GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Ecosystem services provided by epiphytic plants in rainforest transformation systems of Sumatra, Indonesia

M.Sc. Thesis

Agriculture - Ressourcemanagement

By **Dominik Ganser**

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Supervisors:

Prof. Dr. Teja Tscharntke

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Accomplished at the Department of Agroecology

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1 Abstract

The expansion of oil palm (*Elaeis guineensis*) plantations results in a serious loss of biodiversity and associated ecosystem services. Protecting last remnants of primary forest may be a strategy to protect biodiversity, enhancing biodiversity due to counteract negative aspects in an already cleared forest can be another. In this study, I examine the role of epiphytes inhabiting oil palm trunks and their possible influence on arthropod and more specifically ant (Hymenoptera Formicidae) communities in oil palm plantations in Jambi province, Sumatra, Indonesia. Moreover, this study considered the possible effects of the plantation edge habitats on epiphytes and associated arthropod communities. Finally, I investigated the ecosystem service of decomposition in the leaf axils of the oil palm trees. Samples of soil were taken out of the leaf axils of eighty oil palm trees at two different heights (2 metre, 4 metre), located half at the centre and half at the edge of eight plantations (n=160). With the help of Winkler extractor's arthropods were separated from the soil and later analyzed in the laboratory. Litter bags were placed in each of the sampled centre trees and the mass loss after two and four months were determined. In this study I did not find that epiphytes influence associated arthropod communities or more specifically Formicidae communities. However, oil palm trees at the edge of plantations host more arthropod and ant individuals and higher arthropod taxa richness than oil palms in the centre of plantations. Moreover, the amount of organic matter and the height where the arthropod samples were taken on the oil palm tree was also important predictors of arthropod community structure. Additionally, decomposition rate after four months were significant lower with high ant abundance, indicating that predatory ants may influence the work of decomposing arthropods. These results show the importance of studying the interaction of functional groups more deeply and promote the need of patches different from oil palm to raise the heterogeneity of the landscape and to enhance the biodiversity of otherwise simplified landscapes.

2 Introduction

The intensification and expansion of agriculture associated with rapid land use change is seen as the greatest threat for biodiversity worldwide (Donald 2004; Fitzherbert et al. 2008; Danielsen et al. 2009). For many species it is not possible to survive in simplified ecosystems with regular human disturbance (Koh 2007). Additional land for agriculture is sparse worldwide and the demand for agricultural products will further increase (Hansen et al. 2009; FAO 2009). In particular the market for vegetable oils to fulfill food, cosmetic and biofuel markets in Europe or food demand in China and India is expanding rapidly (Basiron 2007; Danielsen et al. 2009, FAO 2009). The production of oil palm (*Elaeis guineensis*) in particular, as the highest yielding vegetable oil crop per unit area (Donald 2004) has increased by 55% between 2001 and 2006, mostly due to the expansion of area cultivated (FAO 2009). A hot climate with high rainfall during the year, together with lowland areas in most of Southeast Asia meets oil palm’s needs perfectly (Fitzherbert et al. 2008). In particular, Indonesia and Malaysia alone produce 80% of global palm oil (Koh and Wilcove 2007). At the same time Southeast Asia is one of the world´s most biodiverse regions (Sodhi et al. 2009). It harbors unique biodiversity with a high variety of globally endemic species (Myers et al. 2000; Koh and Wilcove 2007). Hence there is an overlap of areas suitable for oil palms plantations and those with importance for biodiversity.

Tropical rainforests are the most biologically diverse terrestrial ecosystem on earth and Indonesia hosts 11% of the remaining tropical rainforests in Southeast Asia (Koh and Wilcove 2007). But since the 1970s Indonesia has experienced a rapid land use change (Hansen et al. 2009) with primary forest being transformed to large scale monocultures plantations such as rubber and oil palm (Danielsen et al. 2009). In particular, Sumatra and Kalimantan lost ~40% of lowland forest from 1990 until 2005 (Fitzherbert et al. 2008). Since 2007 plantation expansion directly contributed 27% of regional deforestation in Indonesia (Carlson et al. 2012). Furthermore the projections of additional land demand for palm oil production in 2020 range from 10 to 28 Mha (Wicke et al. 2011). The mostly negative consequences of forest transformation for biodiversity have been described in several studies (e. g. Tscharntke et al. 2005; Fitzherbert et al. 2008; Koh & Wilcove 2008; Danielsen et al. 2009). Land-use change, which turns forest into cropland such as oil palm plantations, leads to a simplification of habitats. For example, plantations have a more uniform tree age structure, sparse undergrowth and higher human disturbance than primary forests (Peh et al. 2006; Danielsen et al. 2009), which can lead to a much lower species richness in plantations than in forest (Fitzherbert et al. 2008).

A group which is highly affected by land use change is arthropods. With 6.1 million species, arthropods are the most dominant group and host the majority of biomass in tropical regions (Basset et al. 2012). The simplification of habitats have crucial negative impacts for various taxa such as bees (Liow et al. 2001), butterflies (Dumbrell and Hill 2005) or ants (Fayle et al. 2010), because there are less nesting sites or food resources available. However, arthropods are crucial in an ecosystem and provide numerous services such as pollination, decomposition, soil turnover, pest predation or providing a food source for predators (Agosti and Alonso 2001; Turner and Foster 2008; Fayle et al. 2010). Decomposition is a particulary important service to increase soil fertility and microbial activity (Moradi et al. 2014). The transformation of complex organic compounds by detritivorous organisms into accessible organic and inorganic compounds available for plants, which also provide habitat for many arthropod taxa (Stuntz et al. 2002), shows the complex suite of interactions between organisms. Whereas abundance of arthropod individuals or their species richness describe a community in numbers and their diversity, decomposition rates can provide a direct relation between biodiversity and ecosystem services (Huhta 2007).

Although plantations are generally bad for biodiversity, one aspect that could potentially increase their potential to harbor biodiversity are epiphytes. Fayle et al. (2010) have shown that the epiphytic plant species *Asplenium nidus* (bird nest fern’s) on oil palm trunks house almost the same number of ant species compared with rainforests and therefore can be seen as possible refuges for organisms in otherwise simplified habitats. Moreover they can be crucial for nutrient cycle regulation and can influence microclimatic conditions in tropical habitats (Díaz et al. 2010). This is due to epiphyte species providing a stable microclimate in otherwise hot and dry plantations through their ability to buffer variation in temperature and water evaporation (Freiberg 2001). These abilities are potential ecosystem services for organisms such as arthropods (Stuntz et al. 2002). Epiphytes are characterized as plants using other (non-parasitical) plants as growing sites (Benzing 1990; Nieder et al. 2001). They are distinguished as highly specialized growth forms for living in the forest canopy (Zotz 2013). Epiphytes are key biodiversity indicators for tropical regions, because they are easily identified and, even more importantly, sensitive to microclimatic change (Turner and Foster 2008; Sodhi et al. 2010; Wilcove et al. 2013). For many farmers epiphytes in oil palm plantation are seen as obstacles for harvesting (Koh 2008) and therefore most farmers remove them either by cutting or by the use of herbicides (pers. observation). However, by encouraging the growth of epiphytes on oil palm trunks it may increase habitat heterogeneity in these highly simplified hectare wide or larger monocultures (Hansen et al. 2009). The presence of more varied habitats within these landscapes could lead to alternative resources for arthropods, a higher spillover of individuals and the presence of edge species (De Vries et al. 1997; Gibson et al. 2006; Koh 2008).

There is little known about the interaction between epiphytes and the arthropod communities in oil palm plantations. Although there have been a few studies investigating theses interactions, previous studies have either focused only on the epiphyte species bird´s nest fern *Asplenium nidus* (Turner and Foster 2008; Fayle et al. 2010), or the majority studies in oil palm plantations have concentrated on ground dwelling (Lucey and Hill 2012; Bruehl 2001) or canopy arthropods (Philpott et al. 2006; Bos et al. 2007).

Here, I examine the role of epiphytes inhabiting oil palm trunks and their possible influence on arthropod and more specifically ant (Hymenoptera Formicidae) communities. Moreover, this study considered the possible effects of the plantation edge habitats on epiphytes and associated arthropod communities. Finally, I investigated the ecosystem service of decomposition in the leaf axils of the oil palm trees. This research attempts to conclude how management and conservation strategies could be encouraged to counteract negative aspects in highly simplified ecosystems such as oil palm plantations. I hypothesize that high epiphyte cover on oil palms provide a higher abundance and more diverse community structure of arthropods and in particular of ants. This would also result in a higher decomposition rate reflecting higher organism activity. Moreover, I hypothesize that there is a higher abundance of arthropods in oil palms at the edge rather than at the center of plantations due to a higher species exchange with other habitats.

