The Effect of Tree Enrichment in an Oil Palm Plantation on the Biodiversity of the Understorey Vegetation

Master's Thesis
for achievement of the academic degree

Master of Education (M. Ed.)

Biology & Geography

Submitted by

Lena Sachsenmaier

born on 29th April 1991
in Schwäbisch Gmünd, Germany
Marsiliusstraße 62, 50937 Köln
sachsenmaierlena@gmail.com
Student's ID: 7314528

Cologne, December 2018

Universität zu Köln
Mathematisch-Naturwissenschaftliche Fakultät
Department für Biologie: Botanisches Institut – AG Linstädter

The Effect of Tree Enrichment in an Oil Palm Plantation on the Biodiversity of the Understorey Vegetation

Masterarbeit
zur Erlangung des akademischen Grades

Master of Education (M. Ed.)

(Gymnasium/Gesamtschule)

für Biologie und Geographie

vorgelegt von

Lena Sachsenmaier

geboren am 29. April 1991
in Schwäbisch Gmünd
Marsiliusstraße 62, 50937 Köln
sachsenmaierlena@gmail.com
Matrikelnummer: 7314528

Köln, Dezember 2018

Supervisor: **PD Dr. Anja Linstädter**

Co-supervisor: Prof. Dr. Ute Höcker

In the framework of the Collaborative Research Centre (CRC) 990:

Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems (Sumatra, Indonesia), University of Göttingen

Project Group B – Biota and ecosystem services

Field work carried out between 15th January – 15th April 2018

Date of announcement: 5th October 2018

Date of submission: 14th December 2018

"The greatest threat to our planet is the belief

that someone else will save it"

Robert Swan

Abstract

Tropical regions worldwide and in particular the island state of Indonesia have been affected by high deforestation rates and a severe land-use change to agricultural landscapes such as oil palm monocultures. This is generally linked to a loss in biodiversity and ecosystem functioning. Reduced-impact agroforestry appears to have considerable potential to mitigate these losses. To explore the processes, constraints and trade-offs for ecological restoration in already existing oil palm plantations, the Collaborative Research Centre (CRC) 990 established a Biodiversity Enrichment Experiment in Sumatra (Indonesia). A key element among the various ecosystem variables and biotic characteristics investigated in the experiment is the understorey vegetation, an ecologically important but inadequately studied group. The aim of this Master's thesis is the deeper knowledge about the effects of enrichment plantings in oil palm plantations on the diversity, the composition, and the structure of the understorey vegetation. The understorey vegetation was expected to alter according to the gradients of the experimental key variables: size and tree diversity level of the enriched islands. The conducted understorey vegetation survey consists of vascular plant species inventories in all 56 plots of the experiment and additional data collection concerning species-area relations. The results of the study show that the species pool has already increased compared to the baseline survey five years ago. However, species diversity, composition, and vegetation structure were not clearly dependent on the gradients of the plot size and tree diversity level but more strongly influenced by other factors, such as canopy cover. The comparison of the enriched plots with the managed as-usual plots showed a considerable shift in the species community. In addition, a significantly increased proportion of tree and seedling species and cover was found in the plots with experimental treatment. In the context of ecological restoration, these findings can be interpreted as an already positive development. However, due to the early stage of succession, assessments of the success of enrichment plantings in oil palm plantations are limited. This study contributes to a deeper understanding of biodiversity restoration in palm oil plantations and the role of the understorey in this context.

Keywords:
oil palm, agroforestry, tree enrichment, biodiversity, understorey vegetation, ecological restoration

Zusammenfassung

Tropische Regionen weltweit und insbesondere der Inselstaat Indonesien sind von hohen Entwaldungsraten und einem starken Landnutzungswandel hin zu Agrarlandschaften wie Palmölmonokulturen betroffen. Dies ist in der Regel mit einem Verlust von Biodiversität und der Funktionsfähigkeit von Ökosystemen verbunden. Die Agroforstwirtschaft scheint ein erhebliches Potenzial zur Minderung dieser Verluste zu haben. Um die Prozesse, Einschränkungen und Kompromisse für die Renaturierung in bereits bestehenden Ölpalmenplantagen zu erforschen, hat der Sonderforschungsbereich (SFB) 990 ein Biodiversitätsanreicherungsprojekt in Sumatra (Indonesien) aufgebaut. Ein Schlüsselelement unter den verschiedenen im Experiment untersuchten Ökosystemvariablen und biotischen Eigenschaften ist die Vegetation im Unterwuchs, eine ökologisch wichtige, aber unzureichend untersuchte Gruppe. Ziel dieser Studie ist es, die Auswirkungen von Anreicherungs-pflanzungen in Palmölplantagen auf die Diversität, die Zusammensetzung und die Struktur der Vegetation im Unterwuchs zu untersuchen. Es wurde erwartet, dass sich die Vegetation im Unterwuchs entsprechend den Gradienten der experimentellen Schlüsselvariablen ändern würde: Größe und Baumdiversität der Versuchsflächen. Die durchgeführte Erhebung besteht aus der Bestandsaufnahme der Gefäßpflanzenarten auf allen 56 Versuchsflächen und einer zusätzlichen Datenerhebung zum Arten-Areal-Verhältnis. Die Ergebnisse der Studie zeigen, dass sich der Artenpool im Vergleich zur Basiserhebung vor fünf Jahren bereits vergrößert hat. Allerdings waren Diversität, Zusammensetzung und Struktur der Vegetation nicht eindeutig von den Gradienten der Parzellengröße und der Baumdiversität abhängig, sondern stärker von anderen Faktoren wie der Baumkronenbedeckung. Der Vergleich der angereicherten Parzellen mit den normalen Plantagenparzellen zeigte eine deutliche Veränderung der Artengemeinschaft. Darüber hinaus wurde ein signifikant erhöhter Anteil an Arten und Deckungsgrad von Bäumen und Sprösslingen in den Parzellen des Experiments gefunden. Diese Ergebnisse können im Hinblick auf Renaturierung bereits als eine positive Entwicklung interpretiert werden. Aufgrund des frühen Sukzessionsstadiums sind jedoch jegliche Bewertungen des Erfolgs von Anreicherungspflanzungen in Palmölplantagen begrenzt. Diese Studie trägt dennoch zu einem vertieften Verständnis der Renaturierung in Palmölplantagen und der Rolle des Unterwuchses in diesem Zusammenhang bei.

Stichworte:
Palmöl, Agroforstwirtschaft, Baumanreicherung, Biodiversität, Unterwuchs, Renaturierung

Acknowledgements

Table of Content

List of Figures

List of Tables

List of Abbreviations

%	per cent	kha	kilo hectare
B	boron	km	kilometer
BEE	Biodiversity Enrichment Experiment	km²	square kilometer
C	carbon	m	meter
Ca	calcium	m²	square meter
cf	compare to *(Latin: confer/ conferatur)*	Mg	magnesium
		N	nitrogen
cm	centimeter	P	phosphor
CO_2	carbon dioxide	pH	potential hydrogen (relative acidity/alkalinity of solutions)
CRC	Collaborative Research Center		
DAAD	Deutscher Akademischer Austauschdienst	PROMOS	Programm zur Steigerung der Mobilität von Studierenden deutscher Hochschulen
DBH	diameter at breast height	S	sulphur
DFG	Deutsche Forschungsgemeinschaft	Si	silicon
EFForTS	Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems	UNJA	University of Jambi
		UNTAD	University of Tadulako
e.g.	for example *(Latin: exempli gratia)*		
FAO	Food and Agriculture Organization		
ha	hectare		
i.e.	that is to say/in other words *(Latin: id est)*		
IPB	Bogor Agricultural University		
K	potassium		

1. Introduction

1.1 Biodiversity and its Hotspots in Southeast Asia

The term biodiversity describes the total sum of all the plants, animals, fungi, and microorganisms on Earth, with their genetic and phenotypic variation (intraspecific diversity), the communities (interspecific diversity) and the ecosystems (ecosystem diversity) of which they are part of (Dirzo & Mendoza 2008), and can focus on the numbers of entities as well as on the evenness of their distribution, the differences in their functional traits, and their interactions (Hooper et al. 2005). There is unequivocal evidence that biodiversity plays a central role in the stability of ecosystem functions (Barnes et al. 2018; Cardinale et al. 2012). In addition, biodiversity loss does not only alter ecosystem functions but also ecosystem services. The optimization of ecosystems for certain provisioning services, such as biofuel, fiber and food, indeed enhanced these services in the past but also reduced other services, particularly regulating services (Cardinale et al. 2012). Due to its huge impact on humanity, the conservation of biodiversity is one of the most important global tasks in the following decades.

The most evident geographic distributional pattern of biodiversity is the increase in species diversity with lower latitude (Dirzo & Mendoza 2008). Therefore, the very rich and exclusive reservoirs of biodiversity on Earth are to be found in tropical ecosystems (Sodhi et al. 2004). At least two-thirds of the Earth's terrestrial biodiversity host in tropical rain forests (Gardner et al. 2010) which are therefore the most species-rich terrestrial ecosystems (Corlett & Primack 2011). Concerning the group of plants it is estimated that two-thirds of all angiosperm species are found within the tropics (Pimm & Joppa 2015). In these regions alone 96 % of all tree species on Earth appear (Poorter et al. 2015) with fewer numbers in Africa than in the Neotropics and the Asia-Pacific (Slik et al. 2015).

Southeast Asia is globally outstanding for its high diversity in many plant and animal groups. This region overlaps according to Myers et al. (2000) with four out of 25 global biodiversity hotspots: Indo-Burma, Philippines, Wallacea and Sundaland. The hotspot Sundaland is located on the southeast extension of the continental shelf of Southeast Asia and includes the Malay Peninsula, as well as the Indonesian islands Sumatra, Borneo, Java and Bali. It is declared as one of the *hottest* biodiversity hotspots worldwide (Myers et al. 2000). Due to its unique geological history with the collision of several tectonic plates, fluctuating sea-levels and the isolation of islands, Sundaland is a leading hotspot in terms of endemism with 15.000 endemic plant species (5,0 % of global total) and 701 endemic vertebrates (2,6 % of global total) (Myers et al. 2000; Sodhi et al. 2004; Sodhi et al. 2010). Because of the high values of endemism richness and the limited space on islands, these regions are especially vulnerable to anthropogenic impact and should therefore get the highest priority in global biodiversity conservation (Kier et al. 2009).

1.2 Deforestation and Land-Use Change in Sumatra

In contrast to the urgent need of conservation of vulnerable ecosystems on islands, Sundaland's primary forests have been threatened by deforestation and forest degradation for a long time. By 2010, deforestation had claimed approximately 65 % of the original peat swamp forests of Sundaland, and 70 % of the original lowland forests (Wilcove et al. 2013). The island state of Indonesia is world leader in the clearing of tropical forest. In the year 2012, a higher primary forest loss was reported for Indonesia (0.84 Mha) than for Brazil (0.46 Mha) with an increasing rate between 2000 and 2012 (Margono et al. 2014). When comparing the Indonesian islands, Sumatra is the one with the highest deforestation rate. Until 2012 it lost 17.63 % of its primary forest compared to 2000 (2,857 kha) (Margono et al. 2014).

Sodhi et al. (2004) predicted that 13 to 42 % of all species in Southeast Asia will become regionally extinct by 2100. Although more recent models show lower projections than those of 2004 (Wilcove et al. 2013), the immense loss of biodiversity stays one of the most important consequences of deforestation. Additionally, primary forests are the largest above-ground carbon stores in the world (Houghton et al. 2009) and their deforestation contributes considerably to global carbon dioxide (CO_2) emissions (Hooijer et al. 2010).

The causes of land-cover change are quite difficult to assign and quantify because of a lack of reliable data and complex instead of single causes. The large-scale deforestation in Southeast Asia definitely began during the 1800s with the agricultural expansion according to the rising demand for rice, and later for other perennial export crops, including rubber, oil palm and coconut (Flint 1994). Commercial logging activities started due to an increasing demand for Asian timber in the 1950s and gained further importance as one of the main reasons for deforestation since that time. Stibig et al. (2014) declared the conversion of forest to cash crop plantations as the main cause of forest loss in Southeast Asia. Especially oil palm is blamed for deforestation (Koh & Wilcove 2008), what is reasonable due to the exorbitant and ongoing increase of palm oil production and harvested areas in Indonesia since the 1990s (FAO 2018). Abood et al. (2015) account fiber plantation and logging concessions for the largest forest loss in Indonesia, and ranked the oil palm industry third, before mining activities and mixed concessions.

Recent studies show, that the proportion of oil palm plantations replacing forests in Sumatra declined from 54.7 % (1995-2000) to 9.2 % (2010-2015) (Austin et al. 2017). This trend of establishing plantations on agricultural land and scrubland instead of forest areas will maybe be enforced by zero-deforestation commitments among oil palm growers and consumer goods companies in the future (Austin et al. 2017). However, oil palm production continues to be a notable driver of deforestation.

Indonesia is the world leading palm oil fruit producing country with 160 Mio tons per year (2016) and shows a considerable distance to the second ranked Malaysia (86 Mio t) and a great distance to further production countries such as Thailand, Colombia, and Nigeria (Figure 1) (FAO 2018).
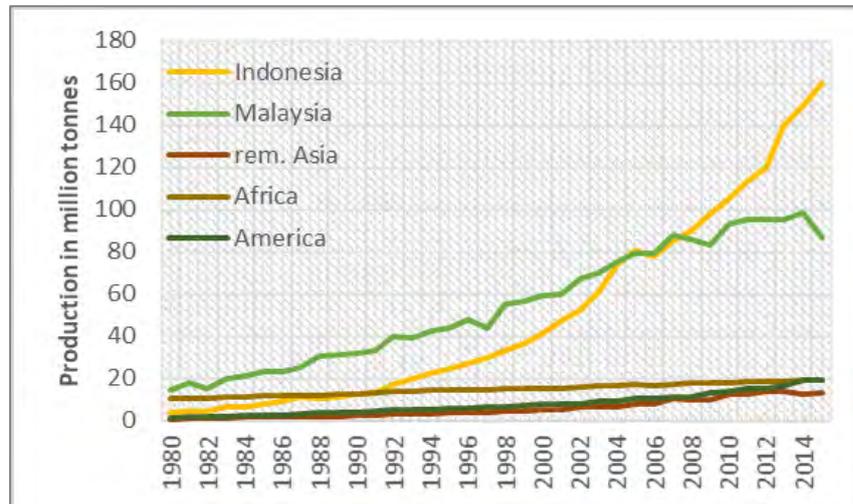
Figure 1: Palm oil fruit production in million tons between 1980 and 2016 (FAO 2018)

Although rubber is another economically important agricultural product with rising demand, the acreage of 3.6 Mio ha is less than half of the palm oil area of 9.3 Mio ha in 2016 (FAO 2018). Palm oil contributes as a financially important export product to Indonesias' economy (World Growth 2011) and is due to the high proportion of small holder farmers (39.1 % area and 32.7 % production, 2016) also considerable from a social point of view (INOBU 2016; Kementerian Pertanian, Sekretariat Direktorat Jenderal Perkebunan 2017). As the global demand for a suitable vegetable oil, which fulfills the needs for cooking, food ingredients, biofuels as well as detergents and other chemicals is still rising, palm oil consumption and production is expected to highly rise in future times (Mishra et al. 2017).

1.3 Oil Palm Plantations and their Impacts on Plant Biodiversity

The oil palm *(Elaeis guineensis*, Jacq.) is part of the Arecaceae plant family, native to tropical Africa and requires similar environmental conditions for growth as tropical rainforest (Corley & Tinker 2016). Palm oil trees grow up to 20 m height. The typical commercial lifespan of an oil palm is about 25 years with a peak fruit production between seven and eighteen years and a gradually decrease of yield afterwards. The disturbing impact of the steadily rotating harvest is relatively low compared to other cash crops, as single chosen fruit bunches are cut off with a sickle or a hooked knife and carried manually to the nearby road collection point for the transport to oil mills (Corley & Tinker 2016).

Figure 2: Oil palm agriculture in Jambi Province (Sumatra, Indonesia). (A) Palm oil plantation *PT Humosindo* with buffalo grazing; (B) Cleared area for reestablishment of plantations; (C) Manual harvest of palm oil fruit bunches with a hooked knife. (pictures by Lena Sachsenmaier)

The establishment of large-scale oil palm monocultures in former forest areas has severe environmental consequences. The plantations are structurally less complex than natural forests, have a lower canopy and are undergrown by a sparse understorey vegetation (Fitzherbert et al. 2008). The focus on ecosystem functions concerning the conversion of forest to oil palm plantations shows globally important decreases in greenhouse gas regulations, habitat provision, medicinal, genetic and ornamental resources and recreation potential (Dislich et al. 2017) as well as an increase of the surface temperature (Sabajo et al. 2017). However, some ecosystem services, such as carbon sequestration and soil protection, may be better provided by oil palm plantations than by other annual crops or grassland (Albrecht & Kandji 2003; Corley & Tinker 2016; Danielsen et al. 2009; Fitzherbert et al. 2008). The conversion of rainforest into rubber and oil

palm monocultures declines above- and below-ground carbon stocks, and changes microclimatic conditions (Drescher et al. 2016). The transformation also decreases energy fluxes, reduces soil fertility and leads to a higher level of soil erosion (Allen et al. 2015; Barnes et al. 2014; Guillaume et al. 2015; Guillaume et al. 2018).

A decline of species richness from forest towards intensive agricultural landscapes has been observed for most animal groups (Clough et al. 2016; Drescher et al. 2016; Gibson et al. 2011). Oil palm plantations are the tree plantations with even fewer species than other plantations (Fitzherbert et al. 2008; Foster et al. 2011; Savilaakso et al. 2014). Concerning species richness, Danielsen et al. (2009) reviewed several studies and always found lower numbers of species in oil palm plantations compared to forests. Vertebrate species richness was less than half (38 %) than in natural forests. Correspondingly only 29 % similarity in species community composition between oil palm and forest was reported. Likewise, Barnes et al. (2014) recorded severe losses in animal species richness (45 % decline), animal density (48 % decline) and biomass (52 % decline) as well as a systematic shift from predator to omnivore dominance when comparing forest and oil palm systems. Investigations of birds show, that not only species richness is reduced, but also the group of frugivores is absent in oil palm and rubber monocultures (Prabowo et al. 2016). That means, apart from the reduced species numbers, several qualitative changes in species composition have already been detected. The link between animal species and plant species is quite close, so a loss of plant species richness is likely to correspond with a loss of animal diversity. However, studies concerning the understorey vegetation of oil palm plantations are still quite rare.

Rembold et al. (2017a) documented a loss in plant species richness, changes in the floristic composition and vegetation structure in addition to increased alien plant invasions in comparison to forest and tropical agricultural landscapes. In oil palm landscapes 25 % of all species, and 62 % of all individuals belonged to the alien group. The plant communities in oil palm showed a high density of herbaceous weeds but a low beta diversity (Rembold et al. 2017a). Furthermore, a pronounced loss in the understorey plant phylogenetic diversity is observed, when tropical rainforest is converted to monoculture plantations (Kusuma et al. 2018).

Because of the numerous negative environmental impacts of palm oil plantations, which are already published, palm oil production has become highly controversial and the call for more sustainability in agroforestry as well as the demand for forest conservation projects is getting more intense.

1.4 Restoration and Biodiversity Enrichment

It is a huge challenge to balance between the demand for agricultural production area and area for biodiversity conservation. Degraded forests have the potential to recover back to higher carbon and biodiversity value forest if abandoned for the naturally restoration processes (Chazdon & Guariguata 2016), but alterations of biodiversity appear quite slow (Wheeler et al. 2016). Natural recovery is not always possible, as land is still used for agricultural purpose. Furthermore, there is a variety of reforestation methodologies, which as well have the ability to enhance biodiversity and improve ecological functioning within actively used land (Lamb et al. 2005). Especially in an area where most forests are already lost, biodiversity restoration can be integrated into the management of existing agricultural landscapes (Foster et al. 2011; Koh et al. 2009). One of several design options is to involve the planting of dispersed small clumps of trees within an agricultural matrix (Stanturf et al. 2014). This restoration technique consisting of cluster plantings takes advantage of the process of applied nucleation and its success has already been demonstrated in several experimental set ups (Cole et al. 2010; Corbin et al. 2016; Corbin & Holl 2012; Zahawi & Augspurger 2006). These cluster islands act as essential stepping stones for species' long-distance dispersal (Saura et al. 2014) and are more cost-effective than tree plantings over large areas (Zahawi et al. 2013).

The successful application of tree plantings in tropical agricultural systems supplementary needs to take in account the productivity of desired goods as an equal goal (Lamb et al. 2005). Therefore, native tree species with high benefit for ecosystem functions and simultaneously high socio-economic value for the communities must be selected. Although there are a few studies of intercropping systems with palm oil (Corley & Tinker 2016), that resulted in rather negative yield effects, except when intercropped with Cacao (Egbe & Adenikinju 1990), there are huge knowledge gaps regarding the ecological and socio-economic consequences of biodiversity enrichment in oil-palm landscapes. Likewise, there is still no consensus on the most effective island size, the most effective number of planted species and the most effective species composition in an economic and ecologic way.

Initial results from the biodiversity enrichment experiment (EFForTS-BEE) in Sumatra, in the scope of which the master thesis was conducted, show enhanced oil palm yields inside as well as directly adjacent to the experimental plots after two years, that at least compensate for the reduced number of oil palms due to thinning. As planted trees grow taller, this effect on yields may change (Gérard et al. 2017). In the same experimental set-up, the ecological effects of the enrichment show already positive trends concerning bird and invertebrate communities one year after establishment. Regarding the experimental factor size of the tree islands, the group of invertebrates show significantly positive correlations in diversity and abundance. As the organism groups of birds and invertebrates are essential for the initiation of natural succession, further biodiversity enrichment in the future looks promising (Teuscher et al. 2016).

1.5 Aim of the Study

The study is conducted within the framework of the *Collaborative Research Center (CRC 990)* "Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems (Sumatra, Indonesia) (EFForTS)", which forms a cooperation project between the University of Göttingen, and three Indonesian universities, Bogor Agriculture University (IPB), University of Jambi (UNJA) and University of Tadulako (UNTAD) and which is funded by the *Deutsche Forschungsgemeinschaft* (DFG). Within the project group B *(Biota and Ecosystem services),* the research group *B11* established the *Biodiversity Enrichment Experiment (EFForTS-BEE) in an Oil Palm Plantation* in 2013 to investigate if gap enrichment plantings are a suitable method for biodiversity enrichment in oil palm plantations and if the planted tree islands act as nuclei for colonization of flora and fauna. In addition, the socio-economic and ecological trade-offs in this context need to be explored.

The first studies of the EFForTS-BEE project about the enrichment effects on birds, invertebrates, seed dispersal, herbivory, water infiltration, and light competition in the different plots are partly completed and partly ongoing (Gérard et al. 2017; Teuscher et al. 2016). However, data concerning the understorey vegetation is lacking until now.

The tree layer of forest stands strongly affects the understorey layer composition and richness (Mölder et al. 2008), due to its influence on light interception, temperature, air humidity (Barbier et al. 2008), water and nutrient availability and on the litter layer (Li et al. 2017). Tree species diversity may increase the variation in ecological conditions. The higher level of structure of a mixed forest is leading to a higher level of habitat heterogeneity in the understorey and thus increases microsite availability for herb layer species. In consequence, a higher tree layer diversity would be expected to ensure a more diverse understorey. The understorey layer itself provides habitats for mammals, insects and other animal groups. Its biomass enters food webs and affects nutrient storage and cycling, what contributes to a higher overall forest productivity (Mölder et al. 2008). In addition, the species of the understorey interact competitively and facilitatively with tree recruits and control tree species regeneration (Gilliam 2007).

Thus, the understorey has strong influence on the future composition of the tree layer (Ampoorter et al. 2015; Gilliam 2007). The knowledge about the structure and the diversity of the understorey vegetation is therefore an essential key information in any restoration and enrichment context.

That is why this study's primary aim is assessing the effect of tree planting in an oil palm plantation on the structure and diversity of the understorey vegetation.

As the investigation of the two key aspects of the experimental treatment – size and tree diversity of the enrichment islands – aim at having a deeper comprehension of the process related to ecological restoration of oil-palm landscapes (Teuscher et al., 2016), they also represent the key experimental factors of this study.

It is hypothesized that…

(a)   …the species diversity of the understorey vegetation increase with rising plot size and plot tree diversity level.

(b)   ...the species composition of the understorey vegetation varies among plot size and plot tree diversity level.

(c)   …the structure of the understorey vegetation is affected by plot size and plot tree diversity level.

2. Material and Methods

2.1 Study Area

The EFForTS project conducts research in Jambi Province in Sumatra, Indonesia. Jambi Province extends over an area of 50,106 km^2 between the Barisan mountain range in the west towards the southern Malacca Strait in the east (Figure 3). The climate is humid tropical with two peak rainy seasons around March and December, and a dryer period during July to August (Drescher et al. 2016). The dominant soil type in the region is loamy Acrisol (Allen et al. 2015). The primary natural vegetation is *Dipterocarp*-dominated lowland rainforest (Laumonier et al. 2010).
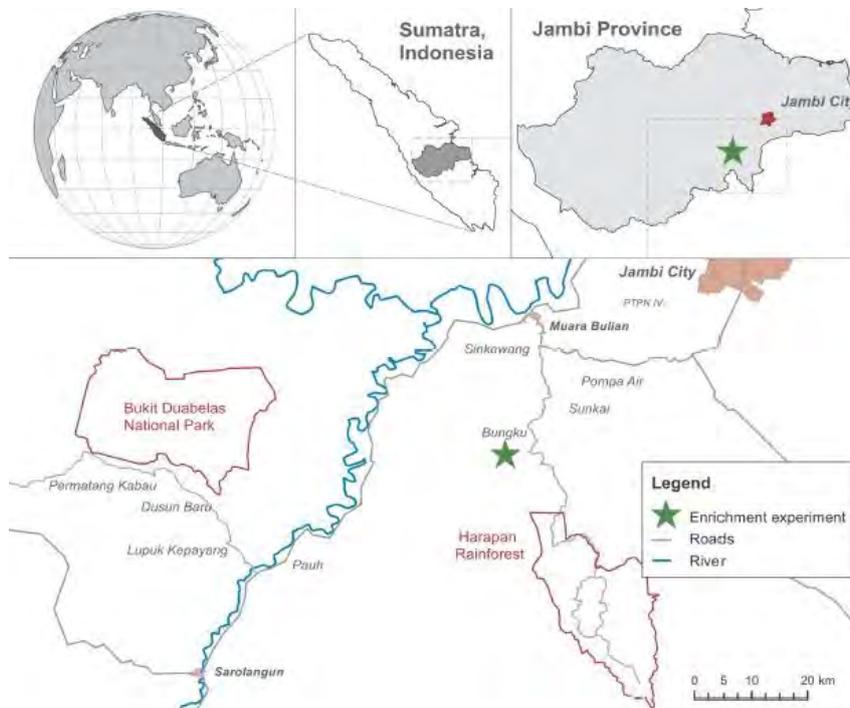
Figure 3: **Map of the study area (Drescher et al., 2016; modified by Teuscher et al., 2016)**

As of 2018, more than 669,000 ha of rubber and more than 497,000 ha of oil palm are being cultivated in Jambi Province (Badan Pusat Statistik 2018). The site of the subproject *Biodiversity Enrichment Experiment (BEE) in an Oil Palm Plantation* was established on a palm oil plantation of PT. Humusindo Makmur Sejati (01.95° S /103.25° E) near Bungku village (Figure 3). This plantation consists of an inhomogeneous palm age structure of currently ca. 10 - 16 years and is planted with a density of ca. 143 palms per ha in a 9 m x 9 m triangular grid. The management of the plantation includes regular manual weeding of the understorey, removal of epiphytes, and fertilizer application (N, P, K, Mg, B, S, Si, Ca). Livestock farming is carried out on the plantation area whereas the application of herbicide is only rare (Teuscher et al. 2016).

2.2 Design of the Biodiversity Enrichment Experiment

The experimental site was set up in December 2013 in an existing oil palm plantation by planting tree islands in an area of about 2.8 ha. The experiment consists of 52 tree islands of different sizes (5m x 5m, 10m x 10m, 20m x 20m, 40m x 40m) (Figure 4: A). The plots vary in tree species composition and diversity (0, 1, 2, 3, or 6 species) following a random partitions design (Bell et al. 2009). On each plot of 25 m² six trees were planted, on the 100 m² plots 25 trees, on the 400 m² plots 100 trees and on the 1,600 m² plots 400 trees; this sums up to a total number of 6,354 planted trees (Teuscher et al. 2016). To improve light conditions by around 40 %, selected oil palms were cut prior to planting (Figure 4: B). Due to the fact that the 5 m x 5 m plots were set up in between existing oil palms, no palms have been cut there. So, in all plots with treatment, the planted trees can interact and compete with each other, as well as with oil palms (Figure 4: C). All plots with treatment were fenced to keep out mammals and protect in this way especially the tree saplings.

ID	Tree species	Family	Local name	Purpose
A	*Parkia speciosa*	Fabaceae	"Petai"	fruit
B	*Archidendron pauciflorum*	Fabaceae	"Jengkol"	fruit
C	*Durio zibethinus*	Malvaceae	"Durian"	fruit
D	*Dyera polyphylla*	Apocynaceae	"Jelutung"	latex
E	*Peronema canescens*	Lamiaceae	"Sungkai"	timber
F	*Shorea leprosula*	Dipterocarpaceae	"Meranti tembaga"	timber
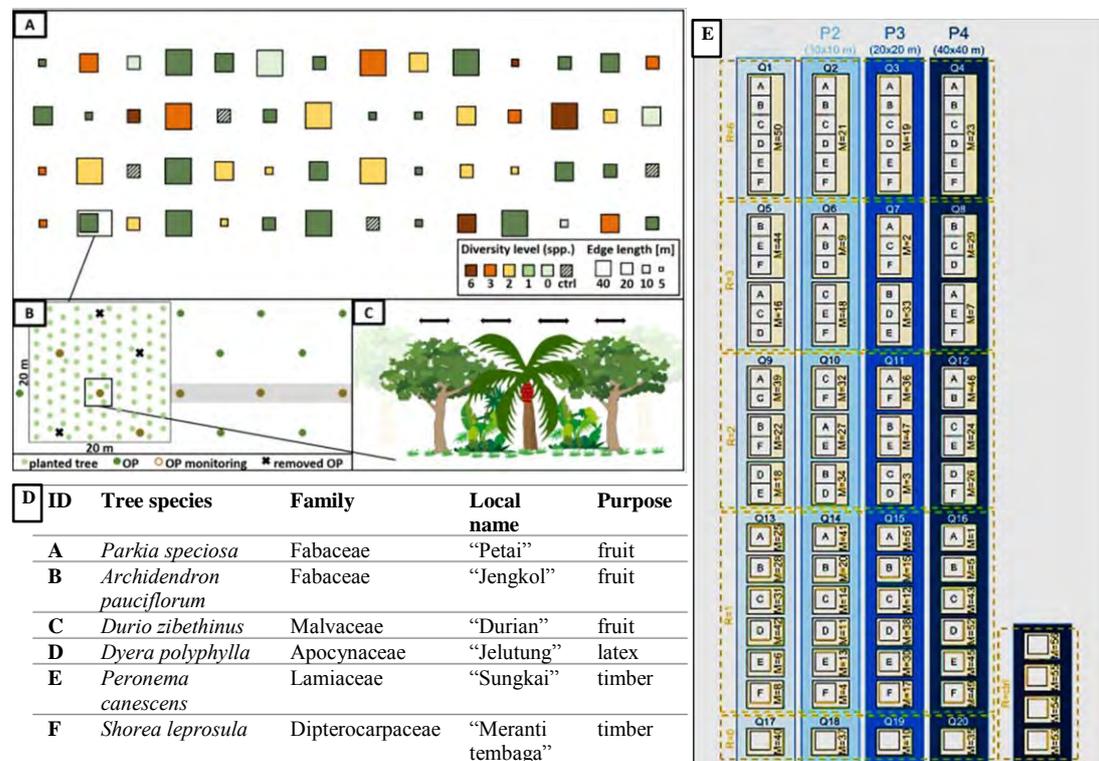
Figure 4: **Design of the Biodiversity Enrichment Experiment (EFForTS-BEE).**
(A) Overview of the plots: 52 tree islands with systematically varying tree diversity (diversity level of 0, 1, 2, 3, and 6), identity and composition as well as plot size (25 m², 100 m², 400 m², 1600 m²) and species composition were established. On all the plots with treatment (52 plots – diversity level 0-6), a special management is applied, that consists of the stop of fertilizer and pesticide application and the manual weeding in the first two years after establishment. Additionally, there are four control plots of the same size (10 m x 10 m), on which no trees were planted (no treatment) and which are managed as-usual. This results in a total of 56 plots (Teuscher et al. 2016). (B) Oil palms (OP) were cut on the plot with treatments in order to enhance light conditions. Trees were planted in a 2 × 2 m grid. Perpendicular to each plot, three oil palms were selected to monitor services and disservices of the tree islands on surrounding oil palms (Teuscher et al. 2016). (C) Planted trees interact/compete with each other as well as with the oil palms (IAN Image, 2015; modified). Manual weeding stopped after two years to allow for natural succession (Teuscher et al. 2016). (D) Planted tree species with local name and main economic purpose. (E) Experimental design adopting a random partitions design (see Bell et al. 2009 for further information). At each level of diversity, each tree species is represented exactly once (Teuscher et al., 2016).

