The effect of land use change on pollen/spore rain in tropical lowland of Sumatra (Indonesia)

M.Sc. Thesis

Agriculture – Ressourcemanagement

By

Katharina Reuter

Matriculation number: 21010572

Supervisors:

Prof. Dr. Hermann Behling

Prof. Dr. Teja Tscharntke

MSc. Siria Biagioni

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Department of Palynology and Climate Dynamics,

Georg-August University Göttingen

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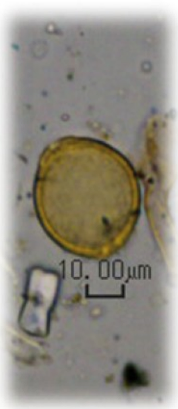

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Table of contents:

1. Abstract

The biodiversity hotspots in Sumatra are threatened by the vast land conversion from rainforest into rubber and Oil Palm plantations. These changes might be causing losses not only of biodiversity but also of associated ecosystem functions. In the province of Jambi, mainly the land use systems Forest (remnant), Jungle Rubber, Rubber and Oil Palm exist, which are characterized by different plant species compositions.
Pollen and spore dispersal is a basic process for plant reproduction and the production of pollen grains in certain plants are important resources for pollinators. Thus it is important to attain an understanding of pollen/spore rain changes due to land use conversion. In this study I analyzed pollen/spore traps in all four land use systems to quantify changes in pollen/spore production and diversity.

In total 201 pollen and spore taxa from 66 families were identified. Low (100 grains) and high counts (300 grains) for both, alpha and beta diversities reflect similar patterns, which indicate that a low count of 100 pollen grains can already reveal diversity patterns in pollen/spore rain. The results show that pollen and spore rain is affected by changes in land use.
Patterns of palynological alpha, beta and gamma diversity showed a descending trend from Forest, Jungle Rubber, Rubber to Oil Palm systems. However, compared to floristic beta diversity, the palynological beta diversity in Oil Palm is high, possibly due to different levels of management in Oil Palm plantations as preliminary comparison of pollen/spore rain composition in herbaceous species with number of weeding treatments show a negative correlation. However, further investigations on the long-term pollen/spore rain analysis are needed to confirm these findings.

2. Introduction

South-east Asia is one of the world's biodiversity hotspots with exceptionally high numbers of endemic species, which are currently being threatened by rapid land conversion (Koh and Wilcove, 2008; Sodhi et al., 2004).

Particularly in Indonesia land conversion has occurred at very large scales, mostly in uncontrolled terms (Firman, 2000). Due to an increasing demand for Palm Oil, in Indonesia natural rainforest and peatland are converted into Oil Palm plantations (Wicke et al., 2011) but as well into Rubber plantations (Murdiyarso et al., 2002).
Within Indonesia, the island of Sumatra was characterized by a wide range of natural vegetation types (Laumonier, 1997) and high species richness (Barnes et al., 2014). However, since the 1990s conversion of tropical rainforests into secondary crops or monoculture plantations is taking place (Murdiyarso et al., 2002), leading to decreasing plant diversity and less architectural complexity (Foster et al., 2011). As a consequence, Sumatra is a suitable example to study the effects of land use conversion on biodiversity and ecosystem functions (Barnes et al., 2014).

The Collaborative Research Center (CRC990) is an international collaboration project between Germany and Indonesia. The collaboration started in 2012 with the aims to investigate the effects of land use changes in order to enhance ecological functions and ecosystem services in Jambi, Sumatra. One research aspect included in the CRC990 project is the study on modern pollen/spore rain.
Besides other methods (e.g. vegetation surveys and faunal indicator species), pollen and spore diversity is a tool to capture vegetation structure and landscape diversity (Matthias et al., 2015).

Seed-bearing plants produce pollen and the pollen itself can vary in size and structure depending on the parental species which has produced it. Spores are another reproductive grain, which are produced by cryptogams, such as mosses, liverworts or ferns. Pollen and spores mainly differ in their function, but both require dispersal to successfully reproduce (Moore et al., 1991).
In general plants produce extremely resistant pollen which is designed for the transport from anther to stigma so that fertilization can occur. Thus for pollination to occur, transport of pollen grains is crucial, it can take place in different ways. Pollen can be dispersed by wind, animals, mainly insects, or by water (Faegri and Iversen, 1989). The grains which are released in the air can be transported by wind and thus it is possible to "capture" them using traps. One of the principles of palynological analysis is that pollen/spore rain is representative of the vegetation composition

around the site of collection (Hjelle, 1999). However, this assumption can be biased by differences in the reproductive strategies of different plant species. Different pollination strategies of plants like self compatible pollination, animal pollination or wind pollination lead to differences in the amount of produced pollen (Faegri and Iversen, 1989).

Pollen and spore dispersal is a fundamental aspect of reproduction (Martin et al., 2009) necessary to maintain genetic diversity (Sork and Smouse, 2006). Analyzing the patterns of gene flow in context of the landscape structure, it is crucial to manage genetic diversity of endangered populations (Manel et al., 2003). Resilience of plant species to fragmentation is determined by the amount of pollen gene flow and the diversity of the pool, the pollen is immigrating from (Sork and Smouse, 2006).

Thus it is important to obtain a detailed understanding on how land conversion is influencing pollen/spore rain, which is mirroring the reproduction of the vegetation. Despite its importance, a study analyzing the effects of land use change on pollen and spore rain in Sumatra was not yet carried out. Additionally, as shown by the study of Jantz et al. (2014) pollen/spore rain can be a useful method to access plant biodiversity pattern in tropical ecosystems.

The main aim of the present study is to investigate changes in pollen/spore rain due to different land use in Sumatra. To achieve a better understanding of pollen spectra in tropical environments, pollen traps can be used as an effective method (Gosling et al., 2003). Using the pollen traps from Sumatra, the pollen/spore rain of four different land use systems (Forest, Jungle Rubber, Rubber and Oil Palm) was analyzed and tested for the following hypothesis:

H1:
(A) A good separation of pollen and spore assemblage exists on different land use systems; so forth pollen/spore rain is affected by land use changes.

(B) At the regional level, pollen/spore rain can reflect landscape heterogeneity or landscape homogeneity.

H2: There exist similar patterns of α- ,ß-, γ- diversity between pollen/spore assemblages and vegetation data. For pollen and spores the relation is already apparent for low count (100 pollen grains per trap). Pollen/spore rain analysis can be used as a tool to compare level of plant diversity in different land use systems.

H3: Differences in management level is reflected in the pollen/spore rain. Pollen diversity of herbaceous pollen taxa increases with decreasing management level with consequent increase in pollen resources for certain pollinator groups.

This is the first study looking at the effects of land use change not only on plant diversity but also on pollen/spore rain which is an important indicator for the overall functionality of ecosystems.

3. Study region and design

The research was conducted in the tropical lowland of the Jambi province in Sumatra, Indonesia (Fig. 1). The two selected study regions are Harapan and Bukit Duabelas (Fig. 1c). Harapan is located 60 km southwards from Jambi city and Bukit Duabelas is situated about 110 km westwards from Jambi city (Allen et al., 2015).

The climate of the study region is tropical with mean annual temperature of 26.7 ± 1°C and with mean annual precipitation of 2235 ± 385 mm, with the rainy season starting in October and lasting until April (Allen et al., 2015). Due to the favorable tropical climate and soil conditions, there is a high variation in vegetation types and a wide range in species richness, which is necessary for ecosystem stability (Whitten et al., 2000).

Natural vegetation in the Jambi province is diverse and includes lowland to montane, mangrove and peat swamp rainforests. However, the natural landscape would be predominantly dominated by moist lowland rainforest. Due to vast agricultural conversion over the past 30 years, natural forests are continuously disappearing (Verbist et al., 2005). Lowland forests are selectively logged, while the cultivation of Oil Palm and Rubber plantations increases (Whitten et al., 2000). In both, Harapan and Bukit Duabelas regions, the four most common land use systems of Sumatra can be found, namely Forest remnant or logged Forest, Jungle Rubber agroforest, Rubber and Oil Palm monocultures (Fig. 1c and Appendix 1). The land use systems Forest, Jungle Rubber, Rubber and Oil Palm represent a gradient of increasing management.

For each land use system 4 replicates were chosen in both regions for a total of 16 plots per region and 32 field plots, each plot including subplots. Each core plot measured 50 m x 50 m with minimum distance of 200 m to the next plot (Allen et al., 2015). Plots were located between 50 and 100 m a.s.l. and the slope varied between 2 and 12% (Guillaume et al., 2015). Within the core plots, subplots of 5x5 m^2 are established where most of the destructive activities are carried on. Plots of Oil Palm and Rubber plantation are representative for monocultures with an average age of 14 (Oil Palm) and 13 (Rubber) years. A less intensively managed system is represented by Jungle Rubber, an agroforest system where after selective logging and planting of rubber trees, no management is further applied, leaving the vegetation to regrowth undisturbed. All plantations were managed by smallholders. Jungle Rubber was treated in small amounts by fertilizers, but in

Oil Palm and Rubber plantations fertilizers were used in a higher amount. To control weeds growth in the Oil Palm and Rubber plantations mainly glyphosates or paraquat were applied, but in some parts manually work served as a control (Krashevska et al., 2015). The least managed of the 4 land use systems is forest remnant which is used as reference site for lowland rainforest. These are found in both regions and are the Harapan Rainforest and Bukit Duabelas National Park. The rainforest in Harapan and in the National Park Bukit Duabelas can be classified as forest remnants close to natural lowland rainforest (Guillaume et al., 2015).

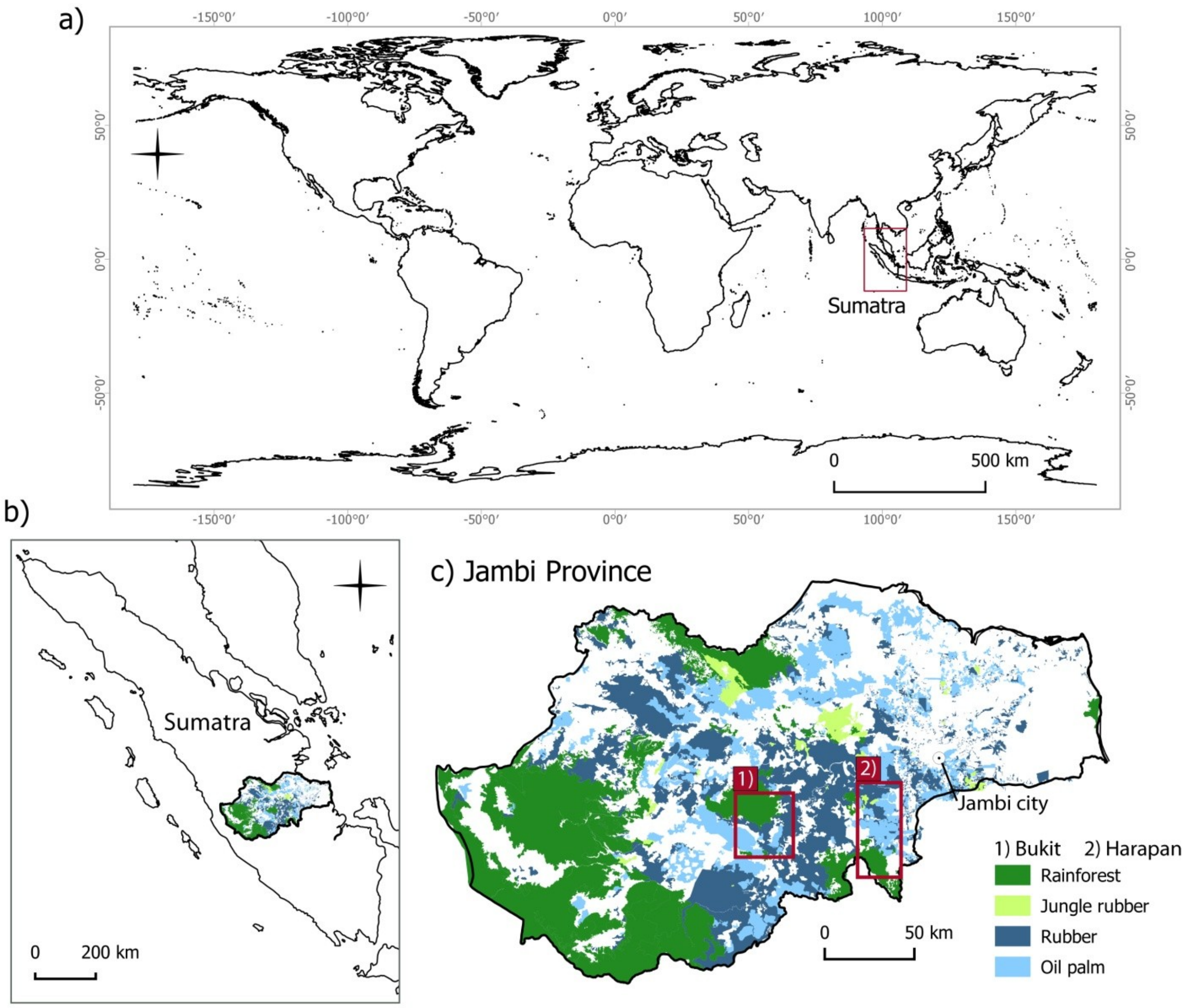


Figure 1: a) World map, red square is indicating the location of Sumatra, b) Enlargement of Sumatra with the Jambi Province highlighted, c) The Jambi Province with the four main land use systems (Forest, Jungle Rubber, Rubber, Oil Palm) and the two study regions Bukit Duabelas (1) and Harapan (2). Data source for land use systems based on Melati et al. (2015).