3 Methods

3.1 Study area

The research was conducted in two landscapes within Jambi province, Sumatra, Indonesia. These landscapes were adjacent to the Bukit Duabelas National Park and the Harapan rainforest. Located in central Sumatra, Jambi Province has a tropical climate with a potential vegetation of tropical lowland rainforest, which is said to be one of the most diverse and complex ecosystems on earth (Whitten et al. 2000). But due to change of land use in the past decades, Sumatra has lost huge areas of its rainforest (Hansen et al. 2009). In the last 20 years oil palms has become one of the most dominant agricultural systems in Sumatra.

3.2 Study design

In each of the two landscapes four replicates of oil palm plantations were investigated (Figure 1). The plantations were selected in dry lowland areas (below 400m above sea level), with similar soil conditions and similar oil palm tree age (15 years). All plantations are owned by smallholders, who continued their usual management of the plantation during the research. The management consists of manual removal of epiphytes; harvesting every two weeks and the application of herbicides, insecticides and fertilizer. Herbicides and insecticides were applied to the ground and to the oil palm trunks. The timing and quantity of applications differed between plantations.

In each plantation ten oil palm trees were chosen, five oil palm trees at the center of a 50 m x 50 m set research plot and five at the edge of the plantation (Figure 1). In order to be able to investigate the role of neighboring vegetation on biodiversity and decomposition, we selected plantations which had different types of non-oil palm vegetation types bordering the plantation. Possible categories for edge vegetation types were: weedy rubber, jungle rubber, secondary forest or scrub. Where it was not possible to find such a category bordering the plot, the nearest possible edge to the plantation was investigated.

To be selected, an oil palm had to fulfill three characteristics: (i) trunk height of at least six metres, (ii) distance to another selected oil palm of at least ten metres and (iii) no visible damage. Moreover to be chosen as a center oil palm, there had to be at least twenty metres from the edge. In total eighty oil palm trees were randomly chosen within the eight study plantations.

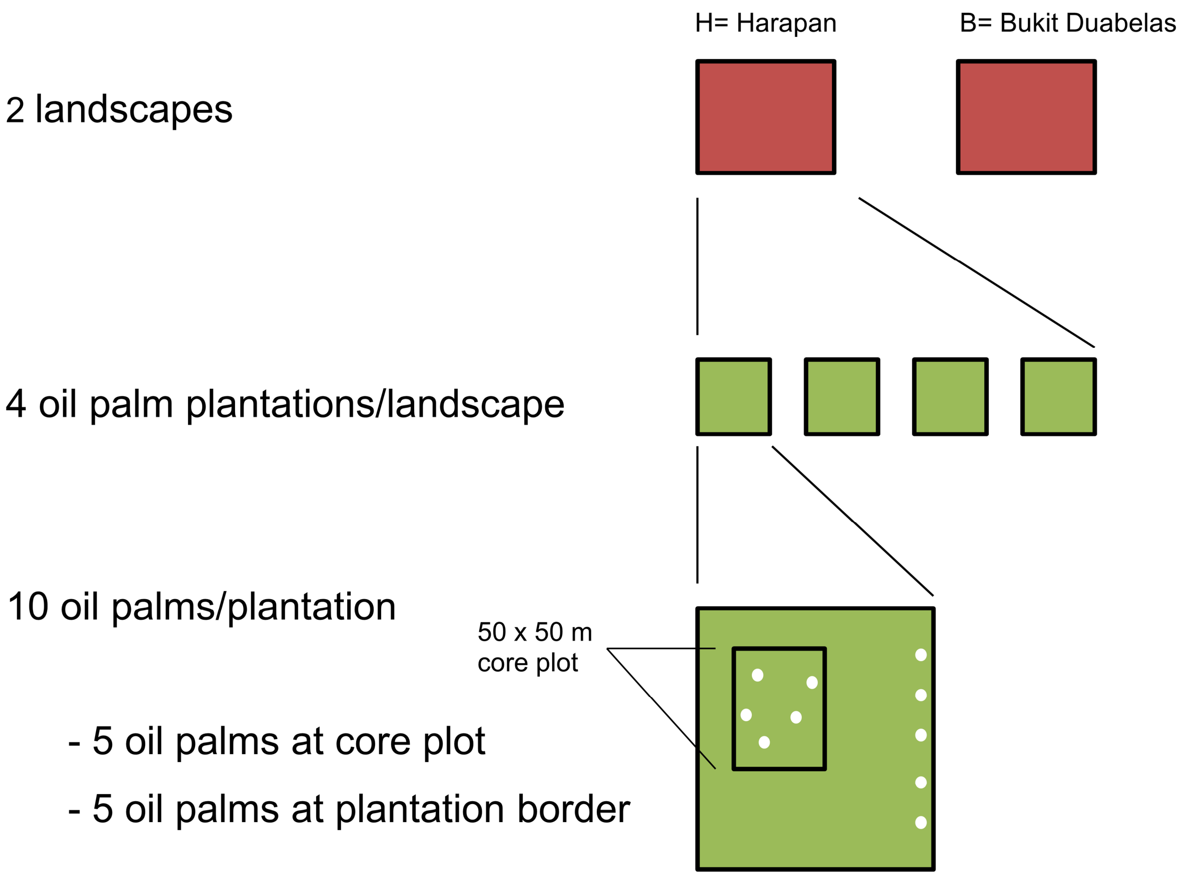

Figure 1. Schematic structure of the study design.

3.3 Data collection

3.3.1 Measurement of vegetation variables

For every oil palm studied, a data set was put together, including photographs of each tree. The vegetation variables identified were (i) epiphyte cover, (ii) epiphyte species and (iii) ground cover. Epiphyte cover was defined as the proportion of vascular plants covering the oil palm trunk. A scale from personal evaluation from one (low) to six (high) was used (Appendix 5). For the epiphyte species, the type and abundance of all epiphytes on the oil palm were visually scanned, identified and noted down. Just the five most common epiphytic and accidental epiphytic plants were noted following 'Common wayside plants of Sumatra' composed by Dr. Katja Rembold. Unknown species were not taken into account. The ground cover is the proportion of ground next to the oil palm within a two metre radius covered by other plants and shrub as an indicator for herbicide use. A scale from 1 (low) to 3 (high) from personal evaluation was used (Appendix 5).

3.2.1 Arthropod sampling

The samples and data was collected during the dry season from May to June 2014. The sampling of arthropods was always conducted at the same time of the day (11:00-13:00) to have similar microclimate conditions. At two heights (2m, 4m) one litre of organic matter was taken from inside the leaf axils of 10 oil palms per plot (5 centre, 5 edge). In total there were 160 samples. In the case of there not being one litre of organic matter in one leaf axil, more leaf axils at the same height were sampled. The organic matter was transported to the laboratory in cotton bags. There, the samples were sieved with a wire sieve with a mesh width of 10 cm.

After sieving the samples, they were weighed to gain the wet weight of each sample. Following this, the finer sieved portion of the organic matter was put into Winkler extractors.

These extraction method is a established method to separate arthropods from leaf litter or the organic matter (Agosti and Alonso 2001). The organic matter was placed into elastic 6-mm mesh inlet bags, which were suspended inside the Winkler sack (Agosti et al. 2000). At the bottom of these, a falcon tube filled with 100 ml 75% ethanol was placed (Besuchet et al. 2011). Organisms in the soil migrating from the inlet sack fall down and were collected in the falcon tubes.

After 72 hours the soil was removed and checked again. An extraction time of 72 hours is sufficient especially for ants (Kalif and Moutinho 2000; Krell et al. 2005), however, to get a better result, each sample was checked again by hand. The organic matter from each sample was put separately into an oven for 48 hours days at 80°C and weighed again to obtain the dry weight of the organic matter. The moisture content of the soil was calculated as a percentage of dry organic matter:

$$MC\% = (WW - WD) / WD \times 100$$

where: WW = Mass wet organic matter WD = Mass dry organic matter

Arthropods were then identified to order in the laboratory using binocular microscopes and the key ‘Hymenoptera of the world’ (Goulet and Huber 1993). The different taxa of arthropods were then defined into functional groups (i) omnivore, (ii) herbivore, (iii) detrivore and (iii) predator. The ants (Hymenoptera Formicidae) were furthermore identified to genus and then to morphospecies level using ‘Key to the workers of the 100 ant genera and 12 ant subfamilies of Borneo in English and Malay‘ by Fayle et al. (2010). The ant genera were further defined as (i) predatory or (ii) not predatory using General & Alpert (2012).

3.2.2 Measurement of decomposition rate

To determine decomposition rate in the oil palm leaf axils I placed litter bags in each of the five centre oil palm study trees (described above) at each plantation. Edge oil palms were not sampled due to the fact, that they were not within the core project plot and it could not be guaranteed they would be left untouched for a long time period. In each oil palm I put 12 litter bags at two heights (2 m and 4 m). In total there were 480 litter bags. The litter bags were left for two time periods, taking six from each location after two months, and six after four months.