On the plots with treatment, special management was applied: stop of fertilizer, herbicide and pesticide application and regular manual weeding for the first two years after establishment to support the planted tree saplings (Teuscher et al. 2016).

The six different planted tree species are native multi-purpose species, which are attractive in an agroforestry context because of either fruit, timber or latex (Figure 4: D). At each level of diversity, each tree species is represented exactly once (Figure 4: E).

Additionally, four control plots of the same size (10 m x 10 m) without any experimental treatment were set up, which are managed as-usual and not fenced. Cattle and buffalo grazing, regular manual weeding as well as fertilizer application around the palms is common on these plots. Due to the fact that no trees were planted on these plots, no palm trees have been cut as well (Teuscher et al. 2016).

In total, the experiment comprises 56 plots (Figure 4: A,E). Each plot size is represented by 13 plots with treatment. When summed up, the treatment '0 planted tree species' and '6 planted tree species' are represented by each four plots. The same amount applies for plots with the control treatment. The diversity level 1 comprises twenty-four plots, diversity level 2 twelve plots and diversity level 3 eight plots (Table 1). Nevertheless, each plot is unique because of its combination of plot size, diversity level and the composition of tree species, i.e. the experiment comprises no true repetition plots.

Table 1: **Overview of the plots in the Biodiversity Enrichment Experiment, listed with the number of plots in each category of tree diversity level (number of planted tree species) and plot size.**

Diversity Level Plot Size	0 Tree Species	1 Tree Species	2 Tree Species	3 Tree Species	6 Tree Species	Control	Total
5 m x 5 m	1	6	4	2	1	0	13
10 m x 10 m	1	6	4	2	1	4	(13+4) 17
20 m x 20 m	1	6	4	2	1	0	13
40 m x 40 m	1	6	4	2	1	0	13
Total	4	24	12	8	4	4	(52+4) 56

The plots were set up with a minimum distance of 85 m between them, although most of them have a much farer distance in between. The spatial arrangement of the plots in the plantation was completely random and the plots were not aggregated according to partitions, blocks, or diversity levels (Appendix C).

2.3 Data Collection

2.3.1 General Strategy and Sampling Situation

The data collection ran throughout the months of January to April 2018 consisting of an initial practice phase of training identification skills (23th January – 2th February), a pre-study of testing and optimizing the measurements and training methodology skills (5th February – 15th February), the main data collection (22th February – 25th March) and an additional data collection for the species-area relationship (26th March – 10th April).

In each of the 56 plots one randomly distributed subplot of 5 m x 5 m is already established, which is not fenced but marked with cordon. All measurements, apart from the additional species-area data collection (chapter 2.3.5), were only conducted within these subplots. In the plot size category 5 m x 5 m the subplot is equivalent to the entire plot. The four control plots were treated equally. To ensure management as usual, the plots and subplots of control treatment were neither fenced nor marked with cordon but with plastic pipes in the four corners.

The main data collection consisted of a survey on subplot level, in which surface cover and litter layer data were collected, and a survey on species level within the subplot, which included species identity, abundance, cover estimations, and shoot length measurements (Figure 5).
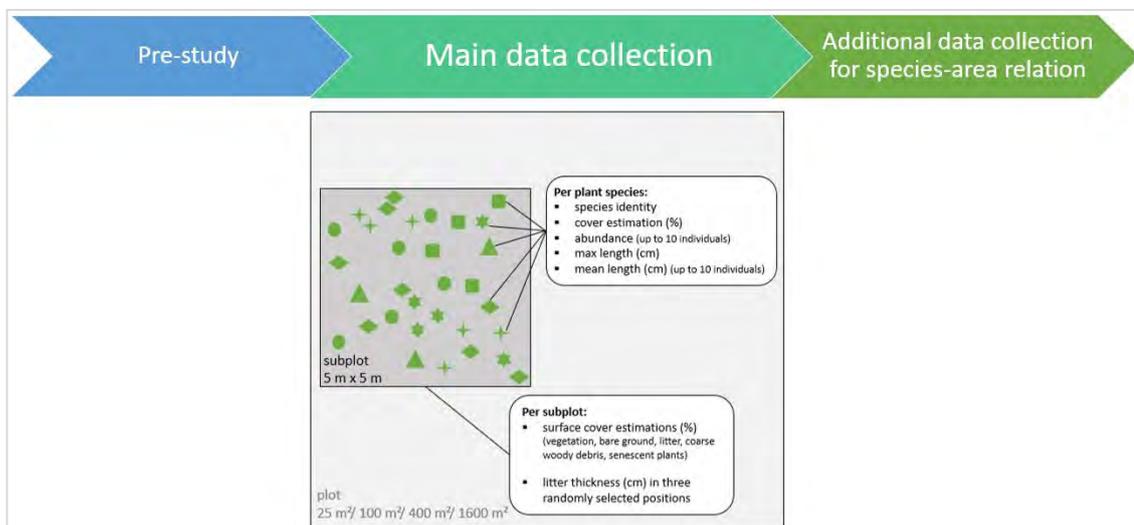
Figure 5: **General sampling strategy, consisting of a pre-study, the main data collection with a survey on subplot level and a survey on species level, and an additional data collection for the investigation of the species-area relationship.**

Other measurements of other studies, such as intensive microclimate measurements, litter investigations, seed and pollen samplings, LAI measurements, and water infiltration measurements also took place at the same time in the same subplots. For these reasons, measuring instruments such as litter bags, seed traps, pollen traps, climate stations, and chili plants (for a pollen experiment) were permanently present in the subplot.

Especially for periodic insect observations and the emptying of seed traps the subplot experienced much disturbance in the form of trails and bended plant individuals. Therefore, the level of disturbance was estimated within a scale from 0 to 5 before starting with any measurements concerning the understorey.

Due to the change between rainy and dry season, weather conditions varied a lot throughout the data collection period. The rainfalls resulted in muddy roads, which created difficulties concerning the access to some plots. Some plots were flooded or showed signs of a flooded status before, which made some data collection difficult and may influence the data itself.

The sampling area incorporate a quite high abundance of venomous snakes (esp. Sumatran Cobra: *Naja sumatrana)* and wild boars (*Sus scrofa var. vittatus*). Close to suspected nests or known whereabouts few measurements could not carried out exactly because of security reasons and were therefore just estimated.

2.3.2 Pre-Study

The pre-study examined all 13 plots of the plot size category 5 m x 5 m. Instead of taking the entire subplot into account, three quadrats of 1 m x 1 m size were set up with a square frame made up of plastic pipes, which could be transported and installed easily Figure 6). The randomly distribution of the quadrats inside the subplot was carried out before and drawn on a subplot map. Due to the presence of measurement installations from other studies in the subplot, the fixed quadrat positions had to be shifted sometimes.

In each quadrat, surface cover data was collected, following the same approach as in the main data collection (chapter 2.3.3). On species level within the quadrat, species identity, abundance, cover estimation, and shoot length measurements of one individual per species took place, following the same approach as in the main data collection as well (chapter 2.3.4). Subsequently the whole subplot was searched for additional species, that didn't occur in the quadrats so far, and if present, treated in the same way as species in the quadrats.

Figure 6: **Pre-study measurements. (A) Installation of the square frame made up of plastic pipes on randomly selected location within the subplot. (B) Installed 1m x 1m square frame for understorey plant data sampling. (pictures by Lena Sachsenmaier)**

The pre-study aimed in practicing the cover estimations on a smaller area, before estimating the 5 m x 5 m subplots, as there is strong evidence that training is likely to increase precision in visual estimations (Symstad et al. 2008). Another aim was finding parts of the sampling design that can be optimized or shortened. Due to time-saving reasons the most abundant species that occurred in all plots of the pre-study with a high individual number were identified and treated differently in the main data collection (chapter 2.3.4).

2.3.3 Data Collection concerning Subplot Surface Characteristics

In each subplot the ground cover [%] of vegetation, litter, woody coarse debris, senescent plants, and bare ground was estimated (Table 2). The estimations were carried out by two persons, as multiple observer studies reveal estimates closer to true values because extreme values may be adjusted (Wintle et al. 2013). Although visual estimations are quite subjective and erroneous, the comparability of the values is given, when the data collectors remained the same over the whole collection period, i.e. the pattern of intra-observer error stays the same (Morrison 2016). The estimations were carried out in absolute percent ratios from 0 % to 100 %. Accurate estimations in absolute percent ratios between 0 % and 1 % would have been almost impossible on an area of 25 m². That's why, although not following the Braun-Blanquet scale (Braun-Blanquet 1928) in general, the category < 1 % for everything less than 1 but more than 0 was added, and later transformed to the value of 0.1 %. The vegetation cover was estimated on breast height, so for vegetation, only the parts of the plants under 1.3 m were included into the cover estimations. Plants, which rooted outside the subplot but had any cover inside the subplot were included in the cover estimations. Measurement installations of other studies (Figure 7) in the subplot such as litter bags, seed traps, pollen traps and chili plants were counted as bare soil, if they repressed the understorey vegetation, as litter, if they were covered by litter, and as vegetation, if they were completely covered by vegetation or in the case of the seed traps, vegetation could grow undisturbed beneath (Table 2). In case there was an oil palm trunk fully or partly inside the subplot, it was considered as bare soil. Trunks and other parts (< 1.3 m) of planted tree individuals were considered as vegetation.

Table 2: **Categories and their definitions for the cover estimations on subplot level**

Cover category	Definition
Vegetation	All parts of vascular plants that are alive and < 1.3 m height, even if the plant itself roots outside the subplot area. All parts of planted tree individuals (if < 1.3 m) are included, but oil palm trunks (plus possible epiphytes growing on the trunk) are excluded and considered as bare soil.
Litter	All dead plant materials that are not part of the plant any more, i.e. leaves, culms, flowers, fruits, roots, and woody parts, which do not meet criteria for the category woody coarse debris.
Woody coarse debris	All dead snags and logs of mid-point diameter ≥ 1 cm and length ≥ 25 cm.
Senescent plants	All plants in the final stage of senescence, but nevertheless not yet part of the dead litter layer. All dead or dying standing vegetation, which cannot be determined unequivocally neither as alive vegetation nor as litter, is included in this category as well.
Bare ground	All parts of bare ground (e.g. soil, rock or stones) plus all measurement installations of the project, as e.g. litter bags, if they are not covered by any other category (vegetation, leaf litter...) and oil palm trunks.

Additionally, the thickness of the litter layer [cm] was measured in three randomly chosen positions inside each subplot with a metal ruler. The ruler was adjusted in such a way, that the point 0 directly started on the soil surface. The height of the litter layer was read at the point of the highest erected part of litter. If the randomly chosen measuring point did not consist of any litter, another point of measurement was chosen, so that the value of 0 cm thickness is impossible. Out of the three values in each subplot the mean value per subplot was calculated.

2.3.4 Data Collection concerning Species Data

In each subplot all present species of vascular plants (i.e. mosses and lichens were excluded) have been identified as far as possible. Species, that could be confidently categorized as being different from the other species, but could not be identified on species level, were included as morphospecies (chapter 2.4). Besides information about the species itself, information about the plant family and growth form (Table 3) was collected. All epiphytes growing on stems of trees or palms were excluded from this understorey data collection, whereas vine species, which rooted in the ground and climbed up stems of trees or palms, were included.

Table 3: **Growth form classification (based on Edwards (1983), FGDC (2008), Australian National Herbarium (2011a))**

Growth form	Definition
Tree	Self-supporting, perennial, woody plants that generally have a single main stem (trunk) and are normally branching above ground level
Shrub	Self-supporting, perennial, woody plants that are generally multi-stemmed (erect, spreading or prostrate stems) and normally branching at or near ground level
Seedling	Several currently unidentified non-herbaceous seedlings that might either become a tree, a shrub, or a liana.
Vine	Not self-supporting, ground-rooting, and wining or climbing plants with relatively long stems, can be woody (liana) or herbaceous.
Herb	Vascular plants without significant woody tissue above the ground, which may be annual, biennial, or perennial but always lack significant thickening by secondary woody growth and have perennating buds borne at or below the ground surface. If woodiness is evident, this is restricted to the permanent lower portions of the plant at or near ground level.
forb	All herbs, which cannot be classified as ferns, graminoid or vines according to the determination below.
fern	Vascular plants that reproduce by spores and have neither flowers nor seeds, i.e. all true ferns *(Polipodiophyta)* and fern allies *(Lycopodiophyta)*.
graminoid	Grass or grass-like plant, including grasses *(Poaceae)*, sedges *(Cyperaceae)*, rushes *(Juncaceae)*, arrow-grasses *(Juncaginaceae)*, and quillworts *(Isoetes)*.

In case of unknown species, that could not be identified directly in the field, the individual was photographed in detail, the properties important for the subsequent identification noted in the remarks and a latex test for wooden species carried out. One individual of the unknown species was collected for the herbarium (chapter 2.3.6), if it occurred anywhere outside the subplot. It was considered that the selected individual for the herbarium is vigorous, not insect-damaged and a representative of the population. In the case of existing flowers and fruits, they were collected as well. Only if possible without broader disturbance and only if more than ten individuals of the species were present, roots, bulbs or other underground parts were carefully dug up. To avoid any disturbance of the subplot, the unknown species was not collected, if no other individual could be found outside the subplot. Tree seedlings, which deserve special protection due to their importance in restoration contexts, were generally not collected for the herbarium. In the case of already well-developed shrubs or trees, some branches and/or leaves were collected. After identification, for each plant species the ground cover in percent was estimated inside the subplot (Figure 7). The method of cover estimation is the same than for surface cover (chapter 2.3.3).

Individuals which rooted outside the subplot, but had any cover inside the subplot, were included in the cover estimations. As plant species can grow in different layers the combined species cover could be more than 100 %, and on the other hand also less than 100 %, if vegetation cover is only a part of the surface cover.
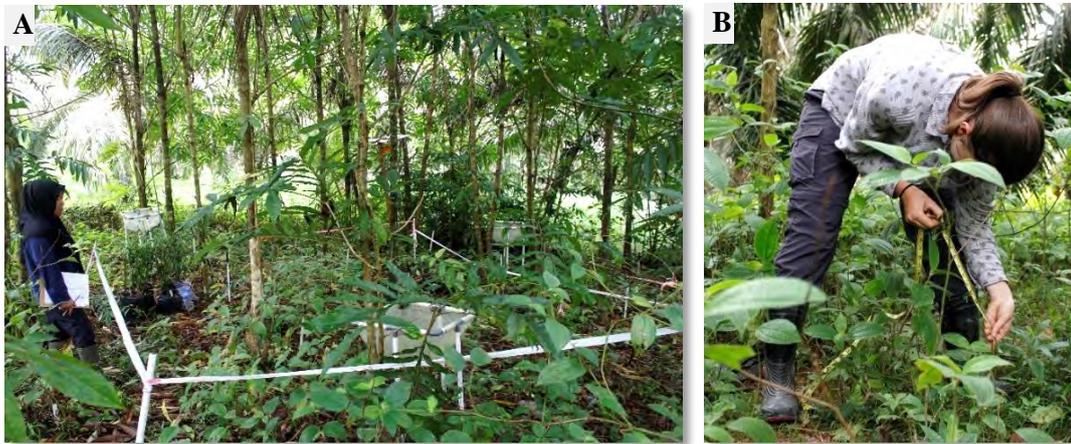
Figure 7: **Data Collection. (A) Conducting cover estimations on subplot level. Seed traps and climate stations that are installed in the subplot belong to other studies within the EFForTs-BEE project and were ignored. (B) Measurement of individual shoot lengths (up to 10 per species) with a simple measuring tape (pictures by Lena Sachsenmaier).**

Subsequently, the individuals of each species inside the subplot were counted up to 10 individuals. If two or more narrow standing stems could not completely be considered as belonging to one individual, they were counted as two or more individuals. The shoot length [cm] from up to 10 individuals per species were measured with simple measuring tapes (Figure 7). The individual with the maximum shoot length was always included; the remaining measurements were carried out on randomly selected individuals. The individual shoot length was defined as the distance between the lowest visible point of the stem (directly above the soil) and the top of the main stem for dicotyledons, until the top of the longest leave part for monocotyledons and the top of the longest pinna for ferns. For the measurement of the shoot length all climbing individuals were removed from their host plant or the fence as far as possible and adjusted again after the measurement. If they were climbing too high or too difficult to untangle, the length was estimated. Because of time considerations, seven species, that were determined as most abundant species based on the pre-study results, were treated differently concerning the shoot length measurements and abundance counting. These individuals were not counted exactly but just determined as more than or less than 10 individuals. Furthermore, instead of 10 randomly selected individuals for shoot length measurements, the subplot was divided in four imaginary quadrats, in which each of them the individual with the maximum shoot length was measured. So, the number of measurements for these species is not dependent on the real number of individuals, but dependent on the presence or absence in each part of the plot and ranges between 0 and 4 measurements.

2.3.5 Additional Data Collection for Species-Area Relation

For the investigation of the relationship between species richness and size of the sampling area, a separate species-area relation survey was conducted. Due to the time-consuming sampling only the plots of tree diversity level 0, tree diversity level 6 and the control plots could be involved in this survey. Through continuous sampling all new vascular species that did not occur within the sampling area of the subplot, were added to the data set. The sampling area was stepwise expanded from the subplot (5 m x 5 m) to an area of 10 m x 10 m, 20 m x 20 m and 40 m x 40 m as far as the plot size allows the expanding (Figure 8). The sampling strategy consists of a search in a loop-shaped pathway, carried out by two persons simultaneously, so that as few species as possible were missed. With a long stick the vegetation was constantly pushed to the side, to discover plants, possibly growing beneath. Due to the density of the vegetation, individuals smaller than 10 cm height were excluded. Species, that could be confidently categorized as being different from other species, but could not be identified on species level, were included as morphospecies. Besides information about the species itself, information about the plant family and growth form (Table 3) was collected. In contrast to the previous study, no cover estimations or shoot length measurements were carried out. Plastic pipes and ropes were used to mark out the area of investigation, whose exact location was chosen spontaneously by the simplest way of handling the measurement, but always in a nested design. With this design, data concerning species richness of one plot per plot size in each tree diversity level could be collected (Figure 8) and explicitly related to the size of the sampling area in the analysis.
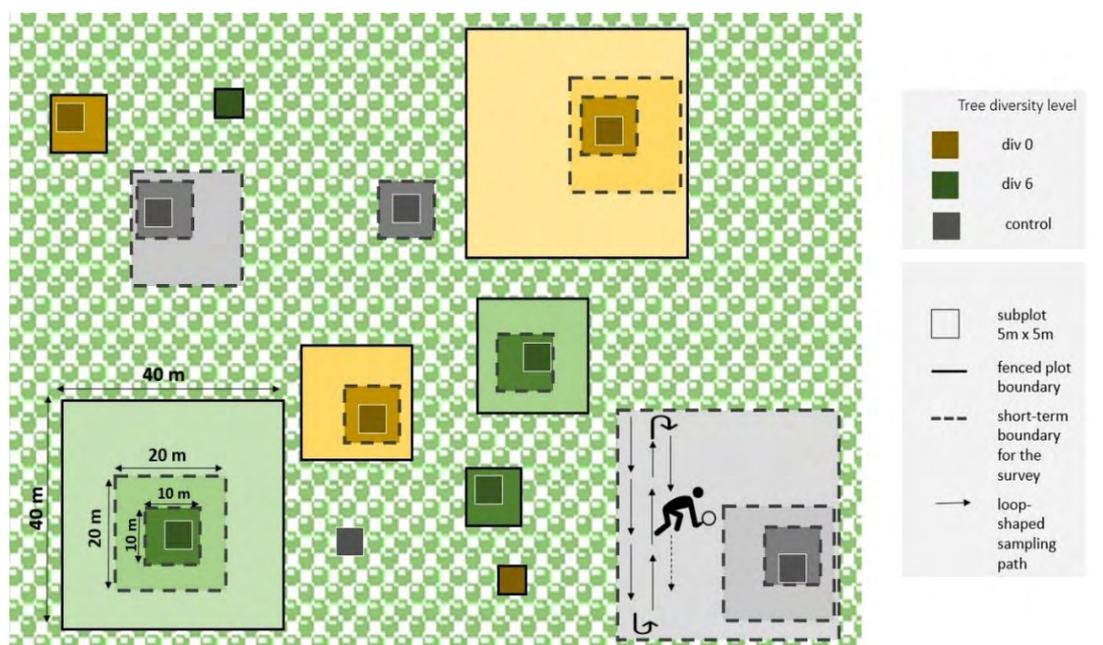
Figure 8: Sampling Design of the Species-Area-Relation Survey.
The survey included the sampling area of four subplots of each tree diversity level (div 0: zero tree species planted; div 6: six tree species planted; control: no trees planted and management as usual), which are then stepwise expanded until the outer boundary of the plot (step 1: 10m x 10m; step 2: 20m x 20m; step 3: 40m x 40m). The exact location of short-term boundaries (installed ropes) for the survey were chosen spontaneous by the simplest way of handling the measurement. The sampling strategy consists of a loop-shaped search for additional species, that did not occur in this plot before (own figure).

2.3.6   Herbarium Work

To allow and support accurate identification, herbarium specimens were collected. The method of collection and preservation of specimens followed the instructions of Australian National Herbarium (2011b), Queensland Herbarium (2016), and University of Florida/ Florida Museum of Natural History (1995). Before proceeding the collected individuals for preservation, they were carefully photographed in front of a black background, with label and millimeter scale (Figure 9). All parts of the individual, which are important for identification, were photographed separately in close-up shots. All plant photos were digitally edited, labeled, sorted, and archived using the Digital Asset Management (DAM) software *digiKam,* version 5.9.0.
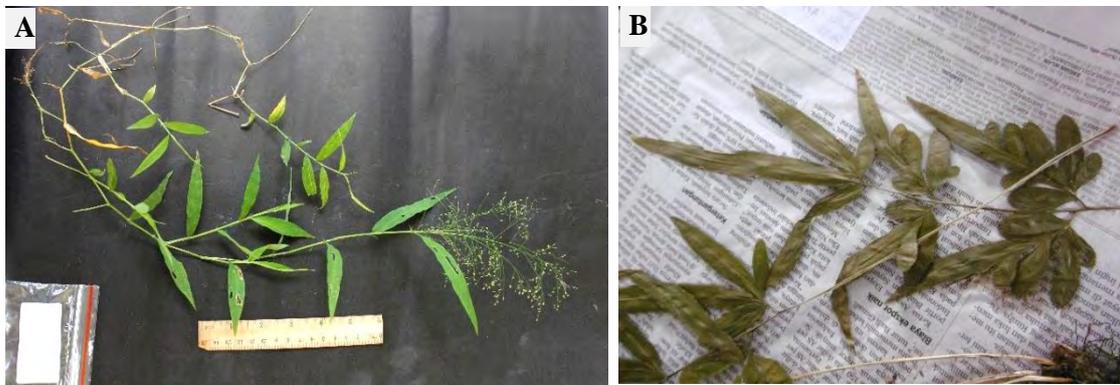
Figure 9: Herbarium work. (A) Specimen of *Cyrtococcum patens,* placed for botanic photographing. (B) Specimen of *Pteris cf. ensiformis* after pressing and drying process. (pictures by Lena Sachsenmaier)

Collected specimens were stored in plastic bags with damp papers inside but pressed as quickly as possible after collection, mostly on the same day. A simple field press, consisting of various hardwood frames with strong webbing straps, was used. Each specimen was placed in a fold of several sheets of newspaper and placed in the press. Woody or bulky specimens were halved or sliced before pressing and separated by cardboard from delicate ones. Plant individuals too large for a single sheet of newspaper were divided and pressed as a series of sheets. The press was placed in a simple field drying oven, which had very unstable temperatures due to regular electricity failure.

The dried and pressed specimens (Figure 9) were and are still stored in the EFForTS lab in the University of Jambi (UNJA), as there was no permit for the export of plant material out of the country.

2.3.7   Additional Data from other Studies

This study is focusing on the understorey vegetation and could therefore not collect data from other compartments of the ecosystem as well. Nevertheless, permission was granted to use data already collected by other researchers.

Data concerning the canopy cover of the plots in the EFForTS-BEE was collected by the Masters' student Hendrik Lorenz in March 2018 *(University of Göttingen, Faculty of Forest Sciences and Forest Ecology, Biodiversity, Macroecology & Biogeography, EFForTS project group B11)*. Using a camera with fish eye lens in each subplot middle one picture was taken, binarized, and its proportion of white pixel subsequently calculated using an algorithm. The result of gap fraction in percent could be converted in canopy cover in percent by subtracting the gap fraction from 100 percent.

Data concerning the soil characteristics of the plots in the EFForTS-BEE were collected by the doctoral researcher Nina Hennings *(University of Göttingen, Faculty of Forest Sciences and Forest Ecology, Soil Science of Temperate Ecosystems, EFForTS project group B04).* Out of soil samples, collected in winter 2017 on each subplot, the content of nitrogen (N) and of carbon (C) were identified and the C:N ratio was calculated.

2.4 Data Preparation

All plant species from the 56 subplots and from the 9 plots of the species-area relation collection have been identified as far as possible, i.e. preferably to species level, whenever possible to genus level, at least to family level. Some species, particularly seedlings, could not been identified any further, and keep their morpho species name. All names were checked following The Plant List 2013 , Version 1.1 (http://www.theplantlist.org).

Main literature and websites used for identification:

- Utteridge & Bramley (2015). The Kew Tropical Plant Family Identification Handbook.
- Rembold et al. (2017b). Common wayside plants of Jambi Province (Sumatra, Indonesia).
- EFForTS Sumatra Plant Database (www.sumatranplants.uni-goettingen.de)
- The Kew Herbarium Catalogue (www.kew.org/herbcat)
- Naturalis Biodiversity Center (http://bioportal.naturalis.nl)
- The Flora of China (www.efloras.org)
- Flora Malesiana (www.flora.malesiana.org)
- Plants of Southeast Asia (http://asianplant.net/)
- Ferns of Laos, Thailand and Cambodia (http://rbg-web2.rbge.org.uk/thaiferns/)
- NParks Flora & Fauna Web Singapore (https://florafaunaweb.nparks.gov.sg/)

The identified plant species were classified in alien or native to the study region. Due to the poor information about the natural distribution of plants in this area, species were only declared alien, if the species in question a) was listed as being invasive/introduced/alien in Indonesia by at least one of the references (SEAMEO BIOTROP (2013), CABI (2018), Kleunen et al. (2015)) and none of the other references said different, b) at least one of the references declared its native range outside Indonesia and none of the other references declared it being native, c) is a cultivated plant that is not native in Sumatra, even if it is not listed in any of the main references. All species, that could not unequivocally be declared as alien according to the previous criteria, were declared by implication native. All unknown morpho species were considered as having an undefined status of origin. It should be paid attention to the fact, that native species may probably attract less attention and are less known than alien ones, i.e. the species group of undefined status of origin will probably consist of far more native than alien species.

2.5 Data Analysis

To enter, organize and combine the different data sets *Microsoft Excel (Version 2016)* was used. All statistical analyses and graphics were performed in the open source software *R Studio Version 3.5*.1 (R Core Team 2018), using the package *ggplot2* (Wickham 2016) for visualization.

Data concerning species diversity

For the analysis of understorey diversity the edited data concerning species identity was further processed. A simple measure of the variety of species, based on a count of the number of species in a certain area or sample, is called species richness (Spellerberg 2008) and was calculated for each subplot. As attempts to identify one ideal diversity measure mostly fail, it is recommended to report at least two measures (Morris et al. 2014; Whittaker 1972). For this study it might be interesting to include the concept of evenness, that refers to the extent to which each species is represented among the sample.

That's why *Shannon's* index was calculated; an index that has been derived from the Shannon function *H* (Shannon & Weaver 1964) and is expressed as follows:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i$$

where p_i is the proportion of individuals found in species *i*. For a well-sampled community, this proportion can be estimated as $p_i = n_i/N$, where n_i is the number of individuals in species *i* and *N* is the total number of individuals in the community. As in this study the individuals were counted only up to the number of 10 individuals, for this calculation the cover estimations per species were used instead of abundance data. The value of the Shannon index obtained from empirical data usually falls between 1.5 and 3.5 and rarely surpasses 4 (Margalef 1972). The Shannon index was selected among other biodiversity indices because of its simplicity and because sample size has little effect on the index (Spellerberg 2008). Another of the Shannons' advantage is that it confounds two aspects of diversity: species richness and evenness. However, as an increase in the index may arise either as a result of greater richness, greater evenness, or indeed both, it can be sometimes difficult to interpret (Magurran 2011). That's why it can be advantageous to calculate additionally a separate evenness index, as Pielou's evenness J':

$$J' = \frac{H'}{H_{max}} = \frac{H'}{\ln S}$$

,whereas the maximum diversity (H_{max}) that could possibly occur would be found in a situation where all species had equal abundances, i.e. if H' = H_{max} = ln S (Pielou 1969, 1975).

The calculation of Pielou's evenness, always resulting in a value between 0 and 1, was carried out additionally in this study for all subplots. Both indices were calculated using the R package *vegan,* version 2.5.2 (Oksanen et al. 2018).

With the help of simple linear models and boxplot comparisons it was investigated if and what kind of effect the plot size and the tree diversity level have on the three measure of species diversity, namely species richness, Shannon diversity and Pielou's evenness.

Outliers, that tend to bias the results and their interpretation, could be important especially an experimental design like this (chapter 2.2), in which every sampled plot has individual characteristics. Therefore, outlier subplots were only excluded if the researchers' observations led to the conclusion, that in these cases the subplots are not representative for the plot itself, which was the case concerning species diversity for two plots in the study (Plot 2: size 20 m x 20 m, diversity level 3; Plot 15: size 20 m x 20 m, diversity level 1).

Species accumulation curves help to analyze the relationship between species richness and sampling effort. These kinds of curves plot the increasing number of recorded species as a function of sampling effort (Colwell & Coddington 1994). In the context of this study the sampling effort is represented by the accumulated subplot collection areas of 25 m² each. As the order in which samples are added to the total species pool, affects the shape of the curve, the sample order must be randomized (Colwell & Coddington 1994).

These randomized species accumulation curves including its standard derivation were calculated, using the function *'specaccum'* within the R package *vegan* (Oksanen et al. 2018). If the accumulation curve displays a permanent increase further sampling effort is assumed with more species. When the species accumulation curve demonstrates a saturated development the species inventory was sufficient to detect the full extent of species richness corresponding to the area (Gotelli & Colwell 2011; Ugland et al. 2003).

As the SAC itself is a strongly negatively biased estimator of species richness, which is because there are always species that are missed during sampling, non-parametric estimator such as *Jackknife 1* can be used for reducing the underestimation of the true number of species (Colwell & Coddington 1994). The first-order jackknife estimate of species richness is based on the number of species that occur in only one sample (L),

$$S_{jack1} = S_{obs} + L\left(\frac{n-1}{n}\right)$$

,where n is the number of samples (Miller 1964). The extrapolated species richness curve with the estimator Jackknife 1 was carried out with the function *'poolaccum'* of the R package *vegan* (Oksanen et al. 2018). With SACs and their *Jackknife* extrapolation curves, calculated for each plot size level as well as for each tree diversity treatment, the effect of plot size and tree diversity treatment on the total species richness could be visualized.