4. Material and methods

4. 1 “Trapping” pollen and spores

In order to capture the pollen/spore rain spectra for each land use system, Behling pollen traps (Jantz et al., 2013) were installed in September to collect pollen/spore rain from the plots for 1 year.

Each trap consists of a plastic tube which is placed about 10 cm above the ground and is hold by a fixing pole (see Figure 2 and Appendix 1). The tube is filled with 5 ml liquid glycerol, synthetic cotton and on the top it is covered by a mosquito net to reduce disturbance from animals or litter and prevent the cotton from being removed. In tropical regions heavy rainfalls occur, thus it is necessary to prevent the pollen from pouring out of the pollen trap. In the Behling trap glycerol is used, which has a higher density compared to water. Consequently the incoming rainfall can flow out of the trap without taking the pollen, which is trapped in the synthetic cotton and in the glycerol (Jantz et al., 2013).

Pollen traps were installed in September 2013 (10.-14.09.2013) and recollection was carried out in the time span between the 9th and 10th of September in 2014. In total 64 pollen traps were installed in the plots (2x plot) in both regions, Bukit Duabelas (Fig. 3a) and Harapan (Fig. 3b). The two pollen traps were randomly placed within the 50 x 50 m plot. Of the 64 pollen traps placed in the study area, 39 were recovered intact and were analyzed (Appendix 2). The dataset therefore includes 13 pollen traps of Forest, 9 of Jungle Rubber, 9 of Rubber and 8 samples from Oil Palm plots.

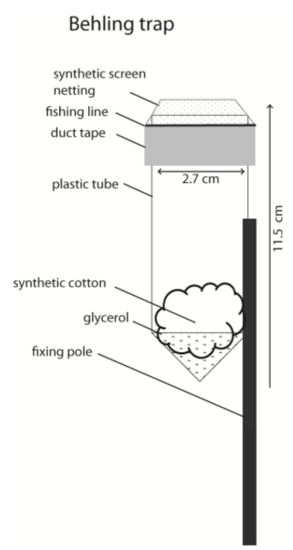
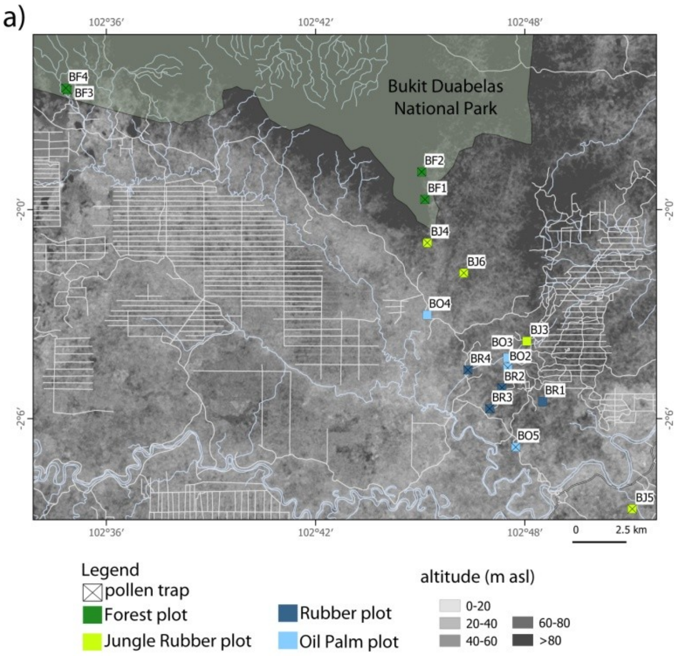


Figure 2: Schematic draw of a Behling pollen trap. (Modified after Jantz et al. 2013)



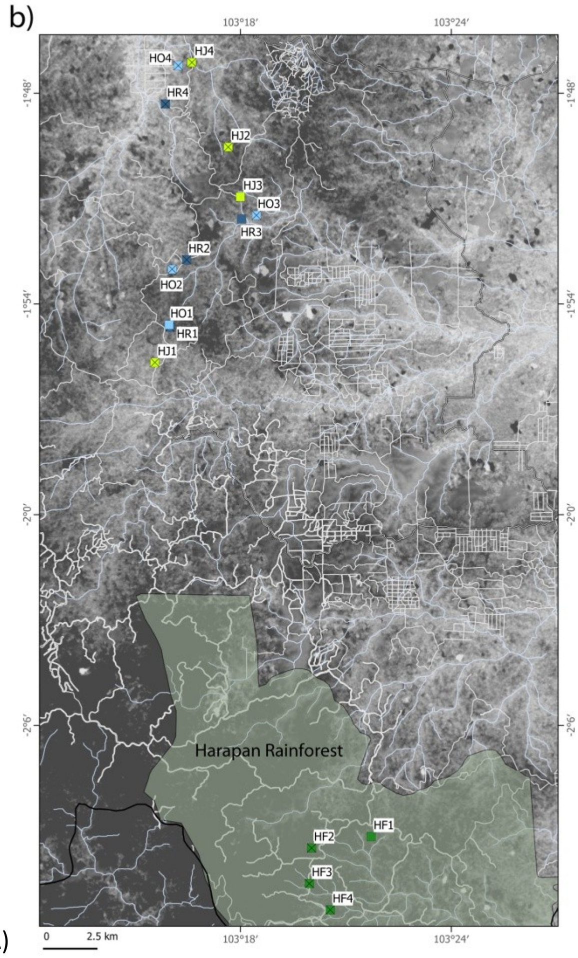


Figure 3: The two study regions a)Bukit Duabelas and b) Harapan. All core plots of the four different land use systems are presented. x= a pollen trap is installed on the plot, BF=Bukit Forest, BJ=Bukit Jungle Rubber, BR=Bukit Rubber, BO=Bukit Oil palm, HF=Harapan Forest, HJ=Harapan Jungle, HR=Harapan Rubber, HO=Harapan Oil Palm.

(Maps: Digital Elevation Model ASTER, a product of METI & NASA)

4.2 Vegetation data

Vegetation data collection was carried out during a vascular plant inventory by Katja Rembold in the year 2013 (project BO6). The plant inventory was carried out on all 32 core plots. On each core plot trees were recorded and within the 5 subplots all herbaceous plants, seedlings, shrubs and small trees (dbh ≤ 10cm) were identified and counted. Whenever possible, herbarium specimens were prepared of three individuals per species for identification and later deposition at several Indonesian herbaria (Herbarium Bogoriense, BIOTROP Herbarium, UNJA Herbarium, Harapan Rainforest Herbarium). The vegetation data of B06 (unpublished) are used in this study for comparison with pollen data regarding biodiversity patterns.

4.3 Palynological analysis

Each pollen trap was firstly washed with distilled water trough a 2 mm mesh sieve to remove large size materials. In a second turn pollen traps were sieved through a 150 µm mesh sieve to exclude medium size materials from the samples. Two *Lycopodium* tablets were added as marker to each sample. Afterwards the filtrate was centrifuged and Erdtman acetolysis (Bush et al., 2001) was carried out, to remove cellulose material. Due to remaining siliceous particles, for 23 samples acid florid (HF) treatment followed. The resulting pollen concentrates were mounted in glycerol to a microscope slide to enable pollen and spore counting and identification under the microscope. For each trap, two datasets were created, the first one with a total sum of at least 100 and the second with a total sum of at least 300 pollen grains counted. Fern spores were counted as well in both cases, but were excluded from the total pollen sums. Pollen and spores were identified to the lowest taxonomic level achievable, using the reference collection at the Department of Palynology and Climate Dynamics, University of Goettingen, which includes specimens collected from the plots, as well as available published atlas (e.g. Huang, 1972; Wang, 1995; Jagudilla-Bulalacao, 1997). In case taxonomic identification was not possible, grains were defined as morphotypes. Three samples (BR1: pt036, BR3: pt038 (Rubber) & BJ5: pt034 (Jungle)) were excluded from the data analysis due to low pollen content as the minimum count of 300 pollen grains per sample could not be achieved.

The annual pollen influx (pollen grains/cm^2/year) was calculated by using the number of *Lycopodium* markers counted in each sample. Relative proportions (%) were calculated based on the total pollen and spore influx sum.

4.4 Numerical analyses

4.4.1 Multivariate statistical analysis

Non-metric multidimensional scaling (NMDS) was applied to examine the separation between the palynological assemblages from the different land use systems and between regions (Harapan and Bukit). NMDS is a method, which evaluates the data set dissimilarity and directionality. The aim of the NMDS is to show complex relations within a dataset in a more simple dimensional space. Thus the NMDS is representing the rank order of the multivariate data at a lower dimensional space

(Schüler et al., 2014). NMDS was performed in R using the “vegan” package (Oksanen et al., 2015) using square root transformed pollen relative proportions. The Bray- Curtis distance was used to determine the NMDS distance matrix. Kruskal stress function was calculated to imply the degree of correspondence between input data and points produced by the NMDS graph in the increasing number of dimensions. A Kruskal stress value of zero represents a completed representativeness of the input data in the dimension calculated (Schüler et al., 2014).

4.4.2 Palynological and floristic diversity patterns

Pollen and spore grains can rarely be identified to species level and the level of taxonomic identification varies for different groups of plants. As a consequence, a reduction to a higher systematic level, i.e. family, has been proposed for studies involving analysis of palynological diversity in the tropics (Jantz et al., 2014). The assumption behind the applicability of the taxonomic surrogacy is that, in highly diverse tropical ecosystems, the number of plant families is linearly correlated with the number of species. We test this assumption using the Pearson's product-moment correlation between number of pollen and spore taxa and family.

As it was defined in the Convention of Biological Diversity (CBD), biodiversity is the variability within species, between species and the diversity of ecosystems (CBD, 1992). It is important to assess biodiversity, on the one hand to analyze the present status of biodiversity, on the other hand to understand which aspects are driving biodiversity changes in future.
Whittaker (1960) divided biodiversity into three levels and thus introduced the terms alpha, beta and gamma diversity. This division enables a precise look to different spatial scales and to environmental gradients.

<u>Alpha diversity:</u>

Alpha diversity is defined as “the richness in species of a particular stand or community…” (Whittaker, 1960) and it is a measure of species number on a local scale, where biological processes like niche structure or biological interactions play an important role.

The floristic and palynological alpha diversities were calculated using the Simpson index in PAST (Hammer et al., 2001). Simpson’s index of diversity takes into account the number of species/taxon present, as well as the relative abundance of each species/taxon. As species/taxon richness and evenness increase, so does diversity. The value of this index ranges between 0 and 1, and to greater values correspond greater diversity. Palynological alpha diversity was calculated using pollen and spore influx data per pollen trap for both the 100 and 300 datasets. Floristic alpha diversity was estimated using the abundance count data of trees species (at the plot level) and understory species (at the subplot level).

Beta diversity:

Whittaker (1960) defined beta diversity as the variability in community composition or the extent of community differentiation in relation to environment patterns. As Tuomisto (2010) pointed out there are several definitions of "beta diversity" in ecological literature. According to Arellano and Halffter (2003) beta diversity can be described as the difference of species between two sites, communities or regions. Anderson et al. (2011) described two main measures of beta diversity, the turnover and variation. Turnover is the measure of changes in community structure between sampling units among spatial, temporal and environmental gradients, while variation, represents the variation in community structure among samples within a given area.

The assessment of beta diversity plays a crucial role in biodiversity conservation by providing information of the variation of species composition (Bacaro et al., 2012). For instance a high beta diversity is leading to a higher stability of communities, especially to higher resilience in disturbed ecosystems (Pilotto, 2015). Thus it is important to understand how beta diversity of plants is affected by different land use systems. In the present study beta diversity is measured as the species dissimilarity between plots per land use system. The palynological and floristic beta diversity was estimated by the calculation of the Bray-Curtis dissimilarity matrix. This Bray-Curtis-measure includes the calculation of a plot-to-plot distance matrix (Bacaro et al., 2012) for both pollen/spores and plant data. Bray-Curtis distance was calculated between plots of the same land use system. When Bray-Curtis distance shows a value of 1, the objects do not have any family in common (Leyer and Wesche, 2007). To see if there were significant differences between land use systems, the Kruskal-Wallis test was applied.

Gamma diversity or landscape richness:

Gamma diversity can be defined as the total diversity of a landscape or the product of the alpha diversity and beta differentiation among the communities (Whittaker, 1977). While alpha diversity is locally defined, gamma diversity reflects the landscape scale and thus depends on historical and geographic processes. Moreover on the landscape level human actions, for example the fragmentation of vegetation, can be reflected in the measure of gamma diversity (Arellano and Halffter, 2003). Thus gamma diversity allows to scale up the effects of land use change on plant communities on a larger scale. We measure gamma diversity as the total species diversity on a regional level with the two replicates represented by the Bukit and Harapan regions. To estimate palynological and floristic gamma diversity at the landscape level we used the total richness per land use system (total of Forest, Jungle Rubber, Rubber and Oil Palm). As richness is dependent on the count we applied individual rarefaction to downscale the effect of different count (pollen grains) and individuals (plants) in the pollen traps and plot inventories to each dataset, using PAST (Hammer et al., 2001).

4.4.3 Effects of management on pollen rain in Oil Palm plantations

For the pollen traps located in Oil Palm plantations, the numbers of pollen taxa and family which could be ascribed to herbaceous plant species are used. Data of pollen traps located on the same plot are summed.