The litter bags were 10 x 10 cm with a mesh size of 2 mm and were filled with 3 grams of dried epiphyte leaves. The species *Nephrolepis acutifolia* was used for the reason that it was the most common epiphytic species found in all sampled plantations. The leaves were dried for 48 hours at 60°C. The litter bags were marked, weighed and put into the leaf axils and fixed with pins. After removal from the trees the leaves from the litter bags were dried to a constant weight in the laboratory at room temperature and weighed again. Decomposition rates were calculated using exponential decay function (Olson 1963):

$$W = W_0 \exp(-kt)$$

where: W = *amount dry matter remaining at time* t; W_0 = *initial amount dry matter;* k = *decomposition rate*

3.3 Statistical analyses

Means and standard deviations were calculated for numbers of individuals and species, and higher ranked taxa. Species and higher ranked taxa accumulation curves were used to find out if the sampling effort was sufficent to find all species and higher ranked taxa of the study area (Magurran 2004) using the R package vegan, version 2.0-9 (Oksanen et al. 2013).

I tested oil palm parameters (epiphyte cover, epiphyte species richness, location (centre/edge), height, dry organic matter, moisture content) on (i) total arthropod abundance,

(ii) arthropod abundance with Formicidae excluded, (iii) Formicidae abundance, (iv) arthropod taxon richness, and (v) Formicidae genus richness (n=160) using linear mixed effect models (LME). Moreover, I tested oil palm parameters (without location) and above described community parameters on (i) decomposition rate after 60 days and (ii) 120 days using LMEs (n=80). Plantation and oil palm tree functioned as random effects for all models. The natural logarithm ($\log_e$) was calculated for the response variables (+1 due to some zero abundance) as they did show no normal distribution. I hypothesized that epiphyte cover would influence arthropod and ant abundance and richness significantly and moreover that trees at the edge of the plantation have a higher abundance of both taxa and Formicidae genera. LMEs were implemented within the nlme package in R (Pinheiro et al. 2013) and were refitted with maximum likelihood (ML). To determine significance, P-values were used from the output table given by the anova of the LME model. All data was analyzed in R version 3.0.3 (R Development Core Team 2008).

4 Results

4.1 Arthropod, Formicidae and epiphyte community in the study system

In total 6929 arthropod individuals were found over all plots (n=160). The individuals were identified to 34 taxonomic groups (Appendix 1, Table 1). The most abundant group was Hymenoptera (4516, 65% of total arthropod abundance), 99% of which were Formicidae. Aside from Hymenoptera Formicidae, the groups with highest proportion of total community abundance were Isopoda (403, 17%), Collembola (326, 14%), Araneae (240, 10%), Dermaptera (204, 8%) and Arcari (183, 7%). There were more individuals in Bukit Duabelas landscape (61%) than in Harapan landscape (39%). The taxonomic groups Isoptera, Amphipoda, Squamata and Protura were found only in the Harapan landscape, whereas Scorpio and Pauropoda were only in the Bukit Duabelas landscape. The mean abundance of arthropods excluding ants was 15.11 ± 19.84 per sample and a taxon richness of 5.84 ± 3.18 per sample (Appendix 1, Table 1). There were sixteen arthropod taxon defined as omnivores (43% Formicidae excluded), six detrivores (35% Formicidae excluded), four predators (13% Formicidae excluded), and five herbivore (4% Formicidae excluded). The taxon accumulation curves pass into saturation phase suggesting that sample completeness of arthropods was comparatively high (Figure 2).

A total of 4516 Formicidae individuals were found in the collected samples, representing seven subfamilies and 42 genera (Appendix 1, Table 2). The subfamily with the highest representation was Myrmicinae (73%), followed by Dolichoderinae (10%) and Ponerinae (7%). The most common genus was Proatta with 734 individuals (16%), followed by Pheidologeton with 540 individuals (12%), from which 98% were found in Bukit Duabelas landscape. The average number of individuals per sample was 28.23 ± 44.4 with an average genus richness of 3.21 ± 1.99 per sampled plot (Appendix 1, Table 3). The abundance per sample ranged widely, from 0 to 338. There were nine Formicidae genera (42% of total

Formicidae individuals) with predatory feeding behaviour, and the others were detritivores (Appendix 1, Table 2). The genus accumulation curve passes into saturation phase suggesting that sampling effort almost fully captured the richness of Formicidae community (Figure 2).

The most common epiphytes species in the plots were *Nephrolepis spec*., *Asplenium longissimum*, *Goniophlebium percussum*, *Vittaria ensiformis* and *Vittaria elongata*. The species *Nephrolepis spec*. was found in all plots. Moreover there were three accidential ephiphytes found: *Elaeis guineensis*, *Clidemia hirta* and *Asystasia gangetica*. The average species richness of the most common epiphyte and accidential epiphyte species was 4.45 ± 1.78 per plot (Appendix 1, Table 3).

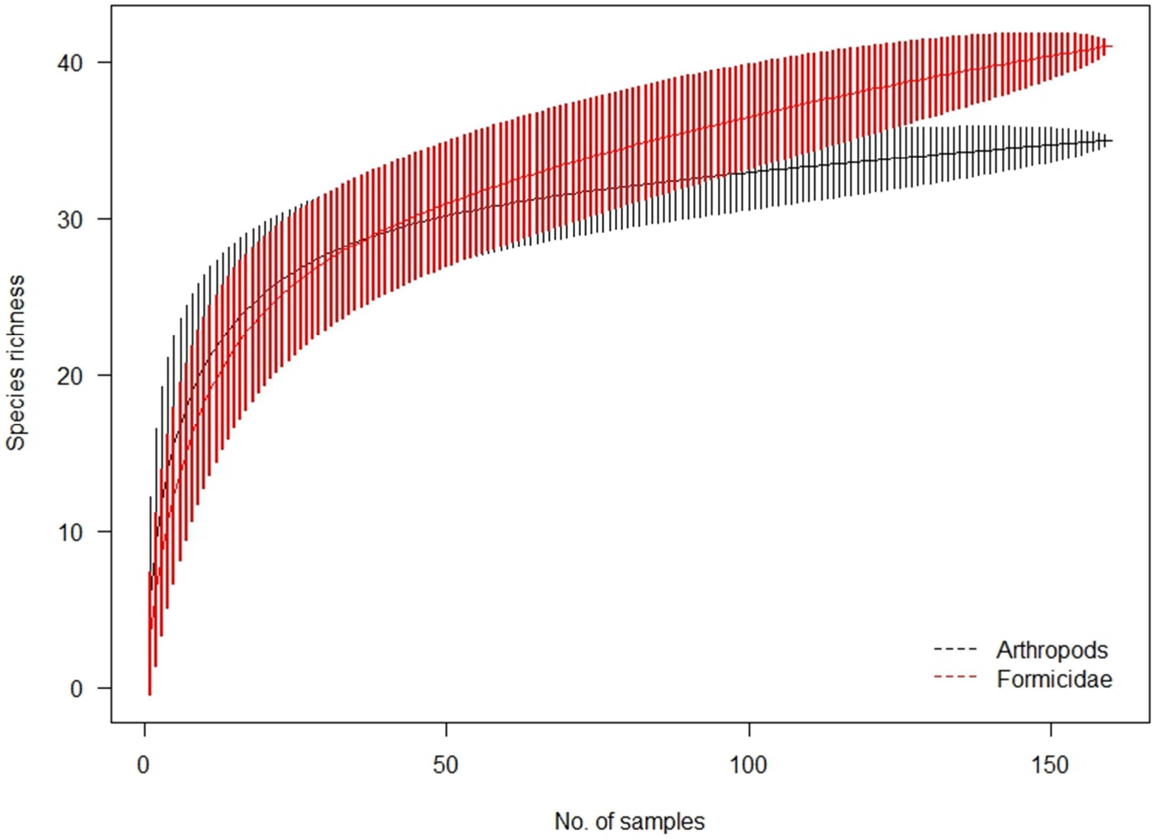

Figure 2. Genus (and higher-ranked taxon) accumulation curve for all samples (n=160). 100 permutations.

4.2 The effect of epiphytes and edge habitats on arthropod and Formicidae communities

Epiphyte cover did not explain variation in arthropod abundance (p-value=0.33, Appendix 2, Figure 3a) and arthropod taxon richness (p-value=0.59, Appendix 2, Figure 3c). The same is true for epiphyte species richness for arthropod abundance (p-value=0.99, Appendix 2) and taxon richness (p-value=0.77, Appendix 2). Also, both epiphyte cover (p-value=0.27, Appendix 2, Figure 3b) and epiphyte species richness (p-value=0.25, Appendix 2) did not explain any significant differences in Formicidae abundance or Fomicidae genus richness (p-value=0.19; p-value=0.72, Appendix 2, Figure 3d).

Significantly more arthropods were observed in edge habitats compared to centre habitats (p-value=0.0383, Appendix 2, Figure 4a). Moreover the edge habitat had a positive effect on arthropod taxon richness (p-value=0.0508, Figure 4c). I also found that there was a significantly higher abundance of Formicidae in the edge habitats compare to centre (p-value=0.0250, Appendix 2, Figure 4b), however this was not the case for Formicidae genus richness (p-value=0.72, Appendix 2 Figure 4d).