As species are not distributed uniformly in space and because of the fact that clumping can occur due to localized dispersal, accumulated sampling plots that lie scattered in space (Figure 10b) will very likely produce a curve that bows upward (Scheiner 2003). In comparison, a contiguous sampling in a nested sampling area (see Figure 10a), is likely to encounter less species than a dispersed set of samples.
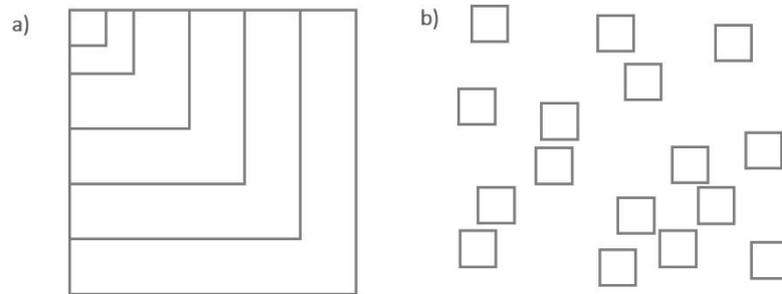
Figure 10: **General sampling schemes that result in different species-area curves. (a) strictly nested quadrat sampling; (b) sampling of quadrats displaced irregular and noncontiguous in space. (own figure based on Scheiner (2003))**

The corresponding species-area curve may form an irregular pattern. The rate of increase in species richness is expected to decrease within a community as the area increases, but when a community boundary is crossed, the number of species found can again rise rapidly (Scheiner 2003).

That's why, out of the data sampled in a nested design (2.3.5), further species area curves for tree diversity treatment 0, tree diversity treatment 6 and control treatment have been visualized. These species-area curves are based on the real area expanding until an area size of 1.600 m² in a nested design (Figure 10a) instead of randomly accumulated plots. Out of the values for each sampling area expand of each category of plot size or tree diversity treatment the mean and its standard deviation were calculated and presented in the curve.

Data concerning species composition

For each species, its frequency in percent, as the presence on subplots (100 % = present on all 56 plots), as well as mean cover in percent was calculated out of the collected data.

The values of cover and shoot length of the species *C. hirta* were displayed across tree diversity level in boxplots and across plot size in linear models.

Using the R package *eulerr* (Larsson 2018) Venn diagrams were developed in order to give an overview of how many species are exclusive for each treatment and how many overlapping species presences occur between the treatments. Data basis for these diagrams were the species-area relation data collection in the three treatments (control, diversity level 0 and diversity level 6) which made it possible to compare the effect of sampling area size on shared and unique species proportion.

To visualize the evenly or dominated distribution of species, rank-abundance plots are useful (Magurran 2011). As in this study cover data instead of absolute individual abundance data was collected, rank-cover plots were created. Along the x-axis species were ranked according to their cover, whereas the y-axis shows the proportion of cover. The rank-cover plots were carried out for each treatment concerning tree diversity and plot size, using the command *rankabundance* in the R package *BiodiversityR* (Kindt & Coe 2005).

The proportion of alien and native species according to species richness and species cover was visualized among tree diversity treatment and plot size in simple bar plots with error bars.

The proportions of the tree and seedling species richness and cover were calculated and the differences between plots of diversity level 0, tree enriched plots and the control plots were visualized in simple bar plots with error bars.

Data concerning vegetation structure

The collected growth form data in percent of species richness and species cover was visualized among tree diversity treatment and plots size in simple stacked bar plots.

The mean litter layer thickness [cm] per subplot was calculated out of the three measurement repetition values per subplot of the data set. The data concerning total vegetation cover [%] and total litter cover [%] was not prepared any further. The combined species cover, i.e. the sum of all species cover in a subplot, was divided by the total vegetation cover and multiplied by 100, to get an idea of how dense the vegetation is growing:

$$Vegetation\ density\ [\%] = \frac{combined\ species\ cover\ [\%]}{total\ vegetation\ cover\ [\%]} * 100$$

The effect of plot size and tree diversity treatment on the structural component data, i.e. litter layer thickness [cm], total litter ground cover [%], total vegetation ground cover [%], and vegetation density [%] was analyzed.

To get an overview of the productiveness of understorey vegetation the maximum shoot length per species was grouped across tree diversity level and plot sizes. Due to their different growth habit vines would have biased the shoot length strongly and therefore have been excluded. As the focus is the understorey vegetation, all grasses (esp. bamboo) and trees with shoot length more than 2 m were excluded as well.

For the combination of diversity results with structure results a few apparently interesting variables were correlated using simple linear models.

To prove if the diversity of the understorey vegetation is driven by other than the experimental factors, canopy cover, C:N ratio of the soil and level of disturbance was included in the analysis. Using simple linear models, the effect of the canopy cover, the C:N ratio of the soil as well as the effect of disturbance on the Shannon diversity, on the proportion of tree species, and on the proportion of native species was tested. As the data set is not consisting of many explanatory variables and as in this case the exploration with selected relationships between different variables was considered as more informative, model selection was not carried out.

Significance testing

In all cases, the distribution of the data was examined for its normality using graphical methods and the *Shapiro-Wilk-Test* (Shapiro & Wilk 1965). Concerning the plot size, a continuous trend instead of differences in size groups were expected. Therefore, for the plot size effect linear regressions were carried out and presented by bold lines and the R² and p-value if statistically significant. For better representation in the figure the scales of the plot sizes (25, 100, 400 and 1600 m²) were logarithmically transformed. Additionally, the plot size groups were treated as categorial groups and tested similarly like the tree diversity groups.

All treatment groups were tested by an *analysis of variance (ANOVA)*, followed by a post-hoc *Tukey's Honest Significant Difference Test (Tukey's HSD)* to know between which groups the differences are lying. If the results were statistically significant, they were reported with the help of letters above each group in the graph, whereas groups sharing the same letter have no statistically significant differences. The levels of significance used in this study, were < 0.05 % (weakly significant, *), < 0.01 % (significant, **), and < 0.001 % (highly significant, ***).

In case of heteroscedasticity corrected pairwise comparisons were carried out with the help of the R command for general linear hypotheses *'glht'* in R package 'multcomp' (Hothorn et al. 2008) and R command for fitted models *'sandwich'* in R package 'sandwich' (Zeileis 2004). For dealing with heteroscedasticity in linear models, the correction of the residuals was carried out by the use of weighted regressions, using the option *'weights'* in the *lm()-function* in R.

3. Results

3.1 Species Diversity

During data collection in the 56 plots of the experiment, in total 230 vascular plant species belonging to at least 63 plant families, could be found. Of these 230 species recorded, 139 could be assigned to species level, 10 to genus level, 46 to family level and 35 remain listed as morpho-species. A complete species list is to be found in the Appendix A. The mean species richness over all plots of the experiment reveals a value of 21,54 (±8) species per subplot. A closer look at how the species richness differs between the different treatments of the experiment reveals that the lowest species richness was found in the plots with tree diversity level 0 where no trees were planted. The species richness of the plots with tree diversity level 1, 2, 3, and 6 shows higher values than level 0, whereas the group of tree diversity level 6 has the lowest mean species richness among the group with tree enrichment (Figure 11 A).
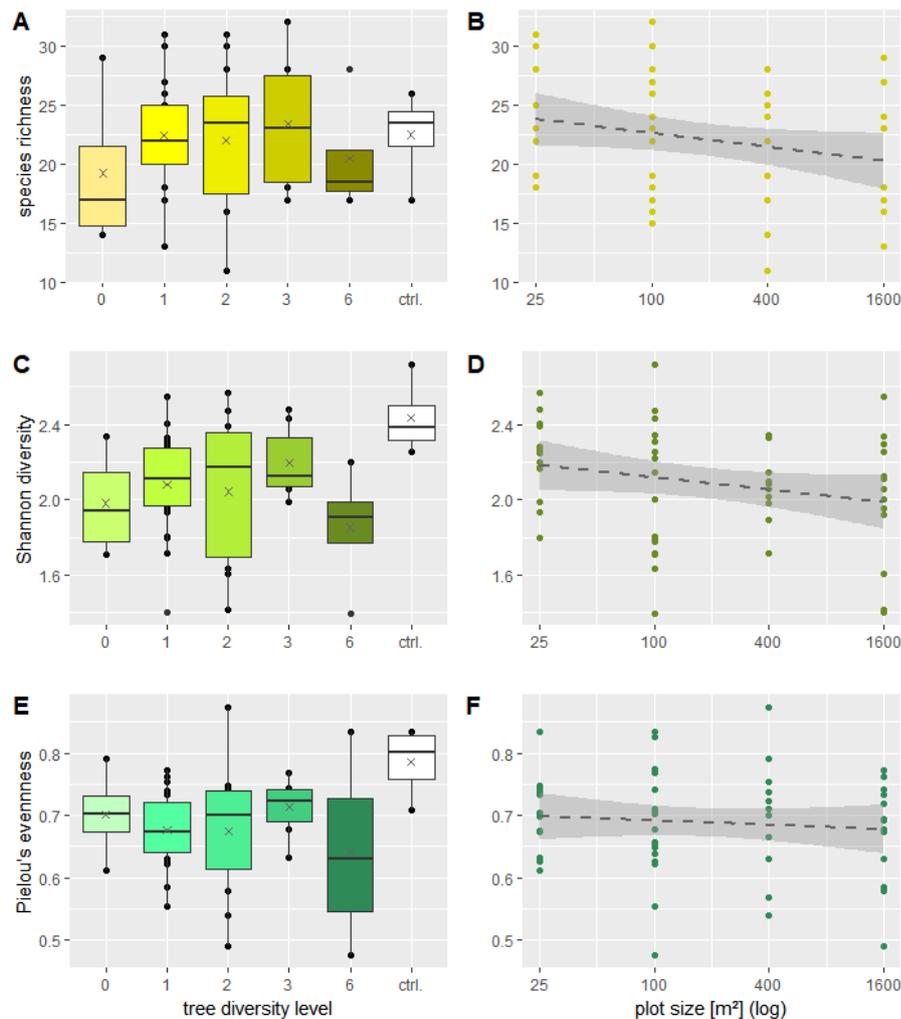
Figure 11: **Understorey plant diversity across the tree diversity level of the plots (0 - (n=4), 1 - (n=23), 2 - (n=12), 3 - (n=7), 6 - (n=4), ctrl. – control (n=4)) and across the plot size (25m²-5mx5m (n=13); 100m²-10mx10m (n=13); 400m²-20mx20m (n=11); 1600m²-40mx40m (n=13), including understorey species richness (A,B), understorey Shannon's diversity index (C,D) and Pielou's evenness (E,F).**
No significant differences between were found (ANOVA, significance p <0.05).

The species richness of the control plots shows a mean of 22,5 (± 3,9) species, what is distinctively higher than the plots with diversity level 0 and 6 (Figure 11 A). The values of Shannon diversity index are showing a similar distribution pattern, whereas the mean Shannon diversity of the control plots is clearly the highest one (Figure 11 C). The focus on Pileou's evenness index shows that the species growing in the control plots are most evenly distributed among the different treatment groups. The evenness of the diversity level 0, 1, 2, 3, and 6 are not varying a lot among each other (Figure 11 E).

The analysis of the experimental effect of plot size indicates that neither species richness nor Shannon diversity or Pielou's evenness is influenced strongly by plot size. A slightly visible trend can be seen from higher species richness and Shannon diversity in smaller plots (size 5 m x 5 m) to lower species richness and Shannon diversity in bigger plots (size 40 m x 40 m) (Figure 11 B, D). Regarding the plot size effect on Pielou's evenness no differences among the groups could be detected (Figure 11 F).

Concerning diversity for both experimental factors, plot size and tree diversity level, no statistically significant differences could be detected.

As the differences between the groups of enriched plots (diversity level 1, 2, 3, 6) are quite small and without any clear pattern, it is worth joining this group and looking at the differences to control plots and plots without enrichment plantings. A statistically significant difference between enriched plots (diversity 1-6) and the control plots exists concerning the Shannon diversity as well as the Pielou's evenness. So, the tree enriched plots are less diverse and its species less evenly distributed than the non-treated palm oil plantation (Figure 12 B,C).
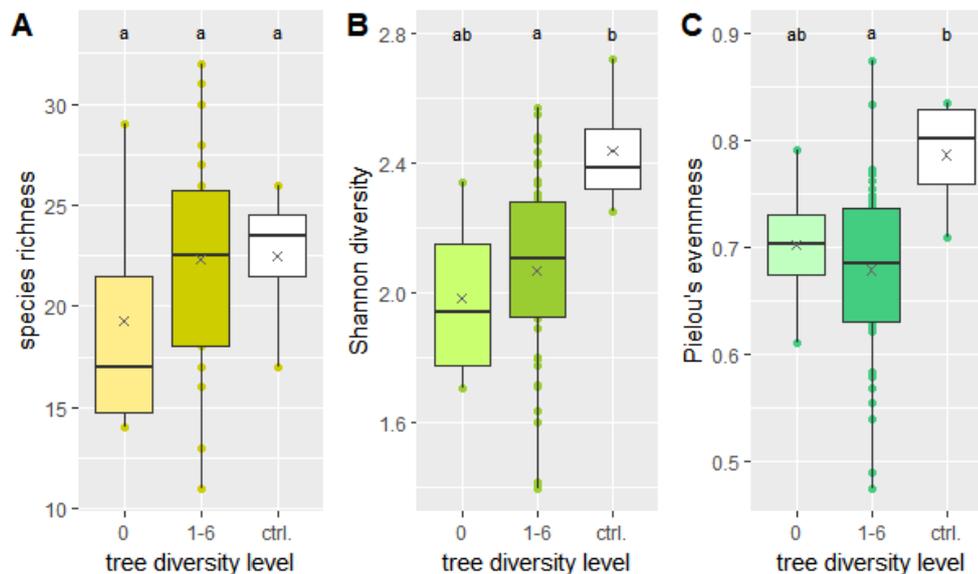
Figure 12: **Understorey plant diversity across grouped tree diversity level of the plots (0 - no trees planted (n=4), 1-6 – one, two, three or six tree species planted (n=46); ctrl. - no treatment and management as usual (n=4)), including understorey species richness (A), understorey Shannon's diversity index (B) and understorey Pielou's evenness (C).**
Letters indicate significant differences between categories (ANOVA/Tukey´s Honest Significant Differences, significance p<0.05).

The calculated species area curves provide information about the total and extrapolated species pool as well as the relation between species richness and sampling effort (Figure 13).

The species richness for all plot size categories is rising with increasing sampling effort quite steeply and does not show any saturated trend so far. This means that the sampling effort was far not enough to detect the real existing species richness. The comparison between the subplots of different plot sizes indicate that the species pool of the smaller plots is even bigger than the pool of the larger plots (Figure 13 A). Extrapolation with *Jackknife 1* estimates a species pool of 131 species, when accumulating 13 subplots (area of 325 m²) of plot size category 25 m², in
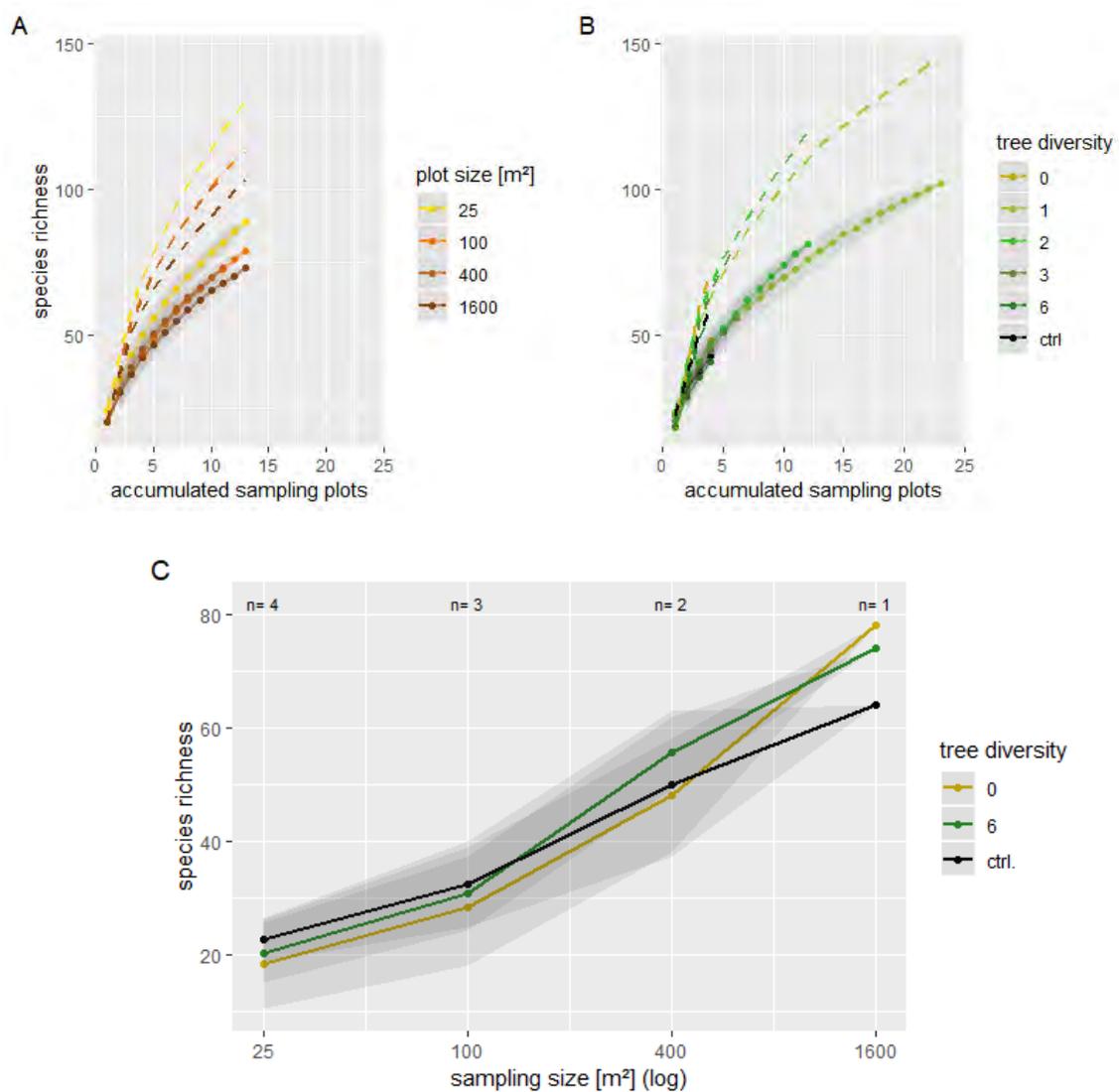
Figure 13: Species Area Curves.
(A) Mean species richness of each category of plot size in randomly accumulated sampling plots (each plot of 25 m² size). Plot size categories (25m²-5mx5m (n=13); 100m²-10mx10m (n=13); 400m²-20mx20m (n=11); 1600m²-40mx40m (n=13).

(B) Mean species richness of each category of tree diversity in randomly accumulated sampling plots (each plot of 25 m² size). Tree diversity categories: 0 - no trees planted (n=4), 1 - one tree species planted (n=23), 2 - two tree species planted (n=12), 3 - three tree species planted (n=7), 6 - six tree species planted (n=4), ctrl. - no treatment and management as usual (n=4). Gray shaded areas indicate the standard deviation. Dashed lines indicate estimated species richness based on data of the Jackknife 1 estimator.

(C) Mean species richness of categories of tree diversity in a nested design of continuously expanded sampling area. Gray shaded areas indicate the standard deviation.

comparison with 103 species, when accumulating 13 subplots (area of 325m²) of plot size category 1600 m². So, related to the same area, smaller plots seem to contain even more species than larger plots (Figure 13 A).

Comparing the accumulated species area curves of different tree diversity level is not possible because of the strongly varying sampling effort per category (n = 4; n = 8; n = 12; n = 24). The control plots, as well as the plots of diversity level 0 and level 6 could be only accumulated to a sampling area of 100 m² each (n = 4). The steep rising curves indicate that the sampling effort is, especially in that case, far not enough to be able to know or to estimate the existing species pool (Figure 13 B). The same applies to the increasing species richness curve with accumulated subplots of diversity level 1, 2, and 3. Even the curve of tree diversity level 1, whose subplots could be accumulated to an area of 600 m² (n = 24), is still rising, so even this sampling effort is not enough and much more sampling effort would have been necessary to reach an asymptotic curve (Figure 13 B). With the accumulation of 24 plots of 25 m² each could be reached an estimated pool of 145 species on a summed-up area of only 600 m².

For getting an idea of the real relation between species richness and area size, the species area curve out of the nested sampling data was produced (Figure 13 C). In general, all three curves show the same trend of rising species richness with increasing sampling area. The curve of the control plots shows the highest starting mean among the groups but lies at a sampling area of 1,600 m² with a value of 64 species below the plots of diversity level 0 (78 species) and diversity level 6 (74 species). As the sampling area of 1,600 m² was only sampled once per category (n = 1) this difference cannot be considered as reliable. The same applies for all other different values of the curves, as lying within the range of standard deviation (Figure 13 C).

This result should be more seen as an indication, that the comparably high species richness of the control plots, when looking at the mean of the subplots (Figure 11; Figure 12), may alter if the sampling size is expanded (Figure 13 C).

3.2 Species Composition

The pre-study of this study identified seven species, which were present on all 13 plots of the plot size category 25 m² with high individual numbers, and therefore declared as 'most-abundant species'. These are the fern species *Adiantum latifolium* (Pteridaceae), the grasses *Axonopus compressus* (Poaceae), *Centotheca lappacea* (Poaceae), *Cyrtococcum patens* (Poaceae), and *Ottochloa nodosa* (Poaceae), as well as the invasive species *Asystasia gangetica* (Acanthaceae) and *Clidemia hirta* (Melastomataceae) (Figure 14). These seven most abundant species are responsible for more than 58 % of the combined cover in the 56 examined plots.

F*igure 14:* Most abundant species as sampled in the pre-study.
Species belong to the plant family of Acanthaceae (C), Melastomataceae (D), Poaceae (A,E,F,G) and Pteridaceae (B) (pictures by Lena Sachsenmaier).

In the main data collection these seven species have been confirmed as the most frequent species as being present on 86 – 100 % of all sampled subplots (Table 4). Additionally, the shrub species *Melastoma malabathricum,* fern species *Nephrolepis bisserata,* and the oil palm seedlings (*Elaeis guineensis)* have considerably high frequencies, whereas among these, only *Nephrolepis bisserata* has high importance regarding cover (Table 4).

Table 4: **Most frequent species. Frequency as percent of presence (100 % = present on all 56 subplots).**

species	family	frequency [%] (presence on subplots)	mean cover [%]
Asystasia gangetica (L.) T.Anderson	Acanthaceae	100	13
Clidemia hirta (L.) D. Don	Melastomataceae	98	31
Ottochloa nodosa (Kunth) Dandy	Poaceae	98	9
Cyrtococcum patens (L.) A.Camus	Poaceae	95	7
Centotheca lappacea (L.) Desv.	Poaceae	93	4
Adiantum latifolium Lam.	Pteridaceae	91	15
Axonopus compressus (Sw.) P.Beauv.	Poaceae	86	3
Melastoma malabatricum L.	Melastomataceae	75	4
Nephrolepis bisserrata (Sw.) Schott	Nephrolepidaceae	70	12
Elaeis guineensis Jacq.	Arecaceae	70	3

The shrub species *Clidemia hirta* stands out particularly. This species is covering 31 % of each subplot in average and shows peak values of up to 70 % cover. Calculated all species cover values together, *C. hirta* is responsible for 23 % of the combined cover in the plots and was moreover present in all subplots, except one.

Concerning the effect of tree diversity level on the cover of *C. hirta* some differences could be detected (Figure 15 A). Whereas the treatment of diversity level 0 is not differing much between the levels 1, 2, and 3, the tree species rich plots of level 6 show the obviously lowest mean cover value of 15 % with low standard deviation in comparison. The control plots also contain clearly less *C. hirta* cover than the plots of diversity level 0 – 3, but its mean cover lies with 18 % still above the plots of the highest tree diversity (Figure 15 A).
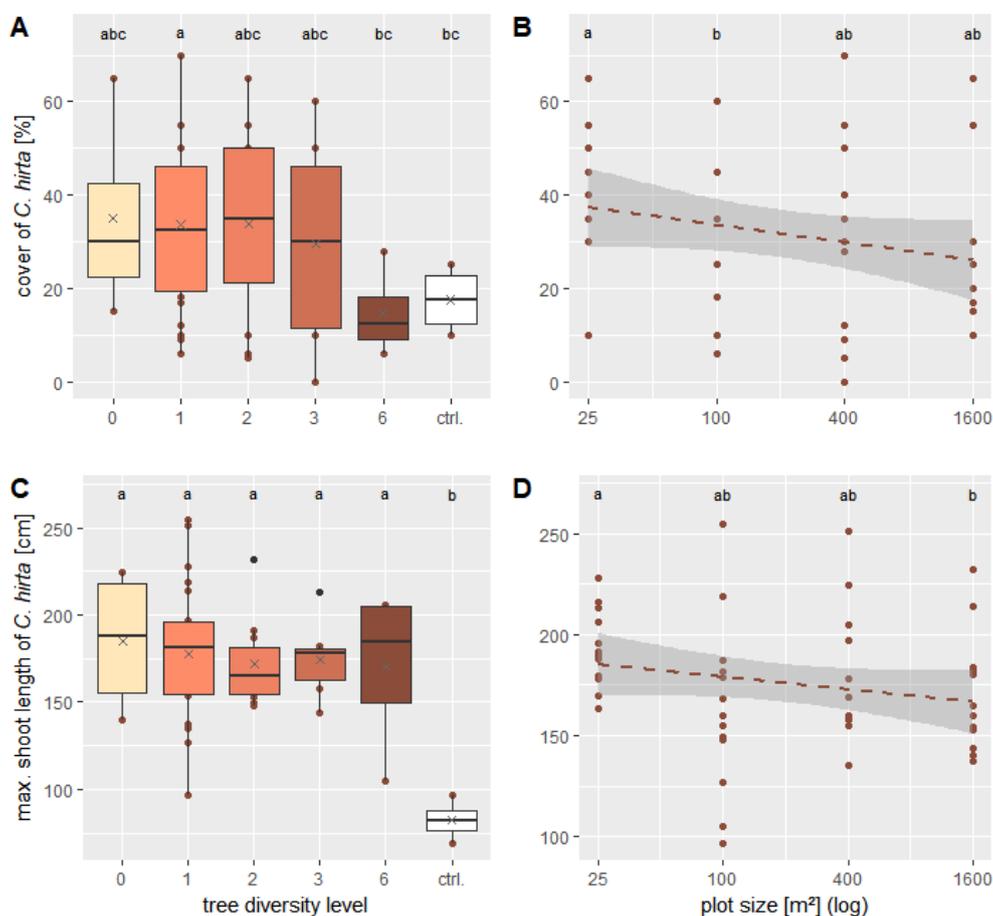
Figure 15: The shrub species *Clidemia hirta* regarding its (A,B) cover and regarding its (C,D) maximal shoot length, across (A,C) tree diversity level (0 - no trees planted (n=4), 1 - one tree species planted (n=24), 2 - two tree species planted (n=12), 3 - three tree species planted (n=8), 6 - six tree species planted (n=4), ctrl. - no treatment and management as usual (n=4)) and across (B,D) plot size (25m²-5mx5m; 100m²-10mx10m; 400m²-20mx20m; 1600m²-40mx40m (each n=13).
Letters indicate statistically significant differences (ANOVA, robust pairwise comparisons (general linear hypotheses - Tukey contrasts); significance level $p < 0.05$).

C. hirta seems to cover more area in the smaller plots than in the larger plots. There is a slight trend of decreasing cover of *C. hirta* with increasing plot size, which is only significant between plots of 25 m² and 100 m². The shoot length gets shorter with increasing plot size, whereas only differences between the group of smallest and the group of largest plot size are significantly different (Figure 15 B).

In rank-cover plots the outstanding importance of *C. hirta* in the understorey species community becomes apparent as well (Figure ; Figure 17). All rank-cover curves are starting with a very steep slope that merged in to a shallow straight tail, indicating few species very dominant in cover, and lots of species that have almost the same proportion of cover. It becomes obvious, that the most dominant species in each treatment group or plot size group are mostly the ones, defined as *most abundant species* in the pre-study before (Figure 14).
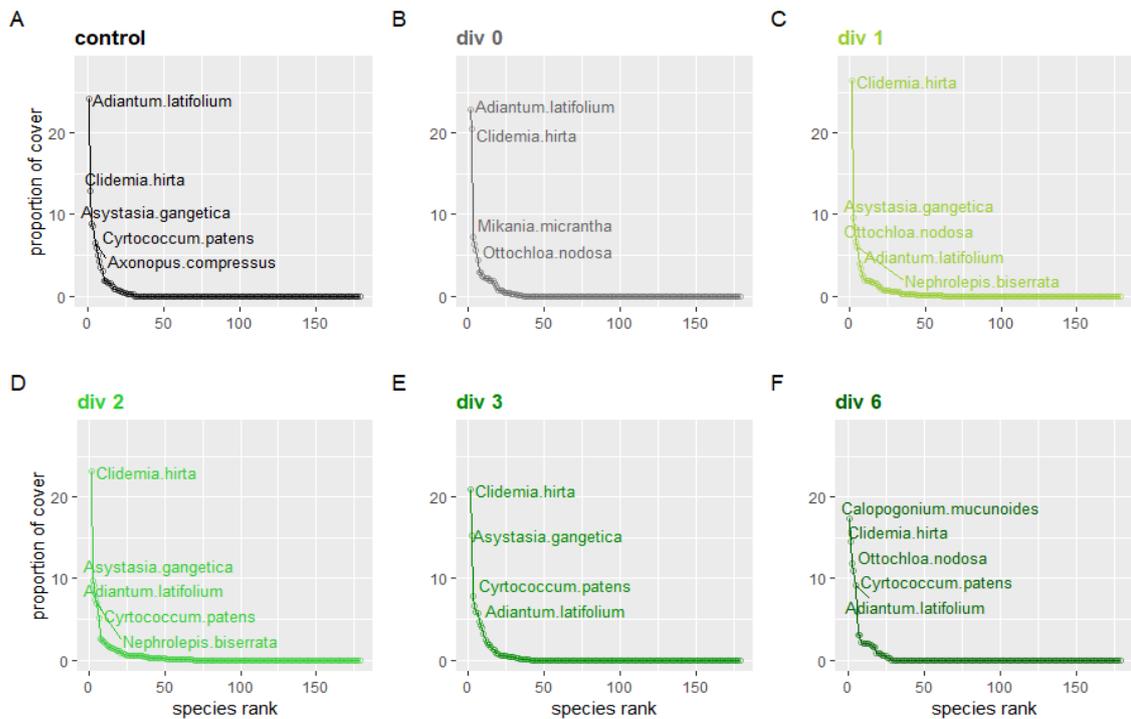
Figure 16: Rank-Cover-Curves (Whittaker-Plots): Proportional cover of species per tree diversity level ((A) control - no treatment and management as usual (n=4); (B) div 0 - no trees planted (n=4); (C) div 1 - one tree species planted (n=24); (D) div 2 - two tree species planted (n=12); (E) div 3 - three tree species planted (n=8); (F) div 6 - six tree species planted (n=4)) shown in order to their ranking. All species with values y>5 are labeled with the corresponding species name.
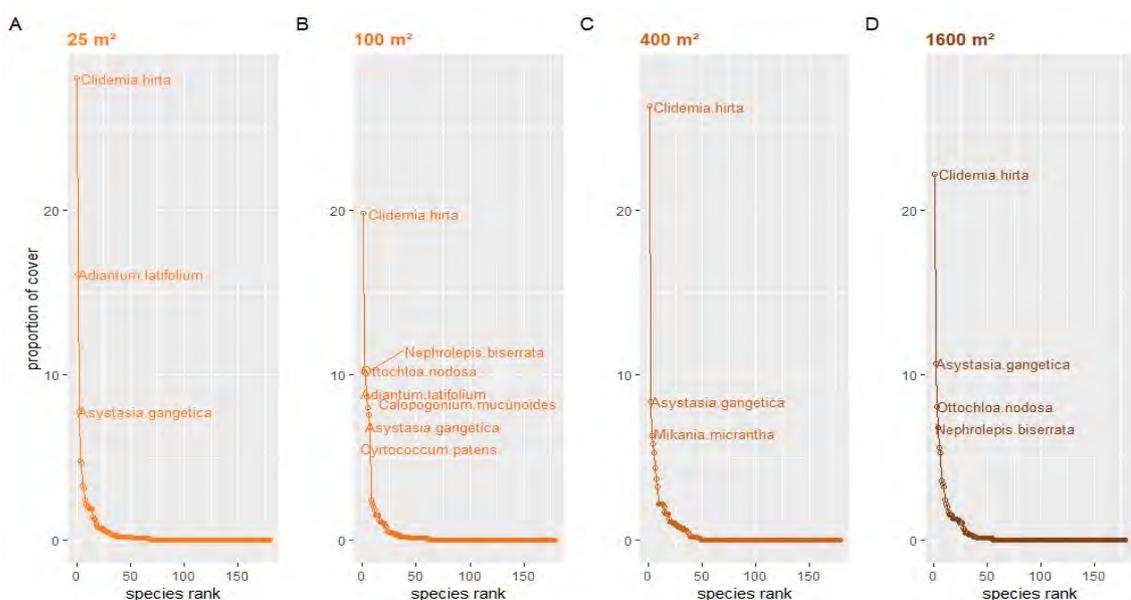
Figure 17: Rank-Cover-Curves (Whittaker-Plots): Proportional cover of species per plot size level ((A) 5m x 5m; (B) 10m x 10m; (C) 20m x 20m; (D) 40m x 40m; each group n=13) are plotted on the y-axis and rank of species on the x-axis. All data points with values y>6 are labeled with the corresponding species name.