Information on the treatments carried out on the Oil Palm plots includes weeding of understory plants, pruning of Oil Palm, sprayed pesticides and use of fertilizers (Kotowska et al., 2015). For the correlation analyses the reported number of weeding per plot are used. Data are selected from the plots where pollen traps are available and for the period September 2013 to September 2014, corresponding to the time of collection of pollen/spore rain.

5. Results

5.1 Pollen and spore results

In total 201 taxa (pollen, spores and unknown morphotypes) were identified during pollen counting (see Appendix 3: pollen diagram including all taxa). The majority of pollen and spore grains were identified at least to family level and percentage of unknown grains were always below 4%. The pollen diagram (Fig. 4) represents the palynological assemblage of the pollen traps per land use system showing total influx (grains/cm^2/year), habitus groups (%) and most important taxa (%) per land use system. Pollen and spore taxa percentage values are summed into habitus characteristics such as: woody (w), herbaceous (h), varia (v) and ferns. Rubber tree (*Hevea brasiliensis)* and Oil Palm (*Elaeis guineensis)* were excluded from the woody group in order to assess the relative proportions of different groups which are not cultivated in the land use systems.

Regarding the total influx a clear decreasing trend can be observed from low managed Forest (41,000 grains/cm^2/year) and Jungle Rubber (22,000 grains/cm^2/year) to highly managed system like Rubber (21,000 grains/cm^2/year) and Oil Palm (17,000 grains/cm^2/year) (Fig. 4a). Similarly to the total pollen influx, woody group shows decreasing percentage values with increasing management intensity from Forest (47%), Jungle Rubber (41%), Rubber (31%) and Oil Palm (30%). The maximum in herbaceous group is found in Rubber (33%) followed by Forest (30%), Jungle Rubber (23%) and lower values are found in Oil Palm (17%).

On the family level highest influx is found in the forest traps with Moraceae (16%), Menispermaceae (7%) and Piperaceae (5%) as the most important families (Appendix 3). Pollen traps of Jungle were mainly represented by Euphorbiaceae (9%), Moraceae (8%), Burseraceae (5%). Most common families in Rubber plantations were Urticaeae (12%), Moraceae (8%) and Burseraceae (5%). The families Arecaceae (18%), Urticaceae (4%) and Elaeocarpaceae (3%) are of major importance in Oil Palm plantations.

The most important pollen taxa in the Forest traps are in order *Artocarpus* (11%), *Piper* (5%), *Porterandia anisophylla* (5%) (Fig. 4b). Taxa highly represented in Jungle Rubber are *Canarium* (5%), *Artocarpus* (4%), Fabaceae (4%). In pollen traps of Rubber plots, *Elatostema* (12%), *Hevea brasiliensis* (6%) and *Canarium* (5%) are the most dominant. Most important taxa in Oil Palm plantation traps are *Elaeis guineensis* (30%), *Oncosperma* (17%) and *Elatostema* (4%).

Regarding the group of ferns, the families of Nephrolepidaceae (6%), Lycopodiaceae (2%), Blechnaceae (2%) are most common in forest traps. Within Jungle Rubber plots mainly Lycopodiaceae (11%), Nephrolepidaceae (6%), Dennstaedtiaceae (2%) play a major role. Nephrolepidaceae (5%), Dennstaedtiaceae (3%) and Lycopodiaceae (3%) are the most relevant families in Rubber plots. In Oil Palm the families of Polypodiaceae (4%), Nephrolepidaceae (3%) and Dennstaedtiaceae (2%) show highest influx values.

The most relevant fern taxa in Forest are *Nephrolepis* (6%), *Lindsaea II* (2%) and *Stenochlaena palustris* type (2%). *Lindsaea II* (9%), *Nephrolepis* (6%) and *Lindsaea orbiculata type* (2%) are the most abundant taxa in the Jungle traps. For the traps in the land use system Rubber, *Nephrolepis* (5%), *Microlepia* (3%) and *Lindsaea II* (3%) show highest values. Highly present spore taxa in Oil Palm plots are (Unknown241 (6%)), *Nephrolepis* (3%), Polypodiaceae (3%) and *Microlepia* (2%).

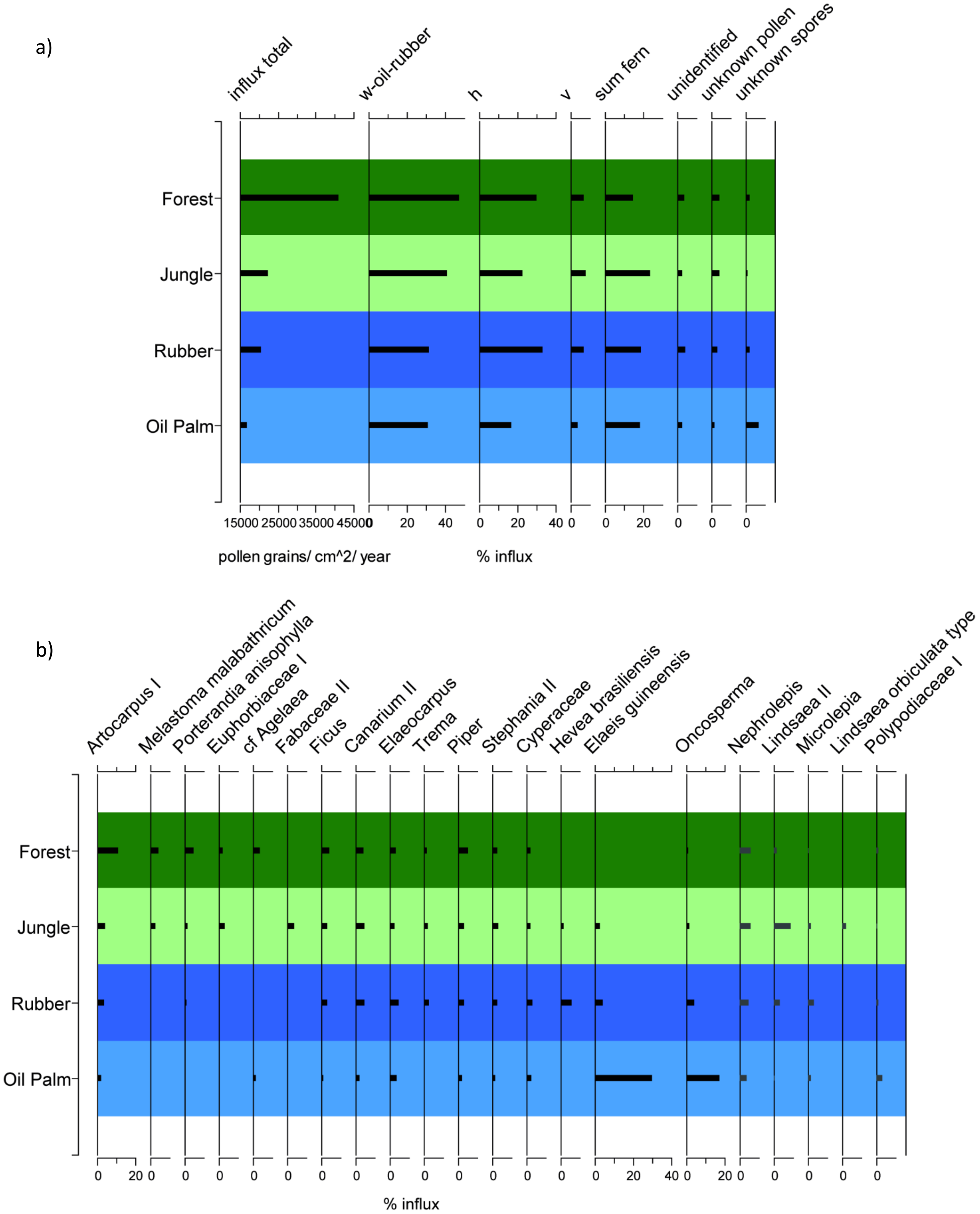


Figure 4: Summary pollen diagram showing influx per land use system (Forest, Jungle Rubber, Rubber, Oil Palm). In a) total influx is measured in pollen grains/cm^2/year. Woody taxa influx (without *Hevea brasiliensis* & *Elaeis guineensis*), influx of herbs (h), influx of varia habitus (v), ferns, unidentified and unknown pollen and unknown spores are shown in percentage values. In b) the most common pollen taxa (in black) and spore taxa (in grey) are represented in percentage of the influx per land use system.

5.2 Taxonomic surrogacy

A clear linear correlation is found between number of palynological taxa and family (p-value < 0,001, R^2= 0,83) and number of plant species and family (p-value < 0,001, R^2= 0,83) (Appendix 4) and thus the taxonomic surrogacy can be applied for the present data. Pollen and spore data is always represented on family level.

5. 3 Multivariate statistical analysis

The NMDS of the pollen and spore family data provides a better overview of the differences in the traps assemblage composition of different land use systems (Fig. 5). The first two axes are shown for which a final solution was reached after 2 trials and a low kruskal stress (0,169) indicates a good overlap between point in the axes and dataset. The NMDS shows a good separation between the land use systems. In particular, pollen traps from Forest are located in the left part of the diagram, whereas pollen traps from Oil Palm plots are clustered in the opposite direction. Forest traps are correlated with Myrtaceae, Phyllantaceae, Moraceae, Menispermaceae, Lycopodiaceae, Pteridaceae and Sapotaceae. Between the Forest and Oil Palm traps, the Jungle Rubber and Rubber traps are located, which are slightly overlapping. The Jungle Rubber traps are correlated with families of Gnetaceae, Cyperaceae, Lycopodiaceae, Urticaceae, Moraceae-Urticaceae, Caprifoliaceae and Gentianaceae. Traps from Rubber are mainly driven by Cyperaceae and Urticaceae. Pollen traps from Oil Palm plantations are mainly correlated with Arecaceae, Orchideaceae and Dennstaedtiaceae. The pattern of the samples distribution shows a separation between land use systems, from low managed systems (Forest) to highly managed systems (Oil Palm). Jungle Rubber and Rubber plots are in the middle of the graph thus separating from the other two land use systems, although the separation between these two systems is not clear. Figure 5a shows the NMDS of the family of pollen and spores in the traps for the two regions studied, Bukit Duabelas and Harapan. The solution was reached after 13 trials (Bukit Duabelas) and after 1 trial (Harapan), in both cases the kruskal stress were low for the first two dimensions (Bukit Duabelas: 0,131; Harapan: 0,094). For Bukit Duabelas (Fig. 5b) a similar pattern to Figure 5a can be seen, Forest and Jungle Rubber traps are closer together and Oil Palm traps are clustered close to Rubber traps. However, Bukit Duabelas region (Fig. 5b), is characterized by a better separation of Jungle Rubber and Rubber traps. A different pattern can be seen for the Harapan traps (Fig. 5c). At the left margin of the axis the Forest traps are clustered, in the middle part Jungle Rubber and Rubber traps are overlapping. Oil Palm traps are located in the right half of the axis.

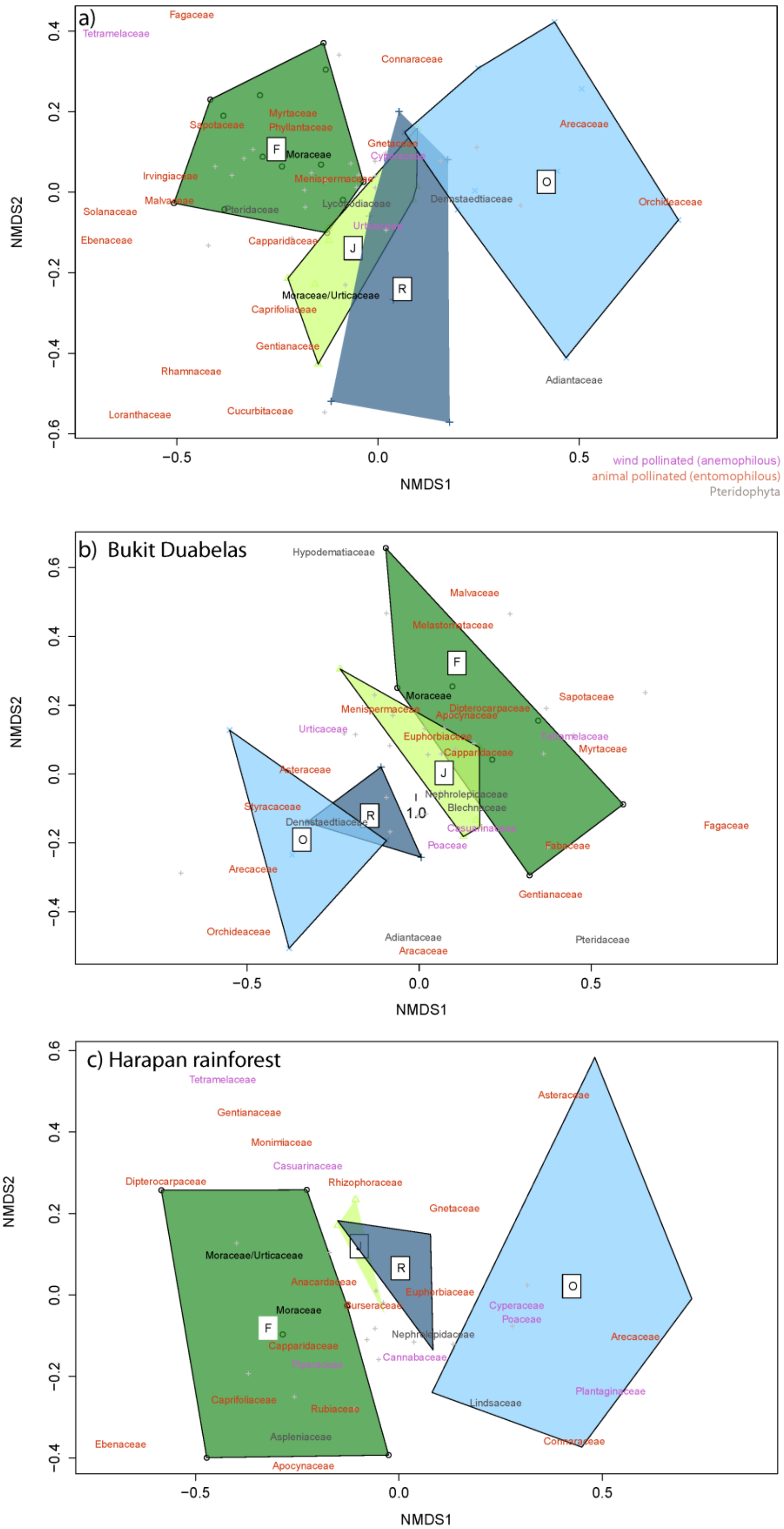


Figure 5: Non-metric multidimensional scaling (NMDS) diagram showing pollen and spore family assemblages per land use system. The polygons represent the different land use systems: F= Forest, J= Jungle Rubber, R= Rubber and O= Oil Palm. Figure a) is representing both study regions together, whereas in b) Bukit Duabelas and c) Harapan are shown separately. Different colors indicate different strategies of pollination (purple= wind pollinated, red= animal pollinated. In grey= Pteridophyta).