Height was positively correlated with arthropod abundance (p-value=0.0002, Appendix 2, Figure 5a), Formicidae abundance (p-value=0.0198, Appendix 2, Figure 5b) and for arthropod taxon richness (p-value=0.0492, Appendix 2, Figure 5c). However, the same pattern was not observed for Formicidae genus richness (p-value=0.22, Appendix 2, Figure 5d).

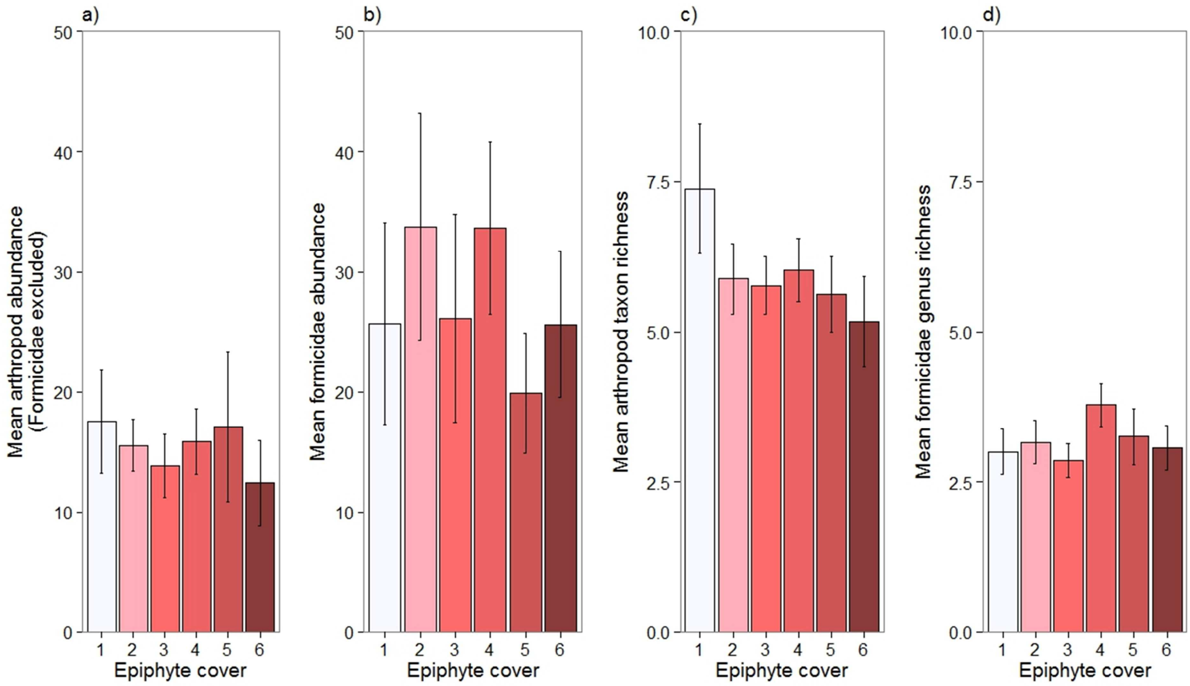

Figure 3. The relationship between epiphyte cover (1=very low, 6=very high) and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae genus richness in oil palm plantation (n=160). The error bars indicate the standard errors.

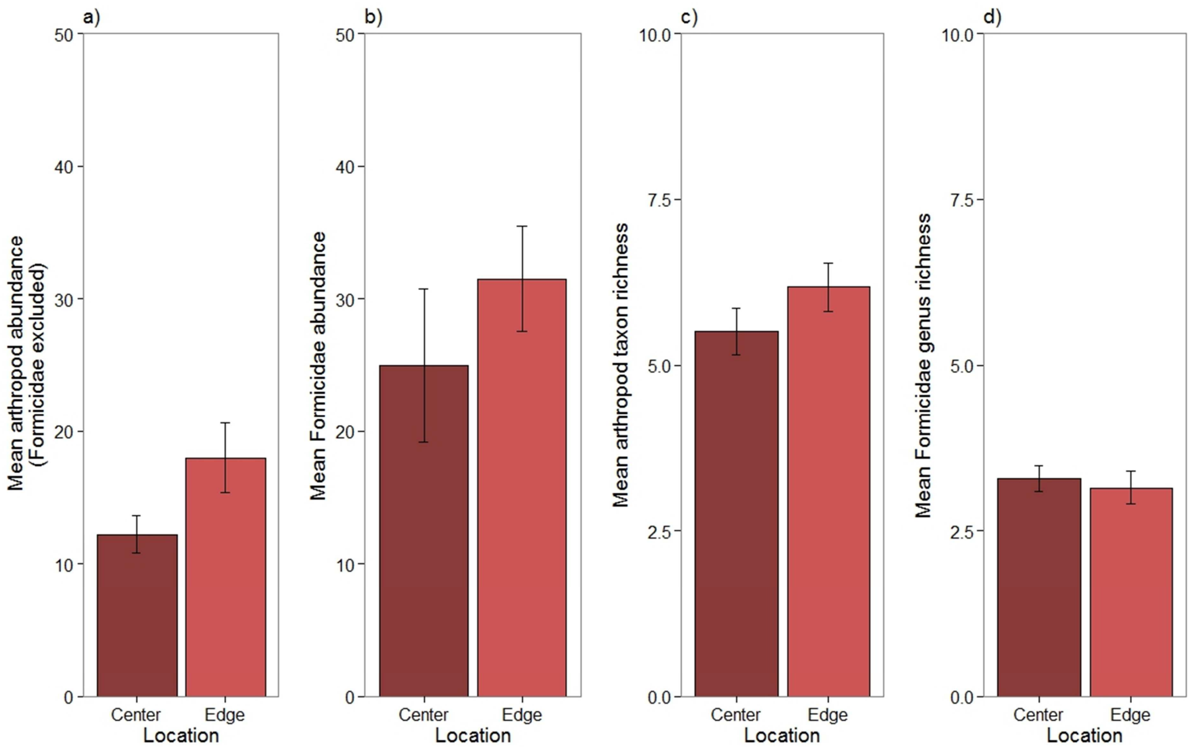

Figure 4. The relationship between location (center, edge) of oil palm trees and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae genus richness in oil palm plantation (n=160). The error bars indicate the standard errors.

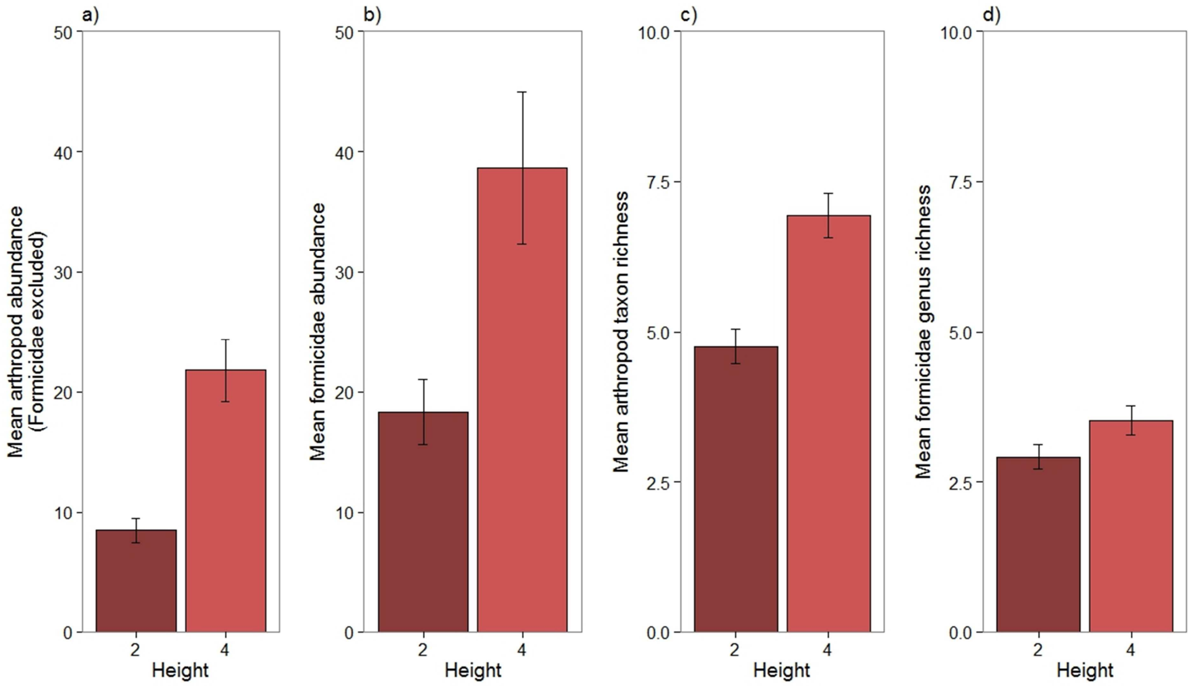

Figure 5. The relationship between height (2m, 4m) of the oil palm trees and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae genus richness in oil palm plantation (n=160). The error bars indicate the standard errors.