The only dominant species which are not part of this group, are the native fern *Nephrolepis bisserata* and the alien invasive vines *Calopogonium muconoides* and *Mikania micanthra*.

Comparing the different treatment groups of the experiment, the curves exhibit quite similar patterns (Figure 16). All treatment groups, except the tree diversity level 6, show a quite long distance between the most dominant species and ones ranked second, third, or fourth. The curve of diversity level 6 shows quite small distances between the most dominant species, which indicates a more evenly distribution in cover. In the control treatment it is not *C. hirta*, which is the most dominant species in cover, but *A. latifolium*, whereas *C.hirta* is ranked second with quite large distance in between (Figure 16). The differences in the rank-cover curves of different plot size levels are almost negligible (Figure 17). In all size groups, *C. hirta* is the most dominant species with a quite large distance to the second ranked species. The shortest distances between the ranked species are to be found in the plots of plot size 100 m². In these plots, as well as in the plots of size group 1600 m², *C. hirta* reveals a lower proportion of cover, although it is still first ranked (Figure 17).

Grouping the species by their origin (native/alien) gives more information about the character of the species community in the understorey (Figure 18). In each subplot, in average 35 % of all species are alien species and 58 % have native origin. In contrast, the alien species cover far more area (58 %) in comparison with native species (39 %). Looking on the plots of different tree diversity treatment groups, the proportion of alien and native species in species richness does not differ much (Figure 18 A). The focus on combined species cover reveals, that the plots with diversity level 0 have the highest absolute and the highest proportional combined cover of alien
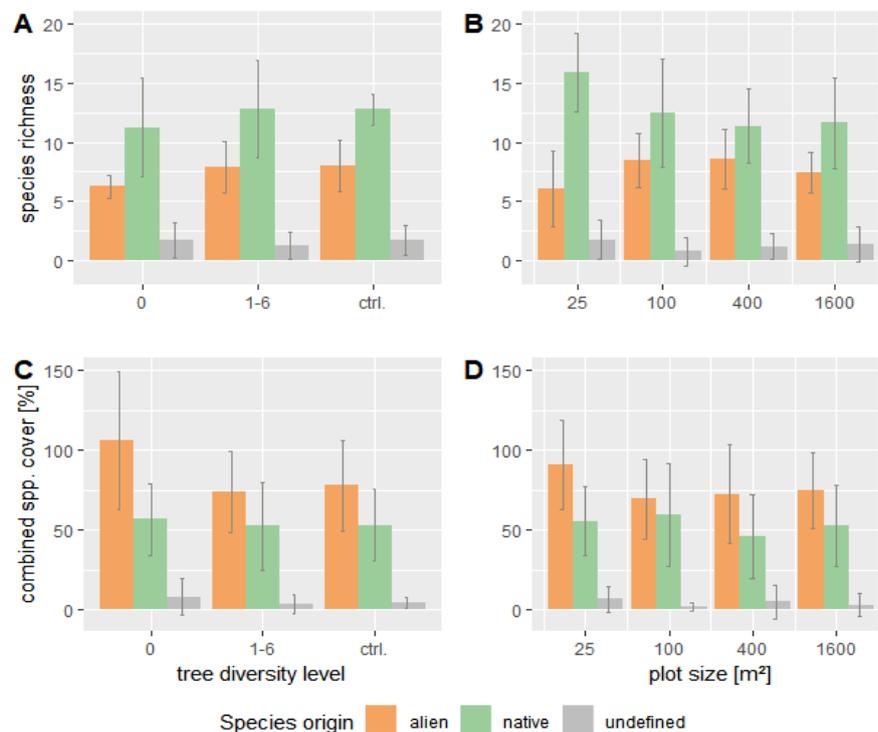
Figure 18: **Species origin, divided in the groups alien, native and undefined status. Species origin in mean number of species across tree diversity level (A) and across plot size (B). Species origin in combined species cover [%] across tree diversity level (C) and across plot size (D). Error bars indicate standard deviations.**

species among the treatment groups. The control plots have still a higher combined cover of alien species than the enriched plots, although the difference is minor (Figure 18 C). Displaying species origin across different plot sizes of the experiment leads to the result that the smallest plots are not only species richer than the others but also have absolute and proportional more native species than the larger plots. Nevertheless, among the larger plots, the largest plot size of 1,600 m² has still a higher proportion of native species than the plots of 100 m² and 400 m² (Figure 18 B). In contrast, the plots of 25 m² size are the ones with the highest absolute combined cover (91 %) and relative combined cover of alien species. The lowest proportional alien species cover is comprised by the plots of 100 m² size, although the differences are not very clear (Figure 18 D). All differences between alien and native species proportion among the diversity and size treatments of the experiment are not statistically significant.

A closer look at the shared and unique species per experimental treatment gives information about the species composition (Figure 19). In the comparison of the mean of four subplots per treatment (control, tree diversity level 0, tree diversity level 6) it is to be seen that every treatment group contains a high number of unique species that are not shared with any other treatment group. Nevertheless, all three treatment groups share more species with the other two treatment groups as they have in unique. The plots of diversity level 0 have the highest number of unique species, but in general there are no major differences between the treatment groups, comparing the subplots of 25 m² each (Figure 19).
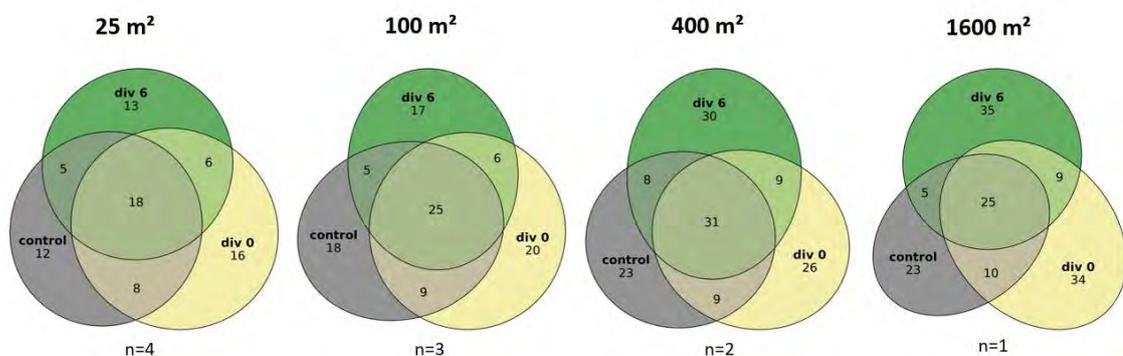
Figure 19: Venn Diagrams showing total numbers of shared and unique understorey species between three treatment levels (div 0 - no trees planted; div 6 - six tree species planted; control - no treatment and management as usual), each diagram represents different sampling area sizes (as labeled above). The size of shared area in the Venn ellipses correspond proportional to the number of shared species.

Comparing three plots of 100 m² in each treatment group, the pattern of proportion is quite similar. The higher number of species compared to the sampling size of 25 m² are made up out of unique species for each treatment group as well as shared species among the treatment groups (Figure 19). Referring to the comparison of species on a sampling size of 400 m² (n=2) it becomes obvious that again all treatment groups could gain unique species, but the diversity level 6 could gain most, increasing its number of unique species by 13 species. Considering species sampled on the size of 1,600 m², they have the highest proportion of unique species in each treatment group. The highest number of unique species is comprised again by plots of diversity level 6, the lowest

number of unique species are to be found in the control plots which could not gain any new species when expanding the sampling area from 400 m² to 1,600 m² (Figure 19).

In general, there is a strong trend of increasing unique species with increasing sampling size for all treatment groups which applies only weakest for the control plots. It seems that the species pool of unique palm oil species may already be completed at a size of 400 m². So, there are not only more unique species in the experimental plots, but also a stronger trend of increasing unique species with increasing area. The closer look on the shared species indicates that plots of diversity level 6 and the control plots are sharing the lowest number of species, whereas control plots and diversity level 0 are sharing most. For all treatment groups, the proportion of shared species with increasing sampling area is getting smaller as could be seen in the decreasing size of the Venn ellipses (Figure 19).

In a restoration context of former forest landscapes, it is of interest to focus the proportion of tree species in the understorey (Figure 20). The control plots show an mean tree and seedling species richness of only 4.2 %, whereas the proportion of plots of diversity level 0 lies with a mean richness of 10.4 % even higher than the enriched plots (9.2 %) (Figure 20 A). Focusing the species cover instead of richness, the pattern is quite similar, but with stronger differences. The cover of tree and seedling species is proportional highest in the group of diversity level 0 (9.5 %) which is more than twice as high as the cover of the enriched plots (4.7 %). In control plots tree and seedling species are covering only 0.5 % in average (Figure 20 B).
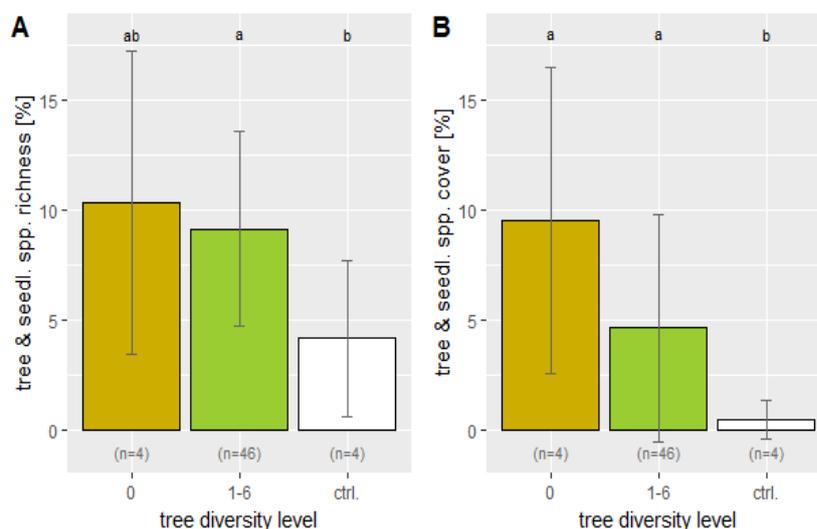
Figure 20: **Mean proportion of tree and seedling species in the subplots in terms of species richness (A) and species cover (B) across tree diversity level 0 (n=4), subsumed level 1,2,3, and 6 (n=46), and control (n=4).**
Error bars show standard deviation of the mean value. Letters indicate significant differences between the groups (ANOVA, robust pairwise comparisons (general linear hypotheses - Tukey contrasts); significance level p < 0.05).

Summarized, this shows a significantly, very strong, and positive effect of the experimental treatment on trees in terms of coverage and species number. This effect seems to be even stronger but not significant when the plot area was just fenced for regrowth, but with no trees planted.

3.3 Understorey Structure

Categorizing species according to their growth form gives information about the understorey structure. Looking at the proportion of species richness across the different experimental treatments (Figure 21), it becomes visible that in general, the graminoid species, the fern species, and the forb species make together around three-quarters of all species, whereas there are in decreasing order less shrub species, vine species, tree species, and seedlings (Figure 21 A,B). Focusing the species cover instead of species richness, the proportion of seedlings become negligible, shrub species cover is more important, forb species loose importance, and occasionally vines cover has quite conspicuous proportion (Figure 21 C,D).

Comparing the species richness of different tree diversity treatment groups, the plots with planted trees (1 - 6) are showing the same pattern with negligible differences and no clear trend. Plots of diversity level 0 contain the highest proportion of vine species as well as tree species among all groups. In contrast, the regular palm oil plantation contains much more forb species than the other plots and remarkable less tree and shrub species. The proportion of tree species shows a decreasing trend from diversity level 0 to diversity level 1 - 6 to control (Figure 21 A).
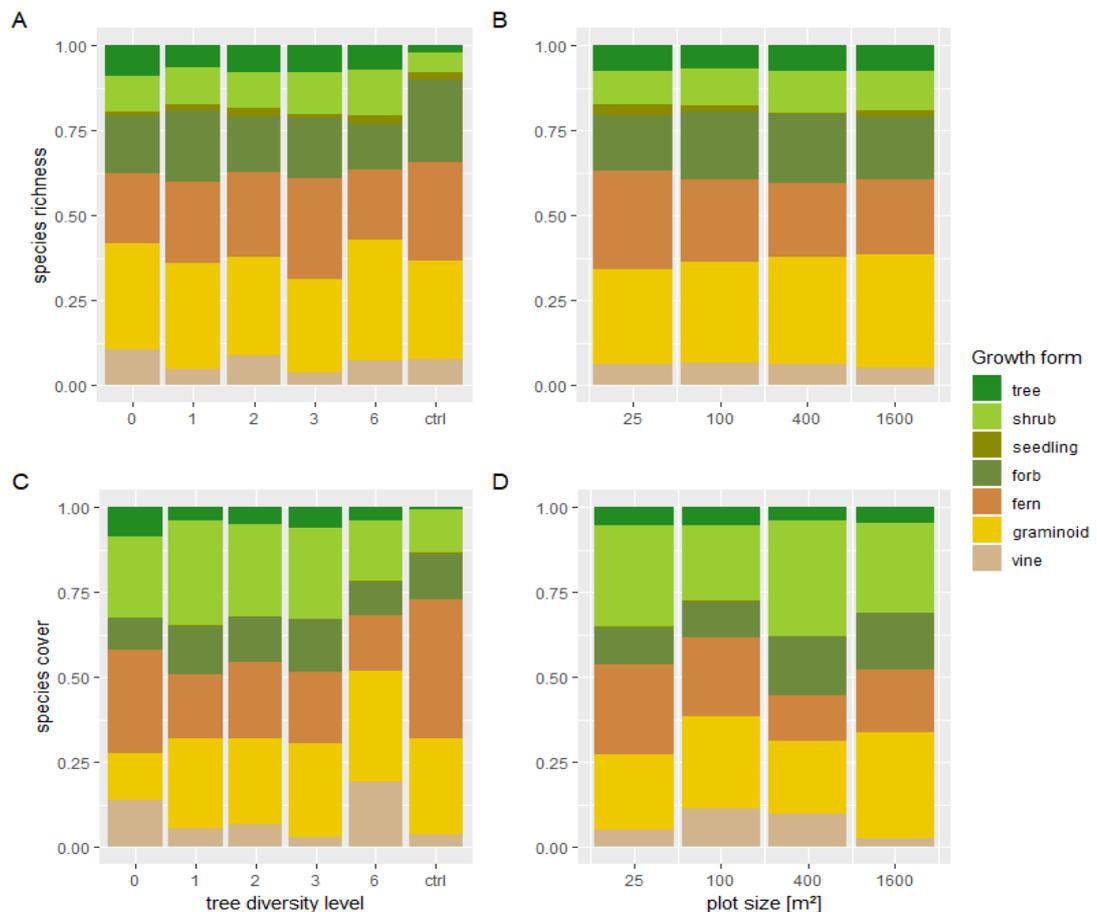
Figure 21: Proportional species richness (A,B) and proportional species cover (C,D) differences between the categories of tree diversity level and plot size, grouped according to the growth form of species.
(for definitions of growth form categories see chapter 2.3.4)

Focusing the species cover instead of species richness, the same decreasing trend of the proportional tree species cover from diversity level 0 to diversity level 1 - 6 to control treatment is even stronger (Figure 21 C). The proportional cover of shrub species is highest in diversity level 1 plots and is decreasing to the highest tree diversity level, whereas the control plots show the lowest shrub species cover. The proportion of fern species cover is very dominant in the control plots, still quite dominant in the diversity level 0 plots, and play a less important role in the tree diversity plots 1 to 6. The vine cover is remarkably high in the highest as well as in the lowest diversity level. Graminoids seem to be less important in the cover proportion of diversity level 0 than in the other plots (Figure 21 C). The different growth forms of species by species richness across the different plot sizes of the experiment do not show any notable divergences (Figure 21 B). Focusing species cover across the plot sizes, some minor differences occur. Vine cover appears more important in small and middle size plots and becomes negligible in the largest plots of 1,600 m². In contrast, graminoid cover has its highest proportion among plot sizes in the largest plot size. Shrubs and ferns show more extended covers in the small plots of 25 m² than in the largest ones of 1,600 m². However, in none of the growth form groups a clear trend from small to large plots is visible (Figure 21 D).

The results of the litter layer thickness of the subplots display a thickness range from 2 cm to 10,5 cm with several variations between the treatment groups of the experiment. The litter layer of enriched plots differs quite considerably from the usual palm oil plots, in the way that enriched plots have a deeper mean litter layer than the control plots. Within the group of the enriched plots the higher tree diversity level plots (level 3 and 6) comprise a deeper litter layer than the ones with lower tree diversity (Figure 22 A). The litter layer depth across the different plot sizes of the experiment indicates a trend from thinner litter layers in smaller plots to thicker litter layers in larger plots (Figure 22 B). The estimations of the total litter cover in percent of the subplot reveals values of mainly between 0 % and 30 % with rare values up to 59 %. The litter cover is extending with increasing tree diversity level from 0 to 6. The plots of the highest tree diversity level comprise the notable highest mean of litter cover (32 %) but show also high deviation. Lowest proportional litter cover is showed by the plots of diversity level 0 (7 %), whereas the control plots have a mean litter cover of 14 % (Figure 22 C). The focus on the differences in plot size results in an only very slight trend from less litter cover in smaller plots to a higher litter cover in larger plots which is not statistically significant (Figure 22 D).

The estimations of the vegetation cover per subplot area reveals values that lie predominantly between 50 – 100 % with some outliers down to 30 %. Looking at the differences in tree enrichment groups, it becomes obvious that the highest understorey vegetation cover (85 %) is to be found in the plots of diversity level 0 where no trees were planted. There is a noticeably trend from high vegetation cover in lowly enriched plots (level 1) to low vegetation cover in highly enriched plots (level 6).
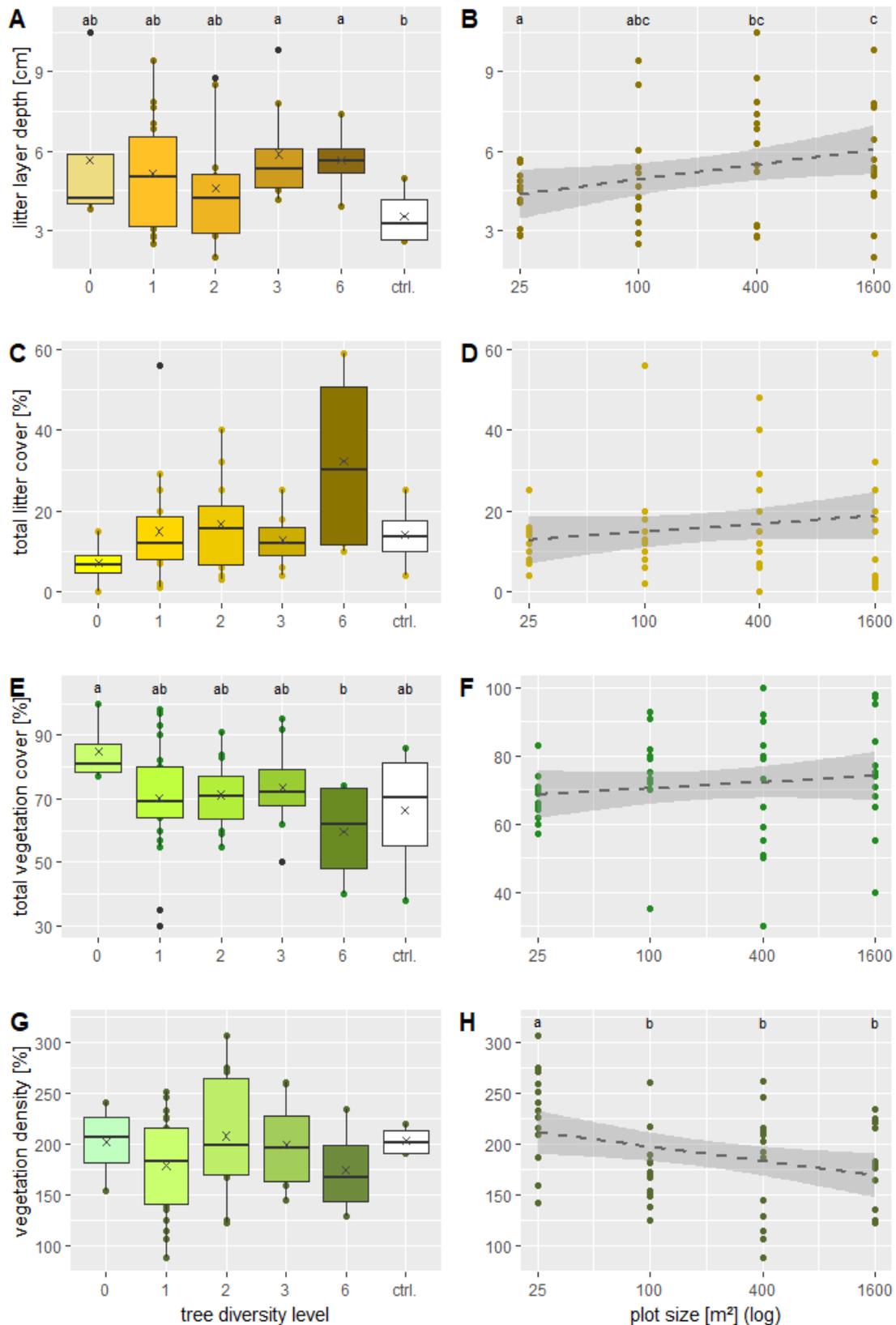
Figure 22: **Understorey vegetation and litter structure across tree diversity level of the plots** *(0 - no trees planted (n=4), 1 - one tree species planted (n=24), 2 - two tree species planted (n=12), 3 - three tree species planted (n=8), 6 - six tree species planted (n=4), ctrl. - no treatment and management as usual (n=4))* **and across the plot size** *(25m²-5mx5m; 100m²-10mx10m; 400m²-20mx20m; 1600m²-40mx40m (each n=13),* **including litter layer depth** (A,B), **total litter cover** (C,D), **total vegetation cover** (E,F) **and vegetation density** (G,H).
Letters indicate significant differences between size or tree diversity categories (ANOVA, robust pairwise comparisons (general linear hypotheses - Tukey contrasts); significance level p < 0.05).

The control plots show a high deviation with a relatively low mean vegetation cover of about 66 % (Figure 22 E). Concerning the experimental factor plot size, the understorey vegetation cover does not show much differences. A very slight trend from less vegetation cover in smaller plots to more extended vegetation cover in larger plots is notable (Figure 22 F).

The density of vegetation, as added combined species cover, reveals values between 100 % and 300 %. The highest median density among the treatment groups has diversity level 0 followed by the control plots. Among the enriched plots, the plots of the highest enrichment level are the least dense ones. The differences are statistically not significant (Figure 22 G).

Looking at the density of understorey vegetation within the different plot size treatments, an explicit trend from high density in small plots to low density in large plots is observed. The understorey vegetation of the plots of size 25 m² is significantly denser than the other plot sizes (Figure 22 H).

To get an idea about the viability and performance of the understorey vegetation, out of the measured maximal shoot length of each species the mean was calculated and displayed across treatment groups of the experiment (Figure 23).
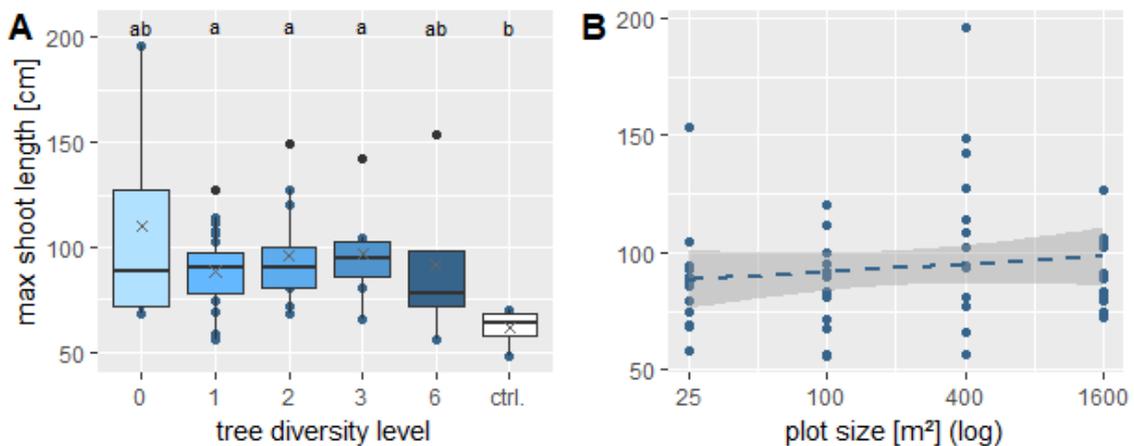
Figure 23: **Maximum shoot length of understorey vegetation, calculated as the mean per subplot out of the maximum shoot length of each species.**
Vines are completely excluded; all shoot length values > 200 cm of trees, shrubs and bamboo species are excluded as well. Letters indicate statistically significant differences (ANOVA, robust pairwise comparisons (general linear hypotheses - Tukey contrasts); significance level p < 0.05).

The mean maximal shoot length of all shoots in the plots of tree diversity level 0 is the highest, lying by high standard deviation at 110.3 cm. The means of tree enriched plots of level 1 to 6 are between 88.5 cm and 96.6 cm maximum shoot length without notable trend. The shoots of understorey vegetation in the control plots are remarkably shortest and significantly shorter than the shoot length of plots with diversity level 1 to 3 (Figure 23 A). The maximum shoot length doesn't differ much across different plot sizes of the experiment, nevertheless a slight trend of increasing maximum shoot length by increasing plot size is visible (Figure 23 B).

The search for interesting relationships between structural parameters of understorey vegetation with the diversity variables of the study resulted in the correlation of vegetation density with species richness and litter layer depth with species richness (Figure 24).
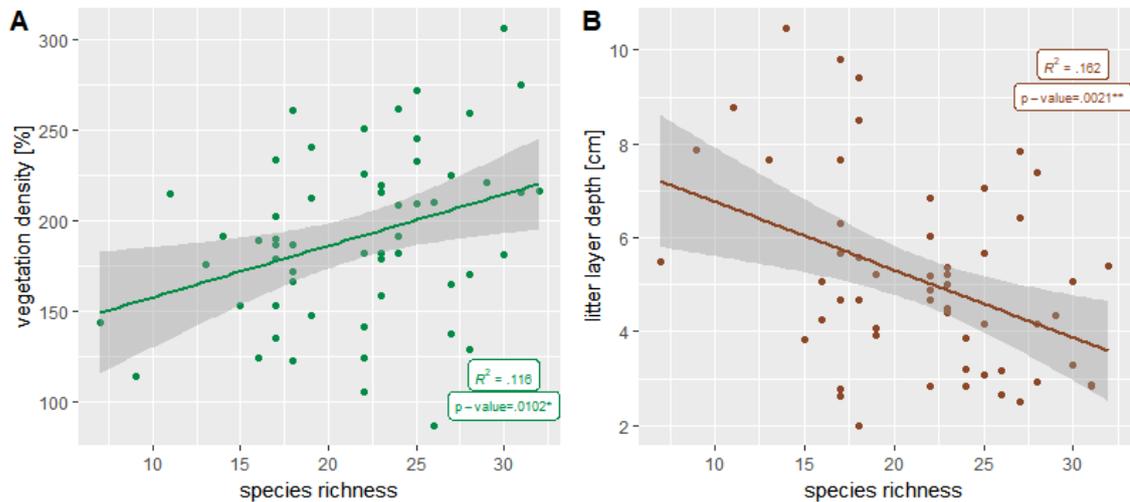
Figure 24: **Relationship between species richness and (A) vegetation density and (B) litter layer depth, visualized with the help of linear regression models.**
Shaded area indicates error. Bold lines indicate significant linear model R² results.

The higher the density of understorey vegetation, the more species could be found in the plots ($R^2 = 0.116$; $p = 0.0102*$) (Figure 24 A). In contrast, the litter layer depth is significantly negative correlated with species richness (Figure 24 B). The thicker the litter layer, the smaller the species richness in the understorey vegetation becomes ($R^2 = 0.162$; $p = 0.0021**$). Other structural parameters of the understorey vegetation show no or only weak correlations to other variables of this study.

3.4 Effect of Additional Variables

As the effect of the two key experimental factors – plot size and tree diversity level – on the diversity of the understorey vegetation is hard to interpret unequivocally with the given results, additional variables are included that may also influence the diversity of the undergrowth.

The effect of canopy cover, the soil C:N ratio as well as the level of disturbance on Shannon diversity index, proportional tree species richness and proportional alien species richness are displayed in Figure 25.
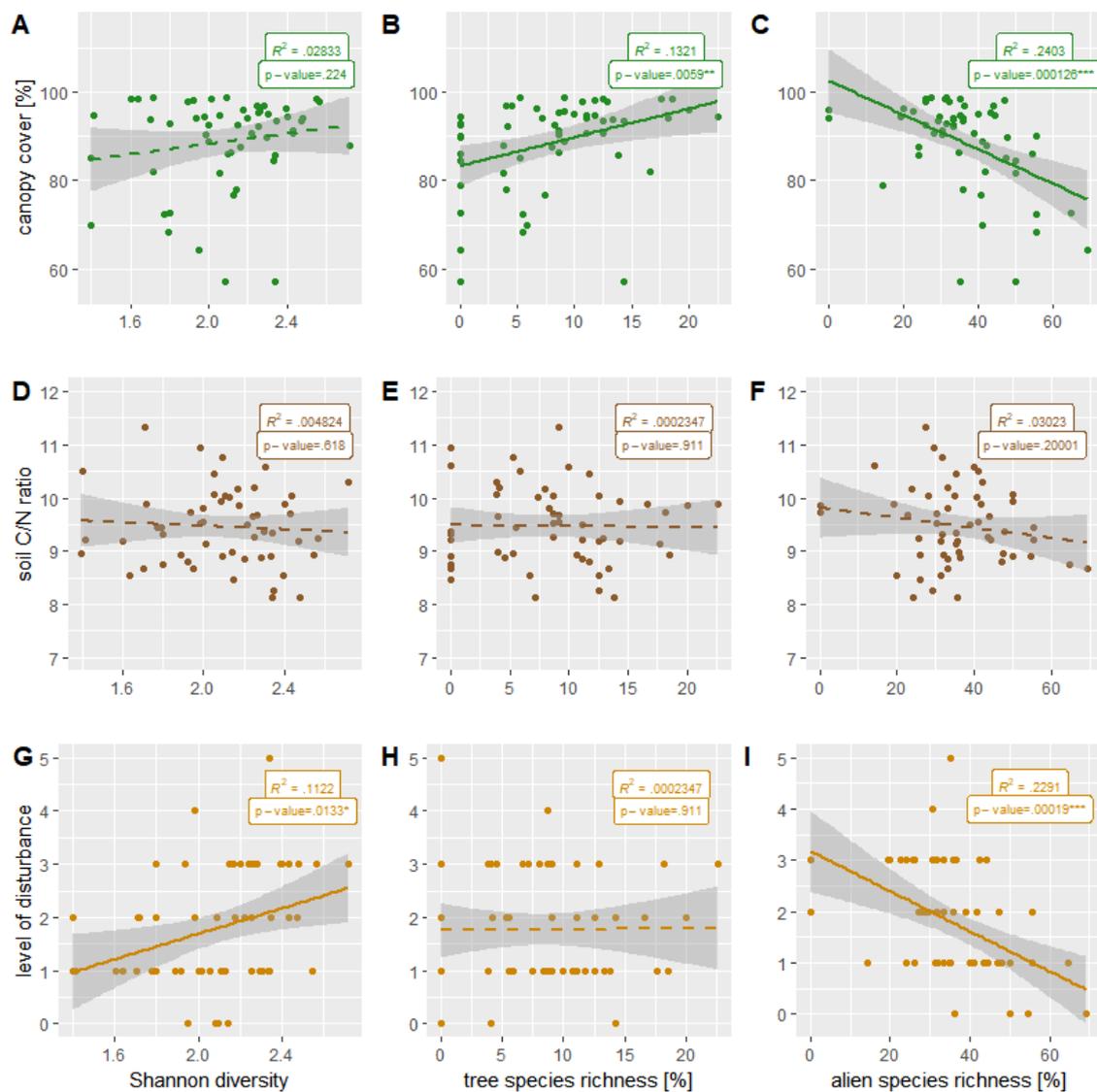
Figure 25: **Effect of canopy cover (A-C), soil C:N ratio (D-F) and level of disturbance (G-I) on the Shannon diversity index (A,D,G) (n=54), the proportion of tree species richness in the understorey (B,E,H) (n=56) and the proportion of alien species richness in the understorey (C,F,I) (n=56).**
Errors are shown by shaded areas. Bold lines indicate significant results of robust linear regression models with weighted observations (significance p<0.05); dashed lines indicate possible trends, that are not statistically significant.