5. 4 Palynological and floristic diversity patterns

5.3.1 Alpha diversity

Results from the Simpson's Diversity Index for both palynological and floristic family data on the different land use systems are shown in Figure 6. For the alpha diversity of pollen traps I repeated the analysis two times for both low count (100 pollen grains; Fig. 6a) and higher count (300 pollen grains; Fig. 6b) datasets. As test for normality (Shapiro-Wilkson test) showed that some of the land use systems indices data were not normally distributed, the non-parametric Kruskal-Wallis test was used to test for differences between land use systems indices distributions (Dytham, 2011).

The palynological richness for the low count dataset (100 pollen grains) (Fig. 6a) results show that the land use systems Forest (median=0,89), Jungle Rubber (median=0,87) and Rubber (0,88) do not differ significantly from each other. On the other hand, the land use system of Oil Palm (median= 0,70), shows significantly lower values than Forest and Rubber.

The palynological alpha diversity for the high count dataset (300 grains) (Fig. 6b) shows similar trends such as high values not significantly different for Forest (median=0,90), Jungle Rubber (median=0,90) and Rubber (median=0,90) traps, but significantly different values for the Oil Palm traps (median= 0,71).

In comparison to the palynological alpha diversity, the floristic alpha diversity (Fig. 6c) shows a trend of decreasing alpha diversity from Forest (median=0,90), Jungle Rubber (median=0,85), Oil Palm (median=0,79) and Rubber (median= 0,73) plots. The only significantly different land use system being Rubber which is significantly different from Forest and Jungle Rubber.

alpha - diversity

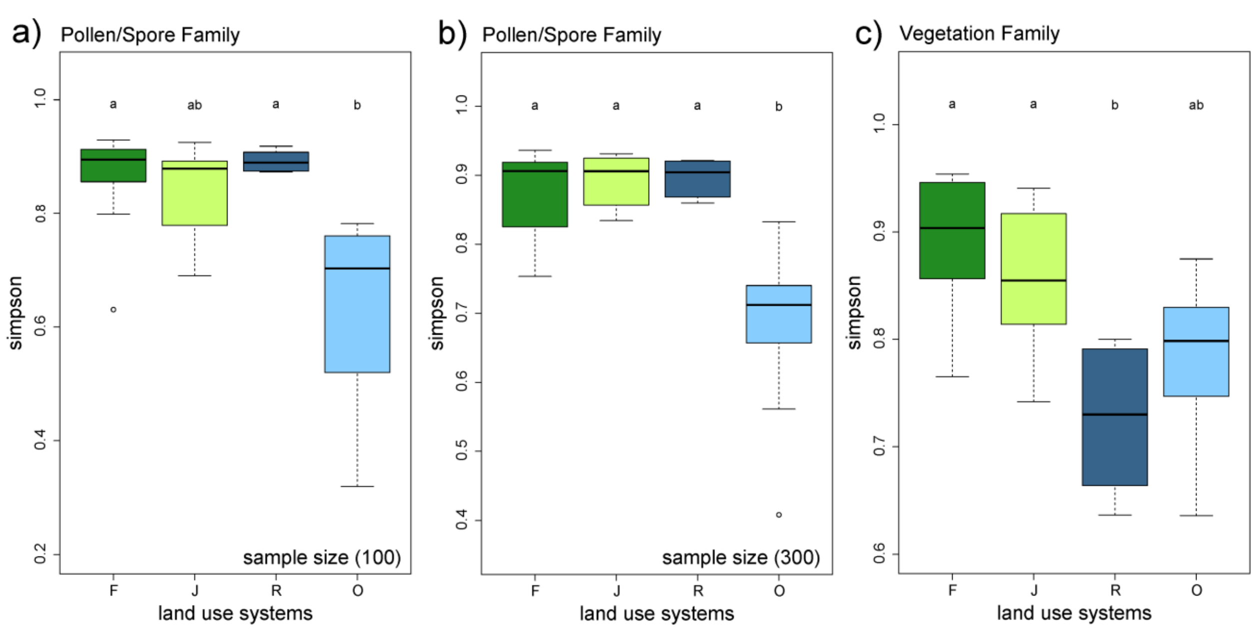


Figure 6: Palynological alpha diversity is calculated with a) small sample size (100), b) large sample size (300) and in c) floristic alpha diversity based on vegetation survey data are shown. Simpson index was estimated with the program PAST (Hammer et al., 2001) and Kruskal-Wallis test was applied to determine differences between land use systems. Different letters indicate significant differences.

5.3.2 Beta diversity

The results for the beta diversity measures are shown in Figure 7. The palynological dissimilarity was calculated using the Bray – Curtis dissimilarity measures. The analyses were repeated for different count dataset (low count 100 and high count 300), using influx data at both high and low taxonomic levels (family and taxa). The same repeated analyses were performed with the plant dataset (same Figure). As for the Simpson indices, the Bray – Curtis dissimilarity measures returned values which were not normally distributed for some of the land use systems. Therefore, the non-parametric Kruskal-Wallis test was used to test dissimilarities between land use systems. P-values show significant results for all datasets, the low count (p-value < 0,000), the high count (p-value = 0.001553) and for the vegetation dataset (p-value < 0,001).

For the family palynological low count dataset (100 grains) (Fig. 7a), a decreasing trend in palynological beta diversity can be observed, along the gradient of management level, from Forest (median=0,78) to Jungle Rubber (median=0,69) to Rubber (median=0,65) to Oil Palm (median=0,64). Forest is significantly different from Jungle Rubber, Rubber and Oil Palm traps.

The same trend is observed for the family high count dataset (Fig. 7b). Palynological beta diversity is decreasing, from Forest (median=0,71) to Jungle Rubber (median=0,66) to Rubber (median=0,54) except for Oil Palm which shows higher beta diversity (median=0,59). Again Forest traps show a significantly higher palynological beta diversity than Rubber and Oil Palm.

Based on presence absence data, the floristic beta diversity (taxonomic level; Fig. 7c) shows a similar trend of decreasing beta diversity from Forest (median=0,84) to Jungle Rubber (median=0,73), Rubber (median=0,71) and Oil Palm land use systems (median=0,56). Floristic beta diversity in Forest, Jungle Rubber and Rubber plots is significantly higher than in Oil Palm plots.

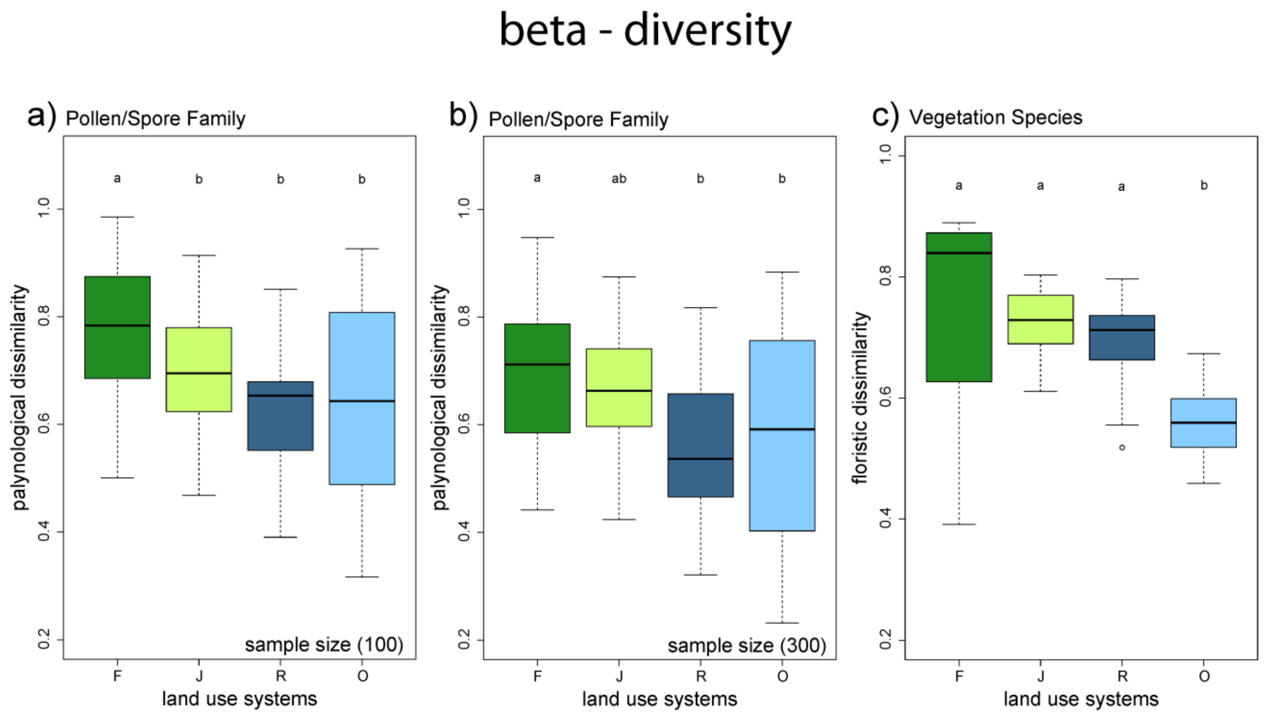


Figure 7: Beta diversity is represented for a) small sample size (100), b) large sample size (300) for palynological family level and c) for vegetation species based on presence-absence data. Bray-Curtis dissimilarity matrix was used to compute palynological and floristic beta diversity and Kruskal-Wallis test was used to analyze occurring differences. Different letters indicate significant differences between land use systems.

5.3.3 Gamma diversity or land use richness

Accumulation curve

Palynological accumulation curves for both, high and low taxonomic levels are represented in Figure 8. At both family and taxa levels, all land use systems show a similar trend by approximating the asymptote within the reached count of grains.

While the accumulation curves in palynological richness are similar for the four land use systems (Fig. 7a), the pattern is different when looking at floristic richness (Fig. 7b). For both floristic taxonomic levels, Forest and Jungle Rubber show steep accumulation curves, whereas the land use systems Rubber and Oil Palm approximated the asymptote within the reached count of individuals.