Increased ground cover had a significantly negative influence on abundance (p-value=0.0223, Appendix 2, Figure 6a) and taxon richness of arthropods (p-value=0.0034, Figure 6c), indicating that there are more individuals and taxa in habitats with less ground cover. However, abundance (p-value=0.68, Appendix 2, Figure 6b) and genus richness (p-value=0.24, Appendix 2, Figure 6d) of Formicidae was not dependent on ground cover.

When testing the effect of dry organic matter on genus richness of Formicidae, I found a significant variation (p-value=0.0011, Figure 7d, Appendix 2). Moreover, I found that dry organic matter had both a positive effect on the abundance (p-value<0.0001, Figure 7a, Appendix 2) and taxon richness of arthropods (p-value=0.0001, Figure 7c, Appendix 2). Finally, Formicidae genus richness can be explained by moisture content (p-value=0.03, Figure 8d, Appendix 2).

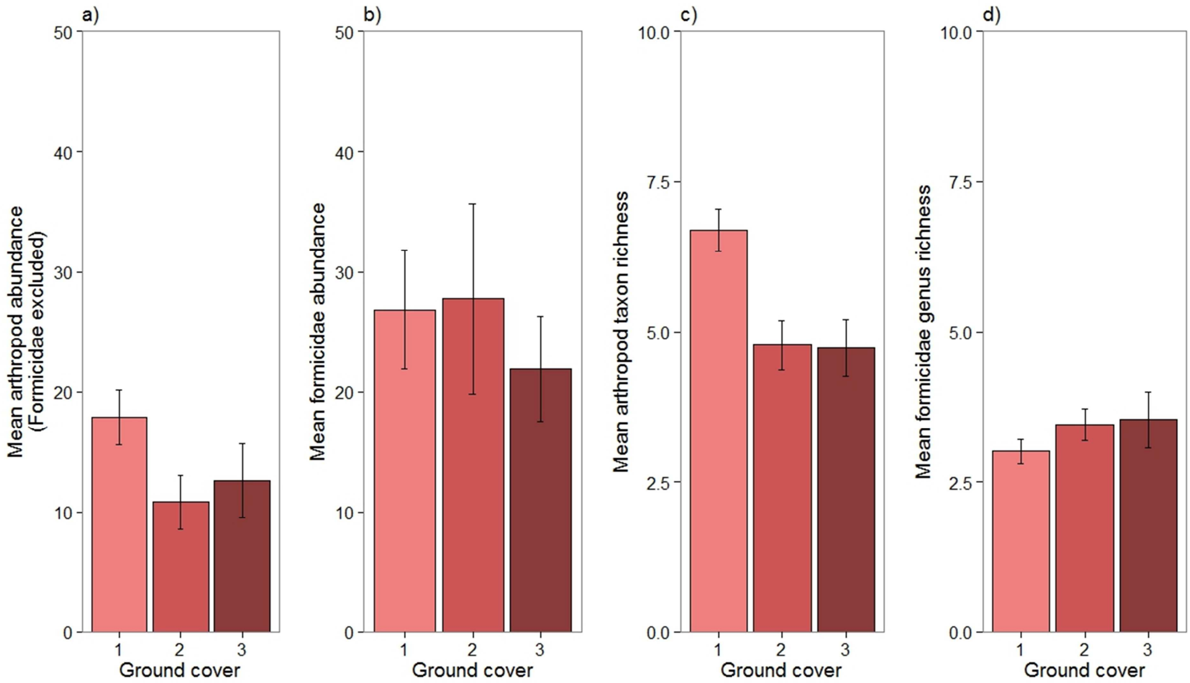

Figure 6. The relationship between ground cover (1=low, 3=high) and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae genus richness in oil palm plantation (n=160). The error bars indicate the standard errors.

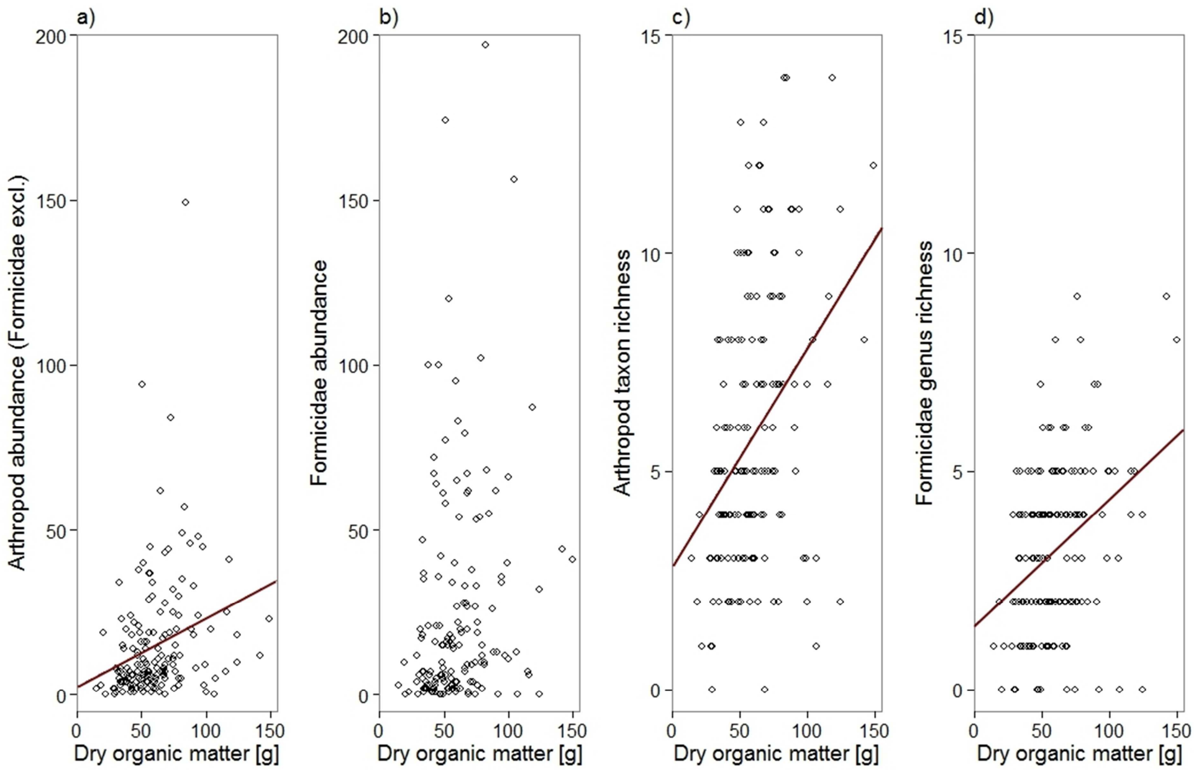

Figure 7. The relationship between dry organic matter [g] and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness, and (d) Formicidae genus richness in oil palm plantation (n=160).