The canopy cover of the subplots, i.e. light conditions, seems to be an important driver of Shannon diversity (Figure 25 A), tree species richness (Figure 25 B), and alien species richness (Figure 25 C).

The higher the canopy cover, i.e. the less light availability, the higher the Shannon diversity, although, this trend is only slightly visible and not statistically significant (Figure 25 A). The same applies for the canopy effect on tree species richness of the subplots. The statistically significant ($p = 0.0059**$) linear model shows that the percentage of canopy cover increases with a higher proportion of tree species (Figure 25 B). On the proportion of alien species, the canopy cover has an influence in the opposite direction. The higher the percentage of canopy cover, the less the proportion of alien species, i.e. the more light is available, the more alien species are growing. The resulting linear model is statistically highly significant ($p = 0.000126***$) (Figure 25 C).

The C:N ratio of the soil does not to have any influence on the diversity of the understorey. Neither the effect of the C:N ratio on the Shannon diversity, nor on the tree species richness follows any linear trend (Figure 25 D,E). Regarding the effect of the soil C:N ratio on the proportion of alien species, a slight trend of decreasing alien species with increasing C:N ratio is visible but not statistically significant (Figure 25 F).

The level of disturbance seems to have at least partly quite strong influence on the diversity of the understorey. When the disturbance of the subplot is quite severe, the Shannon diversity is significantly ($p = 0.0133*$) higher, than at a lower level of disturbance (Figure 25 G). In contrast, the level of disturbance seems to have no influence on the proportion of tree species (Figure 25 H). Surprisingly, the level of disturbance has a significantly ($p = 0.00019***$) negative influence on the proportion of alien species, i.e. the less disturbance, the more alien species occur (Figure 25 I).

4. Discussion

4.1 The Effect of Experimental Treatment on Understorey Plant Diversity

The overall species pool of 230 species recorded in the whole experimental site is quite impressive and is much larger than expected. In the baseline survey prior to tree planting Teuscher et al. (2016) found only a total of 92 vascular plant species on the 52 experimental plots. In average they recorded a species number of 16,67 (± 4,55) per subplot (Teuscher et al. 2016), which is less than the mean species richness of 21,54 (± 5,8) per subplot in this study. However, the subplots of their survey were only of 2 m x 2 m size and are not located on the same spot than the subplots of this study, so the comparability of the results is quite limited.

Rembold et al. (2017a), who investigated the vascular plant species richness on plots in a palm oil plantation nearby, found an average of 67,63 (± 15,2) species per plot, but not excluding epiphytes and taking in account five 5 m x 5 m subplots per plot. A closer look on the species accumulation curves of this study (Figure 13) reveals that even if accumulating five subplots the species numbers are still lying below the ones of Rembold et al. (2017a). The reasons for this could be inaccuracies in the sampling due to a lack of experience of the author of this study and different management strategies between the two plantations.

In the EFForTS-BEE plots Teuscher et al. (2016) detected a significant positive relationship of litter invertebrate family richness and herb layer invertebrate abundance with plot size one year after tree planting. The diversity of the organism group of invertebrates is described as essential for ecosystem functioning (Barnes et al. 2014; Ewers et al. 2015) what indicates its key role in conservation and restoration. Assuming that vegetation is an important habitat for invertebrates, which can be specifically adapted to specific vegetation types, in this study understorey plant diversity was expected to increase with increasing plot size as well. The results are not in accordance with the expectations, showing even a very slight inverted effect of decreasing understorey diversity with increasing plot size. As different experimental studies with a close look at the effect of island size in restoration are rare, possible reasons of these results stay unknown. However, it could be observed that larger plots show a more pronounced patchy pattern of understorey vegetation than smaller plots. So, it may be possible that larger plots do not really comprise less species in the whole plot than smaller plots but do so due to the patchy structure in the subplot of the investigation (chapter 4.4). The plots of the smallest experimental plot size are surrounded by managed as-usual plantation, whereas the subplots of larger plots are randomly distributed inside the plot but not located on the plot borders. It might be possible that because of this, the small plots comprise species that prefer the tree enriched plot conditions and additionally

species that prefer normal plantation conditions and this niche overlap, the so called 'edge effect', might lead in the sum to a higher species richness (Kunin 1998).

In the initial survey of the EFForTS-BEE plots Teuscher et al. (2016) recorded significantly more bird species on the enriched plots than on the managed as-usual plots only one year after establishment. As birds are a well-documented seed dispersal species group in tropical systems (Tscharntke et al. 2008), it is expected that the enriched plots would comprise more understorey species as well compared to the managed as-usual plots. However, the results are contradictory to the expectations. The control plots show higher species richness, higher Shannon diversity index and higher Pielou's evenness than the enriched plots. Especially the high value of Pielou's evenness, indicating an evenly distributed species community, is surprising as Rembold et al. (2017a) reported a highly uneven distribution of understorey species for oil palm landscapes. Dislich et al. (2017) reviewed ecosystem functions in oil palm plantations and concluded that the ability of palm oil plantations to provide habitats is depending on the plantation age and on management intensity. With increasing age of a plantation canopy closes and this leads to higher structural complexity. The plantation of this study was planted between 2001 and 2007 and is therefore younger as the stands Rembold et al. (2017a) conducted research that were already 14 - 21 years old. Further, the intensity of plantation management is supposed to be different. The site of this study, *PT. Humosindo*, is a privately hold plantation which is less intensively managed than other large-scale plantations. Fertilizer quantities are in the lower range and herbicides are only rarely used when there are not enough workers for manual weeding. Additionally livestock farming is practiced in the plantation (Teuscher et al. 2016). A study from Slade et al. (2014) indicates that cattle grazing may provide an opportunity to enhance biodiversity within oil palm habitats. Cattle grazing leads to a high abundance of dung beetles which are responsible for important ecosystem functions such as nutrient recycling, enhanced soil structure, and improved soil hydrological properties. These altered ecosystem functions could therefore increase plant growth (Slade et al. 2014). Additionally, cattle grazing can have a positive effect on seed dispersal (Janzen 1984). Both, regular cattle grazing and regular manual weeding, represent an intermediate disturbance on understorey vegetation. At intermediate intensities of disturbance that produce a stage of nonequilibrium, the highest diversity is suggested (Connell 1978; Hobbs & Huenneke 1992). Huston (1979) introduced the idea that species richness is at its maximum when disturbance counteracts competitive exclusion. This could be a possible explanation for the findings of this study. The difference in species diversity between the control plots and the treatment plots might have their origin in the absence of man-made disturbance carried out by the plantation management. Beukema et al. (2007) underlines the huge impact of management practices such as weeding on the plant diversity in Sumatran rubber agroforests. In subtropical understorey in China the absence of disturbance enhanced fast growing grasses and woody species with high biomass production that outcompeted other understorey species (Germany et al. 2017).

These findings are in accordance with the observations of this study. In plots of tree diversity level 0, where management is absent and no trees were planted, the diversity is quite low and the understorey is higher, comprising more fast-growing species than the other plots. The strong non-weeding effects that probably lead to an increased competition with increased biomass but decreased species richness corresponds exactly to the treatment effects observed in the experimental forest stands in subtropical China (Germany et al. 2017).

It was expected that the understorey diversity is correlated positively to the diversity of the tree layer. Forests with higher tree species diversity have been shown to be more structured in horizontally and vertically dimensions than monocultures (Morin et al. 2011). That may lead to a higher level of habitat heterogeneity in the understorey and thus increased microsite availability for understorey species. Additionally, a higher level of habitat heterogeneity can result in a higher level of resource partitioning in the tree layer and a decreased competition intensity within the herb layer (Beatty 2003; Huston 1979). In consequence, a more diverse tree layer would be expected to ensure a more diverse understorey layer. In the present study, this was not the case, as the control plots with monoculture overstorey showed the highest values in understorey species richness, Shannon diversity, and Pielou's evenness. Among the enriched plots the understorey diversity values did not increase with increased tree diversity (Figure 11). Although the positive effect of overstorey diversity on understorey diversity is often promoted it has rarely been studied in the past (Barbier et al. 2008). The more recent available studies concerning the relationship between the diversity of these two forest layers do not show uniform results. In contrast to the results of the present study, Vockenhuber et al. (2011) reported the clear correlation of increased tree species richness with increased species richness of the herb layer for leaved deciduous forest in Central Europe. This effect is primarily attributed to the resource availability and environmental conditions in lower forest layers altered by the tree species (Vockenhuber et al. 2011). In another study the herb layer vegetation of deciduous forest stands appeared as well to be more diverse under diverse canopy species than under beech-dominated stands (Mölder et al. 2008). The effect was declared to be probably an indirect effect influenced by the altered environmental factors soil pH and litter layer thickness through canopy tree species (Mölder et al. 2008). However, the results of the present study are in accordance with the results of an experimental study in subtropical China by Germany et al. (2017) that could not show a significant effect of tree richness on herb layer richness as well. Correspondingly, the observations of Both et al. (2011) resulted in the absence of tree richness effects on the herb layer. Similar results are available for the shrub layer (Yang et al. 2017).

The initial results of the EFForTS-BEE survey one year after tree planting could not show any effect of the different levels of tree diversity on any of the responses concerning birds and invertebrates (Teuscher et al. 2016) which corresponds to the results of this study. Teuscher et al. (2016) suggested that this is due to the fact that probably the overall habitat complexity at the

plantation scale is more important than at a local scale which may change in an advanced stage of the experiment. The overall observed strong individuality of all plots of the experiment can be a further explanation for the absence of an effect of tree diversity level.

Summarized, the results indicate that the experimental factors plot size and tree diversity are not the main drivers of understorey diversity, which is therefore mainly influenced by others.

Commonly, light is considered to be the major limiting factor of forest vegetation cover and richness, at least in temperate and boreal forests (Barbier et al. 2008). In a study of Brosofske et al. (2001) canopy cover alone explained 22 % of the variation in understorey species richness and is considered as a primary variable influencing species richness and Shannon diversity in the understorey vegetation. In a deciduous forest study by Vockenhuber et al. (2011) canopy cover seem to be one of the most important predictors for herb species richness and cover as well. The fact that high canopy cover decreases herb species richness is explained by the exclusion of grassland species due to missing adaptions to low light conditions in the forest understorey (Vockenhuber et al. 2011). In this study canopy cover seem to have a slight non-significant influence on understorey Shannon diversity as well, however, the other way around: Species diversity is slightly increasing with decreasing light conditions. It has to be considered that the plots of the experiment are in an early stage of succession. It is likely that after the gap fall due to oil palm cut, few pioneer species shoot up and suppress others, why species richness is low at enhanced light conditions. Furthermore, light-vegetation relationships might better be explained by past light conditions rather than by current light regimes because of the slow reaction of the species pool (Thomas et al. 1999). Besides light availability other explaining variables for herb species richness are described. Soil characteristics such as soil moisture (Lenière & Houle 2006), nutrient availability (Brosofske et al. 2001), and the soil pH (Hofmeister et al. 2009) are often correlating with understorey vegetation characteristics. The C:N ratio is described as a suitable indicator of substrate quality and nitrogen limitation of forest soils (Small & McCarthy 2005). In subtropical forest stands a wide C:N soil ratio predicted lower herb layer species richness (Germany et al. 2017), whereas in deciduous forest the ratio showed no influence on any herb layer attributes except the proportion of forbs (Vockenhuber et al. 2011). Similar results can be obtained from this study, as the C:N ratio of the soil does not relate to the Shannon diversity of the understorey vegetation. One reason of the lacking relationship could be that nitrogen is mostly not seen as the limiting factor for tropical lowland forest communities (Vitousek 1984).

Another factor identified as determinant of forest understorey diversity is the mass of the litter or humus layer (Gonzalez et al. 2009; Vockenhuber et al. 2011). A thick litter layer can act as a physical barrier that inhibits germination and emergence of understorey plants as seeds under litter are deprived of light and seeds on the litter layer cannot root easily. Understorey species differ according to their ability to penetrate litter, so a thick litter layer may have strong impact

on the species community composition. Additionally, the litter layer is influencing microclimatic conditions on the floor such as humidity and temperature. The litter layer itself is influenced by tree density, microbial and faunal soil communities, and the tree species (Barbier et al. 2008). Several authors, reviewed by Barbier et al. (2008), suggest that an observed effect of tree species on understorey diversity may result from alterations in litter thickness among tree species. In deciduous forest with increasing mass of humus layer both the herb species richness and the herb layer cover decrease (Vockenhuber et al. 2011).

The predicted high impact of the thickness of the litter layer on the understorey diversity could be confirmed with this study, if focusing on species richness. The deep litter layer might act as physical inhibitor for some species what leads to overall less species. This result gives the hint that probably the surprisingly high species richness of the control plots occurs because of very sparse and thin litter layer due to the lack of trees and management.

The distance to the edge of the forest also turns out to be a strong influence parameter on understorey diversity (Chazdon & Guariguata 2016; Gonzalez et al. 2009; Vockenhuber et al. 2011). The close proximity to existing forest areas is recommended as one of the key conditions that favor natural regeneration as a tool for forest restoration in the tropics (Chazdon & Guariguata 2016). As tiny patches of secondary forest close by could already have an impact on the understorey diversity of the study site, spatial investigations of the study results are strongly recommended.

The look on other tree enrichment experiments reveals, that although no clear effects of tree diversity on the understorey diversity could be found, enrichment had at least an effect on understorey species composition (Germany et al. 2017).

4.2 Species Composition across Experimental Treatment

The results of the most important species regarding frequency and cover of this study show the outstanding relevance of the species *Clidemia hirta (L.) D.Don (Melastomataceae)*, a neotropical bird-dispersed shrub. It is described as occurring mainly at the sides of trails, roads, clearings, and on steep embankments with exposed soil even under closed primary forest canopies (Peters 2001). It is partly considered as a highly damaging invasive species and potential threat to regeneration in tree-fall gaps due to high suppressing potential against the native canopy tree species (Peh 2010; Peters 2001). However, as dominating mainly in disturbed areas, the extent of damage for conservation areas has not yet been clarified (Peh 2010; Teo et al. 2003).

The results concerning the cover of *C. hirta* reveal that the cover is comparatively low on the managed as-usual palm oil plots and lowest on the plots of highest tree diversity. The maximum shoot length of C. hirta does not differ much between the enrichment levels but is distinctively low on the control plots. This indicates that not the lack of tree planting but the plantation management could be the reason for the weak performance of *C. hirta* on the control plots. The regular weeding and cattle grazing may have a special effect of suppressing *C. hirta* as a fast-growing species, so that it loses its advantage in competition and thereby gives other species broader chances to grow up. This could be a possible explanation for the surprisingly high species richness in the managed as-usual plantation plots.

The comparison of the species list of initial understorey sampling of Teuscher et al. (2016) demonstrates that understorey plant community composition already changed since the establishment of the experiment. Species that were present in the baseline survey prior to tree planting could not be confirmed in this study five years later. However, many species are growing nowadays in the experimental site that could not be sampled in the baseline survey five years ago (Teuscher et al. 2016).

The rank-cover-plots underline the importance of *C. hirta*. Furthermore, in plots of diversity level 6 other dominant species besides *C. hirta* seem to be involved and the shallower gradient of the curve indicates higher evenness. On the control plots *C.hirta* is secondly ranked with quite remarkable distance to the first ranked species *A.latifolium*. Its weak presences on these plots concerning cover could be again explained with the management. In contrast, *A.latifolium* is a dense but low-growing fern species, that may not be affected too much from manual weeding operations. Grass species seem to play a greater role than expected in the quite shady palm and tree environment. Their overall presence might be due to enhanced light conditions because of palm cutting prior to tree planting.

The most frequent, although not that abundant, species was *Asystasia gangetica*, which is native to tropical Africa and meanwhile naturalized in several regions of the Paleotropics (Luján et al. 2011). It is known as a major invasive weed in Malaysia, Indonesia, and the Pacific Islands,

especially in coffee, oil palm, and rubber plantations (CRC Weed Management 2003). Furthermore, the grass species *Axonopus compressus* and the fern species *Adiantum latifolium*, which are among the most abundant species as well, have their origin in tropical America. Summarizing, among the most frequent species, the most abundant species, and the species with highest cover, the group of aliens is always well represented. In average, 35 % of all species on a subplot were considered as alien species. Although there are distinctively more native species than alien species, alien species are dominating regarding the cover. Comparing this number of alien species with the results of Rembold et al. (2017a), this is a quite high proportion for an oil palm plantation. One possible reason for the high number of alien species may be that nearby the plantation there are only very few forest patches left. Without a native seed bank in primary forest nearby, native seed dispersal is complicated.

However, Rembold et al. (2017a) reported a much higher number of alien individuals than native individuals in oil palm which is in accordance with the results of this study regarding the species cover. Disturbance has been found to be related to the presence of non-native plant species (McIntyre & Lavorel 1994). Alien species are often better competitors and colonizers on disturbed sites and can displace or eradicate native species what can result in an alteration of species composition. That is why the relatively high proportion of alien species itself is not surprising in a disturbed agroforestry landscape like oil palm plantations.

The plots of 25 m² size are showing the highest number of alien cover, which follows the theory of disturbance, as these plots experienced the most intense disturbance among experimental plots. Nevertheless, plot size does not seem to influence the proportion of alien species in a clear pattern. The tree enrichment does not show a definite effect on the proportion of alien species as well. This may be possible due to the short time passed since tree planting. Alien species are often early successional species with a rapid life cycle and therefore extremely successful in disturbed areas (Catford et al. 2012; Radosevich et al. 2007). That is why it might be possible that their proportion will reduce with increasing time passed since the establishment of the experiment. However, following the theory that disturbance would be the main driver of the proportion of alien and native species in understorey community, one would expect that the plots that are managed as-usual show the highest proportion of alien species. In contrast, not the managed as-usual plots but the plots of diversity level 0 have the highest number of alien species and alien cover. Surprisingly in this study, the proportion of alien species could not be explained with a high level of disturbance. In contrast, the results of this study show that the less disturbance the plots experienced, the higher the proportion of alien species gets (Figure 25 I). Although disturbance is generally described as having a positive impact on non-native plants, the strength of this impact depends primarily on the disturbance type and the habitat type (Jauni et al. 2015). As well, it may be possible that other factors are more important predictors for the alien proportion than the level of disturbance.

As in the plots of diversity level 0 during the establishment of the experiment the same amount of oil palms has been cut than in all enriched plots but no tree saplings have been planted, the enhanced light conditions could be the reason for the high alien species performance. Wahyuni et al. (2016) concluded that the canopy cover is probably one of the main factors influencing the distribution of invasive plant species, such as *C. hirta*, in agricultural systems.

For this study, indeed the proportion of alien species is significantly related to canopy cover. The less light due to canopy closure was available, the less alien species were present (Figure 25 C). This strong relationship leads to the assumption that in future the proportion of alien species will decrease in the enriched plots due to further canopy closure because of tree growth.

Even more interesting than the look at the species origin seems to be the comparison of unique and shared species per treatment group. The mere fact that 88 species were found that grow exclusively on the plots with experimental treatment proves the strong effect of the experiment regarding the understorey species composition. The continuous trend of increasing unique species with increasing area leads to the assumption that the effect might be intensified by increasing the experimental area. Extremely interesting seems the fact that the trend of rising unique species with increasing area applies only weakest for the control plots whose species pool may almost be completed at an area size of 400 m².

The results of the study conducted by Rembold et al. (2017a) confirms that oil palm understorey communities can comprise other species than communities in rubber plantations and forest. Nevertheless, it was not expected that a shift in community composition could be reached so clearly due to experimental treatment in an oil palm plantation. However, with a sample size of one plot of 1,600 m² size per treatment category, it must be considered that these observed effects can also be based on coincidence. Further, it cannot be confirmed that the effect on community composition is due to tree enrichment. The plots without planted trees but fenced for regrowth showed a similar number of unique species which they neither shared with the control plots nor with the enriched plots. It remains to be open whether the extremely positive effect in a restoration context was really caused by the tree plantings or whether the stop of management is sufficient for such a shift in understorey community composition. Most likely, there is no single reason but a bundle of reasons which lead to the results.

Furthermore, as the natural vegetation in the study site would be tropical lowland rainforest, it might be important to look at the forest dependency of the understorey species communities.

First qualitative comparisons with species lists from the nearby protected areas of *Harapan Rainforest* and *National Park Bukit Duabelas* indicate that more forest-dependent species are to be found in the enriched plots than in the managed as-usual plantation. The quantification of these results, however, would first require a completely identified species list of the present study, which is still pending.

Nevertheless, these qualitatively changes in species composition might be a fruitful avenue for further research. Many tropical species are strongly dependent on forests and are therefore not present in the agricultural landscapes (Mendenhall et al. 2016). With the conversion of forest to palm oil plantations these species might be replaced by species from other habitats, what emphasizes the importance of forest as a species reservoir (Rembold et al. 2017a).

If the tree enrichment experiment could lead to a higher proportion of forest-dependent species in the plantation, this would be a remarkable success for species conservation.

An important precondition for successful restoration is a high number of native tree seedlings in the understorey (Chazdon 2003) that might provide the basis for future recovery into a species rich secondary forest. In this respect, the results of this study are to be interpreted with great hope. A very strong and positive effect of the experimental treatment on trees and tree seedlings in terms of coverage and species number could be demonstrated. Curiously, there are even more tree and seedling species with even more coverage when the plot area was just fenced for regrowth, but no trees were planted. Therefore, again it remains unclear whether the positive development concerning tree species was caused by the tree plantings, by the stop of management or, more likely, by other multiple and interacting factors.

According to the results of this study, the canopy cover is definitely a significantly important predictor of the proportion of tree species, whereas the soil C:N ratio and the level of disturbance do not show any relationship to the amount of tree species in the understorey. Due to the strong relation to canopy cover, a further increase in tree and seedling species in the enriched plots with further tree growth can be predicted.

4.3 Structural Differences across Experimental Treatment

The look on species classified according to its growth habit revealed that all plots are generally herb-dominated concerning richness and cover. Compared to the results of Rembold et al. (2017a) concerning understorey growth form patterns in usual palm oil plantations, this is not surprising at all. The increased proportion of fern coverage in the control plots will probably be due to the dense presence of the species *A.latifolium*. The increased cover of vines in the plots of diversity level 0 could be explained by increased light conditions, however, the results from the plots with the highest enrichment do not fit to this explanation. Since the number of samples is small in both treatment groups (n = 4), it is very likely that these differences are attributed to the random success of a vine species. The conspicuous success of tree and seedling species affects the species composition even more than the structure, why these results were explained in more detail in the previous chapter (chapter 4.2).

As the subplot cover categories bare soil and woody debris are not covering much area, the cover of vegetation corresponds contradictory to the cover of litter. As expected due to tree leaf fall, the plots with planted trees comprise more litter cover than the plots without planted trees. Correspondingly the surface of plots with planted trees consist of less vegetation cover than enriched plots. Due to disturbance and management in the plantation the vegetation cover of control plots was suggested to be less pronounced than the results revealed. This could be explained by the fact that the last plantation weeding before data collection have been carried out irregularly more than six months ago, so understorey vegetation already had enough time to recover quite well. However, litter cover as well as litter layer depth rise with increasing plot size. As litter is an important functional element in forests, it can be assumed that a larger size of the enrichment islands may be favorable for restoration.

Litter layer depth shows roughly the same pattern than the litter cover of rising values with tree diversity level and lowest value for the control plots. However, the litter layer depth is quite high in the plots of diversity level 0, although they do not comprise any planted trees. The reason for this could be the very high growth rates and biomass dynamics of the pioneer species in this early successional stage (Lasky et al. 2014), what produces high amounts of litter as well.

The very low litter layer depth of the managed as-usual palm oil plantation could be explained by the absence of tree leaf litter and by the low quantities of understorey biomass because of regular weeding. With the absence of a closed deep litter layer the physical inhibition effect for seed germination is lacking. This is why it can be a favorable effect for understorey diversity (Barbier et al. 2008). In the present study, this relationship between litter layer depth and species richness could be confirmed in a simple statistically significant linear model. The thicker the litter layer in the subplot were, the less species were found in the understorey.

The weeding effect gets obvious, looking at the mean maximal shoot length per plot. The managed as-usual oil palm plots show a remarkable low maximal shoot length which can be explained by regular manual weeding and cattle grazing in the plantation area. Between the plots with treatment the differences are not very pronounced. The plots of diversity level 0 have the highest mean of shoot length, however, with a huge variation between the plots. The explanation could probably be again the enhanced light conditions in the plots without tree planting. Height growth is positively correlated with light environment (Poorter 2001) and during pioneer phase especially gap-associated species invest most of their biomass in the shoot growth (King 1991). The high standard deviation of the plots of diversity level 0 is not fitting into this explanation scheme. However, it must be considered that not only planted trees are able to change light conditions, but also pioneer shrubs, pioneer trees and especially fast-growing bamboo species.

Correspondingly, light conditions are a possible explanation for the results of high understorey density in the plots of tree diversity level 0. If an area is left for natural regrowth, species that are relatively shade intolerant, herbivore tolerant, and have a rapid vegetative growth can built a recalcitrant understorey layer that is very dense (Royo & Carson 2006). The relatively high density of the understorey of the managed as-usual plots correspond to results of Rembold et al. (2017a). Compared to other land-use systems they reported the highest understorey density for palm oil plantations (Rembold et al. 2017a). As in their study density is defined as the individual numbers recalculated per square meter, the direct comparison with cover density of the present study is not meaningful. However, the results from Rembold et al. (2017a) show that the forest understorey of tropical lowland forests in Central Sumatra is not very dense. Since one of the hopes of the tree enrichment experiment is the result of an understorey vegetation being more similar to native forest understorey than to the usual vegetation in a palm oil plantation, the results of this study are to be regarded as a positive shift. The least dense understorey in the highest tree enrichment level and the densest vegetation in the plots without planted trees confirm that the density is influenced by tree enrichment and not only by the lack of plantation management. The reasons are seen to be related to tree leaf litter, assuming that a more pronounced litter layer leads to less biomass and therefore less dense vegetation. Interestingly the understorey of small plots of the experiment are significantly denser than larger plots. If this is again related to the results of Rembold et al. (2017a), it could be assumed that regarding the understorey density a larger size of enrichment islands is beneficial in restoration contexts.

However, in this study a significant positive correlation between vegetation density and species richness could be found. Conversely, this means that a lower and thus more forest-like density of vegetation is to be seen rather negatively regarding to the number of species. Regardless, the correlation does not represent a cause-effect relationship and many other variables may influence this relationship. Most likely, this relationship will alter with the further process of succession.

4.4 Limitations of the Study

As shown in the previous chapters of the discussion, an introductory understanding of the effect of tree enrichment on the understorey vegetation could be achieved. Nevertheless, the limitations of the study must be critically assessed.

First, there are several methodological aspects that are limiting the results of the study. The quite time-consuming pre-study could gain interesting assessments about the most abundant species in the plots and represented a suitable framework for training the measurements and estimations why it is still considered necessary. The decision to measure the seven most abundant species (identified based on the pre-study) in a different way than other species had to be made due to time constraints. Nevertheless, it is a disadvantage that the two groups of species, abundant and not-abundant, had to be treated separately in statistical analysis. The fact that the shoot length of abundant species was measured less often than the shoot length of rare species contrasts with their importance on the plots. However, the data of four maximal shoot length measurement per abundant species on each subplot instead of the mean length out of ten measurements gives a better impression in regard to the invasive character of species such as *C. hirta* that can be used in further investigations of EFForTS-BEE.

The measurement of the plant shoot length instead of plant height allows hints to be drawn on biomass production and competition. Length measurements are considered to be easier to perform accurately and may be more suitable for purposes of determining growth and vigor than height measurements (Heady 1957). Furthermore, the decision for length measurement was a suitable method to include creeping species or species with a not-straight shoot axis, such as some grasses and ferns, in the species comparison. This would have become problematic with height measurements. Nevertheless, conclusions on structural components of the vegetation are quite challenging without having an impression of the vertical dimension through plant height data.

Data collected by cover estimations are known to have an observer bias to unknown extend. This well-known bias was tried to keep small with two data collectors remaining the same over the complete collection period. As it is difficult to carry out correct cover estimations without obtaining a 'global view' of the entire plot, the use of relatively small quadrats is suggested (Morrison 2016; Vittoz & Guisan 2007). Unfortunately, this was not possible due to time constraints and comparability with other environmental variables of the project but was therefore carried out in the pre-study as a quality reference. Additionally, cover estimations in forest understorey with vegetation growing in many different layers are supposed to be erroneous. Characteristics of the plants that make them difficult to notice, such as small size, narrow leaves or a 'winding' growth form as well as varying light levels over the course of a day may bias the record (Kéry & Gregg 2003; Moore et al. 2011; Morrison 2016).

But, although the additional counting of all present individuals per species, i.e. real abundance data, would have been desirable, the time-saving cover estimations were enough to identify general trends.

Although the default metric of biodiversity remains species richness, among ecologists it is growing awareness that other dimensions of biodiversity affect ecosystem functionality (Naeem et al. 2012). More recent biodiversity experiments have been designed to incorporate these dimensions (Grossman et al. 2018). Kusuma et al. (2018) points out that the focus on species number in understorey vegetation is quite limited and it is worth taking a look on the phylogenetic diversity instead. Furthermore, a functional approach to plant diversity generally improves the understanding of environmental effects as well as the impact of organisms on ecosystems (Petchey & Gaston 2006) and is therefore declared as the future core of ecological research (Garnier et al. 2016). Although some aspects of functionality were included in this study, the full functional approach could not be provided.

There are also some challenges owing to the experimental design. In the experiment the set of plot-specific combinations of plot size, tree diversity level, and species composition is not repeated, i.e. every plot comprises its unique combination of experimental treatments. For the analysis of the results this means that it is highly recommended to include every single plot. This might be problematic, if some measurement errors occurred or plot data sets are outlying enormously, which would normally justify the exclusion of certain data points. For the statistical analysis, Bell et al. (2009) suggest using only linear models in such an experimental set up for testing the influences of plot size, diversity level and species composition. If the data does not suggest linear relationships, this is a quite challenging proposal. Therefore, these suggestions could not be accepted in all cases.

The main data collection of this study took place in only one randomly distributed but already installed subplot per plot which causes further challenges. The observed vegetation showed partly a very patchy pattern of species richness, species composition as well as vegetation structure in all plots, what leads to the conclusion that one subplot as the representative of the whole plot is far too less for assuming general trends of diversity, composition, and structure of the understorey (Figure 26).