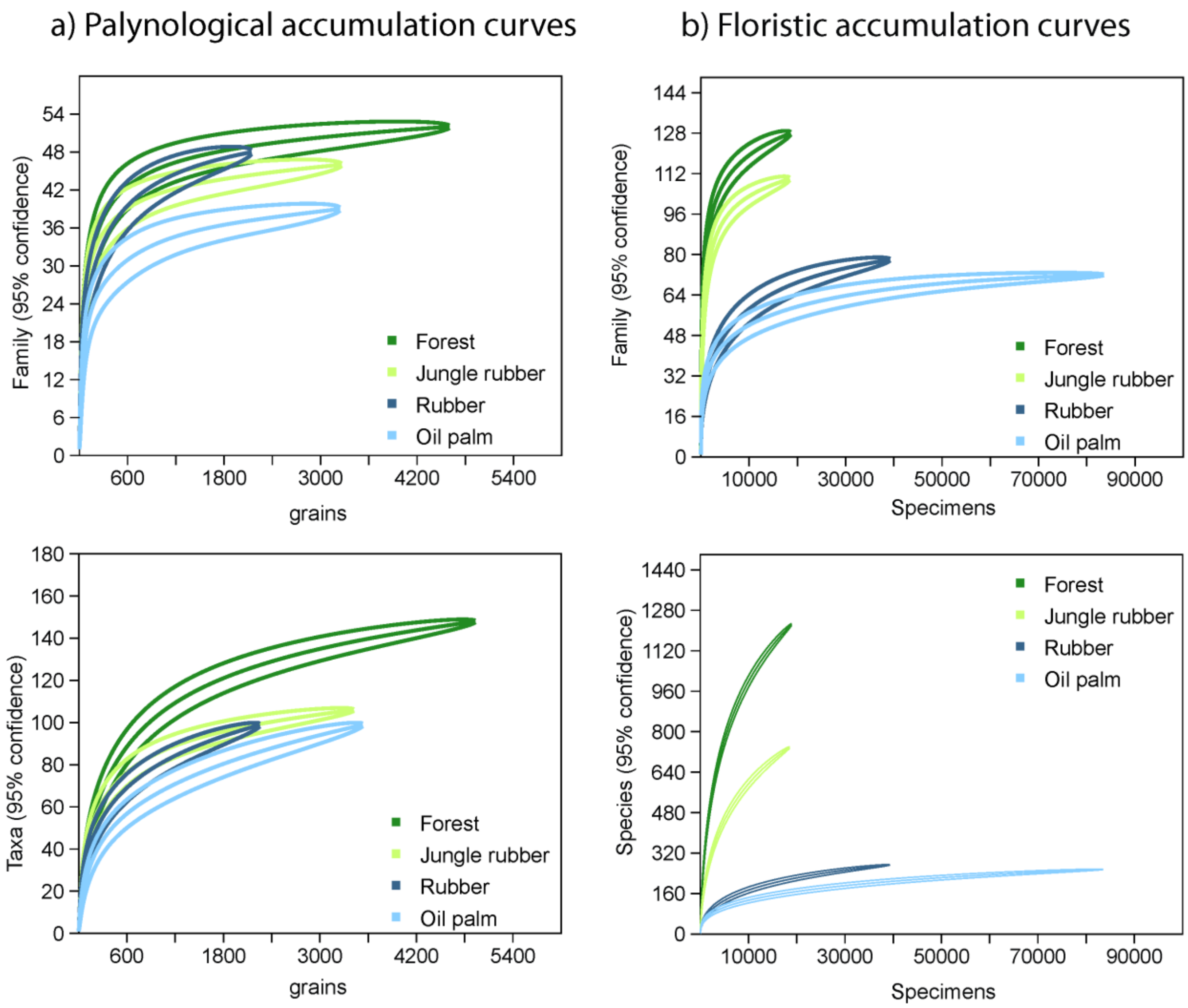


Figure 8: Accumulation curves and 95% confidence intervals are shown. a) Palynological accumulation curves for both family and taxa and b) Floristic accumulation curves for family and species. Different colors indicate the different land use systems: dark green=Forest, light green=Jungle Rubber, dark blue=Rubber, light blue=Oil Palm.

Richness

Results of the individual rarefaction for the palynological and floristic richness are shown in Figure 9 for both high and low taxonomic levels. On the family level palynological richness (count of 2000 pollen and spore grains) (Fig. 9a) for Forest is reaching 49 families, Jungle Rubber 44 families, Rubber 48 families and Oil Palm 37 families. Similar to the family level, palynological richness on the taxa level decreases with increasing management. Number of different taxa estimated for a count of 2000 grains is 123 for Forest, 97 for Jungle Rubber, 96 for Rubber and 83 for Oil Palm.

For a count of 18400 individuals, floristic richness (Fig. 9b) for family level is decreasing from Forest (128 families), Jungle Rubber (110 families), Rubber (68 families) to Oil Palm (59 families). On the species level a very similar pattern can be observed. Within Forest plots 1214 different species are found, for Jungle Rubber 737 species, for Rubber 216 species and for Oil palm 164 species.

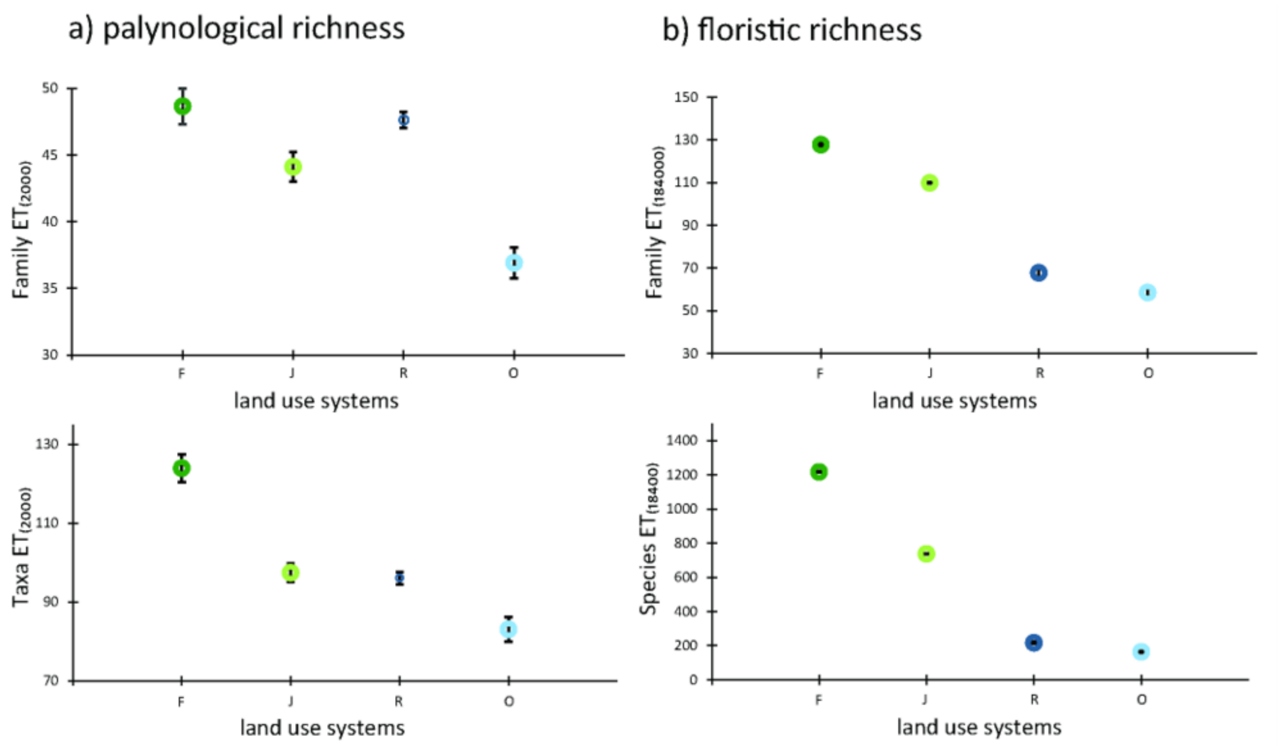


Figure 9: Individual rarefaction for pollen/spore and vegetation data. a) Palynological richness for family and taxa level is based on a count of 2000 pollen grains. b) Floristic richness for family and species is based on a count of 184000 individuals. Different colors indicate the different land use systems: dark green=Forest, light green=Jungle Rubber, dark blue=Rubber, light blue=Oil Palm.

Results of the rarefaction for the pollination strategies show different patterns for entomophilous and anemophilous pollen family (Fig. 10). The diversity of entomophilous pollen (Fig. 10a) is higher in Forest, Jungle Rubber and Rubber (27 different families in a count of 1100 pollen grains), while it is lower for Oil Palm (18 different families). In comparison anemophilous pollen diversity (Fig. 10b) show a decreasing trend from Forest (7 families in a count of 110 pollen grains) to Jungle Rubber (6 families) to Rubber (5 families), except Oil Palm (6 families).

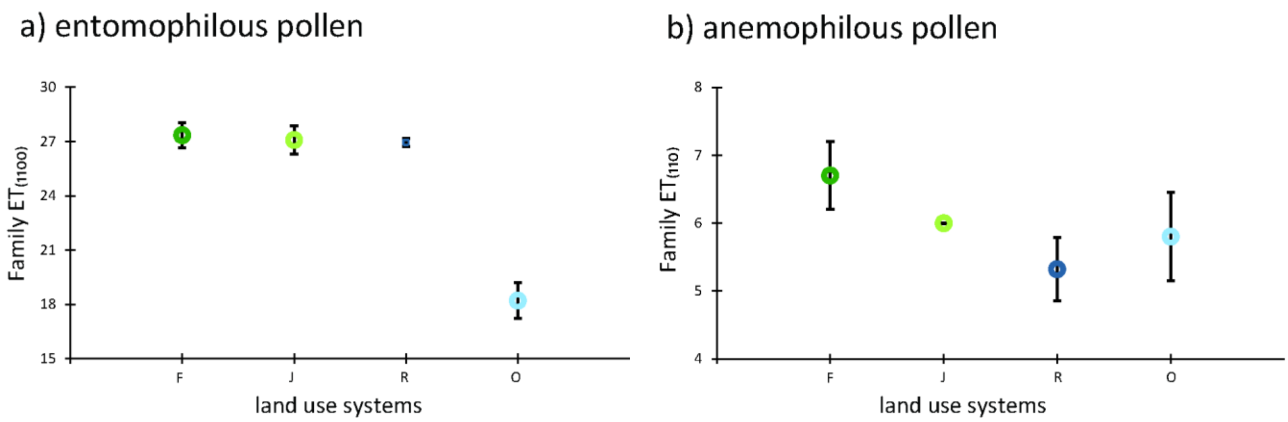


Figure 10: Different forms of pollination are divided into a) entomophilous pollen and b) anemophilous pollen. Based on the family level, rarefaction results are presented for each land use system: dark green=Forest, light green=Jungle Rubber, dark blue=Rubber, light blue=Oil Palm.

5.4 Effects of management on Oil Palm pollen rain

Figure 11 shows the scatterplots of number of herbaceous pollen taxa and family against applied weeding in the Oil Palm plantation plots. A general negative linear correlation is found between both number of taxa and family and weeding, correlations are significant for both.

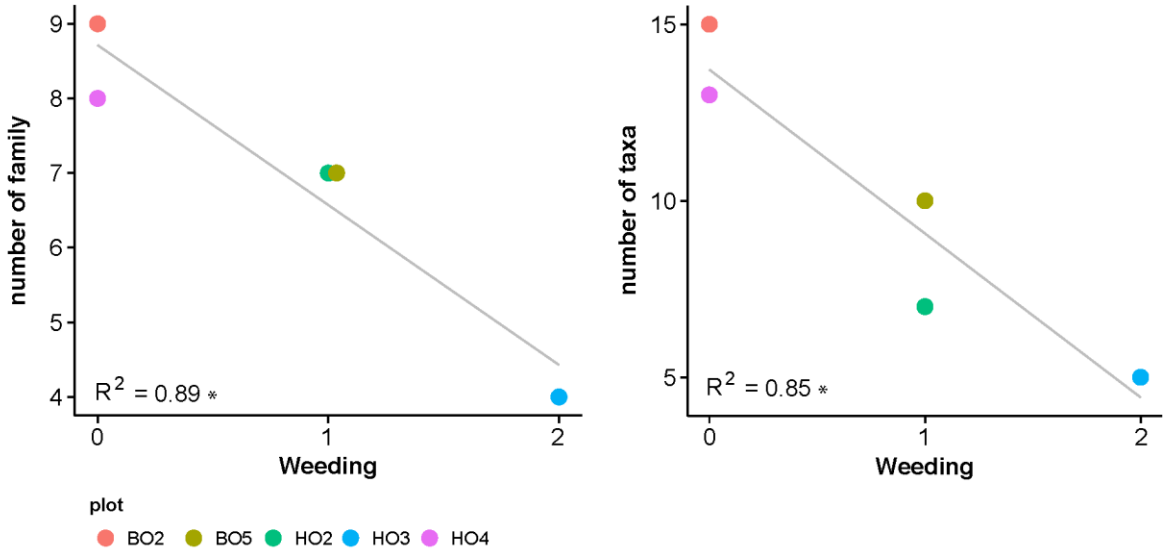


Figure 11: Effect of weeding on herbaceous plants on different Oil Palm plots. Linear relations were analyzed for both number family and number of taxa. Different colors denote different Oil Palm plots: red= BO2, light green= BO5, dark green= HO2, blue= HO3, purple= HO4.

6. Discussion

6.1.1 Pollen/spore rain composition reflects land use changes (H1:A)

Results from the analysis of a one year pollen and spore rain from Jambi show that a good separation exists between pollen and spore assemblages on different land use systems. The results of the overall pollen and spore spectra revealed that traps located on the different land use systems are characterized by different pollen and spores (Fig. 4). This suggests that, despite differences in pollen and spores production and dispersion strategies, pollen/spore rain is affected by changes in the land use systems included in this study (Forest, Jungle Rubber, Rubber and Oil Palm).

Interestingly, the total pollen influx decreased with increasing management level from Forest to Jungle Rubber to Rubber to Oil Palm. Pollen dispersal mainly shapes the gene flow within and among plant populations, whereas seed dispersion is often more locally restricted (Scheepens et al., 2012). Isolating populations due to habitat fragmentation can affect pollination and reproduction success of plants and thus it is shaping the genetic structure of plants (Pellegrino et al., 2015). According to Kaufman et al. (1998) pollen flow is the main contributor to gene flow for plant populations. The results of the pollen diagram (Fig. 4) show a decrease in pollen influx, which might indicate a decrease in the general pollen flow.