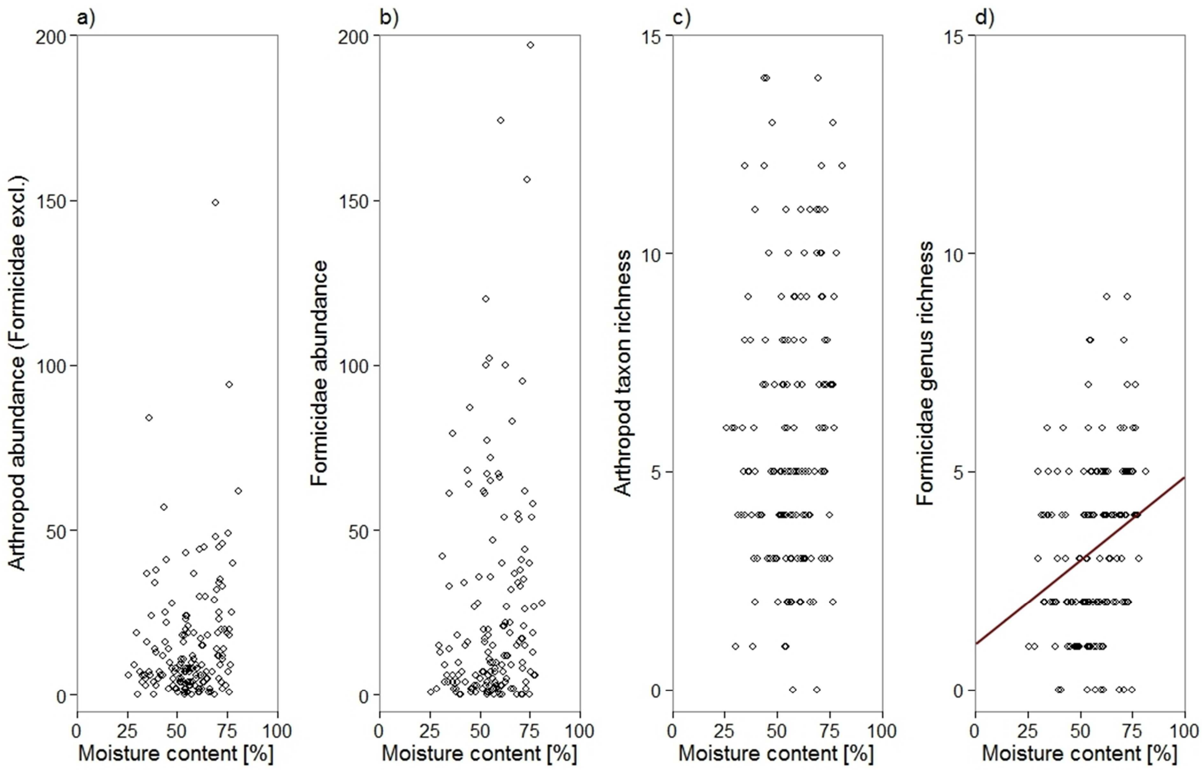

Figure 8. The relationship between moisture content [%] and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness, and (d) Formicidae genus richness in oil palm plantation (n=160).

4.3 The effect of plantation characteristics and arthropod and Formicidae communities on decomposition

After sixty days there was a mean loss of organic material in the litter bags of 1.55 ± 0.51 gram, which is loss of organic matter due to decomposition of more than half (52%). In comparison I found that there was a mean loss of organic material in the litter bags after four months (120 days) of 1.88 ± 0.47 gram (61%) (Appendix 1, Table 3). When testing the effect of oil palm characteristics on decomposition rate after sixty days, I found that dry organic matter (p-value=0.0471, Appendix 2) and moisture content (p-value=0.0163, Appendix 2, Figure 11a) did explain variation. When testing the effect of the response variables on decomposition rate after 120 days, I found that moisture content (p-value=0.0001, Appendix 2, Figure 10b) and ground cover (p-value=0.0110, Appendix 2) have both a positive effect.

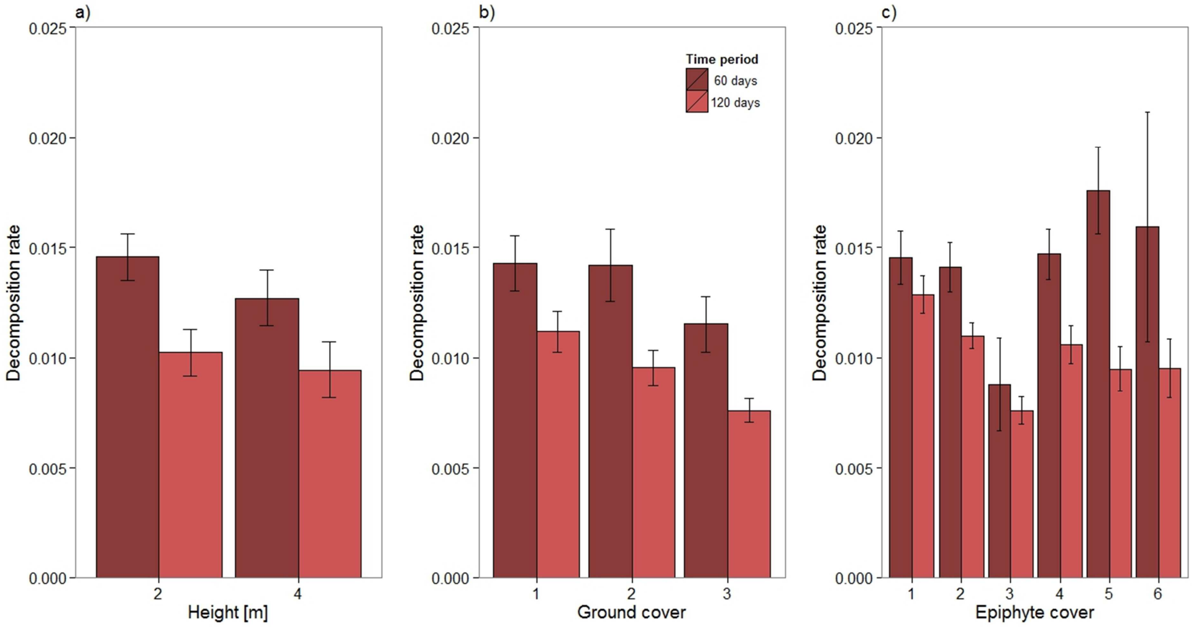

Figure 9. The relationship between decomposition rate after 60 and 120 days and (a) height (2m, 4m), (b) ground cover (1=low, 3=high), and (d) epiphyte cover (1= very low, 6= very high) of centred oil palm trees (n=80). The error bars indicate the standard errors.

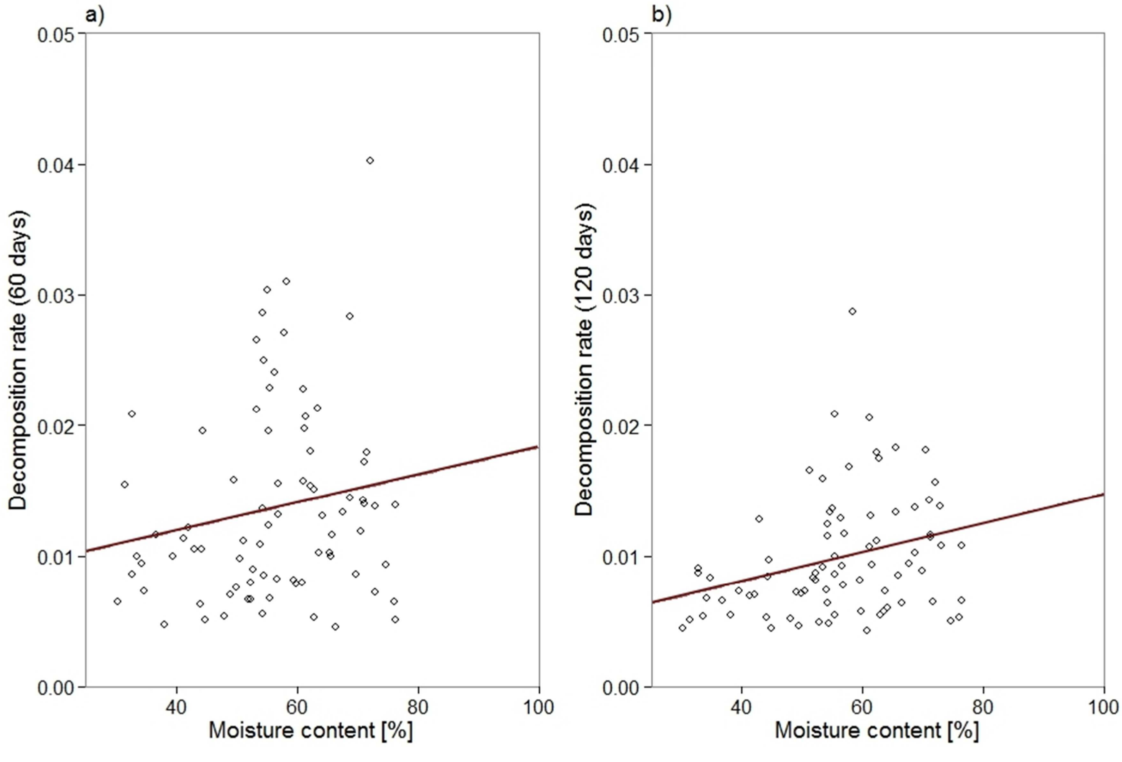

Figure 10. The relationship between moisture content [%] and (a) decomposition rate after 60 days and (b) decomposition rate after 120 days [%] in oil palm plantation (n=80).

Besides that arthropod abundance (p-value=0.17, Appendix 2) and taxon richness (p-value=0.88, Appendix 2) did not explain variation in decomposition rate after sixty days. Furthermore there were no effect of Formicidae abundance (p-value=0.71, Appendix 2) and genus richness either (p-value=0.66, Appendix 2). However, arthropod taxon richness (p-value=0.0504, Appendix 2, Figure 11a), Formicidae abundance (p-value=0.0217, Appendix 2, Figure 11c) and Formicidae genus richness (p-value=0.0318, Appendix 2, Figure 11b), though not arthropod abundance (p-value=0.24, Appendix 2), did affect decomposition rate after 120 days. When excluding predatory Formicidae from the whole Formicidae abundance, I could not find any significant effect on decomposition rate after 120 days (p-value=0.46, Appendix 2), although there is a positive trend of decomposing Formicidae on decomposition rate in comparison to total Formicidae abundance (Figure 11d). Finally, the different functional groups of arthropod taxa did not explain any variation in the decomposition rates.