 The high volume of simultaneous investigations in the same subplot leads to further impairments. The researchers carrying out other surveys in the subplot had a considerable impact on the sensible understorey through trampling down and ripping out plant individuals to get through dense vegetation and unintentional soil compaction due to the constant generation of soil vibration to protect against cobras. Furthermore, foreign seeds were brought into subplots due to the depositing of chili plants in soil-filled plastic bags in each subplot for a pollination project. Especially in the smallest plot size (5 m x 5 m) where the subplot corresponds to the plot, these high intensities of disturbances could be clearly observed.
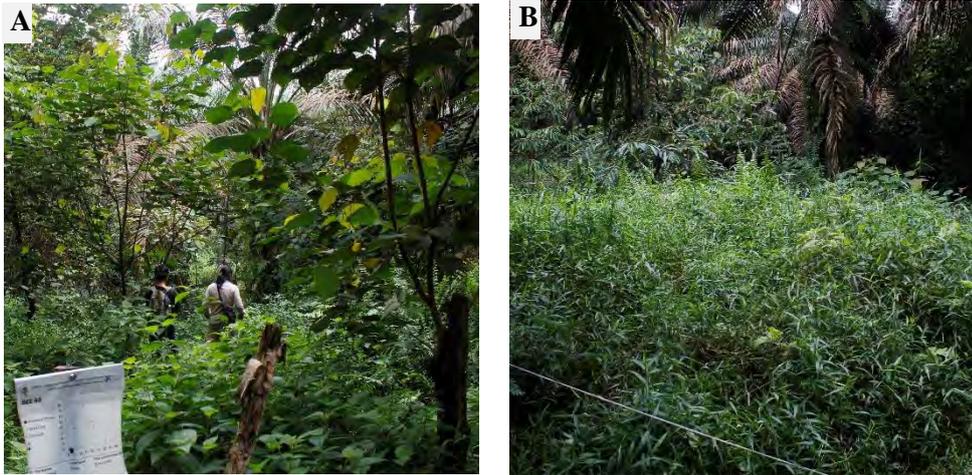
Figure 26: Subplot as representative of the plot. A Plot of 40 m x 40 m size and diversity level 1 (Plot ID 43), showing a dense cover of *Clidemia hirta* in almost the whole plot area (A), but a dense grass cover with almost complete absence of *C. hirta* in the corresponding subplot area (B). This example shows, that the subplot often could not represent the plot (pictures by Lena Sachsenmaier).

Not only in this case the plots of the smallest size form a separate group. It could be observed that some plant individuals, especially grasses and climbers, benefit from the fence of the outer plot boundary, which is simultaneously the subplot boundary for the small plots. Some species (e.g. *Cyperus difformis*) obviously preferred the protection of some measurement installations, such as seed traps. Individuals of these species could be detected frequently growing underneath and often seemed to grow higher and more vigorous than under normal conditions.

One of the presumptions of this experiment is that the planted tree islands could act as 'stepping stones' between forest patches. In this context, the location of the experiment within the landscape must be seen critically, as meanwhile there are no larger forest patches nearby. So it is questionable if the tree islands could represent buffer zones that interconnect areas of high conservation value, as suggested by Koh et al. (2009).

As described in the previous chapters of the discussion, the experimentally altered variables (i.e. plot size and diversity level) did not strongly and not unambiguously affect understorey diversity and structure. One important factor of influence could be the location of the plot in the plantation. The plantation area does not have a uniform character and includes a network of roads, paths, streams, slopes, and various altitudes. Vegetation might be strongly affected by nearby roads (seed dispersal), nearby houses (livestock exposure), elevation (microclimate), and riparian character (seed dispersal, soil moisture). These effects could be even stronger and might therefore overlay effects of plot size or tree diversity level.

Further, the tree diversity level at the time of planting is different to the realized number of tree species at the time of this survey. As recorded in February 2018, only around 50 % of the planted trees survived with large variability of survival rates among species. This largely affected the composition, spatial distribution, and number of tree species in the plots. This may explain why there is no clear trend along the diversity gradient.

Another major reason for the mostly non-significant influence of the treatment variables might be owing to the short time that has passed since tree planting in December 2013. It is quite reasonable that in the period of four years since planting some ecological key processes have not yet shown up. This time-lag in the response of ecosystem processes to alterations in plant diversity is also reported from other studies (Cardinale et al. 2012; Eisenhauer et al. 2012). With further growth and crown expansion of the planted trees, the altered light conditions are expected to affect microclimate and soil conditions (Tscharntke et al. 2011). Some of the planted trees are meanwhile already high enough for intense competition, complementarity, and facilitation between each other and with the oil palms which may have further ecological effects as well. The more pronounced flowering and fruiting of the trees over time will attract further animals from larger distances that may fundamentally enrich the seed bank and therefore the understorey vegetation. It must also be taken into account that, since the plots' fencing only deter larger man-made disturbances, but not any other factors, positive effects due to enrichment can spread to the whole plantation. Therefore, detected effects may not be directly and exclusively attributed to the enriched plots although they originated there.

Another aspect to consider is that initially the plots were manually cleared approximately every three months to enhance survival of the planted tree saplings until May 2016. The natural regrowth of understorey vegetation has only been possible since the short time of just two years. It will probably take several years until the novel ecosystems will have developed completely and reliable conclusions on the overall restoration success of the experiment can be drawn.

Further, the opinions on how to achieve large-scale forest restoration in the tropics are divergent. One disadvantage of tree enrichment plantings is that the full range of functional traits present within the local or regional species pool is not represented. By allowing nature itself to decide which species should dominate during natural regeneration, greater diversity can be achieved (Chazdon & Guariguata 2016). Further, naturally regenerated forests are expected to exhibit a less homogeneous and more patchy spatial structure within the understorey due to a more diverse age structure of canopy trees (Chazdon & Guariguata 2016). However, natural regeneration can also encourage the colonization and persistence of undesirable species that arrest or alter successional pathways and lead to species-poor assemblages (Catterall 2016; Cordell et al. 2016; Royo & Carson 2006). In these cases, it might be a promising option to manage the understorey vegetation, especially in order to reduce the effects of alien invasive species (Friday et al. 2015; Nghiem et al. 2015; Swinfield et al. 2016). Due to the outstanding presence of the alien invasive species *C. hirta* in the EFForTS-BEE site the question arises whether targeted management of invasive plants would probably lead to greater restoration success. As further research in this area is urgently needed (Chazdon & Guariguata 2016), the inclusion of the direct comparison of naturally regenerated understorey versus invasive-managed understorey would be promising for this experiment.

5. Conclusion

In conclusion, the present study has enabled a deeper understanding of the effect of tree enrichment on understorey vegetation in oil palm landscapes.

In contrast to the hypotheses, understorey vegetation diversity, composition and structure were not clearly dependent on the gradients of the key variables plot size and tree diversity level. Surprisingly, plantation management seemed to have a stronger impact on the condition of understorey vegetation than other experimental variables. Furthermore, this study reveals that there are various and complex interrelationships of understorey vegetation with other environmental and ecological factors that do not always follow clear gradients (Figure 27).
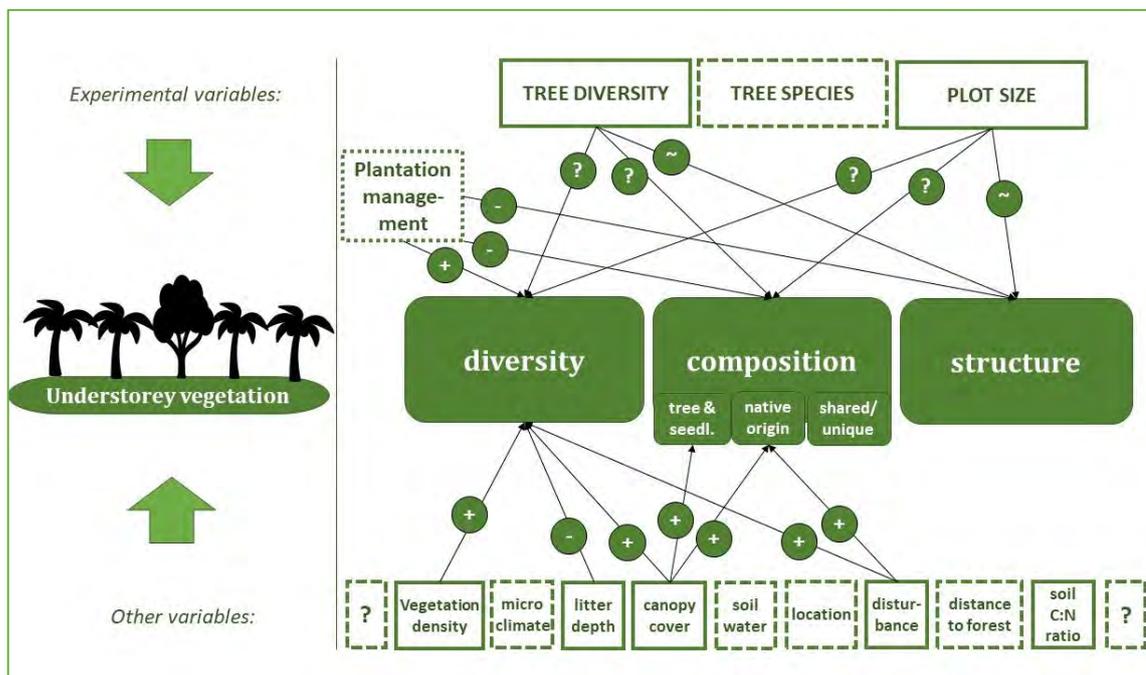
Figure 27: Overview of experimental and other variables and their influence on understorey vegetation aspects. Bold lines indicate included variables of this study, dashed lines indicate not included variables of this study. Arrows indicate relationships. Plus symbols indicate positive correlations, minus symbols indicate negative correlations, question marks stand for unclear relationship, and similarity symbols stand for different relationships between several sub aspects (own illustration).

Compared to the baseline survey prior to the establishment of the experiment, the understorey species diversity already increased which can be interpreted as a positive development in a restoration context. In contrast to what was expected, the understorey species diversity does not increase with either higher tree diversity level or larger plot size. However, it is positively influenced by plantation management. Possible explanations for this surprising result are provided by the thicker litter layer in tree-enriched plots that act as physical inhibitor and the positive relationship between diversity and intermediate disturbance such as manual weeding and livestock grazing.

Concerning the investigation of understorey structure, this study reveals the rising relevance of litter layer thickness and litter cover with increasing tree enrichment level and with increasing plot size. Both experimental key factors have a positive effect on the litter production which is a promising shift towards the structure of the natural forest habitats. However, in this stage of succession litter layer depth seems to be significantly negatively correlated with species richness. As mentioned above, this could be at least one explanation for low species diversity under tree enrichment conditions.

The experimental effects on species composition are even more pronounced than on diversity and structure. The invasive alien species *C. hirta*, which is striking in its frequency and degree of coverage especially on the plots that are not weeded, can be assigned a key role in the composition of the understorey species, but its influence remains uncertain. Whereas the effect on the proportion of species origin is still inconclusive, effects on the proportion of tree and seedling species are quite strong. Plots with experimental treatment comprise significantly more tree and seedling species and consist of more tree and seedling cover than the control plots. This is a key finding of the study and shows that due to the experiment the understorey now might provide a basis for ecosystem restoration and has potential to recover into a secondary forest. As the proportion of tree and seedling species is found to be positively correlated with canopy cover, this promising development is expected to intensify due to further canopy closure in future times. Strong evidence that the experiment leads to a shift in community composition of the understorey is provided by the high proportion of unique species in each treatment group. Particularly encouraging is the sharply increasing number of unique species with increasing plot size in the enrichment plots, but not in the managed as-usual palm oil plots. However, whether the observed shift in community composition due to experimental treatment is a shift toward the natural habitat community, i.e. forest-dependent species, must be elucidated in further studies.

Major limitations of this study are the strongly patchy pattern of understorey in the plots that might bias data sampled in only one subplot and the overall individuality of the plots with its unique combination of experimental treatment what makes it difficult to disentangle single effects. Further, the high mortality rate of planted trees, which is not evenly distributed among the species, leads to a distorted tree diversity gradient and therefore to biased results. Anyway, it will probably take several years until the novel ecosystems are fully developed and reliable conclusions on the overall success of the experiment can be drawn.

Further research concerning understorey should cope with the impact of invasive species, particularly *C. hirta*, and investigate the forest-dependency of the species found in different treatment groups. It is assumed that regarding understorey vegetation, the effect of the individual tree species growing above will be more pronounced than the effect of the tree diversity in general (Germany et al. 2017; Vockenhuber et al. 2011).

That's why it is strongly recommended to include tree species effects in further studies concerning the understorey. Another promising variable to include could be the spatial distribution of the plots with their distance to nearby forest patches. A fully functional approach, additionally to the pure species numbers, would provide deeper understanding of ecosystem functioning and would be closer to recent ecological methods. Furthermore, detailed considerations about the general organization of the experiment, i.e. intervention or natural regrowth, would also be adjuvant.

This study contributes to the general knowledge of understorey vegetation in palm oil landscapes on the one hand, and to the deeper understanding of the effect of enrichment plantings in particular on plant diversity, composition, and structure in the undergrowth on the other hand. The gained information regarding the understorey in the EFForTS-BEE plots can now be related to other ecosystem variables in the project and more comprehensive conclusions can thus be drawn. These substantial contributions support advances in biodiversity enrichment experiments and restoration research in tropical agricultural landscapes. Due to the worsening image of palm oil worldwide, research projects like this one are receiving increased attention from stakeholders in politics and economy. In case of an overall restoration success of the experiment, for the evaluation of which much knowledge is still lacking, the idea of biodiversity enrichment in agricultural landscapes would have probably great outreach. Without endangering the food security of a growing world population, this could make an important contribution to preserving biodiversity and ecosystem functions in times of high deforestation rates and extreme species loss.

References

Abood, Sinan A.; Lee, Janice Ser Huay; Burivalova, Zuzana; Garcia-Ulloa, John; Koh, Lian Pin (2015): Relative Contributions of the Logging, Fiber, Oil Palm, and Mining Industries to Forest Loss in Indonesia. In *Conservation Letters* 8 (1), pp. 58–67. DOI: 10.1111/conl.12103.

Albrecht, Alain; Kandji, Serigne T. (2003): Carbon sequestration in tropical agroforestry systems. In *Agriculture, Ecosystems & Environment* 99 (1-3), pp. 15–27. DOI: 10.1016/S0167-8809(03)00138-5.

Allen, Kara; Corre, Marife D.; Tjoa, Aiyen; Veldkamp, Edzo (2015): Soil Nitrogen-Cycling Responses to Conversion of Lowland Forests to Oil Palm and Rubber Plantations in Sumatra, Indonesia. In *PloS one* 10 (7), e0133325. DOI: 10.1371/journal.pone.0133325.

Ampoorter, Evy; Baeten, Lander; Vanhellemont, Margot; Bruelheide, Helge; Scherer-Lorenzen, Michael; Baasch, Annett; Erfmeier, Alexandra; Hock, Maria; Verheyen, Kris (2015): Disentangling tree species identity and richness effects on the herb layer: first results from a German tree diversity experiment. In *Journal of Vegetation Science* 26 (4), pp. 742–755. DOI: 10.1111/jvs.12281.

Austin, K. G.; Mosnier, A.; Pirker, J.; McCallum, I.; Fritz, S.; Kasibhatla, P. S. (2017): Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments. In *Land Use Policy* 69, pp. 41–48. DOI: 10.1016/j.landusepol.2017.08.036.

Australian National Herbarium (2011a): Habit Growth Form List. Centre for Australien National Biodiversity Research. Canberra. Available online at http://www.anbg.gov.au/cpbr/herbarium/collecting/habit-types.html, updated on 2015, checked on 27.08.2018.

Australian National Herbarium (2011b): Plant Collection Procedures and Specimen Preservation. Centre for Australien National Biodiversity Research. Canberra. Available online at http://www.anbg.gov.au/cpbr/herbarium/collecting/collection-procedures.html, updated on 2015, checked on 26.08.2018.

Badan Pusat Statistik (2018): Provinsi Jambi Dalam Angka 2018. Jambi Province in Figures. Available online at http://jambi.bps.go.id, checked on 24.08.2018.

Barbier, Stéphane; Gosselin, Frédéric; Balandier, Philippe (2008): Influence of tree species on understory vegetation diversity and mechanisms involved—A critical review for temperate and boreal forests. In *Forest Ecology and Management* 254 (1), pp. 1–15. DOI: 10.1016/j.foreco.2007.09.038.

Barnes, Andrew D.; Jochum, Malte; Lefcheck, Jonathan S.; Eisenhauer, Nico; Scherber, Christoph; O'Connor, Mary I.; Ruiter, Peter de; Brose, Ulrich (2018): Energy Flux: The Link between Multitrophic Biodiversity and Ecosystem Functioning. In *Trends in ecology & evolution* 33 (3), pp. 186–197. DOI: 10.1016/j.tree.2017.12.007.

Barnes, Andrew D.; Jochum, Malte; Mumme, Steffen; Haneda, Noor Farikhah; Farajallah, Achmad; Widarto, Tri Heru; Brose, Ulrich (2014): Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning. In *Nature communications* 5, p. 5351. DOI: 10.1038/ncomms6351.

Beatty, S. W. (2003): Habitat heterogeneity and maintenance of species in understory communities. In Frank S. Gilliam, Mark R. Roberts (Eds.): The herbaceous layer in forests of eastern North America. New York: Oxford University Press, pp. 177–197.

Bell, Thomas; Lilley, Andrew K.; Hector, Andy; Schmid, Bernhard; King, Lindsay; Newman, Jonathan A. (2009): A linear model method for biodiversity-ecosystem functioning experiments. In *The American Naturalist* 174 (6), pp. 836–849. DOI: 10.1086/647931.

Beukema, Hendrien; Danielsen, Finn; Vincent, Grégoire; Hardiwinoto, Suryo; van Andel, Jelte (2007): Plant and bird diversity in rubber agroforests in the lowlands of Sumatra, Indonesia. In *Agroforestry Systems* 70 (3), pp. 217–242. DOI: 10.1007/s10457-007-9037-x.

Both, Sabine; Fang, Teng; Böhnke, Martin; Bruelheide, Helge; Geißler, Christian; Kühn, Peter; Scholten, Thomas; Trogisch, Stefan; Erfmeier, Alexandra (2011): Lack of tree layer control on herb layer characteristics in a subtropical forest, China. In *Journal of Vegetation Science* 22 (6), pp. 1120–1131. DOI: 10.1111/j.1654-1103.2011.01324.x.

Braun-Blanquet, J. (1928): Pflanzensoziologie. Grundzüge der Vegetationskunde. Berlin, Heidelberg: Springer (Biologische Studienbücher, 7).

Brosofske, K. D.; Chen, J.; Crow, T. R. (2001): Understory vegetation and site factors: implications for a managed Wisconsin landscape. In *Forest Ecology and Management* 146 (1-3), pp. 75–87. DOI: 10.1016/S0378-1127(00)00447-3.

CABI (2018): Invasive Species Compendium. CAB International. Wallingford, UK. Available online at www.cabi.org/isc, checked on 30.10.2018.

Cardinale, Bradley J.; Duffy, J. Emmett; Gonzalez, Andrew; Hooper, David U.; Perrings, Charles; Venail, Patrick; Narwani, Anita; Mace, Georgina M.; Tilman, David; Wardle, David A.; Kinzig, Ann P.; Daily, Gretchen C.; Loreau, Michel; Grace, James B. et al. (2012): Biodiversity loss and its impact on humanity. In *Nature* 486 (7401), pp. 59–67. DOI: 10.1038/nature11148.

Catford, Jane A.; Daehler, Curtis C.; Murphy, Helen T.; Sheppard, Andy W.; Hardesty, Britta D.; Westcott, David A.; Rejmánek, Marcel; Bellingham, Peter J.; Pergl, Jan; Horvitz, Carol C.; Hulme, Philip E. (2012): The intermediate disturbance hypothesis and plant invasions: Implications for species richness and management. In *Perspectives in Plant Ecology, Evolution and Systematics* 14 (3), pp. 231–241. DOI: 10.1016/j.ppees.2011.12.002.

Catterall, Carla P. (2016): Roles of non-native species in large-scale regeneration of moist tropical forests on anthropogenic grassland. In *Biotropica* 48 (6), pp. 809–824. DOI: 10.1111/btp.12384.

Chazdon, Robin L. (2003): Tropical forest recovery: legacies of human impact and natural disturbances. In *Perspectives in Plant Ecology, Evolution and Systematics* 6 (1-2), pp. 51–71. DOI: 10.1078/1433-8319-00042.

Chazdon, Robin L.; Guariguata, Manuel R. (2016): Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. In *Biotropica* 48 (6), pp. 716–730. DOI: 10.1111/btp.12381.

Clough, Yann; Krishna, Vijesh V.; Corre, Marife D.; Darras, Kevin; Denmead, Lisa H.; Meijide, Ana; Moser, Stefan; Musshoff, Oliver; Steinebach, Stefanie; Veldkamp, Edzo; Allen, Kara; Barnes, Andrew D.; Breidenbach, Natalie; Brose, Ulrich et al. (2016): Land-use choices follow profitability at the expense of ecological functions in Indonesian

smallholder landscapes. In *Nature communications* 7, p. 13137. DOI: 10.1038/ncomms13137.

Cole, R. J.; Holl, K. D.; Zahawi, R. A. (2010): Seed rain under tree islands planted to restore degraded lands in a tropical agricultural landscape. In *Ecological Applications* 20 (5), pp. 1255–1269. DOI: 10.1890/09-0714.1.

Colwell, R. K.; Coddington, J. A. (1994): Estimating terrestrial biodiversity through extrapolation. In *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 345 (1311), pp. 101–118. DOI: 10.1098/rstb.1994.0091.

Connell, Joseph H. (1978): Diversity in Tropical Rain Forests and Coral Reefs. In *Science* 199 (4335), pp. 1302–1310.

Corbin, Jeffrey D.; Holl, Karen D. (2012): Applied nucleation as a forest restoration strategy. In *Forest Ecology and Management* 265, pp. 37–46. DOI: 10.1016/j.foreco.2011.10.013.

Corbin, Jeffrey D.; Robinson, George R.; Hafkemeyer, Lauren M.; Handel, Steven N. (2016): A long-term evaluation of applied nucleation as a strategy to facilitate forest restoration. In *Ecological Applications* 26 (1), pp. 104–114. DOI: 10.1890/15-0075.

Cordell, Susan; Ostertag, Rebecca; Michaud, Jené; Warman, Laura (2016): Quandaries of a decade-long restoration experiment trying to reduce invasive species: beat them, join them, give up, or start over? In *Restoration Ecology* 24 (2), pp. 139–144. DOI: 10.1111/rec.12321.

Corlett, Richard; Primack, Richard B. (2011): Tropical rain forests. An ecological and biogeographical comparison. 2nd ed. Chichester, West Sussex, Hoboken, NJ: Wiley-Blackwell.

Corley, R. H. V.; Tinker, Philip Bernard (2016): The oil palm. Fifth edition. Hoboken NJ: John Wiley & Sons.

CRC Weed Management (2003): Alert list for environmental weeds. Chinese violet (*Asystasia gangetica ssp. micrantha*) - Weed management guide. CRC for Australian Weed Management and the Commonwealth Department of the Environment and heritage. Osmond, S. Aust.

Danielsen, Finn; Beukema, Hendrien; Burgess, Neil D.; Parish, Faizal; Brühl, Carsten A.; Donald, Paul F.; Murdiyarso, Daniel; Phalan, Ben; Reijnders, Lucas; Struebig, Matthew; Fitzherbert, Emily B. (2009): Biofuel plantations on forested lands: double jeopardy for biodiversity and climate. In *Conservation Biology* 23 (2), pp. 348–358. DOI: 10.1111/j.1523-1739.2008.01096.x.

Dirzo, R.; Mendoza, E. (2008): Biodiversity. In Sven Erik Jorgensen (Ed.): Encyclopedia of ecology. Amsterdam: Elsevier, pp. 368–377.

Dislich, Claudia; Keyel, Alexander C.; Salecker, Jan; Kisel, Yael; Meyer, Katrin M.; Auliya, Mark; Barnes, Andrew D.; Corre, Marife D.; Darras, Kevin; Faust, Heiko; Hess, Bastian; Klasen, Stephan; Knohl, Alexander; Kreft, Holger et al. (2017): A review of the ecosystem functions in oil palm plantations, using forests as a reference system. In *Biological reviews of the Cambridge Philosophical Society* 92 (3), pp. 1539–1569. DOI: 10.1111/brv.12295.

Drescher, Jochen; Rembold, Katja; Allen, Kara; Beckschäfer, Philip; Buchori, Damayanti; Clough, Yann; Faust, Heiko; Fauzi, Anas M.; Gunawan, Dodo; Hertel, Dietrich; Irawan, Bambang; Jaya, I. Nengah S.; Klarner, Bernhard; Kleinn, Christoph et al. (2016):

Ecological and socio-economic functions across tropical land use systems after rainforest conversion. In *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 371 (1694). DOI: 10.1098/rstb.2015.0275.

Edwards, E. (1983): A broad-scale structural classification of vegetation for practical purposes. In *Bothalia* 14 (3/4), pp. 705–712. DOI: 10.4102/abc.v14i3/4.1231.

'eFloras (2018): The Flora of China. Missouri Botanical Garden, St. Louis, MO & Harvard University Herbaria, Cambridge, MA. Available online at http://www.efloras.org, checked on 30.10.2018.

Egbe, N. E.; Adenikinju, S. A. (1990): Effect of intercropping on potential yield of cacao in south western Nigeria. In *Café, Cacao, Thé* 34 (4), pp. 281–284.

Eisenhauer, Nico; Reich, Peter B.; Scheu, Stefan (2012): Increasing plant diversity effects on productivity with time due to delayed soil biota effects on plants. In *Basic and Applied Ecology* 13 (7), pp. 571–578. DOI: 10.1016/j.baae.2012.09.002.

Ewers, Robert M.; Boyle, Michael J. W.; Gleave, Rosalind A.; Plowman, Nichola S.; Benedick, Suzan; Bernard, Henry; Bishop, Tom R.; Bakhtiar, Effendi Y.; Chey, Vun Khen; Chung, Arthur Y. C.; Davies, Richard G.; Edwards, David P.; Eggleton, Paul; Fayle, Tom M. et al. (2015): Logging cuts the functional importance of invertebrates in tropical rainforest. In *Nature communications* 6, p. 6836. DOI: 10.1038/ncomms7836.

Federal Geographic Data Committee [FGDC] (2008): National Vegetation Classification Standard. Version 2. Reston, Virginia (USA) (FGDC-STD-005-2008). Available online at https://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation/NVCS_V2_FINAL_2008-02.pdf, checked on 25.10.2018.

Fitzherbert, Emily B.; Struebig, Matthew J.; Morel, Alexandra; Danielsen, Finn; Brühl, Carsten A.; Donald, Paul F.; Phalan, Ben (2008): How will oil palm expansion affect biodiversity? In *Trends in ecology & evolution* 23 (10), pp. 538–545. DOI: 10.1016/j.tree.2008.06.012.

Flint, E. P. (1994): Changes in land use in South and Southeast Asia from 1880 to 1980: A data base prepared as part of a coordinated research program on carbon fluxes in the tropics. In *Chemosphere* 29 (5), pp. 1015–1062. DOI: 10.1016/0045-6535(94)90166-X.

Food and Agriculture Organization [FAO] (2018): FAOStat. Production Crops (Dataset). Latest update: 28.05.2018. Available online at http://www.fao.org/faostat/en/#data/QC, checked on 05.08.2018.

Foster, William A.; Snaddon, Jake L.; Turner, Edgar C.; Fayle, Tom M.; Cockerill, Timothy D.; Ellwood, M. D. Farnon; Broad, Gavin R.; Chung, Arthur Y. C.; Eggleton, Paul; Khen, Chey Vun; Yusah, Kalsum M. (2011): Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. In *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 366 (1582), pp. 3277–3291. DOI: 10.1098/rstb.2011.0041.

Friday, James B.; Cordell, Susan; Giardina, Christian P.; Inman-Narahari, Faith; Koch, Nicholas; Leary, James J. K.; Litton, Creighton M.; Trauernicht, Clay (2015): Future directions for forest restoration in Hawaiʻi. In *New Forests* 46 (5), pp. 733–746. DOI: 10.1007/s11056-015-9507-3.

Gardner, Toby A.; Barlow, Jos; Sodhi, Navjot S.; Peres, Carlos A. (2010): A multi-region assessment of tropical forest biodiversity in a human-modified world. In *Biological Conservation* 143 (10), pp. 2293–2300. DOI: 10.1016/j.biocon.2010.05.017.

Garnier, Eric; Navas, Marie-Laure; Grigulis, Karl (2016): Plant functional diversity. Organism traits, community structure, and ecosystem properties. First edition. Oxford, New York, NY: Oxford University Press.

Gérard, Anne; Wollni, Meike; Hölscher, Dirk; Irawan, Bambang; Sundawati, Leti; Teuscher, Miriam; Kreft, Holger (2017): Oil-palm yields in diversified plantations: Initial results from a biodiversity enrichment experiment in Sumatra, Indonesia. In *Agriculture, Ecosystems & Environment* 240, pp. 253–260. DOI: 10.1016/j.agee.2017.02.026.

Germany, Markus S.; Bruelheide, Helge; Erfmeier, Alexandra (2017): Limited tree richness effects on herb layer composition, richness and productivity in experimental forest stands. In *Journal of Plant Ecology* 10 (1), pp. 190–200. DOI: 10.1093/jpe/rtw109.

Gibson, Luke; Lee, Tien Ming; Koh, Lian Pin; Brook, Barry W.; Gardner, Toby A.; Barlow, Jos; Peres, Carlos A.; Bradshaw, Corey J. A.; Laurance, William F.; Lovejoy, Thomas E.; Sodhi, Navjot S. (2011): Primary forests are irreplaceable for sustaining tropical biodiversity. In *Nature* 478 (7369), pp. 378–381. DOI: 10.1038/nature10425.

Gilliam, Frank S. (2007): The Ecological Significance of the Herbaceous Layer in Temperate Forest Ecosystems. In *BioScience* 57 (10), pp. 845–858. DOI: 10.1641/B571007.

Gonzalez, Maya; Deconchat, Marc; Balent, Gérard (2009): Woody plant composition of forest layers: the importance of environmental conditions and spatial configuration. In *Plant Ecology* 201 (1), pp. 305–318. DOI: 10.1007/s11258-009-9572-9.

Gotelli, Nicholas J.; Colwell, Robert K. (2011): Estimating species richness. In Anne E. Magurran (Ed.): Measuring biological diversity. 9th ed. Malden, Mass.: Blackwell, pp. 39–54.

Grossman, Jake J.; Vanhellemont, Margot; Barsoum, Nadia; Bauhus, Jürgen; Bruelheide, Helge; Castagneyrol, Bastien; Cavender-Bares, Jeannine; Eisenhauer, Nico; Ferlian, Olga; Gravel, Dominique; Hector, Andy; Jactel, Hervé; Kreft, Holger; Mereu, Simone et al. (2018): Synthesis and future research directions linking tree diversity to growth, survival, and damage in a global network of tree diversity experiments. In *Environmental and Experimental Botany* 152, pp. 68–89. DOI: 10.1016/j.envexpbot.2017.12.015.

Guillaume, Thomas; Damris, Muhammad; Kuzyakov, Yakov (2015): Losses of soil carbon by converting tropical forest to plantations: erosion and decomposition estimated by δ(13) C. In *Global change biology* 21 (9), pp. 3548–3560. DOI: 10.1111/gcb.12907.

Guillaume, Thomas; Kotowska, Martyna M.; Hertel, Dietrich; Knohl, Alexander; Krashevska, Valentyna; Murtilaksono, Kukuh; Scheu, Stefan; Kuzyakov, Yakov (2018): Carbon costs and benefits of Indonesian rainforest conversion to plantations. In *Nature communications* 9 (1), p. 2388. DOI: 10.1038/s41467-018-04755-y.

Heady, Harold F. (1957): The Measurement and Value of Plant Height in the Study of Herbaceous Vegetation. In *Ecology* 38 (2), pp. 313–320.