To what extent the land use systems are mirrored by pollen/spore families and are separable by pollen/spore assemblages is clarified in the NMDS (Fig. 5). Forest traps are more strongly represented by woody species (including families like Myrtaceae, Phyllantaceae, Sapotaceae, Moraceae), whereas Oil Palm traps are mostly represented by ferns, herbaceous species and Oil Palm itself, *Elaeis guineensis*. Within the Oil Palm traps, pollen grains of *Elaeis guineensis* dominate the assemblage with the highest influx of grains (Fig. 4). The land use systems Jungle Rubber and Rubber are overlapping each other due to similar taxa occurrence. Although these two land use systems are not as clearly separated as Forest and Oil Palm; however an interesting trend can be observed. Jungle Rubber traps appear to be more similar to Forest traps, whereas Rubber traps are closer to Oil Palm traps. Interestingly the family of Euphorbiaceae, which includes the rubber tree (*Hevea Brasiliensis*) does not show up in the NMDS. This might be explained with the pollen productivity and phenology of this species (Fig. 4). Depending on the solar radiation rubber trees show one or two flowering seasons per year (Yeang, 2007) and fruit set is generally low (Hamzah et al., 2002) which might explain the low pollen production of *Hevea brasiliensis*. Besides self-pollination, cross-pollination occurs in *Hevea brasiliensis*, whereby natural pollination is rare (Lemmens et al., 1995). As a consequence, the distinction of the palynological assemblage in Jungle Rubber and Rubber is not as clear, in comparison with the other two land use systems.

As the NMDS indicates most of the pollen grains are represented by animal pollinated (e.g. Sapotaceae, Myrtaceae) and a few wind pollinated families (Cyperaceae, Urticaceae, Tetramelaceae). No clear division for pollinator strategies per land use system can be observed, suggesting that changes in pollen assemblage on the different land use systems were not driven by groups with different reproductive strategies.

Melastometaceae are one of the most diversified and abundant plant groups in the tropics (Causling and Renner, 2001), in detail *Melastoma malabrathicum* is known as a highly effective weed in many crops or in arable land (Faravani et al., 2008). Thus it is interesting to observe a high pollen influx in Forest traps. In the pollen diagram (Fig. 4) it can be seen that the pollen of *Melastoma malabrathicum* is most common in Forest (4.0%) and Jungle Rubber (2.6%), but of minor importance in more open land use systems like Rubber (0.15%) and Oil Palm (0.22%). As found in the vegetation survey by Katja Rembold, *Melastoma malabrathicum* is most abundant in monoculture systems (unpublished data). *Melastoma malabrathicum* is known as a colonizer of disturbed habitats, pastures, roadsides or light gaps. This species shows adaptive live strategies denoted by fast growing, shade tolerant, high seed dispersal and devoid of pests. These characteristics lead to out-competing of the native flora and thus threaten their occurrence (Faravani and Bakar, 2007). The high pollen influx observed in the Forest traps of *Melastoma malabrathicum* can be associated with gaps in the forest after disturbance occurred (i.e. fall of trees).

The results suggest that population density and fragmentation can lead to changes in pollen production in certain species. While vegetation survey show a dominance of this species in the monoculture systems (Rubber and Oil Palm), the pollen influx suggest that the same species is most common on Forest plots. The different patterns show that this species is easily adapting to new habitats due to disturbance or land use change.

6.1.2 Pollen/spore rain reflects landscape heterogeneity or landscape homogeneity (H1:B)

The NMDS for the two regions of Bukit Duabelas and Harapan (Fig. 5 b,c), revealed marked differences in the pollen/spore rain on the same land use systems. While the traps in Bukit Duabelas showed a greater separation between low management (Forest and Jungle Rubber) and highly managed land use systems (Oil Palm and Rubber monoculture), the pollen traps in Harapan revealed that Forest traps are clearly distinct from the other land use systems including Jungle Rubber. Those differences between the two regions can be explained in terms of heterogeneity and spatial distribution of the land use systems in the two regions. Figure 3 shows the two regions with the different plot locations. The Jungle Rubber plots in Bukit are located close to forest remnant, whereas Rubber plots are located nearby Oil Palm plots. This pattern is reflected in the pollen/spore rain, with the palynological assemblage of the Jungle Rubber traps being more similar to the Forest ones, while the assemblages of Rubber and Oil Palm traps are more similar to each other. Comparing the plot locations of the Bukit Duabelas with the Harapan plots, it can be seen that within Harapan region, the Forest plots are located far from all the other land use system plots. This is again reflected in the pollen assemblage (Fig. 5c) where a clear separation between Forest and all other land use systems is observed. Thus, it seems apparent that the spatial surrounding and overall land use of a region can influence the pollen assemblage. The pollen/spore rain in the plots is partly affected by the adjacent areas, because pollen traps can partly capture also pollen/spore rain coming from outside the plot. In addition to that, Bukit Duabelas is characterized by clay Acrisol soil and Harapan region consists of loam Acrisol soil (Allen et al., 2015). Differences in soil texture can drive local scale differences in plant species composition which influence the pollen/spore rain.

The mentioned aspects like different soil textures, plot location and surrounding land use therefore lead to the results that the Bukit Duabelas region pollen/spore rain was more homogeneous compared to Harapan. In particular Jungle Rubber traps resemble more closely the Forest traps, while the Rubber and Oil Palm traps are more similar to each others in their pollen/spore composition. Hypothesis 2, that landscape heterogeneity or landscape homogeneity can be reflected by pollen/spore rain, is in this case verifiable.

6.2 Palynological and floristic diversity patterns (alpha-, beta-, gamma-diversity) (H2)

6. 2.1 Alpha diversity

One of the main questions in this study was to compare pollen/spore data and vegetation data diversity patterns. The estimated alpha diversities (Fig. 6) revealed that Forest and Oil Palm always show clear differences in palynological and floristic alpha diversity to the extent that both palynological and floristic alpha diversities decreased from Forest plots to Oil Palm plots. The decrease in alpha diversity is in accordance with previous studies emphasizing that land use intensification can cause biodiversity loss, leading to reduced ecosystem services (e.g. Tilman and Lehman, 2001; Flynn et al., 2009). According to Wright (2002) tropical forests show highest alpha diversity in comparison to any other vegetation types. This is related to the fact that forests have a more complex structure compared to Oil Palm monocultures, which are characterized by uniform tree age, lower canopy, less undergrowth and greater human intervention (Fitzherbert et al., 2008). In the study from Kessler et al. (2009) alpha diversity of trees and lianas was highest in forest and decreasing with increasing land use intensity. My results indicate that land use change is affecting pollen/spore rain in a similar way as plant composition when forest is converted to Oil Palm monoculture.

Differences in palynological and floristic alpha diversities can be observed for the land use systems Jungle Rubber and Rubber. This can be explained by the fact that Jungle Rubber and Rubber represent an intermediate stage of land use intensification (Barnes et al., 2014). This intermediate stage is also reflected in the pollen/spore rain, as already seen in Hypothesis 1(A) the systems

Jungle Rubber and Rubber are not clearly separable in their pollen assemblage. As related to the palynological count, the results from the two datasets (100 and 300 counted pollen grains) indicate that patterns in alpha diversity can be already discerned with low count. This confirms Hypothesis 3 that a low pollen count (up to 100 grains) is enough to capture differences in palynological alpha diversity.

6.2.2 Beta diversity

The results of the pollen/spore rain analysis indicate a decrease in beta diversity due to intensified land use, the only exception being represented by Oil Palm (Fig. 7 a,b). A similar decreasing trend in beta diversity from Forest to Oil Palm was obtained from the vegetation survey of Katja Rembold (Fig. 7c). The results of the palynological beta diversity indicate that the effect of land use change is affecting pollen diversity and composition in a similar way as for plant diversity and composition. Nevertheless differences are found in beta diversity patterns between pollen/spore and plants in Oil Palm plantations.

The higher palynological beta diversity in Oil Palm plots might be explained by results of habitat fragmentation. Due to fragmentation more habitat edges occur and species can disperse from one habitat to another (spillover) (Condit et al., 2002; Rand et al., 2006). In tropical Malaysia spillover effects from rainforest plots to adjacent Oil Palm plots were analyzed for butterflies and ants by Lucey and Hill (2012). The results clearly show spillover effects of butterflies from forest into adjacent Oil Palm plantations. As such, species turnover might be used to explain the high palynological dissimilarities in Oil Palm plots. Hypothesis H1:B pointed out that Bukit Duabelas shows a higher palynological heterogeneity compared with Harapan (Fig. 5 b,c). One explanation for this was the pattern of plot locations. Bukit Dueabelas does not have such a clear plot separation as Harapan region. A plot clearly separated from all other land use systems assumable shows less species spillover effects compared to a plot within a region with different land use types in close proximity. Consequently spillover effects of pollen and spore rain from Forest and Jungle Rubber plots to Oil Palm should not be excluded. The differences observed between the palynological and floristic beta diversity in Oil Palm plots, might be related to both spillover effects and differences in the management of the plots. Oil Palm plantations under study are all managed by smallholder farmers. Each household differs in the management and in the intensity at which treatments are carried out in the plantation. In Oil Palm plantations weeds are removed to avoid competition for soil nutrients (Koh and Wilcove, 2008), and chemicals are widely and intensively applied to control pests (Foster et al., 2011). The influence of management in Oil Palm plantations on the pollen diversity will be further tested in Hypothesis 3 (par. 6.3).

6.2.3 Gamma diversity

Palynological richness decreased from low managed Forest to high managed Oil Palm traps, the only exception being for family level for the Rubber system (Fig. 9a). In comparison floristic richness shows a decrease by increasing degree of management from Forest to Jungle Rubber to Rubber to Oil Palm (Fig. 9b).

This general trend is consistent with the review from Fitzherbert et al. (2008), in which the authors found that the conversion of natural Forest, especially to Oil Palm, causes biodiversity loss. Previous studies on biodiversity loss due to land conversion, showed similar results. For instance Schulze et al. (2004) analyzed species richness in the land use systems of near-primary forest, old secondary forest, young secondary forest, agroforestry systems and annual culture. That overall species richness decreases with increasing habitat fragmentation, was confirmed by the study results (Schulze et al., 2004). The conversion of tropical rainforest in to Oil Palm is leading to severe losses in species richness (Barnes et al., 2014), resulting in decline of population genetic diversity (Struebig et al., 2011).

While for family level Rubber represents an outlier in the palynological gamma diversity trend, the floristic gamma diversity shows a clear decreasing effect on richness. This difference in Rubber between palynological and floristic gamma diversity can be due to the low pollen productivity of *Hevea brasiliensis*, which might lead to underrepresentation of *Hevea brasiliensis* in the pollen trap and consequent overrepresentation of other families.

6.2.4 Pollen dispersal strategies and land use change

The results of the pollen/spore rain analysis revealed that a decreasing number of entomophilous pollen grains are found from the more complex (Forest) to less complex system (Oil Palm). Animals, especially bees, are known as major crop pollinators in the tropics serving crucial contribution to ecosystem services (Kremen et al., 2007).

Due to agricultural intensification pollination systems are affected (Tscharntke et al., 2005). As a consequence losses of pollinators occur and this is leading to inhibited ecosystem services, with less yield and income (Haines-Young and Potschin, 2010).

As Klein et al. (2003) showed, there is evidence for a positive relationship between pollination and biodiversity, thus it is important to improve the stability of pollination, for instance by conserving wild pollinators in habitats adjacent to agriculture.

6.3. Effects of management in Oil Palm plantations on pollen/spore rain (H3)

Despite the limited number of measurement (plots) available for the analysis, a general negative trend was found between the number of herbaceous pollen taxa/families and increasing number of weeding on the plots (Fig. 11). This confirms hypothesis 3 that the differences in intensity of management on Oil Palm plots, have an effect on the diversity of pollen/spore rain.

These results could explain the high palynological dissimilarity that was estimated for Oil Palm traps, as Oil Palm plantations are, amongst the land use systems included in this study, the one subjected to the most variable level of management. As the Oil Palm plots belong to different owners, each plot is subjected to a different number of treatments, possibly resulting in higher variability of the pollen/spore rain in the different plots.

That different plantation management is leading to a change in complexity in Oil Palm plantations (Appendix 5) is stated by Foster et al. (2011), thus it is an important variable to take into account when analyzing biodiversity changes and ecosystem functions.

7. Conclusions and outlook

In total 64 pollen traps installed for one year in different plots of transformation systems (Forest, Jungle Rubber, Rubber, Oil Palm), located in tropical central Sumatra, were analyzed regarding the effects of land use change on pollen/spore rain. The results show that pollen and spore assemblages of modern pollen/spore rain are affected by land use change (Hypothesis (H1:A) and that patterns of landscape heterogeneity or landscape homogeneity are reflected in pollen/spore rain (H1:B).

In particular, the NMDS shows that the more heterogeneous the region is (i.e. Bukit Duabelas), the more homogeneous is the pollen/spore rain between land use systems. This suggests that pollen flow might be enhanced by a more heterogeneous landscape structure.

By comparing measures of palynological and floristic diversity, patterns can be found which are driven by land use conversion. In particular, palynological and floristic alpha diversity show similar trends, decreasing from Forest to Oil Palm plots.

Both the palynological and floristic beta diversities show that the Forest is the system with the highest variability both in plant and pollen/spore flow. However, while floristically the Oil Palm plots are the one with the lowest beta diversity, palynologically Oil Palm plots are highly variable. This can be explained as a combination of spillover effect and the different intensity of treatments carried out in the Oil Palm plots. For this last point, preliminary comparison between number of pollen and spore herbaceous taxa/family shows a decrease with increase number of weeding treatments, thus confirming our hypothesis that pollen/spore rain is reflecting different management levels.

Scaling up to the richness per land use systems, both palynological and floristic gamma diversity show a declining trend from Forest to Oil Palm indicating that both floristic and palynological diversities are negatively affected by conversion of Forest to Oil Palm monoculture.