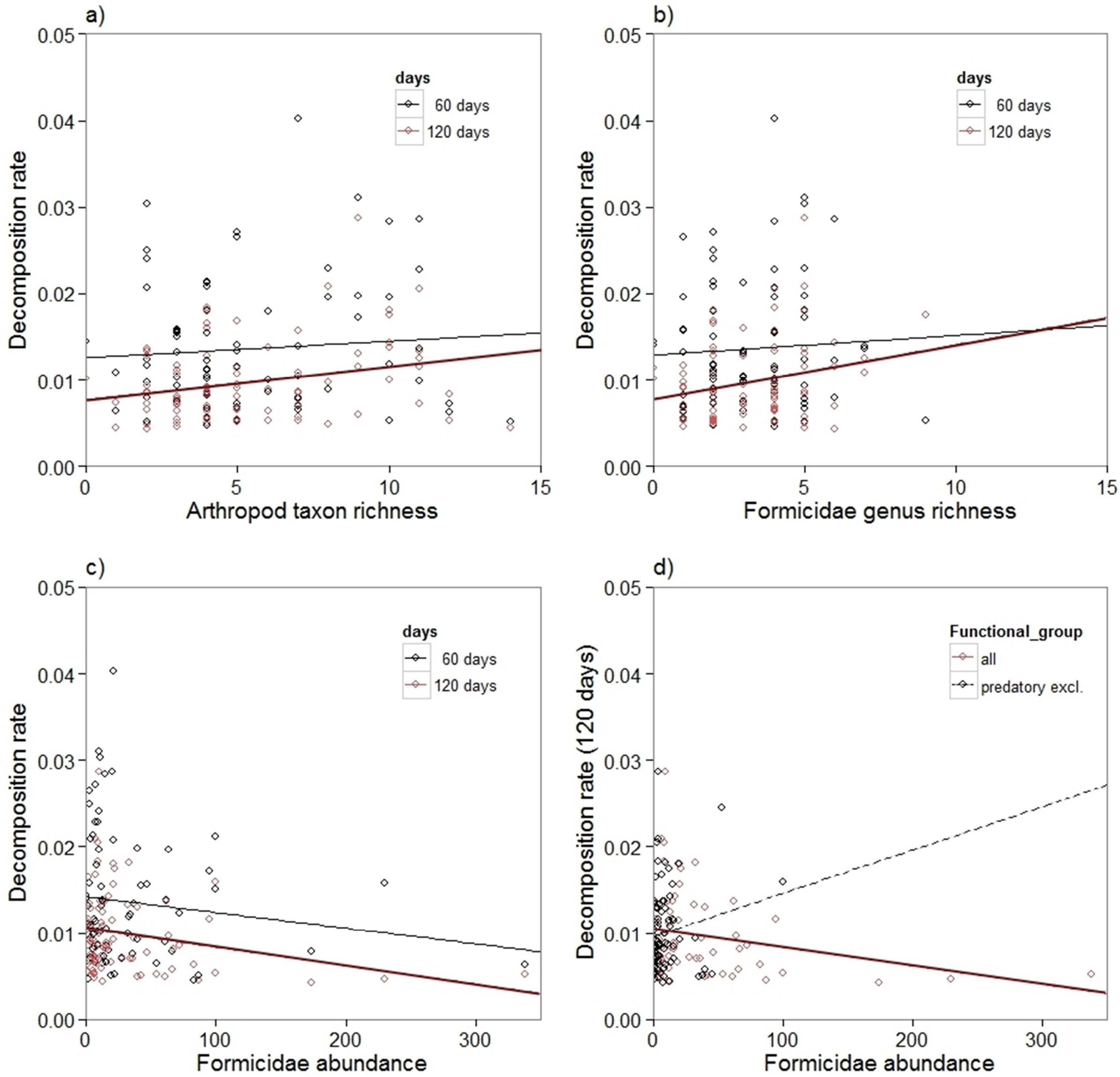

Figure 11. The relationship between decomposition rate after 60 (black) and 120 days (red) and (a) arthropod taxon richness (b) Formicidae genus richness, (c) total Formicidae abundance plus (d) decomposition rate after 120 days on Formicidae abundance and non predatory Formicidae abundance in oil palm (n=80). Dotted line shows no significant relationship.

5 Discussion

5.1 The impact of epiphytic plants on arthropod and Formicidae communities

In this study I did not find that epiphytes influence associated arthropod communities or more specifically Formicidae communities. Surprisingly, in all the tested models neither epiphyte cover nor epiphyte species diversity had an effect on the described parameters. One reason for this could be that the scale used in this study to quantify the epiphyte community may not have been accurate enough to investigate the role of epiphytic species in shaping arthropod communities. For instance, it could lead to better results, if all epiphytic individuals per oil palm tree were counted and identified individually. Another reason may be that the species composition of epiphytes in this study system was not enough to support a comparatively abundant or diverse arthropod community. The diversity of epiphytes on oil palm trees was quite low compared with what has been seen in oil palm plantations elsewhere, nearly every single oil palm shared all of their species. Possibly more importantly, however, is the identity of the species present as they can differ in their potential contribution to ecosystem services (Tscharntke et al. 2005). For instance, *Asplenium nidus* was not common in our study plots, but this species has been described as an important epiphyte species for arthropods in oil palm plantations in previous studies (Fayle et al. 2005; Turner and Foster 2008; Fayle et al. 2010). It forms little baskets with their fronds which collects falling leaves and water (Wee 2005) and provides a cool climate and shelter for arthropods in otherwise hot and dry plantations (Fayle et al. 2010).

The absence of certain epiphyte species in this study may be due to the age structure of the investigated oil palms. A previous study (Krobbach 2014) noted that the amount of organic matter in leaf axils showed a hump-shaped distribution across age classes and old oil palm trees lose their leaf bases and leave a smooth naked stem. Therefore epiphyte species and community structure changed between middle aged (like in this study) and old oil palms

(Altenhövel 2013; Krobbach 2014). Some epiphytic plant species like *Asplenium nidus* have evolved special adaptations to germinate and survive on naked trunks. Epiphytic plants may become more important in the absence of leaf axils and due to the epiphyte structure being habitat available for arthropods whereas leaf axils are absent. Therefore, the age of the oil palms in this study could have impacted both the type of epiphyte species present, the importance of epiphytes as a arthropod habitat and the amount of organic substrate available in the leaf axils as a habitat for arthropods, hence the lack of positive relationship between epiphytes and arthropods in this study.

5.2 The effect of edge habitats on arthropod and Formicidae communities

In this study I found that oil palm trees at the edge of plantations host more arthropod and ant individuals and higher arthropod taxa richness than oil palms in the centre of plantations, supporting my original hypothesis. The most common habitats neighbouring the study sites were jungle rubber and scrub which have higher habitat diversity than oil palm plantations. Although I did not have a control to compare the results when another oil palm plantation neighboured a study site, previous studies support the positive effects of more diverse habitats surrounding the plantations found in this study. Koh (2008) and Lucey et al. (2014) found that adjacent habitats may act as ‘stepping stones’ for some species normally absent in oil palm plantations, whereas monocultures of oil palm enhance the number of mostly generalist species. Also, in monocultures local extinction is a common process and immigration is of major importance (Tscharntke et al. 2005). Bengtsson et al. (2003) suggested that agricultural landscapes should be a mosaic of well connected habitats with different succession status to support high biodiversity and the ability to recover from disturbance. Moreover, my results as well as the previous research taken together provide a strong argument in support of having more patches different from oil palm in the surrounding landscape to enhance species richness in the plantations.

5.3 Arthropod and Formicidae communities influencing decomposition rates

My results showed that decomposition rate after sixty days did not show any correlation with arthropod communities or Formicidae communities. This could be associated with an insufficient time period to show variation in decomposition after sixty days. For instance, Moradi et al. (2014) describes decomposition rate as following an exponential pattern, an example of which is seen in a study by Zaharah and Lim (2000) which observed mass loss of 50% of oil palm leaves after three months or 70% after 8 months respectively. This is close to the amount in this study (52%), although not the same substrate was used.

In contrast, Formicidae abundance had a significant negative effect on decomposition rate after 120 days, and genus richness had a positive effect. The observation that mainly predatory ants were present at the plots with low decomposition rates lead to the assumption that they may have a negative influence the decomposer community. Although there was no significant difference when excluding predatory ants from the model, there is a trend towards higher decomposition rates without predatory ants. This shows the importance of looking at the composition of a community when investigating their influence on ecosystem functions (Wardle et al. 2003). Ants can have significant top down effects on arthropod fauna (Philpott et al. 2004) by certain species becoming ecologically dominant, which leads to a reduction of species richness and evenness of arthropod communities (Hölldober and Wilson 1990). Some species may exclude other species from their territory and food sources (Gibb and Hochuli 2003), which in this case could be detrivorous species which in turn influences decomposition rate. In the case of my finding that there is a significantly higher decomposition rate with a higher number of genera supports the established concept that more species can utilise resources more efficiently, because the probability of having key species is higher (Wardle et al. 2004).