Hobbs, Richard J.; Huenneke, Laura F. (1992): Disturbance, Diversity, and Invasion: Implications for Conservation. In *Conservation Biology* 6 (3), pp. 324–337.

Hofmeister, Jeňýk; Hošek, Jan; Modrý, Martin; Roleček, Jan (2009): The influence of light and nutrient availability on herb layer species richness in oak-dominated forests in central Bohemia. In *Plant Ecology* 205 (1), p. 57. DOI: 10.1007/s11258-009-9598-z.

Hooijer, A.; Page, S.; Canadell, J. G.; Silvius, M.; Kwadijk, J.; Wösten, H.; Jauhiainen, J. (2010): Current and future CO_2 emissions from drained peatlands in Southeast Asia. In *Biogeosciences* 7 (5), pp. 1505–1514. DOI: 10.5194/bg-7-1505-2010.

Hooper, D. U.; Chapin, F. S.; Ewel, J. J.; Hector, A.; Inchausti, P.; Lavorel, S.; Lawton, J. H.; Lodge, D. M.; Loreau, M.; Naeem, S.; Schmid, B.; Setälä, H.; Symstad, A. J.; Vandermeer, J.; Wardle, D. A. (2005): Effects of biodiversity on ecosystem functioning. A consensus of current knowledge. In *Ecological Monographs* 75 (1), pp. 3–35. DOI: 10.1890/04-0922.

Hothorn, Torsten; Bretz, Frank; Westfall, Peter (2008): Simultaneous Inference in General Parametric Models. In *Biometrical Journal* 50 (3), pp. 346–363. DOI: 10.1002/bimj.200810425.

Houghton, R. A.; Hall, Forrest; Goetz, Scott J. (2009): Importance of biomass in the global carbon cycle. In *Journal of Geophysical Research: Biogeosciences* 114 (G2), G00E03. DOI: 10.1029/2009JG000935.

Huston, Michael (1979): A General Hypothesis of Species Diversity. In *American Naturalist* 113, pp. 81–101.

Institut Penelitian Inovasi Bumi [INOBU] (2016): A Profile of Oil Palm Smallholders and Their Challenges of Farming Independently. The case of Seruyan and Kotawaringin Barat Districts in Central Kalimantan, Indonesia. Available online at http://www.inobu.org, checked on 06.08.2018.

Janzen, Daniel H. (1984): Dispersal of Small Seeds by Big Herbivores: Foliage is the Fruit. In *The American Naturalist* 123 (3), pp. 338–353.

Jauni, Miia; Gripenberg, Sofia; Ramula, Satu (2015): Non-native plant species benefit from disturbance: a meta-analysis. In *Oikos* 124 (2), pp. 122–129. DOI: 10.1111/oik.01416.

Jorgensen, Sven Erik (Ed.) (2008): Encyclopedia of ecology. Amsterdam: Elsevier.

Kementerian Pertanian, Sekretariat Direktorat Jenderal Perkebunan (2017): Statistik Perkebunan Indonesia. Kelapa Sawit 2015-2017. Available online at http://ditjenbun.pertanian.go.id/tinymcpuk/gambar/file/statistik/2017/Kelapa-Sawit-2015-2017.pdf, checked on 06.08.2018.

Kéry, Marc; Gregg, Katharine B. (2003): Effects of life-state on detectability in a demographic study of the terrestrial orchid Cleistes bifaria. In *Journal of Ecology* 91 (2), pp. 265–273. DOI: 10.1046/j.1365-2745.2003.00759.x.

Kier, Gerold; Kreft, Holger; Lee, Tien Ming; Jetz, Walter; Ibisch, Pierre L.; Nowickic, Christoph; Mutke, Jens; Barthlott, Wilhelm (2009): A global assessment of endemism and species richness across island and mainland regions. In *PNAS* 106 (23), pp. 9322–9327.

Kindt, Roeland; Coe, Richard (2005): Tree diversity analysis. A manual and software for common statistical methods for ecological and biodiversity studies. Nairobi, Kenya: World Agroforestry Centre.

King, D. A. (1991): Correlations Between Biomass Allocation, Relative Growth Rate and Light Environment in Tropical Forest Saplings. In *Functional Ecology* 5, pp. 485–492.

Kirkup, D. W.; Saw, L. G.; Welzen, P. C. van; Wilde, W. J.J.O. de (Eds.) (2018): Flora Malesiana. Naming, Describing and Inventorying The Flora of Malesia. Available online at https://floramalesiana.org, checked on 14.10.2018.

Kleunen, Mark van; Dawson, Wayne; Essl, Franz; Pergl, Jan; Winter, Marten; Weber, Ewald; Kreft, Holger; Weigelt, Patrick; Kartesz, John; Nishino, Misako; Antonova, Liubov A.; Barcelona, Julie F.; Cabezas, Francisco J.; Cárdenas, Dairon et al. (2015): Global exchange and accumulation of non-native plants. In *Nature* 525 (7567), pp. 100–103. DOI: 10.1038/nature14910.

Koh, Lian Pin; Levang, Patrice; Ghazoul, Jaboury (2009): Designer landscapes for sustainable biofuels. In *Trends in ecology & evolution* 24 (8), pp. 431–438. DOI: 10.1016/j.tree.2009.03.012.

Koh, Lian Pin; Wilcove, David S. (2008): Is oil palm agriculture really destroying tropical biodiversity? In *Conservation Letters* 1 (2), pp. 60–64. DOI: 10.1111/j.1755-263X.2008.00011.x.

Kunin, William E. (1998): Biodiversity at the edge: A test of the importance of spatial "mass effects" in the Rothamsted Park Grass experiments. In *Proceedings of the National Academy of Sciences of the United States of America* 95 (1), pp. 207–212.

Kusuma, Yayan Wahyu C.; Rembold, Katja; Tjitrosoedirdjo, Sri S.; Kreft, Holger (2018): Tropical rainforest conversion and land use intensification reduce understorey plant phylogenetic diversity. In *Journal of Applied Ecology* 10, pp. 1–11. DOI: 10.1111/1365-2664.13201.

Lamb, David; Erskine, Peter D.; Parrotta, John A. (2005): Restoration of Degraded Tropical Forest Landscapes. In *Science* 310 (5754), pp. 1628–1632. DOI: 10.1126/science.1111773.

Larsson, Johann (2018): eulerr: Area-Proportional Euler and Venn Diagrams with Ellipses. R package. Version 4.1.0. Available online at https://cran.r-project.org/package=eulerr, checked on 9/28/2018.

Lasky, Jesse R.; Uriarte, María; Boukili, Vanessa K.; Erickson, David L.; John Kress, W.; Chazdon, Robin L. (2014): The relationship between tree biodiversity and biomass dynamics changes with tropical forest succession. In *Ecology letters* 17 (9), pp. 1158–1167. DOI: 10.1111/ele.12322.

Laumonier, Yves; Uryu, Yumiko; Stüwe, Michael; Budiman, Arif; Setiabudi, Budi; Hadian, Oki (2010): Eco-floristic sectors and deforestation threats in Sumatra: identifying new conservation area network priorities for ecosystem-based land use planning. In *Biodiversity and Conservation* 19 (4), pp. 1153–1174. DOI: 10.1007/s10531-010-9784-2.

Lenière, Alexandre; Houle, Gilles (2006): Response of herbaceous plant diversity to reduced structural diversity in maple-dominated (*Acer saccharum* Marsh.) forests managed for sap extraction. In *Forest Ecology and Management* 231 (1-3), pp. 94–104. DOI: 10.1016/j.foreco.2006.05.024.

Li, Shanshan; Tong, Yuewei; Wang, Zhengwen (2017): Species and genetic diversity affect leaf litter decomposition in subtropical broadleaved forest in southern China. In *Journal of Plant Ecology* 10 (1), pp. 232–241. DOI: 10.1093/jpe/rtw122.

Lindsay, S.; Middleton, D. J. (2012 onwards): Ferns of Thailand, Laos and Cambodia. Available online at http://rbg-web2.rbge.org.uk/thaiferns/, checked on 13.07.2018.

Luján, M.; Gutiérrez, N.; Gaviria, J. (2011): *Asystasia gangetica* (L.) T. Anders, *subsp. micrantha* (Nees) Ensermu (Acanthaceae), a new record for Venezuela. In *Ernstia* 21 (2), pp. 131–137.

Magurran, Anne E. (Ed.) (2011): Measuring biological diversity. 9th ed. Malden, Mass.: Blackwell.

Margalef, R. (1972): Homage to Evelyn Hutchinson, or why is there an upper limit to diversity. In *Transactions of the Connecticut Academy of Arts and Sciences* 44, 211-235.

Margono, Belinda Arunarwati; Potapov, Peter V.; Turubanova, Svetlana; Stolle, Fred; Hansen, Matthew C. (2014): Primary forest cover loss in Indonesia over 2000–2012. In *Nature Climate Change* 4 (8), pp. 730–735. DOI: 10.1038/nclimate2277.

McIntyre, S.; Lavorel, S. (1994): Predicting Richness of Native, Rare, and Exotic Plants in Response to Habitat and Disturbance Variables across a Variegated Landscape. In *Conservation Biology* 8 (2), pp. 521–531. DOI: 10.1046/j.1523-1739.1994.08020521.x.

Mendenhall, Chase D.; Shields-Estrada, Analisa; Krishnaswami, Arjun J.; Daily, Gretchen C. (2016): Quantifying and sustaining biodiversity in tropical agricultural landscapes. In *Proceedings of the National Academy of Sciences of the United States of America* 113 (51), pp. 14544–14551. DOI: 10.1073/pnas.1604981113.

Miller, Rupert G. (1964): A Trustworthy Jackknife. In *The Annals of Mathematical Statistics* 35 (4), 1594-1605, checked on 30.10.2018.

Mishra, P.; Vishwajith, K. P.; Padmanaban, K.; Sahu, P. K. (2017): Modelling and Forecasting of Palm Oil Production, Import, Export, Domestic Supply and Waste in Major Countries of the World. In *Indian Journal of Economics and Development* 13 (2), p. 243. DOI: 10.5958/2322-0430.2017.00175.5.

Mölder, Andreas; Bernhardt-Römermann, Markus; Schmidt, Wolfgang (2008): Herb-layer diversity in deciduous forests: Raised by tree richness or beaten by beech? In *Forest Ecology and Management* 256 (3), pp. 272–281. DOI: 10.1016/j.foreco.2008.04.012.

Moore, Joslin L.; Hauser, Cindy E.; Bear, Jennifer L.; Williams, Nicholas S. G.; McCarthy, Michael A. (2011): Estimating detection–effort curves for plants using search experiments. In *Ecological Applications* 21 (2), pp. 601–607. DOI: 10.1890/10-0590.1.

Morin, Xavier; Fahse, Lorenz; Scherer-Lorenzen, Michael; Bugmann, Harald (2011): Tree species richness promotes productivity in temperate forests through strong complementarity between species. In *Ecology letters* 14 (12), pp. 1211–1219. DOI: 10.1111/j.1461-0248.2011.01691.x.

Morris, E. Kathryn; Caruso, Tancredi; Buscot, François; Fischer, Markus; Hancock, Christine; Maier, Tanja S.; Meiners, Torsten; Müller, Caroline; Obermaier, Elisabeth; Prati, Daniel; Socher, Stephanie A.; Sonnemann, Ilja; Wäschke, Nicole; Wubet, Tesfaye et al. (2014): Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. In *Ecology and evolution* 4 (18), pp. 3514–3524. DOI: 10.1002/ece3.1155.

Morrison, Lloyd W. (2016): Observer error in vegetation surveys: a review. In *Journal of Plant Ecology* 9 (4), pp. 367–379. DOI: 10.1093/jpe/rtv077.

Myers, N.; Mittermeier, R. A.; Mittermeier, C. G.; da Fonseca, G. A.; Kent, J. (2000): Biodiversity hotspots for conservation priorities. In *Nature* 403 (6772), pp. 853–858. DOI: 10.1038/35002501.

Naeem, Shahid; Duffy, J. Emmett; Zavaleta, Erika (2012): The functions of biological diversity in an age of extinction. In *Science* 336 (6087), pp. 1401–1406. DOI: 10.1126/science.1215855.

National Parks Board, Singapore (2013): NParks Flora & Fauna Web. Available online at https://florafaunaweb.nparks.gov.sg/, checked on 15.07.2018.

Naturalis Biodiversity Center (2018): BioPortal. Infomation supplied from the Catalogues of Naturalis Biodiversity Center in Leiden, from the Dutch Species Register and the Catalogue of Life. Available online at http://bioportal.naturalis.nl/, checked on 27.10.2018.

Nghiem, L. T. P.; Tan, H. T. W.; Corlett, R. T. (2015): Invasive trees in Singapore: are they a threat to native forests? In *Tropical Conservation Science* 8 (1), pp. 201–214.

Oksanen, Jari; Blanchet, F. Guillaume; Friendly, Michael; Kindt, Roeland; Legendre, Pierre; McGlinn, Dan; Minchin, Peter R.; O'Hara, R. B.; Simpson, Gavin L.; Solymos, Peter; Stevens, M. Henry H.; Szoecs, Eduard; Wagner, Helene (2018): vegan. Community Ecology Package. Version 2.5-2 R package. Available online at https://CRAN.R-project.org/package=vegan, checked on 9/15/2018.

Peh, Kelvin S.-H. (2010): Invasive species in Southeast Asia: the knowledge so far. In *Biodiversity and Conservation* 19 (4), pp. 1083–1099. DOI: 10.1007/s10531-009-9755-7.

Petchey, Owen L.; Gaston, Kevin J. (2006): Functional diversity: back to basics and looking forward. In *Ecology letters* 9 (6), pp. 741–758. DOI: 10.1111/j.1461-0248.2006.00924.x.

Peters, Halton A. (2001): *Clidemia hirta* Invasion at the Pasoh Forest Reserve: An Unexpected Plant Invasion in an Undisturbed Tropical Forest. In *BIOTROPICA* 33 (1), pp. 60–68. DOI: 10.1111/j.1744-7429.2001.tb00157.x.

Pielou, E. C. (1969): An Introduction to Mathematical Ecology. New York: Wiley-Interscience.

Pielou, E. C. (1975): Ecological diversity. New York: Wiley.

Pimm, Stuart L.; Joppa, Lucas N. (2015): How Many Plant Species are There, Where are They, and at What Rate are They Going Extinct? In *Annals of the Missouri Botanical Garden* 100 (3), pp. 170–176. DOI: 10.3417/2012018.

Poorter, L. (2001): Light-dependent changes in biomass allocation and their importance for growth of rain forest tree species. In *Functional Ecology* 15 (1), pp. 113–123. DOI: 10.1046/j.1365-2435.2001.00503.x.

Poorter, L.; van der Sande, M. T.; Thompson, J.; Arets, E. J. M. M.; Alarcón, A.; Álvarez-Sánchez, J.; Ascarrunz, N.; Balvanera, P.; Barajas-Guzmán, G.; Boit, A.; Bongers, F.; Carvalho, F. A.; Casanoves, F.; Cornejo-Tenorio, G. et al. (2015): Diversity enhances carbon storage in tropical forests. In *Global Ecology and Biogeography* 24 (11), pp. 1314–1328. DOI: 10.1111/geb.12364.

Prabowo, Walesa Edho; Darras, Kevin; Clough, Yann; Toledo-Hernandez, Manuel; Arlettaz, Raphael; Mulyani, Yeni A.; Tscharntke, Teja (2016): Bird Responses to Lowland Rainforest Conversion in Sumatran Smallholder Landscapes, Indonesia. In *PloS one* 11 (5), e0154876. DOI: 10.1371/journal.pone.0154876.

Queensland Herbarium (2016): Collecting and preserving plant specimens, a manual / prepared by Tony Bean, Queensland Herbarium, Science Delivery Division, Department of

Science, Information Technology and Innovation. Second Edition. Department of Science, Information Technology and Innovation. Brisbane.

R Core Team (2018): R. A language and environment for statistical computing. Version 3.5.1. Vienna, Austria: R Foundation for Statistical Computing. Available online at https://www.R-project.org/.

Radosevich, Steven R.; Holt, Jodie S.; Ghersa, Claudio (2007): Ecology of weeds and invasive plants. Relationship to agriculture and natural resource management. 3rd ed. Hoboken, N.J: Wiley-Interscience.

Rembold, Katja; Kreft, Holger (2015): EFForTS Sumatra Plant Database. University of Göttingen, Germany. Available online at www.sumatranplants.uni-goettingen.de, checked on 11/19/2018.

Rembold, Katja; Mangopo, Hardianto; Tjitrosoedirdjo, Sri Sudarmiyati; Kreft, Holger (2017a): Plant diversity, forest dependency, and alien plant invasions in tropical agricultural landscapes. In *Biological Conservation* 213, pp. 234–242. DOI: 10.1016/j.biocon.2017.07.020.

Rembold, Katja; Sri Tjitrosoedirdjo, S. S.; Kreft, Holger (2017b): Common wayside plants of Jambi Province (Sumatra, Indonesia). Version 2. Biodiversity, Macroecology & Biogeography, Faculty of Forest Sciences and Forest Ecology of the University of Goettingen, Germany. Available online at DOI: 10.3249/webdoc-3979.

Royal Botanic Gardens, Kew (2018): The Herbarium Catalogue. Available online at http://www.kew.org/herbcat, checked on 27.10.2018.

Royo, Alejandro A.; Carson, Walter P. (2006): On the formation of dense understory layers in forests worldwide: consequences and implications for forest dynamics, biodiversity, and succession. In *Canadian Journal of Forest Research* 36 (6), pp. 1345–1362. DOI: 10.1139/x06-025.

Sabajo, Clifton R.; Le Maire, Guerric; June, Tania; Meijide, Ana; Roupsard, Olivier; Knohl, Alexander (2017): Expansion of oil palm and other cash crops causes an increase of the land surface temperature in the Jambi province in Indonesia. In *Biogeosciences* 14 (20), pp. 4619–4635. DOI: 10.5194/bg-14-4619-2017.

Saura, Santiago; Bodin, Örjan; Fortin, Marie-Josée (2014): Stepping stones are crucial for species' long-distance dispersal and range expansion through habitat networks. In *Journal of Applied Ecology* 51 (1), pp. 171–182. DOI: 10.1111/1365-2664.12179.

Savilaakso, Sini; García, Claude; Garcia-Ulloa, John; Ghazoul, Jaboury; Groom, Martha; Guariguata, Manuel R.; Laumonier, Yves; Nasi, Robert; Petrokofsky, Gillian; Snaddon, Jake; Zrust, Michal (2014): Systematic review of effects on biodiversity from oil palm production. In *Environmental Evidence* 3. DOI: 10.1186/2047-2382-3-4.

Scheiner, Samuel M. (2003): Six types of species-area curves. In *Global Ecology & Biogeography* 12, pp. 441–447. DOI: 10.1046/j.1466-822X.2003.00061.x.

SEAMEO BIOTROP (2013): Invasive alien species. The Southeast Asian Regional Centre for Tropical Biology, Bogor, Indonesia. Available online at http://kmtb.biotrop.org/collections/spias, checked on 02.11.2018.

Shannon, Claude E.; Weaver, Warren (1964): The Mathematical Theory of Communication. Urbana: The University of Illionis Press.

Shapiro, S. S.; Wilk, M. B. (1965): An Analysis of Variance Test for Normality. (Complete Samples). In *Biometrika* 52 (3/4), pp. 591–611.

Silk JWF (2009 onwards): Plants of Southeast Asia. Available online at http://asianplant.net/, checked on 31.10.2018.

Slade, E. M.; Burhanuddin, M. I.; Climan, J. P.; Foster, W. A.; Naim, M.; Prawirosukarto, S.; Snaddon, J. L.; Turner, E. C., Mann, D. J. (2014): Can cattle grazing in mature oil palm increase biodiversity and ecosystem service provision? ICOP conference paper. In *Planter* 90, pp. 655–665.

Slik, Ferry J. W.; Arroyo-Rodríguez, Víctor; Aiba, Shin-Ichiro; Alvarez-Loayza, Patricia; Alves, Luciana F.; Ashton, Peter; Balvanera, Patricia; Bastian, Meredith L.; Bellingham, Peter J.; Berg, Eduardo van den; Bernacci, Luis (2015): An estimate of the number of tropical tree species. In *Proceedings of the National Academy of Sciences of the United States of America* 112 (33), E4628-9. DOI: 10.1073/pnas.1512611112.

Small, Christine J.; McCarthy, Brian C. (2005): Relationship of understory diversity to soil nitrogen, topographic variation, and stand age in an eastern oak forest, USA. In *Forest Ecology and Management* 217 (2-3), pp. 229–243. DOI: 10.1016/j.foreco.2005.06.004.

Sodhi, Navjot S.; Koh, Lian Pin; Brook, Barry W.; Ng, Peter K. L. (2004): Southeast Asian biodiversity: an impending disaster. In *Trends in ecology & evolution* 19 (12), pp. 654–660. DOI: 10.1016/j.tree.2004.09.006.

Sodhi, Navjot S.; Posa, Mary Rose C.; Lee, Tien Ming; Bickford, David; Koh, Lian Pin; Brook, Barry W. (2010): The state and conservation of Southeast Asian biodiversity. In *Biodiversity and Conservation* 19 (2), pp. 317–328. DOI: 10.1007/s10531-009-9607-5.

Spellerberg, I. F. (2008): Shannon–Wiener Index. In Sven Erik Jorgensen (Ed.): Encyclopedia of ecology. Amsterdam: Elsevier, pp. 3249–3252.

Stanturf, John A.; Palik, Brian J.; Dumroese, R. Kasten (2014): Contemporary forest restoration: A review emphasizing function. In *Forest Ecology and Management* 331, pp. 292–323. DOI: 10.1016/j.foreco.2014.07.029.

Stibig, H.-J.; Achard, F.; Carboni, S.; Raši, R.; Miettinen, J. (2014): Change in tropical forest cover of Southeast Asia from 1990 to 2010. In *Biogeosciences* 11 (2), pp. 247–258. DOI: 10.5194/bg-11-247-2014.

Swinfield, Tom; Afriandi, Roki; Antoni, Ferry; Harrison, Rhett D. (2016): Accelerating tropical forest restoration through the selective removal of pioneer species. In *Forest Ecology and Management* 381, pp. 209–216. DOI: 10.1016/j.foreco.2016.09.020.

Symstad, Amy J.; Wienk, Cody L.; Thorstenson, Andy D. (2008): Precision, Repeatability, and Efficiency of Two Canopy-Cover Estimate Methods in Northern Great Plains Vegetation. In *Rangeland ecology & management* 61 (4), pp. 419–429. DOI: 10.2111/08-010.1.

Teo, Debbie H. L.; Tan, Hugh T. W.; Corlett, Richard T.; Wong, Choong Min; Lum, Shawn K. Y. (2003): Continental rain forest fragments in Singapore resist invasion by exotic plants. In *Journal of Biogeography* 30 (2), pp. 305–310. DOI: 10.1046/j.1365-2699.2003.00813.x.

Teuscher, Miriam; Gérard, Anne; Brose, Ulrich; Buchori, Damayanti; Clough, Yann; Ehbrecht, Martin; Hölscher, Dirk; Irawan, Bambang; Sundawati, Leti; Wollni, Meike; Kreft, Holger (2016): Experimental Biodiversity Enrichment in Oil-Palm-Dominated Landscapes in Indonesia. In *Frontiers in plant science* 7, pp. 1–15. DOI: 10.3389/fpls.2016.01538.

The Plant List (2013). A working list of all plant species. Version 1.1. Available online at http://www.theplantlist.org/, checked on 29.10.2018.

Thomas, Sean C.; Halpern, Charles B.; Falk, Donald A.; Liguori, Denise A.; Austin, Kelly A. (1999): Plant Diversity in Managed Forests: Understory Responses to Thinning and Fertilization. In *Ecological Applications* 9 (3), pp. 864–879. DOI: 10.1890/1051-0761(1999)009[0864:PDIMFU]2.0.CO;2.

Tscharntke, T.; Sekercioglu, C. H.; Dietsch, T. V.; Sodhi, N. S.; Hoehn, P.; Tylianakis, J. M. (2008): Landscape Constraints on Functional Diversity of Birds and Insects in Tropical Agroecosystems. In *Ecology* 89 (4), pp. 944–951. DOI: 10.1890/07-0455.1.

Tscharntke, Teja; Clough, Yann; Bhagwat, Shonil A.; Buchori, Damayanti; Faust, Heiko; Hertel, Dietrich; Hölscher, Dirk; Juhrbandt, Jana; Kessler, Michael; Perfecto, Ivette; Scherber, Christoph; Schroth, Götz; Veldkamp, Edzo; Wanger, Thomas C. (2011): Multifunctional shade-tree management in tropical agroforestry landscapes - a review. In *Journal of Applied Ecology* 48 (3), pp. 619–629. DOI: 10.1111/j.1365-2664.2010.01939.x.

Ugland, Karl I.; Grays, John S.; Ellingsen, Kari E. (2003): The species-accumulation curve and estimation of species richness. In *Journal of Animal Ecology* 72, pp. 888–897. DOI: 10.1046/j.1365-2656.2003.00748.x.

University of Florida/ Florida Museum of Natural History (1995): Preparation of Plant Specimens for Deposit as Herbarium Vouchers. Edited by Marc S. Frank and Kent D. Perkins. Available online at https://www.floridamuseum.ufl.edu/herbarium/voucher.htm, updated on 2017, checked on 24.07.2018.

Utteridge, Timothy M. A.; Bramley, Gemma (Eds.) (2015): The Kew Tropical Plant Families Identification Handbook. Second Edition. Kew: Kew Publishing Royal Botanic Gardens.

Vitousek, Peter M. (1984): Litterfall, Nutrient Cycling, and Nutrient Limitation in Tropical Forests. In *Ecology* 65 (1), pp. 285–298.

Vittoz, Pascal; Guisan, Antoine (2007): How reliable is the monitoring of permanent vegetation plots? A test with multiple observers. In *Journal of Vegetation Science* 18 (3), pp. 413–422. DOI: 10.1111/j.1654-1103.2007.tb02553.x.

Vockenhuber, Elke A.; Scherber, Christoph; Langenbruch, Christina; Meißner, Meik; Seidel, Dominik; Tscharntke, Teja (2011): Tree diversity and environmental context predict herb species richness and cover in Germany's largest connected deciduous forest. In *Perspectives in Plant Ecology, Evolution and Systematics* 13 (2), pp. 111–119. DOI: 10.1016/j.ppees.2011.02.004.

Wahyuni, Indah; Sulistijorini; Setiabudi; Meijide, Ana; Nomura, Miki; Kreft, Holger; Rembold, Katja; Tjitrosoedirdjo, Sri S.; Tjitrosoedirdjo, Soekisman (2016): Distribution of invasive plant species in different land-use systems in Sumatera, Indonesia. In *BIOTROPIA* 23 (2), pp. 124–132. DOI: 10.11598/btb.2016.23.2.534.

Wheeler, Charlotte E.; Omeja, Patrick A.; Chapman, Colin A.; Glipin, Martin; Tumwesigye, Charles; Lewis, Simon L. (2016): Carbon sequestration and biodiversity following 18 years of active tropical forest restoration. In *Forest Ecology and Management* 373, pp. 44–55. DOI: 10.1016/j.foreco.2016.04.025.

Whittaker, R. H. (1972): Evolution and Measurement of Species Diversity. In *Taxon* 21, pp. 213–251.

Wickham, H. (2016): ggplot2. Elegant Graphics for Data Analysis. R package. New York: Springer-Verlag.

Wilcove, David S.; Giam, Xingli; Edwards, David P.; Fisher, Brendan; Koh, Lian Pin (2013): Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. In *Trends in ecology & evolution* 28 (9), pp. 531–540. DOI: 10.1016/j.tree.2013.04.005.

Wintle, Bonnie C.; Fidler, Fiona; Vesk, Peter A.; L. Moore, Joslin (2013): Improving visual estimation through active feedback. In *Methods in Ecology and Evolution* 4 (1), pp. 53–62. DOI: 10.1111/j.2041-210x.2012.00254.x.

World Growth (2011): The Economic Benefit of Palm Oil to Indonesia. Available online at http://worldgrowth.org/site/wp-content/uploads/2012/06/WG_Indonesian_Palm_Oil_Benefits_Report-2_11.pdf, checked on 06.08.2018.

Yang, Bo; Li, Ying; Ding, Bingyang; Both, Sabine; Erfmeier, Alexandra; Härdtle, Werner; Ma, Keping; Schmid, Bernhard; Scholten, Thomas; Seidler, Gunnar; Oheimb, Goddert von; Yang, Xuefei; Bruelheide, Helge (2017): Impact of tree diversity and environmental conditions on the survival of shrub species in a forest biodiversity experiment in subtropical China. In *Journal of Plant Ecology* 10 (1), pp. 179–189. DOI: 10.1093/jpe/rtw099.

Zahawi, R. A.; Augspurger, C. K. (2006): Tropical Forest Restoration: Tree Islands As Recruitment Foci In Degraded Lands Of Honduras. In *Ecological Applications* 16 (2), pp. 464–478. DOI: 10.1890/1051-0761(2006)016[0464:TFRTIA]2.0.CO;2.

Zahawi, Rakan A.; Holl, Karen D.; Cole, Rebecca J.; Reid, J. Leighton (2013): Testing applied nucleation as a strategy to facilitate tropical forest recovery. In *Journal of Applied Ecology* 50 (1), pp. 88–96. DOI: 10.1111/1365-2664.12014.

Zeileis, Achim (2004): Econometric Computing with HC and HAC Covariance Matrix Estimators. In *Journal of Statistical Software* 11 (10). DOI: 10.18637/jss.v011.i10.