Pollination strategies for entomophilous and anemophilous pollen family mainly showed highest number of pollen in complex systems like Forest and Jungle Rubber. Entomophilous pollen diversity is lowest in Oil Palm plantations. The results suggest a loss of resources for pollinators. Thus it would be recommended to protect forest fragments to enable pollination diversity in agricultural dominated landscapes such as the Jambi province in Sumatra.

More on the methodological aspect of the analysis, the compared results from low and high count datasets revealed that for low count of 100 pollen grains, a clear pattern is already found. This suggests that a lower sampling effort would be sufficient to capture patterns in palynological biodiversity changes across the land use systems under study.

To conclude, the results from this study have revealed that conversion of tropical lowland rainforest to intensively managed land use systems, in particular Oil Palm monoculture, is causing loss in both diversity and influx of pollen/spore rain and thus genetic dispersion might be inhibited/limited.

It has been shown that one year of pollen/spore rain can already reflect the influence of land use change but further studies are needed to confirm this pattern. A long-term analysis of pollen rain should be carried out, in order to include into the study the interannual variability characteristic of tropical ecosystems. At present, this is the first study exploring the effects of human-driven land use change on pollen/spore rain in the tropics.

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9. Appendices

Appendix 1

The 4 studied land use systems in Jambi Province. a) Forest (remnant), b) Jungle Rubber, c) Rubber Plantation, d) Oil Palm Plantation and e) & f) installed pollen traps in the field.

Appendix 2

Metadata for all recovered pollen traps including: pollen trap number, plot code, region (Bukit Duabelas or Harapan), year, latitude, altitude, date and time of installation, date and time of collection.

pollen trap n.	plot	region	transformation system	year	latitude	longitude	altitude (m asl)	date installed	time installed	trap collected date	trap collected time
pt045	BF3	Bukit Duabelas	Forest	2013	-1.942846	102.580972	108	13.09.2013	10:22:00	11.09.2014	12:27:38
pt047	BF4	Bukit Duabelas	Forest	2013	-1.941559	102.580754	121	13.09.2013	10:37:00	11.09.2014	12:05:04
pt048	BF4	Bukit Duabelas	Forest	2013	-1.941457	102.580595	97	13.09.2013	10:40:00	11.09.2014	12:14:54
pt057	BF2	Bukit Duabelas	Forest	2013	-1.981676	102.750677	59	14.09.2013	11:18:00	09.09.2014	15:51:42
pt001	HF4	Harapan rainforest	Forest	2013	-2.187697	103.342810	87	10.09.2013	10:04:00	06.09.2014	15:01:08
pt002	HF4	Harapan rainforest	Forest	2013	-2.187391	103.342940	60	10.09.2013	10:24:00	06.09.2014	14:45:06
pt003	HF3	Harapan rainforest	Forest	2013	-2.178346	103.333088	62	10.09.2013	11:24:00	06.09.2014	15:29:03
pt004	HF3	Harapan rainforest	Forest	2013	-2.178531	103.333174	95	10.09.2013	11:36:00	06.09.2014	15:34:55
pt006	HF2	Harapan rainforest	Forest	2013	-2.163546	103.334487	101	10.09.2013	12:01:00	06.09.2014	16:21:56
pt005	HF2	Harapan rainforest	Forest	2013	-2.163701	103.334428	79	10.09.2013	11:52:00	06.09.2014	16:12:35
pt058	BF2	Bukit Duabelas	Forest	2013	-1.981819	102.750659	61	14.09.2013	11:22:00	09.09.2014	15:45:57
pt059	BF1	Bukit Duabelas	Forest	2013	-1.995002	102.752245	67	14.09.2013	13:01:00	09.09.2014	14:52:47
pt060	BF1	Bukit	Forest	2013	-1.994729	102.752458	47	14.09.2013	13:05:00	09.09.2014	14:44:52

		Duabelas									
pt062	BJ4	Bukit Duabelas	Jungle rubber	2013	-2.015610	102.753177	62	14.09.2013	14:29:00	11.09.2014	14:50:59
pt063	BJ2	Bukit Duabelas	Jungle rubber	2013	-2.030043	102.770889	76	14.09.2013	17:10:00	10.09.2014	16:03:20
pt064	BJ2	Bukit Duabelas	Jungle rubber	2013	-2.030105	102.770955	76	14.09.2013	17:12:00	10.09.2014	16:08:43
pt009	HJ1	Harapan rainforest	Jungle rubber	2013	-1.927991	103.259226	67	11.09.2013	09:34:00	07.09.2014	12:24:54
pt024	HJ2	Harapan rainforest	Jungle rubber	2013	-1.825436	103.293955	45	11.09.2013	15:28:00	08.09.2014	12:13:42
pt030	HJ4	Harapan rainforest	Jungle rubber	2013	-1.785227	103.276988	62	11.09.2013	17:41:00	08.09.2014	09:26:01
pt033	BJ5	Bukit Duabelas	Jungle rubber	2013	-2.142913	102.851292	4	12.09.2013	14:28:00	10.09.2014	09:33:54
pt034	BJ5	Bukit Duabelas	Jungle rubber	2013	-2.143023	102.851449	44	12.09.2013	14:32:00	10.09.2014	09:42:30
pt061	BJ4	Bukit Duabelas	Jungle rubber	2013	-2.015601	102.753260	34	14.09.2013	14:27:00	11.09.2014	14:49:34
pt015	HO2	Harapan rainforest	Oil palm	2013	-1.883438	103.267458	80	11.09.2013	12:30:00	07.09.2014	16:07:39
pt016	HO2	Harapan rainforest	Oil palm	2013	-1.883269	103.267504	67	11.09.2013	12:41:00	07.09.2014	16:11:18
pt025	HO3	Harapan rainforest	Oil palm	2013	-1.857630	103.307838	50	11.09.2013	16:06:00	07.09.2014	17:06:37
pt031	HO4	Harapan rainforest	Oil palm	2013	-1.786853	103.270705	71	11.09.2013	17:56:00	08.09.2014	10:05:34
pt032	HO4	Harapan rainforest	Oil palm	2013	-1.786988	103.270666	61	11.09.2013	18:03:00	08.09.2014	10:09:04
pt041	BO2	Bukit Duabelas	Oil palm	2013	-2.075434	102.792209	74	12.09.2013	17:43:00	08.09.2014	18:34:39
pt042	BO2	Bukit	Oil palm	2013	-2.075552	102.792297	67	12.09.2013	17:48:00	08.09.2014	18:30:37

		Duabelas									
pt055	BO5	Bukit Duabelas	Oil palm	2013	-2.113813	102.795084	57	13.09.2013	16:47:00	08.09.2014	17:41:02
pt056	BO5	Bukit Duabelas	Oil palm	2013	-2.113788	102.794934	68	13.09.2013	16:50:00	08.09.2014	17:42:54
pt036	BR1	Bukit Duabelas	Rubber	2013	-2.092045	102.802779	74	12.09.2013	16:10:00	10.09.2014	10:35:56
pt038	BR3	Bukit Duabelas	Rubber	2013	-2.095631	102.783314	71	12.09.2013	16:42:00	08.09.2014	18:06:07
pt017	HR2	Harapan rainforest	Rubber	2013	-1.879381	103.274593	65	11.09.2013	12:56:00	07.09.2014	16:24:51
pt011	HR1	Harapan rainforest	Rubber	2013	-1.911008	103.266942	73	11.09.2013	10:17:00	07.09.2014	13:36:27
pt027	HR4	Harapan rainforest	Rubber	2013	-1.805426	103.264487	66	11.09.2013	16:57:00	08.09.2014	10:49:39
pt037	BR3	Bukit Duabelas	Rubber	2013	-2.095552	102.783056	79	12.09.2013	16:39:00	08.09.2014	18:04:32
pt043	BR2	Bukit Duabelas	Rubber	2013	-2.084927	102.789009	68	12.09.2013	18:08:00	10.09.2014	11:28:35
pt052	BR4	Bukit Duabelas	Rubber	2013	-2.076980	102.773232	59	13.09.2013	14:15:00	10.09.2014	17:40:55

Appendix 3

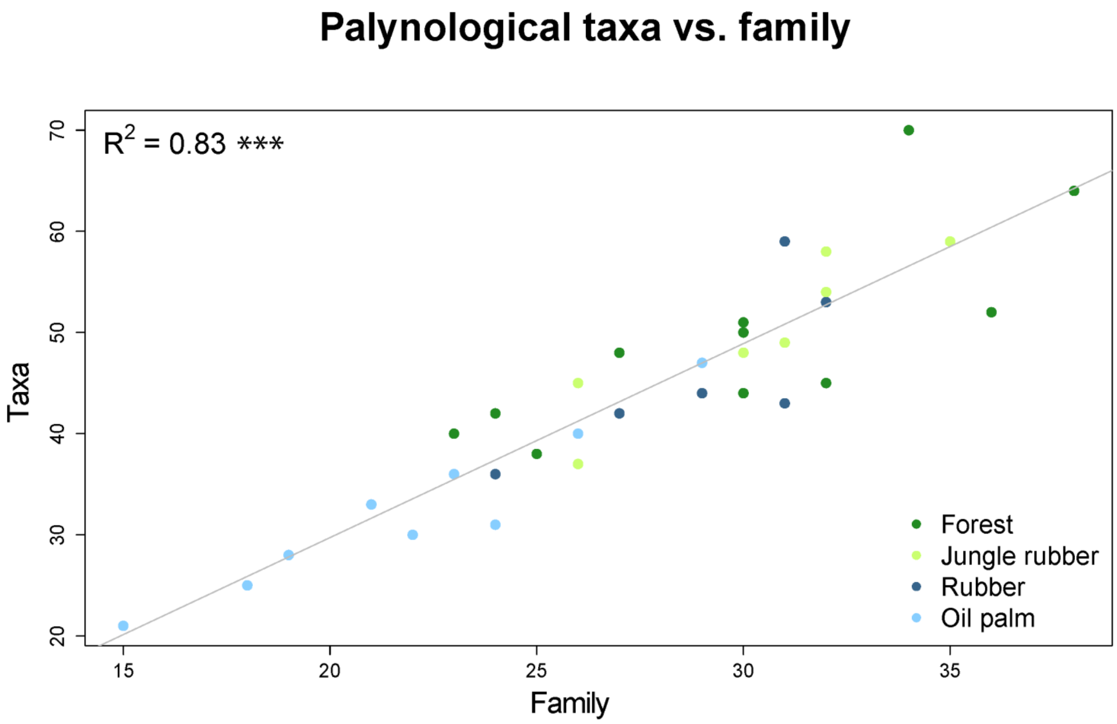
Complete palynological diagram for pollen/spore taxa and family

Appendix 4

Results of the regression analysis

Results of the correlation between pollen family and taxa. R^2, p-value and the equation are given for all land use systems together and separately for Forest, Jungle Rubber, Rubber, Oil Palm.

landuse system	R^2	p-value	equation
all systems together	0.83	0.0000	y=-8.635 X + 1.918
Forest	0.65	0.0009042	y = 0.588 X + 1.633
Jungle	0.86	0.0008323	y = -16.043 X + 2.178
Rubber	0.78	0.06507	y = -16.246 X + 2.152
Oil Palm	0.91	0.0000	y = -6.241 X + 1.762



Linear regression between pollen taxa vs. pollen family. Different colors indicate different land use systems: dark green= Forest, light green=Jungle Rubber, dark blue=Rubber, light blue=Oil Palm.

Appendix 5

a)  b) 

Example of the effect of different managements in Oil Palm plantations, a) a cleared Oil Palm plantation and b) a Oil Palm plantation with high understorey.

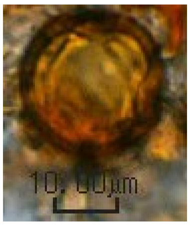
Appendix 6:

Images of selected pollen grains (family order)

A

Anacardiaceae

1) *Mangifera caesia type*



2) cf. *Mangifera*

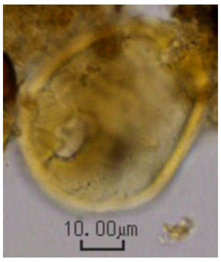
3) *Semecarpus*

Annonaceae

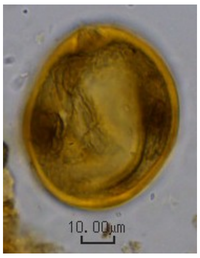
4) Annonaceae *indif.*

Apocynaceae

5) *Allamanda carthartica*



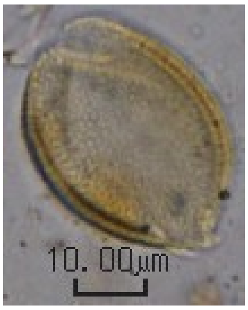
6) Alstonia



7) *cf. Holarrhena*

8) *Parsonia*

Arecaceae



9) Aracaceae indif.

