2.035626	2	2
JR-29	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	616.25	13.40	8.40	102.78118	-2.094814	2	2
JR-30	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	232.05	10.20	9.30	102.78184	-2.093828	0	0

Table 4: List of all rubber phorophytes within the rubber plantations, with structure data, coordinates and number of recorded vascular epiphyte individuals and species.

plot-nr.	family	species	bark roughness	basal area phorophyte [cm²]	hight [m]	start of canopy [m]	longitude	latitude	nr. epiphyte species	nr. epiphyte individuals
R-01	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	733.39	13.20	7.00	102.798787	-2.064326	2	10
R-02	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	588.55	13.70	4.00	102.797989	-2.063647	3	4
R-03	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	215.18	8.00	3.00	102.85151	-2.141313	0	0
R-04	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	1070.79	16.00	8.30	102.852349	-2.140828	0	0
R-05	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	911.08	16.20	8.30	102.75499	-2.015563	4	42
R-06	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	2607.04	19.80	10.00	102.755243	-2.01479	6	38
R-07	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	2272.81	19.00	9.20	102.755546	-2.015338	7	75
R-08	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	535.08	16.10	6.70	102.766684	-2.031032	5	7
R-09	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	133.77	9.10	4.50	102.766041	-2.030938	2	3
R-10	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	827.92	14.70	9.00	102.764853	-2.035978	5	12
R-11	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	232.05	11.70	7.60	102.769668	-2.032882	0	0
R-12	*Euphorbiaceae*	*Hevea brasiliensis*	medium/smooth	2326.92	19.50	8.00	102.769572	-2.033478	2	3

Table 5: Frequency and abundance rank of all recorded epiphyte species as shown in Figure 22. Additionally the abundance group of each species is listed.

species	Rank in jungle rubber frequency	Rank in jungle rubber abundance	Rank in rubber plantation frequency	Rank in rubber plantation abundance	Abundance group
Drynaria quercifolia	1	5	2	1	1
Asplenium nidus	2	4	3	3	1
Davallia denticulata	3	6	1	2	1
Nephrolepis acutifolia	4	13	4	4	1
Vittaria ensiformis	5	3	-	-	1
Dendrobium crumenatum	6	12	5	6	2
Microsorum punctatum	7	10	10	7	2
Pyrrosia piloselloides	8	15	-	-	2
Vittaria elongata	9	8	-	-	1
Acriopsis liliifolia	10	20	-	-	4
Antrophyum callifolium	11	1	6	8	2
Phymatosorus scolopendria	12	22	-	-	4
Monogramma sp.	13	18	11	5	3
Pyrrosia lanceolata	14	23	13	10	4
Bulbophyllum sp. II	15	14	7	11	2
Bulbophyllum sp. V	16	9	-	-	2
Cleisostoma subulatum	17	16	-	-	2
Davallia triphylla	18	26	-	-	4
Dendrobium indragiriense	19	21	-	-	4
Dendrobium leonis	20	2	-	-	2
Ficus sp. I	21	31	-	-	4
Platycerium coronarium	22	27	-	-	4
Pyrrosia angustata	23	28	12	13	4
Pyrrosia longifolia	24	29	-	-	4
Acriopsis densiflora	25	11	-	-	2
Aglaomorpha speciosa	26	24	-	-	4
Bulbophyllum sp. I	27	35	-	-	4
Bulbophyllum sp. III	28	25	-	-	4
Bulbophyllum sp. IV	29	36	-	-	4
Cymbidium sp. I	30	37	-	-	4
Dendrobium aloifolium	31	19	-	-	4
Dendrobium sp. I	32	38	-	-	4
Dendrobium sp. II	33	39	-	-	4
Eria sp. I	34	40	-	-	4
Ficus deltoidea	35	30	-	-	4
Goniophlebium verrucosum	36	41	9	12	4
Humata heterophylla	37	42	-	-	4
Humata repens	38	32	-	-	4
Huperzia sp. I	39	7	-	-	2
Liparis sp. I	40	43	-	-	4
Melastomataceae sp. I	41	44	-	-	4
Melastomataceae sp. II	42	33	-	-	4
Orchidaceae sp. I	43	45	-	-	4
Orchidaceae sp. II	44	46	-	-	4
Polypodiaceae sp. I	45	47	-	-	4
Promatocalpa diffusum	46	17	-	-	4
Promatocalpa sp. I	47	34	-	-	4
Thelasis sp. I	48	48	-	-	4
Dischidia cf imbricata	-	-	8	9	4

Table 6: Results (p-values) of the post-hoc Kruskal-Wallis Nemenyi test for differences of epiphyte individual numbers and epiphyte species numbers between five Johansson zones (JZ1 –JZ5). Test was applied for jungle rubber, rubber plantations and within jungle rubber for native and rubber phorophytes.

Individuals numbers

Jungle rubber

	JZ1	JZ2	JZ3	JZ4
JZ2	0.22	-	-	-
JZ3	0.048	0.97	-	-
JZ4	0.002	0.47	0.86	-
JZ5	< 0.001	0.004	0.04	0.35

Rubber plantations

	JZ1	JZ2	JZ3	JZ4
JZ2	0.35	-	-	-
JZ3	< 0.001	0.54	-	-
JZ4	< 0.001	0.54	1	-
JZ5	< 0.001	0.54	1	1

Native phorophyte within jungle rubber

	JZ1	JZ2	JZ3	JZ4
JZ2	0.85	-	-	-
JZ3	0.66	1	-	-
JZ4	0.1	0.61	0.81	-
JZ5	< 0.001	0.023	0.059	0.51

Rubber phorophyte within jungle rubber

	JZ1	JZ2	JZ3	JZ4
JZ2	< 0.001	-	-	-
JZ3	< 0.001	0.92	-	-
JZ4	< 0.001	0.97	1	-
JZ5	< 0.001	0.85	1	0.99

Species numbers

Jungle rubber

	JZ1	JZ2	JZ3	JZ4
JZ2	0.34	-	-	-
JZ3	0.15	0.99	-	-
JZ4	0.007	0.56	0.82	-
JZ5	< 0.001	0.004	0.017	0.26

Rubber plantations

	JZ1	JZ2	JZ3	JZ4
JZ2	0.35	-	-	-
JZ3	0.007	0.54	-	-
JZ4	0.007	0.54	1	-
JZ5	0.007	0.54	1	1

Native phorophyte within jungle rubber

	JZ1	JZ2	JZ3	JZ4
JZ2	0.98	-	-	-
JZ3	0.96	1	-	-
JZ4	0.34	0.69	0.76	-
JZ5	0.003	0.02	0.03	0.4

Rubber phorophyte within jungle rubber

	JZ1	JZ2	JZ3	JZ4
JZ2	< 0.001	-	-	-
JZ3	< 0.001	0.92	-	-
JZ4	< 0.001	0.97	1	-
JZ5	< 0.001	0.84	1	0.99

Persönliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Masterarbeit zum Thema „Diversität vaskulärer Epiphyten in Gummibaum Agroforstsystemen entlang eines Distanzgradienten zum Bukit-Duabelas Nationalpark in Sumatra (Indonesien)." selbständig und nur unter Verwendung der angegebenen Hilfsmittel verfasst habe. Die Stellen der Masterarbeit, die anderen Quellen im Wortlaut oder dem Sinn nach entnommen wurden, sind durch Angaben der Herkunft kenntlich gemacht.

__________________________________ (Datum, Unterschrift)