Appendices

Appendix A

Complete species list including growh form type (t = tree; sh = shrub; h = herb; se = seedling), frequency in percent of presence (100 % = presence in all 56 subplots), and total cover in percent (summed up percent values of all 56 subplots). Missing values in the columns frequency and cover indicate that this species was not found in the subplots but during the additional data collection for the species-area relation. Alien species are marked by asterisks (*). The species are sorted alphabetically according to the family name in first order and species name in second order within the two major groups of lycophytes & ferns and angiosperms.

family	species	author	GF	frequency	cover
Aspleniaceae	*Asplenium longissimum*	Blume	h	14.29	8.2
Blechnaceae	*Blechnum orientale*	L.	h	7.14	10.1
Blechnaceae	*Stenochlaena palustris*	(Burm. f.) Bedd.	h	8.93	9.1
Davalliaceae	*Davallia denticulata*	(Burm. f.) Mett. ex Kuhn	h	1.79	0.1
Dennstaedtiaceae	*Microlepia speluncae*	(L.) T. Moore	h	14.29	24.2
Dryopteridaceae	*Tectaria barberi*	(Hook.) Copel.	h	1.79	0.1
Dryopteridaceae	*Tectaria vasta*	(Blume) Copel.	h	5.36	2.1
Gleicheniaceae	*Dicranopteris linearis*	(Burm. f.) Underw.	h	-	-
Lindsaeacea	*Lindsaea ensifolia*	Sw.	h	30.36	14.9
Lindsaeacea	*Lindsaeacea sp. 01*		h	-	-
Lygodicaeae	*Lygodium circinatum*	(Burm. f.) Sw.	h	33.93	14.1
Lygodicaeae	*Lygodium flexuosum*	(L.) Sw.	h	26.79	4.2
Lygodicaeae	*Lygodium microphyllum*	(Cav.) R. Br.	h	14.29	2.7
Lygodicaeae	*Lygodium salicifolium*	C.Presl	h	58.93	49.3
Nephrolepidaceae	*Nephrolepis biserrata*	(Sw.) Schott	h	69.64	449.5
Ophioglossaceae	*Helminthostachys zeylanica*	(L.) Hook	h	-	-
Polypodiaceae	*Goniophlebium percussum*	(Cav.) Wagner & Grether	h	1.79	1.0
Pteridaceae	*Adiantum latifolium**	Lam.	h	91.07	754.5
Pteridaceae	*Pityrogramma calomelanos**	(L.) Link	h	5.36	1.2
Pteridaceae	*Pteris cf. ensiformis*	Brum. f.	h	10.71	18.2
Pteridaceae	*Taenitis blechnoides*	(Willd.) Sw.	h	3.57	0.2
Selaginellaceae	*Selaginella cf. plana*	(Desv. ex Poir.) Hieron.	sh	1.79	9.0
Selaginellaceae	*Selaginella cf. wildenowii*	(Desv. ex Poir.) Baker	sh	37.50	78.5
Tectariaceae	*Pleocnemia irregularis*	(C. Presl) Holltum	h	3.57	6.0
Thelypteridaceae	*Christella dentata*	(Forssk.) Brownsey & Jermy	h	67.86	211.8
Thelypteridaceae	*Cyclosorus cf. interruptus*	(Willd.) H. Itô	h	3.57	13.0
Thelypteridaceae	*Cyclosorus cf. megaphyllus*	Ching	h	-	-
Thelypteridaceae	*Pronephrium triphyllum*	(Sw.) Holltum	h	10.71	19.2
Thelypteridaceae	*Sphaerostephanos sp. 01*		h	5.36	3.1
Thelypteridaceae	*Thelypteridaceae sp. 01*		h	1.79	0.1
Thelypteridaceae	*Thelypteridaceae sp. 02*		h	3.57	3.0
Thelypteridaceae	*Thelypteridaceae sp. 03*		h	1.79	3.0

lycophytes & ferns

	Family	Species	Authority			
angiosperms	Acanthaceae	*Asystasia gangetica* *	(L.) T.Anderson	h	100.00	714.1
	Amaranthaceae	*Cyathula prostrata*	(L.) Blume	h	16.07	26.5
	Annonaceae	*Annonaceae sp. 01*		t	1.79	9.0
	Annonaceae	*Maasia sp. 01*		se	1.79	0.1
	Apocynaceae	*Alstonia angustifolia*	Wall. ex A.DC.	t	-	-
	Apocynaceae	*Alstonia scholaris*	(L.) R. Br.	t	8.93	11.1
	Apocynaceae	*Apocynaceae sp. 01*		sh	-	-
	Apocynaceae	*Apocynaceae sp. 02*		h	1.79	0.1
	Apocynaceae	*Apocynaceae sp. 3*		t	17.86	27.3
	Apocynaceae	*Tabernaemontana pauciflora*	Blume	sh	19.64	22.3
	Araceae	*Alocasia wongii*	A.Hay	h	1.79	0.1
	Araceae	*Araceae sp. 01*		h	-	-
	Araceae	*Araceae sp. 02*		h	1.79	0.1
	Araceae	*Araceae sp. 03*		h	1.79	0.1
	Araceae	*Homalomena cf. cordata*	Schott	h	-	-
	Arecaceae	*Elaeis guineensis* *	Jacq.	h	69.64	125.9
	Asparagaceae	*Dracaena elliptica*	Thunb. & Dalm.	h	3.57	3.1
	Asteraceae	*Acmella paniculata* *	(Wall. ex DC.) R.K.Jansen	h	-	-
	Asteraceae	*Ageratum conyzoides* *	(L.) L.	h	8.93	1.4
	Asteraceae	*Asteraceae sp. 01*		h	1.79	20.0
	Asteraceae	*Asteraceae sp. 02*		h	1.79	0.1
	Asteraceae	*Chromolaena odorata* *	(L.) R.M.King & H.Rob.	h	7.14	55.0
	Asteraceae	*Clibadium surinamense* *	L.	h	5.36	16.0
	Asteraceae	*Crassocephalum crepidioides* *	(Benth.) S.Moore	h	-	-
	Asteraceae	*Cyanthillum cinerum*	(L.) H.Rob.	h	-	-
	Asteraceae	*Mikania micrantha* *	Kunth	h	14.29	79.2
	Asteraceae	*Praxelis clematidea*	(Griseb.) R.M.King & H.Rob.	h	-	-
	Asteraceae	*Rolandra fructicosa*	(L.) Kuntze	h	-	-
	Asteraceae	*Struchium sparganophorum*	(L.) Kuntze	h	1.79	0.1
	Asteraceae	*Synedrella nudiflora* *	(L.) Gaertn.	h	-	-
	Cannabaceae	*Trema orientalis*	(L.) Blume	t	10.71	10.0
	Cleomaceae	*Cleome rutidosperma* *	DC.	h	1.79	0.1
	Clusiaceae	*Clusiaceae sp. 01*		h	1.79	0.1
	Clusiaceae	*Clusiaceae sp. 02*		sh	1.79	20.0
	Clusiaceae	*Clusiaceae sp. 03*		h	1.79	15.0
	Convolvulaceae	*Ipomoea cf. sumatrana*	(Miq.) Ooststr.	h	21.43	96.3
	Cucurbitaceae	*Scopellaria marginata*	(Blume) W.J. de Wilde & Duyfjes	h	10.71	2.4
	Cyperaceae	*Cyperus diffusus*	Vahl	h	69.64	89.4
	Cyperaceae	*Cyperus haspan*	L.	h	1.79	1.0
	Cyperaceae	*Mapania tenuiscapa*	C.B.Clarke	h	3.57	8.0
	Cyperaceae	*Rhyncospora colorata*	(L.) H.Pfeiff.	h	1.79	0.1
	Cyperaceae	*Scleria ciliaris*	Nees	h	66.07	120.3
	Cyperaceae	*Scleria sumatrensis*	Retz.	h	3.57	8.0

Family	Species	Authority	Habit	Value1	Value2
Dioscoreaceae	*Dioscorea cf. orbiculata*	Hook.f.	h	5.36	3.1
Dioscoreaceae	*Dioscorea hipsida*	Dennst.	sh	1.79	13.0
Euphorbiaceae	*Croton hirtus* *	L'Hér.	h	3.57	1.1
Euphorbiaceae	*Euphorbiaceae sp. 01*		se	1.79	0.1
Euphorbiaceae	*Euphorbiaceae sp. 02*		t	1.79	0.1
Euphorbiaceae	*Euphorbiaceae sp. 03*		se	-	-
Euphorbiaceae	*Euphorbiaceae sp. 04*		se	1.79	4.0
Euphorbiaceae	*Macaranga bancana*	(Miq.) Müll.Arg.	t	1.79	0.1
Euphorbiaceae	*Macaranga gigantea*	(Rchb.f. & Zoll.) Müll.Arg.	t	1.79	8.0
Euphorbiaceae	*Macaranga heynei*	I.M.Johnst.	t	-	-
Euphorbiaceae	*Macaranga sp. 01*		t	-	-
Euphorbiaceae	*Macaranga trichocarpa*	(Zoll.) Müll.Arg.	t	21.43	89.1
Euphorbiaceae	*Mallotus cf. peltatus*	(Geiseler) Müll.Arg.	t	-	-
Euphorbiaceae	*Mallotus macrostachyus*	(Miq.) Müll.Arg.	t	1.79	1.0
Fabaceae	*Bauhinia acuminata*	L.	h	-	-
Fabaceae	*Bauhinia sembifidia*	Roxb.	h	-	-
Fabaceae	*Calopogonium mucunoides* *	Desv.	h	5.36	136.0
Fabaceae	*Centrosema pubscens* *	Benth.	h	21.43	38.4
Fabaceae	*Dalbergia junghuhnii*	Benth.	se	-	-
Fabaceae	*Dalbergia rostrata*	Hassk.	h	-	-
Fabaceae	*Fabaceae sp. 01*		h	-	-
Fabaceae	*Fabaceae sp. 02*		sh	-	-
Fabaceae	*Millettia sericea*	Benth.	se	3.57	2.1
Fabaceae	*Mimosa pudica* *	L.	h	1.79	0.1
Fabaceae	*Parkia speciosa*	Hassk.	t	1.79	2.0
Fabaceae	*Peltophorum pterocarpum*	(DC.) K.Heyne	sh	-	-
Fabaceae	*Phanera kockiana*	Korth.	h	-	-
Fabaceae	*Spatholobus cf. littoralis*	Hassk.	h	3.57	2.1
Hypoxidaceae	*Molineria latifolia*	(Dryand. ex W.T.Aiton) Herb. ex Kurz	h	26.79	31.3
Lamiaceae	*Clerodendrum deflexum*	Wall.	sh	1.79	1.0
Lamiaceae	*Clerodendrum laevifolium*	Blume	sh	-	-
Lamiaceae	*Hyptis capitata* *	Jacq.	h	3.57	5.1
Lamiaceae	*Lamiaceae sp. 01*		se	-	-
Lamiaceae	*Peronema canescens*	Jack	t	23.21	82.3
Lamiaceae	*Vitex pinnata*	L.	t	1.79	2.0
Linderniaceae	*Linderina crustacea*	(L.) F.Muell.	h	-	-
Linderniaceae	*Lindernia diffusa* *	(L.) Wettst.	h	17.86	2.8
Linderniaceae	*Torenia violacea*	(Azaola ex Blanco) Pennell	h	5.36	0.3
Lythraceae	*Cuphea carthagenensis* *	(Jacq.) J.F.Macbr.	h	-	-
Lythraceae	*Aquillaeia sp. 01*		se	-	-
Malvaceae	*Malvaceae sp. 01*		se	-	-
Malvaceae	*Malvaceae sp. 02*		se	-	-
Marantaceae	*Marantaceae sp. 01*		h	1.79	1.0

Marantaceae	*Marantaceae sp. 02*		h	1.79	0.1
Melastomataceae	*Clidemia hirta* *	(L.) D. Don	sh	98.21	1719.0
Melastomataceae	*Dissochaeta gracilis*	(Jack) Blume	sh	3.57	1.1
Melastomataceae	*Melastoma malabathricum*	L.	sh	75.00	160.5
Meliaceae	*Pseudoclausena chrysogyne*	(Miq.) T.Clark	t	1.79	3.0
Meliaceae	*Swietenia macrophylla*	King	t	3.57	2.1
Menispermaceae	*Arcangelisia flava*	(L.) Merr.	h	1.79	3.0
Menispermaceae	*Hypserpa polyandra*	Becc.	h	1.79	5.0
Menispermaceae	*Menispermaceae sp. 01*		h	-	-
Menispermaceae	*Menispermaceae sp. 02*		h	1.79	20.0
Moraceae	*Ficus aurata*	(Miq.) Miq.	t	1.79	0.1
Moraceae	*Ficus sp. 01*		t	1.79	1.0
Moraceae	*Ficus sp. 02*		t	-	-
Moraceae	*Ficus variegata*	Blume	t	23.21	70.2
Moraceae	*Moraceae sp. 01*		se	-	-
Musaceae	*Musa balbisiana*	Colla	h	3.57	17.0
Myrtaceae	*Decaspermum cf. parviflorum*	(Lam.) A.J.Scott	t	1.79	1.0
Myrtaceae	*Syzygium sp. 01*		t	1.79	6.0
Onagraceae	*Ludwigia octovalvis*	(Jacq.) P.H.Raven	h	1.79	0.1
Opiliaceae	*Opiliaceae sp. 01*		se	-	-
Oxalidaceae	*Oxalis barrelieri* *	L.	h	7.14	0.4
Passifloraceae	*Passiflora foetida*	L.	h	3.57	5.0
Phyllanthaceae	*Breynia racemosa*	(Blume) Müll.Arg.	sh	-	-
Phyllanthaceae	*Phyllanthaceae sp. 01*		sh	-	-
Phyllanthaceae	*Phyllanthus urinaria*	L.	h	44.64	3.4
Piperaceae	*Peperomia pellucida*	(L.) Kunth	h	3.57	0.2
Poaceae	*Axonopus compressus* *	(Sw.) P.Beauv.	h	85.71	129.1
Poaceae	*Bambusoideae sp. 01*	Widjaja	h	8.93	76.1
Poaceae	*Centotheca lappacea*	(L.) Desv.	h	92.86	221.5
Poaceae	*Cyrtococcum oxyphyllum*	(Steud.) Stapf	h	1.79	2.0
Poaceae	*Cyrtococcum patens*	(L.) A.Camus	h	94.64	343.4
Poaceae	*Eleusine indica* *	(L.) Gaertn.	h	-	-
Poaceae	*Imperata cylindrica*	(L.) Raeusch.	h	23.21	101.3
Poaceae	*Ottochloa nodosa*	(Kunth) Dandy	h	98.21	490.4
Poaceae	*Panicum sarmentosum*	Roxb.	h	1.79	20.0
Poaceae	*Paspalum conjugatum* *	P.J.Bergius	h	57.14	114.1
Poaceae	*Paspalum dilatatum* *	Poir.	h	-	-
Poaceae	*Pennisetum polystachion* *	(L.) Schult.	h	1.79	6.0
Poaceae	*Poaceae sp. 01*		h	1.79	25.0
Poaceae	*Poaceae sp. 02*		h	3.57	4.0
Poaceae	*Poaceae sp. 03*		h	7.14	1.3
Poaceae	*Poaceae sp. 04*		h	3.57	8.0
Poaceae	*Sacciolepis indica*	(L.) Chase	h	-	-

Family	Species	Authority	Habit	Col5	Col6
Poaceae	*Steinchisma laxum* *	(Sw.) Zuloaga	h	33.93	125.2
Polygalaceae	*Salomonia cantoniensis*	Lour.	h	0.00	0.0
Rubiaceae	*Canthium horridum*	Blume	sh	-	-
Rubiaceae	*Mussaenda fondosa*	L.	sh	-	-
Rubiaceae	*Nauclea cf. orientalis*	(L.) L.	t	1.79	1.0
Rubiaceae	*Neonuclea sp. 01*		t	-	-
Rubiaceae	*Rubiaceae sp. 01*		se	5.36	4.2
Rubiaceae	*Rubiaceae sp. 02*		t	1.79	0.1
Rubiaceae	*Rubiaceae sp. 03*		t	1.79	0.1
Rubiaceae	*Rubiaceae sp. 04*		t	-	-
Rubiaceae	*Rubiaceae sp. 05*		se	-	-
Rubiaceae	*Rubiaceae sp. 06*		se	1.79	1.0
Rubiaceae	*Rubiaceae sp. 07*		se	-	-
Rubiaceae	*Spermacoce alata* *	Aubl.	h	41.07	24.1
Rubiaceae	*Spermacoce exilis* *	(L.O.Williams) C.D.Adams ex W.C.Burger & C.M.Taylor	h	12.50	1.6
Rubiaceae	*Spermacoce ocymifolia* *	Willd. ex Roem. & Schult.	h	1.79	0.1
Rubiaceae	*Spermacoce sp. 01*		h	-	-
Rubiaceae	*Uncaria cordata*	(Lour.) Merr.	sh	7.14	13.0
Rubiaceae	*Uncaria lanosa var. glabrata*	(Blume) Ridsdale	sh	-	-
Rubiaceae	*Urophyllum cf. trifurcum*		sh	-	-
Rutaceae	*Murraya koenigii*	(L.) Spreng.	h	3.57	0.2
Rutaceae	*Rutaceae sp. 01*		se	1.79	7.0
Sapindaceae	*Nephellium lappaceum*	L.	t	7.14	2.2
Sapindaceae	*Nephellium sp. 01*		t	1.79	1.0
Sapindaceae	*Sapindaceae sp. 01*		t	-	-
Smilacaceae	*Smilaceae sp. 01*		h	-	-
Solanaceae	*Solanum jamaicensis* *	Mill.	h	32.14	58.4
Unknown	*Climber 01*		h	1.79	1.0
Unknown	*Climber 02*		sh	-	-
Unknown	*Climber 03*		sh	-	-
Unknown	*Climber 04*		h	1.79	1.0
Unknown	*Climber 05*		h	-	-
Unknown	*Climber 06*		h	1.79	4.0
Unknown	*Climber 07*		sh	1.79	4.0
Unknown	*Climber 08*		h	1.79	2.0
Unknown	*Climber 09*		h	-	-
Unknown	*Climber 10*		h	-	-
Unknown	*Climber 11*		h	-	-
Unknown	*Climber 12*		h	-	-
Unknown	*Climber 13*		sh	1.79	6.0
Unknown	*Climber 14*		sh	1.79	15.0
Unknown	*Climber 15*		sh	1.79	4.0
Unknown	*Herb sp. 01*		h	-	-

|					
Unknown	*Seedling sp. 01*		se	-	-
Unknown	*Seedling sp. 02*		se	-	-
Unknown	*Seedling sp. 03*		se	-	-
Unknown	*Seedling sp. 04*		se	-	-
Unknown	*Seedling sp. 05*		se	-	-
Unknown	*Seedling sp. 06*		se	-	-
Unknown	*Seedling sp. 07*		se	-	-
Unknown	*Seedling sp. 08*		se	1.79	4.0
Unknown	*Seedling sp. 09*		se	1.79	0.1
Unknown	*Seedling sp. 10*		se	-	-
Unknown	*Seedling sp. 11*		se	-	-
Unknown	*Seedling sp. 12*		se	1.79	0.1
Unknown	*Seedling sp. 13*		se	1.79	0.1
Unknown	*Seedling sp. 14*		se	1.79	0.1
Unknown	*Seedling sp. 15*		se	-	-
Unknown	*Seedling sp. 16*		se	-	-
Unknown	*Seedling sp. 17*		se	-	-
Unknown	*Shrub sp. 01*		sh	-	-
Unknown	*Tree 01*		se	1.79	2.0
Urticaceae	*Pouzolzia zeylanica*	(L.) Benn.	h	3.57	1.1
Verbenaceae	*Lantana camara ***	L.	sh	1.79	1.0
Verbenaceae	*Stachytarpheta indica ***	(L.) Vahl	sh	7.14	20.0
Vitaceae	*Leea indica*	(Burm. f.) Merr.	t	3.57	14.0
Vitaceae	*Tetrastigma cf. curtisii*	(Ridl). Suess	sh	1.79	5.0

Appendix B

Plot based understorey plant data set, including data concerning diversity, composition, and structure, as well as additional variables, used in the analysis.

	exp. variables		diversity				composition					structure								additional variables		
ID	plot size	tree diversity level	spp. richness	Shannon index	Simpsons index	**Pielou's** evenness	tree & seedl. spp.	tree & seedl. cover	alien spp.	alien cover	C. hirta cover	vegetation cover	litter cover	bare soil cover	woody debris cover	litter layer depth	veg. cover density	shoot length	C. hirta shoot length	canopy cover	soil C:N ratio	level of disturbance
	[m²]						[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[cm]	[%]	[cm]	[cm]	[%]		
1	1600	1	23	2.11	0.81	0.67	8.7	19.0	34.8	76.3	55	68	15	12	5	4.40	215.9	83.7	184.0	86.3	10.0	1
2	400	3	7	1.14	0.61	0.59	0.0	0.0	14.3	15.0	0	92	6	2	0	5.50	143.8	142.5	NA	78.9	10.6	1
3	400	2	11	2.10	0.86	0.87	0.0	0.0	54.5	52.0	5	59	40	0	1	8.77	215.3	149.0	178.0	85.9	8.9	0
4	100	1	22	2.00	0.80	0.66	9.1	3.0	40.9	80.2	45	70	10	15	5	6.03	182.3	111.6	254.5	88.9	9.6	1
5	1600	1	24	2.00	0.75	0.63	8.3	6.0	33.3	87.1	55	65	25	10	0.5	2.83	182.5	74.7	214.0	92.4	9.8	1
6	25	1	22	1.93	0.77	0.63	18.2	5.1	0.0	62.1	35	60	25	13	2	2.83	141.5	74.8	187.8	94.0	9.7	3
7	1600	3	27	2.13	0.81	0.68	7.4	6.0	40.7	131.1	10	95	4	1	0	7.83	164.7	102.5	144.0	76.8	10.0	1
8	25	1	25	2.17	0.83	0.68	20.0	2.3	0.0	105.0	50	66	8	25	1	3.07	233.0	58.4	163.5	96.0	9.9	2
9	100	3	18	2.22	0.87	0.77	11.1	8.1	38.9	98.1	35	70	18	12	0	4.67	260.6	99.6	179.0	90.5	9.5	2
10	400	0	14	2.09	0.85	0.79	14.3	17.0	50.0	141.1	35	100	0	0	0	10.47	191.2	196.3	224.5	57.3	9.9	0
11	100	1	27	2.15	0.82	0.65	0.0	0.0	25.9	62.3	35	75	8	16	0	2.50	137.7	90.9	219.0	92.4	8.5	3
12	400	1	22	2.33	0.89	0.75	0.0	0.0	50.0	51.4	12	73	25	1	0.5	6.83	105.6	93.9	158.8	84.4	8.9	1
13	100	1	22	1.71	0.75	0.55	9.1	7.0	27.3	27.3	18	35	56	9	0.5	5.20	124.3	56.2	97.0	98.8	11.3	2
14	100	1	17	1.80	0.69	0.65	0.0	0.0	64.7	94.3	10	80	15	5	0	4.67	152.9	83.1	155.0	72.6	8.8	1
15	400	1	9	1.07	0.58	0.49	0.0	0.0	55.6	81.2	50	80	12	0	8	7.87	114.3	108.3	251.0	90.1	9.2	1
16	25	3	23	1.99	0.76	0.63	8.7	3.1	30.4	64.3	50	70	14	12	4	4.50	158.6	87.3	178.0	90.4	9.5	4
17	400	1	26	2.05	0.79	0.63	3.8	0.1	50.0	47.6	30	90	7	2	1	3.17	87.0	94.5	135.0	81.6	10.1	1
18	25	2	31	2.57	0.87	0.75	12.9	17.1	25.8	78.1	50	69	16	14	1	2.87	274.6	85.5	170.0	97.7	9.2	3
19	400	6	28	1.89	0.76	0.57	10.7	0.3	32.1	42.6	28	51	48	1	0.5	7.40	129.0	76.8	205.0	97.8	8.9	1
20	100	1	30	2.31	0.84	0.68	10.0	10.1	40.0	91.5	45	82	12	6	0	3.30	181.7	91.7	181.5	95.1	10.6	1
21	100	6	19	1.40	0.56	0.47	5.3	0.1	47.4	99.2	6	73	12	15	0	3.93	147.8	55.8	105.2	85.0	8.9	2
22	25	2	25	2.24	0.84	0.70	4.0	7.0	44.0	112.4	40	60	15	25	0	4.17	271.5	68.4	179.5	96.9	9.6	3
23	1600	6	17	1.92	0.77	0.69	11.8	1.1	47.1	40.2	15	40	59	0	1	5.67	233.5	79.3	164.5	98.0	8.8	1
24	1600	2	16	1.60	0.71	0.58	12.5	0.2	31.3	67.0	25	65	32	3	0.5	5.08	124.0	91.5	153.0	98.3	9.2	1
25	25	1	22	2.26	0.85	0.73	9.1	5.0	22.7	112.0	45	64	10	22	4	4.67	250.6	94.7	196.0	95.5	9.7	3
26	1600	2	18	1.41	0.58	0.49	11.1	6.1	44.4	87.3	65	84	3	4	8	2.00	122.5	80.8	232.0	94.7	9.2	1
27	100	2	16	1.64	0.72	0.64	12.5	16.0	31.3	50.0	6	72	20	7	1	4.27	189.3	89.9	149.5	98.3	8.5	1
28	25	1	31	2.40	0.86	0.70	22.6	23.3	19.4	80.0	30	64	12	20	4	2.83	215.6	79.6	196.0	94.4	9.9	3
29	1600	3	17	2.05	0.84	0.74	11.8	5.0	35.3	66.1	25	74	25	0	1	9.80	178.6	104.6	182.5	94.5	10.4	1
30	400	1	17	2.01	0.84	0.71	17.6	7.1	35.3	46.1	9	30	29	40	1	2.77	202.7	56.2	158.0	98.3	9.1	1
31	25	1	22	2.28	0.86	0.74	4.5	2.0	36.4	82.3	30	57	8	35	0.5	4.90	225.6	85.5	228.0	97.0	8.9	3
32	100	2	28	2.47	0.86	0.74	14.3	14.1	35.7	63.2	35	75	13	12	0.5	2.93	170.3	71.4	187.0	93.5	9.2	2

33	400	3	19	2.09	0.80	0.72	5.3	2.0	31.6	79.0	12	50	10	25	10	5.23	212.4	65.9	158.0	98.8	10.8	2
34	100	2	18	1.77	0.69	0.63	5.6	1.0	55.6	37.1	10	91	6	3	0.5	8.50	166.2	120.4	148.0	72.3	9.4	1
35	1600	0	29	2.34	0.85	0.69	13.8	23.0	24.1	79.3	15	77	15	6	2	4.33	220.8	72.7	140.0	85.8	8.1	1
36	400	2	24	1.72	0.63	0.54	16.7	16.1	41.7	112.1	55	83	7	4	6	2.83	261.8	127.3	155.0	81.8	9.9	2
37	100	0	15	1.71	0.79	0.71	13.3	19.0	33.3	59.0	25	79	6	15	0	3.83	153.5	68.0	160.0	93.7	8.7	1
38	400	1	25	2.14	0.81	0.67	4.0	6.0	36.0	83.3	70	79	15	4	2	7.07	245.2	114.2	169.0	78.0	9.0	0
39	25	2	30	2.39	0.84	0.70	6.7	4.0	20.0	129.1	50	71	4	25	0	5.08	306.3	92.8	191.5	96.3	8.5	3
40	25	0	19	1.80	0.75	0.61	0.0	0.0	31.6	145.2	65	83	7	10	0.5	4.07	240.5	104.4	216.0	92.9	9.3	3
41	100	1	18	1.80	0.73	0.62	5.6	8.0	55.6	46.3	6	93	2	5	0	9.40	171.6	95.4	127.0	68.2	9.5	2
42	25	1	25	2.17	0.80	0.67	8.0	0.2	24.0	74.2	55	65	15	20	0	5.67	209.2	69.2	190.0	87.7	10.2	3
43	1600	1	17	1.40	0.63	0.58	5.9	0.0	41.2	47.0	17	97	1	2	0	7.67	135.4	106.2	180.4	69.7	10.5	1
44	25	3	28	2.48	0.86	0.74	7.1	30.1	35.7	85.1	45	62	15	20	3	4.17	259.0	89.8	213.0	93.9	8.1	3
45	1600	1	27	2.55	0.89	0.77	18.5	14.2	25.9	43.1	20	55	18	17	10	6.43	224.7	89.0	154.0	98.4	8.9	1
46	1600	2	23	2.25	0.83	0.72	8.7	2.0	43.5	85.1	30	71	20	8	1	5.37	179.3	90.1	160.0	95.2	9.3	1
47	400	2	24	2.35	0.86	0.74	12.5	7.1	29.2	62.3	35	55	25	15	5	3.20	208.7	80.7	159.8	93.5	8.3	2
48	100	3	32	2.43	0.83	0.70	12.5	10.1	28.1	94.2	60	75	10	15	0.5	5.40	216.7	80.8	168.0	90.7	10.0	2
49	1600	1	23	2.30	0.87	0.73	0.0	0.0	47.8	77.4	20	75	8	7	10	5.23	182.3	83.5	137.2	89.8	9.4	1
50	25	6	18	2.20	0.84	0.83	11.1	15.0	33.3	48.0	10	74	10	15	1	5.58	186.5	153.8	206.0	94.1	8.9	3
51	400	1	17	1.98	0.81	0.70	0.0	0.0	29.4	80.0	40	65	20	15	0	6.30	186.9	102.5	197.0	94.2	11.0	2
52	1600	1	13	1.95	0.83	0.76	0.0	0.0	69.2	84.0	25	98	2	0	0	7.65	175.6	127.0	137.2	64.3	6.3	0
53	100	ctrl.	17	2.34	0.88	0.83	0.0	0.0	35.3	44.0	13	38	15	45	2	2.63	190.3	70.2	79.0	57.3	9.3	5
54	100	ctrl.	24	2.25	0.82	0.71	4.2	0.1	33.3	111.1	25	86	4	10	0	3.87	191.4	48.0	96.5	92.1	10.2	2
55	100	ctrl.	26	2.72	0.90	0.83	3.8	0.1	42.3	68.2	10	61	25	10	4	2.65	210.3	67.2	69.3	87.7	10.3	3
56	100	ctrl.	23	2.43	0.89	0.78	8.7	3.1	30.4	88.1	22	80	12	5	3	5.00	219.4	60.8	84.5	91.2	9.7	3

Appendix C

Map of the study site of the EFForTS-BEE project within the palm oil plantation of *PT Humosindo* showing the exact location of each of the 56 plots with its corresponding plot ID, plot size, and tree diversity level (EFForTS mapping material).
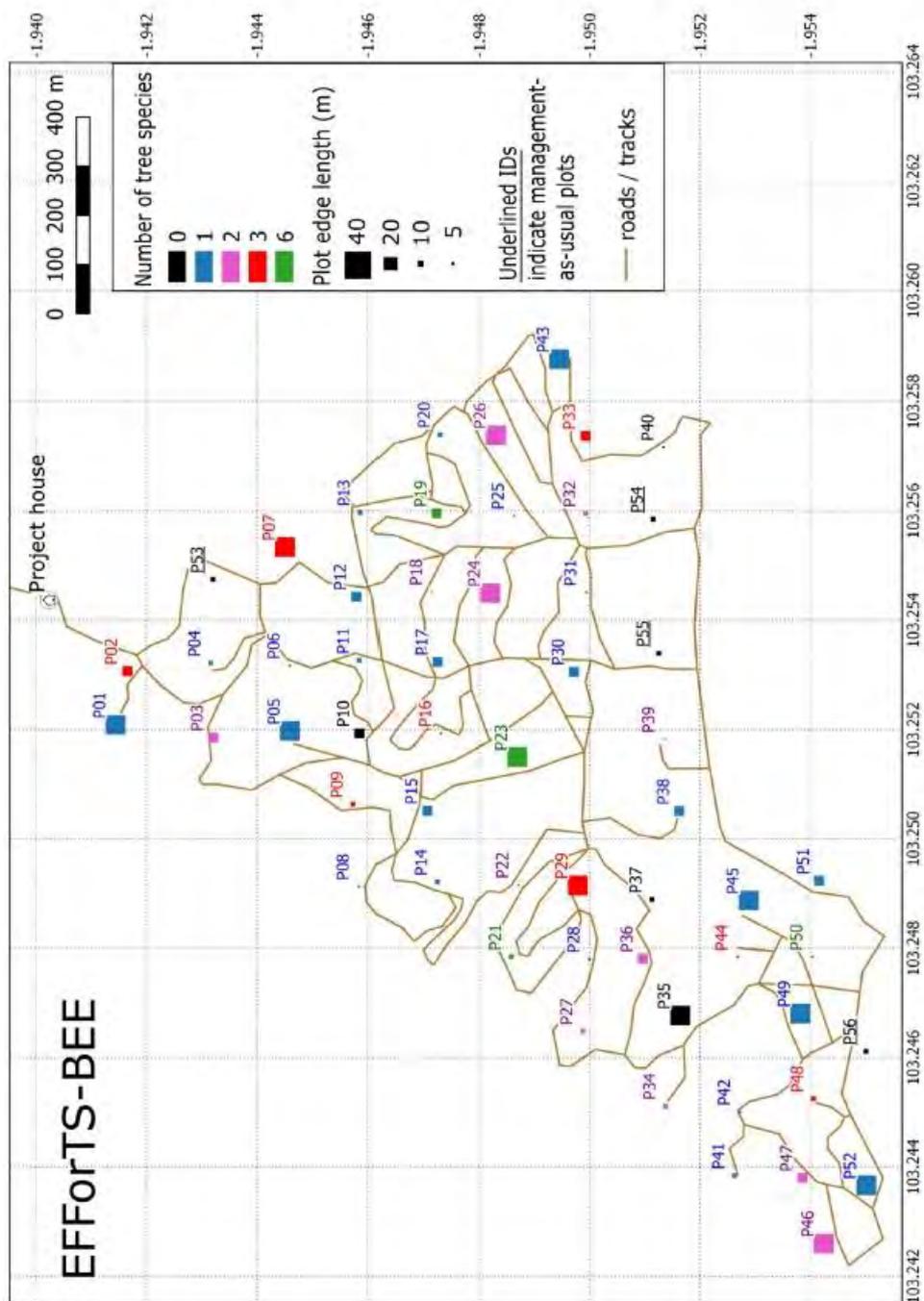
Eidesstattliche Versicherung

Hiermit versichere ich an Eides statt, dass ich die vorliegende Arbeit selbstständig und ohne die Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe.

Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten und nicht veröffentlichten Schriften entnommen wurden, sind als solche kenntlich gemacht.

Die Arbeit ist in gleicher oder ähnlicher Form oder auszugsweise im Rahmen einer anderen Prüfung noch nicht vorgelegt worden.

Ich versichere, dass die eingereichte elektronische Fassung der eingereichten Druckfassung vollständig entspricht.

Köln, 14.12.2018   _____

Lena Sachsenmaier