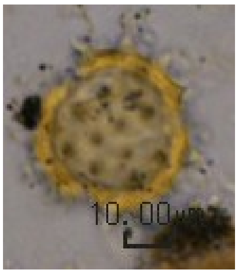
10) *Areca*

11) *Elaeis guineensis*

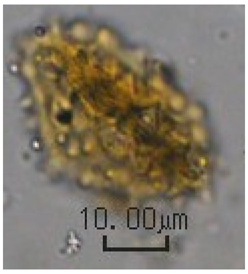
12) *Oncosperma*

B

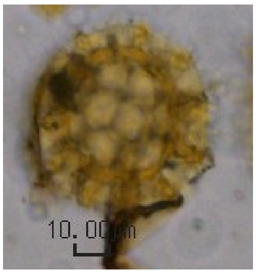
Asteraceae



13) *Ageratum*



14) *Crassocephalum*



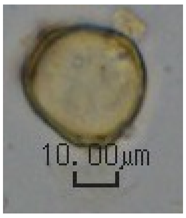
15) *Vernonia glabra*

Burseraceae

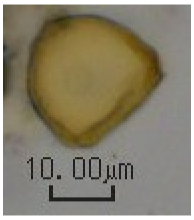
16) *Canarium*

C

Cannabaceae



17) *Gironniera*



18) *Gironniera-Celtis*

19) *Trema*

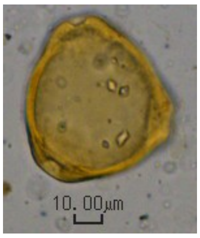
Capparidaceae

20) *Capparis*

Caprifoliaceae

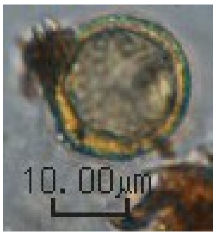
21) *Lonicera*

Casuarinaceae



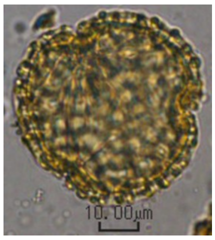
22) *Casuarina*

Connaraceae



23) *cf. Agelaea*

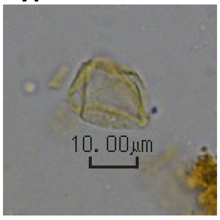
Cucurbitaceae



24) Cucurbitaceae *indif.*

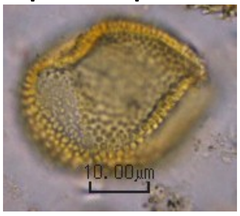
D/E

Cyperaceae



25) Cyperaceae *indif.*

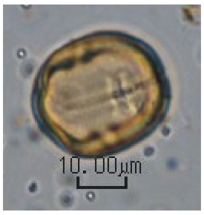
Dipterocarpaceae



26) *Dipterocarpus*

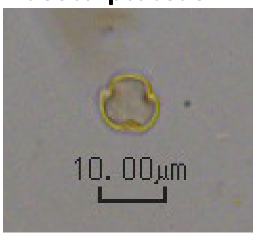
27) Diptero-carpaceae *indif.*

Ebenaceae



28) *Diospyros*

Elaeocarpcaceae



29) *Elaeocarpus*

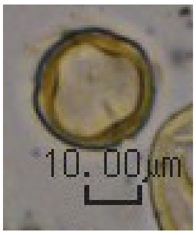
Euphorbiaceae

30) *Blumeodendron*

31) *Endospermum*

32) *Hevea brasiliensis*

F



33) *Macaranga*

Fabaceae

34) *Parkia*

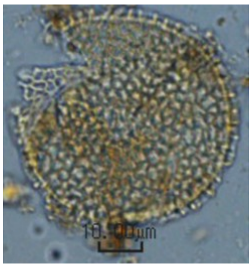
35) Fabaceae *indif.*

Fagaceae

36) *Castanopsis*

G

Gentianaceae

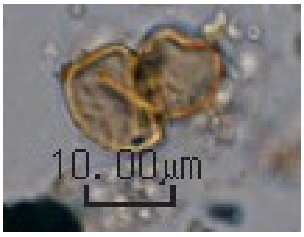


37) *Fagraea*

Gesneriaceae

38) *Cyrtandra*

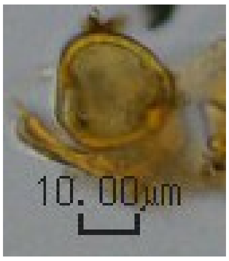
Gnetaceae



39) *Gnetum cuspidatum*

I-M

Irvingiaceae



40) *Irvingia malayana*

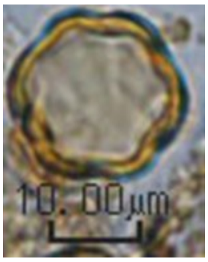
Loranthaceae

41) *Macroselum*

Malvaceae

42) *Durio*

Melastometaceae

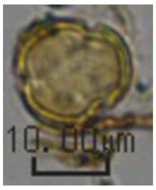


43) *Melastoma malabrathicum*

44) Melastometaceae *indif.*

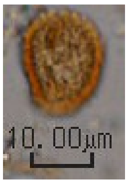
Menispermaceae

45) *Stephania*



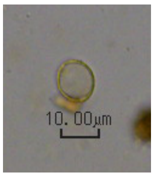
46) *Tinomiscium petiolare*

Monimiaceae



47) Monimiaceae *indif.*

Moraceae



48) *Artocarpus*

49) *Ficus*

50) *Ficus fulva*

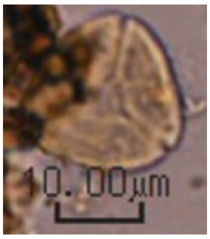
Moraceae-Urticaceae

51) Moraceae-Urticaceae

O/P

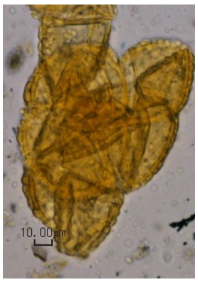
Myrtaceae

52) Myrtaceae *indif.*



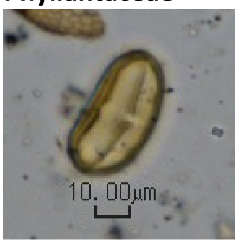
53) *Syzygium*

Orchideaceae



54) Orchideaceae *Indif.*

Phyllantaceae



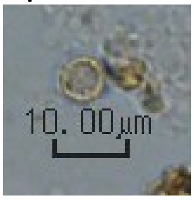
55) *Antidesma*

Piperaceae

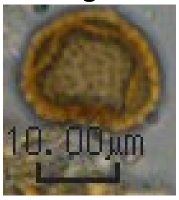
Plantagiaceae

56) *Aporosa*

57) *Baccaurea*



58) *Piper*

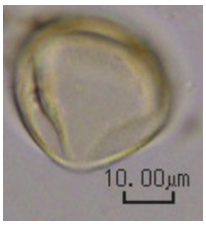


59) *Plantago*

R

Poaceae

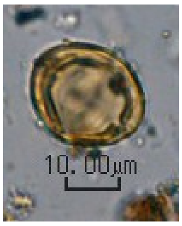
Rhamnaceae



60) *cf. Imperata*

61) *cf. Panicum*

62) *cf. Paspalum*

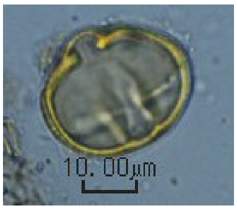


63) *Zizizphus*

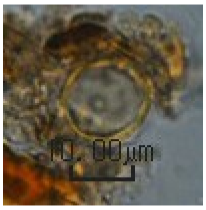
Rhizophoraceae

Rubiaceae

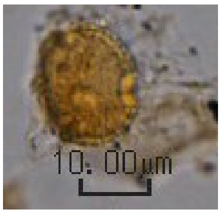
64) *cf. Carallia*



65) Rhizophoraceae *indif.*



66) *Nauclea*

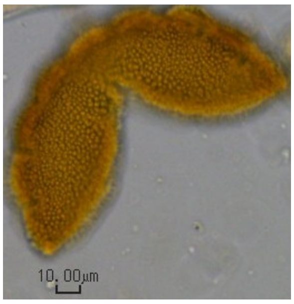


67) *Poterandia anisophylla*

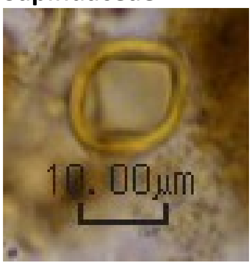
S

Sapindaceae

Sapotaceae



68) *Spermacoce*



69) *Mischocarpus*

70) *Acer*

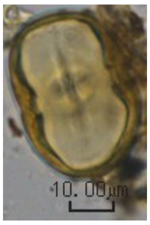
71) *Palaquium*

T

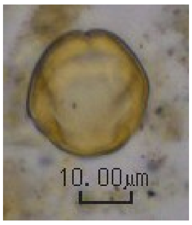
Solanaceae

Styraceae

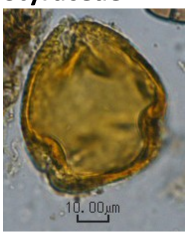
Tetramelaceae



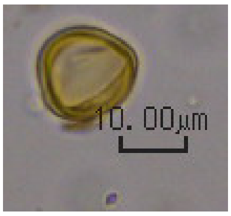
72) *Planchonella*



73) Solanaceae *indif.*



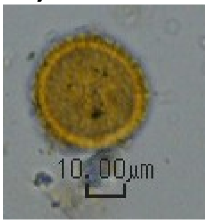
74) *Styrax*



75) *Tetrameles*

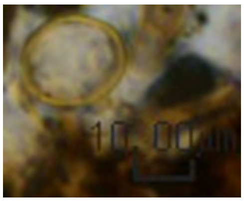
U/V

Thymelaceae

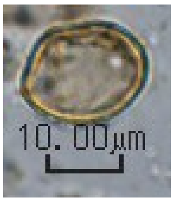


76) Thymelaceae *indif.*

Urticaceae



77) *Elatostema*



78) Urticaceae *indif.*

Vitaceae

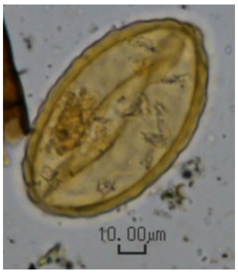
79) *cf. Leea/Trevesia*

Appendix 7

<u>Images of selected spore grains (family order)</u>

A/B

Adiantaceae

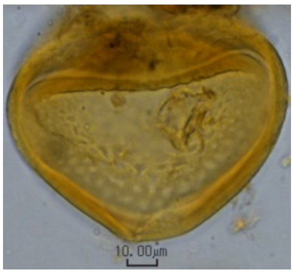


1) Adiantaceae *indif.*

Aspleniaceae

2) *Asplenium*

Blechnaceae



3) *Blechnum*

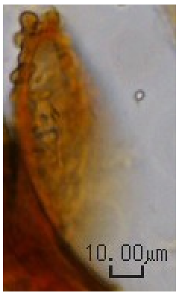
4) *Stenochlena palustris*

D-H

Dennstaedtiaceae

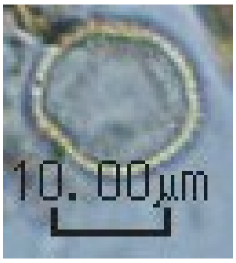
5) *Microlepia*

Dryopteridaceae



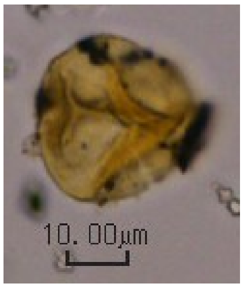
6) Dryopteridaceae *indif.*

Gleicheniaceae



7) *Dicranopteris linearis*

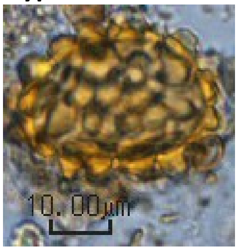
Hymenophyllaceae



8)Hymenophyllaceae *Indif.*

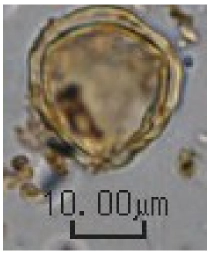
I-L

Hypodematiaceae



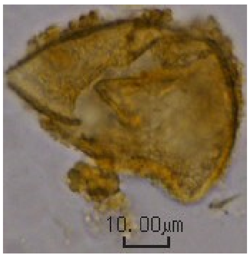
9)*Leucostegia*

Isoetaceae



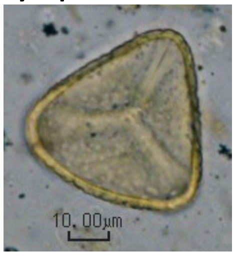
10) *Isoetes*

Lindsaceae



11) *Lindsaea*

Lycopodiaceae



12) *Huperzia*

M-P

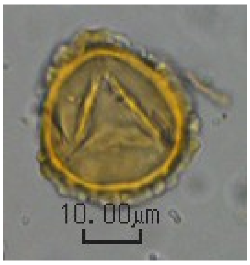
Marattiaceae

13) Marattiaceae *indif.*

Nephrolepidaceae

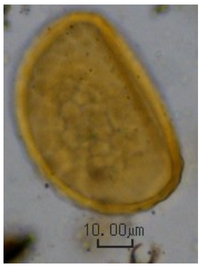
14) *Nephrolepis*

Ophioglossum



15)*Ophioglossum*

Polypodiaceae



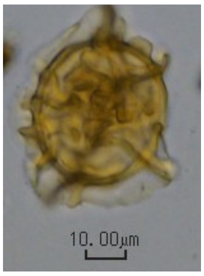
16) Polypodiaceae *indif.*

S

Pteridaceae

17) *cf. Taenitis*

Sellaginellaceae



18) *Sellaginella*

19) *Sellaginella stipulata*

Statement of Originality

I hereby declare that I composed the submitted thesis by myself without having used any other sources then the ones stated therein.

Date:______________________ Signature:______________________