5.4 The impact of oil palm characteristics on arthropod and Formicidae communities

In this study my results showed that the amount organic matter within the oil palm leaf axils plays an important role both in arthropod and Formicidae community structure. I found that the abundance of arthropods and ants as well as the genus and taxon richness showed a positive correlation with total organic matter mass. This is due to the organic matter in leaf axils being important for arthropods as a nesting substrate, food source and shelter in the hot and dry plantations. Although taxa respond differently to the amount of organic matter available (Wardle 2003). Hasegawa (2001) found the amount and composition of organic matter as the main factor influencing overall arthropod abundance in forests. In addition to the amount of organic matter, the height where the arthropod samples were taken on the oil palm tree was also an important predictor of arthropod community structure. There were more individuals of both ants and overall arthropods, as well as increased genus and taxa richness respectively higher on the oil palm tree (4 m compared with 2 m), indicating a more suitable habitat for arthropod communities. A possible explanation for this could be the interaction between organic matter and height, as there is higher organic matter accumulation at 4 m compared with 2 m. Also, higher on the oil palm may have a less stressful climate, the lower parts of the oil palm are significantly warmer and drier throughout the day (Luskin and Potts 2011). Finally, there may be a less intensive use of chemicals higher on the oil palm (pers. obs.), because spraying chemicals at a height above two metres is impractical for the plantation workers. Therefore the higher position might be less disturbed than the lower parts where a frequent use of herbicides and insecticides is common.

The response of arthropods to the final oil palm characteristic, ground cover, was surprising, however, as there was a higher abundance of arthropods where the ground cover was lowest. The amount of ground cover was investigated in this study as a proxy for a measure of the last application of herbicide use and it was expected that arthropod abundance would be higher with ground cover present, although the opposite was the case. These results could indicate that oil palm trees may become habitat islands for arthropods where ground cover plants are absent due to the use of herbicides, with leaf axils, especially those harbouring epiphytes, providing refugia for them.

5.5 Overall conclusions and implications for oil palm plantation management

Although I did not find any direct links between epiphytic plants and arthropod communities at my study sites I am confident that epiphytes can provide crucial ecosystem services within an already high simplified ecosystem, due to their importance in forest systems and the links between oil palm epiphytes and other taxa seen in other studies (Wardle et al. 2003; Koh 2008; Foster et al. 2011; Fayle et al. 2010). Both, ecosystem services (such as decomposition) and disservices depend highly on a complex suite of interactions (Vandermeer 2011). Therefore, I believe the interactions of functional groups such as predators, herbivores or detritivores need to be investigated more thoroughly to fully understand these systems.

This study indicates that higher species richness can be achieved with patches of different more diverse agricultural systems surrounding the monoculture oil palm plantation. In contrast, monocultures can cause the spread of some dominant species and create the opportunity for the invasion of pests over wide areas (Corley and Tinker 2003). A mosaic of different patches of agricultural systems may act as a barrier to pests as well as a stepping stone for beneficial species, too. Even a plantation design of different aged small fields or stripes of oil palms would increase heterogeneity within a plantation (Luskin and Potts 2011) having possible positive implications for biodiversity.

The plantations in this study were characterized as low in epiphyte species richness. One reason for that is probably the frequent removal and the high use of herbicides, which can have negative impact on arthropod communities both directly (Altenhövel 2013) and indirectly (Foster et al. 2011). It should be considered that plantation management may have influenced results in this study due to different applications of herbicides, pesticides or the removal of epiphytes plants at different times. The removal of *Asplenium nidus* in particular is most common, because of their big leaves, which may hinder the work carried out by plantation workers. By having older and bigger epiphytes growing on oil palm trees it may affect arthropod community positively, because they may serve as an island habitat for them and are able to accumulate more organic matter, which was a positive factor in this study. For the implication of oil palm management it should be crucial to stop the removal of epiphytes and correct the false assumption of farmers that epiphytic plants being parasites.

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Appendices

Appendix 1

Table 1. Total arthropod abundance in the studied oil palm plantations (n=8), separated to the two different landscapes (a) Harapan and (b) Bukit12 and grouped by functional groups (omnivore, detritivore, predator, pollinator, and parasitoid).

	No. individuals			Funcional
Taxon	**a) Harapan**	**b) Bukit 12**	**Total**	**group**
Formicidae	*1533*	*2983*	4516	Omnivore
Isopoda	*184*	*219*	403	Detritivore
Collembola	*139*	*187*	326	Detritivore
Araneae	*116*	*124*	240	Predator
Dermaptera	*103*	*101*	204	Omnivore
Arcari	*144*	*39*	183	Omnivore
Coleoptera adults	*56*	*108*	164	Omnivore
Diptera adults	*50*	*79*	129	Omnivore
Blattodea	*47*	*50*	97	Omnivore
unknown	*74*	*5*	79	-
Diplopoda	*11*	*65*	76	Detritivore
Symphyla	*37*	*38*	75	Omnivore
Chilopoda	*27*	*34*	61	Predator
Annelida	*43*	*8*	51	Detritivore
Coleoptera larvae	*27*	*15*	42	Herbivore
Hymenoptera excl.Form.	*16*	*23*	39	Parasitoid
Haplotaxica	*18*	*21*	39	Omnivore
Diplura	*17*	*15*	32	Omnivore
Psocoptera	*17*	*9*	26	Omnivore
Diptera larvae	*1*	*24*	25	Omnivore
Hemiptera	*3*	*21*	24	Herbivore
Orthoptera	*8*	*8*	16	Herbivore
Mollusca	*10*	*5*	15	Detritivore
Lepidoptera larvae	*7*	*7*	14	Herbivore
Isoptera	*12*	*0*	12	Detritivore
Opiliones	*5*	*7*	12	Omnivore
Pseudoscorpions	*7*	*3*	10	Predator
Lepidoptera adults	*3*	*4*	7	Pollinator
Amphipoda	*5*	*0*	5	Detritivore

Archaegnatha	*4*	*1*	5	Herbivore
Thysanoptera	*1*	*2*	3	Omnivore
Protura	*1*	*0*	1	Omnivore
Pauropoda	*0*	*1*	1	Herbivore
Scorpio	*0*	*1*	1	Predator
Total	**2727**	**4202**	**6929**	

Table 2. Total Formicidae abundance in the studied oil palm plantations (n=8), separated to the two different landscapes (a) Harapan and (b) Bukit12 and grouped by feeding behaviour (predator, no predator).

	No. Individual			Feeding
Genus	**a) Harapan**	**b) Bukit 12**	**Total**	**behaviour**
Proatta	*445*	*289*	734	Predator
Pheidologeton	*9*	*531*	540	Predator
Paratopula	*100*	*403*	503	Predator
Pheidole	*176*	*276*	452	Predator
Monomorium	*229*	*211*	440	
Tapinoma	*137*	*266*	403	
Hypoponera	*85*	*123*	208	
Cardiocondyla	*28*	*154*	182	
unknown	*12*	*138*	150	
Aphaenogaster	*36*	*84*	120	
Tetramorium	*67*	*34*	101	Predator
Prionopelta	*1*	*90*	91	
Pyramica	*64*	*0*	64	
Strumigenys	*36*	*27*	63	Predator
Anochetus	*43*	*17*	60	Predator
Euprenolepis	*0*	*56*	56	
Prenolepis	*1*	*53*	54	
Anoplolepis	*17*	*35*	52	
Crematogaster	*1*	*49*	50	
Technomyrmex	*16*	*22*	38	

Ponera	*6*	*24*	30	
Odontomachus	*5*	*15*	20	Predator
Rotastruma	*0*	*17*	17	
Camponotus	*1*	*15*	16	
Rhoptromyrmex	*14*	*0*	14	
Philidris	*0*	*10*	10	
Tetraponera	*0*	*9*	9	
Lordomryma	*0*	*8*	8	
Plagiolepis	*0*	*7*	7	
Pseudolasius	*1*	*6*	7	
Pachycondyla	*0*	*5*	5	Predator
Lasiomyrma	*0*	*2*	2	
Calyptomyrmex	*2*	*0*	2	
Myrmecina	*0*	*2*	2	
Leptogenys	*0*	*2*	2	Predator
Myrmicaria	*0*	*1*	1	
Meranoplus	*1*	*0*	1	Predator
Paratrechina	*0*	*1*	1	
Proceratium	*0*	*1*	1	
Total	**1533**	**2983**	**4516**	

Table 3. Mean and standard deviation of (a) abundance of Arthropods, Arthropods with Formicidae excluded and Formicidae, (b) species richness of arthropods and Formicidae, and (c) decomposition (weight loss after 2 and 4 months) separated to landscape (Harapan, Bukit12), height (2 metre, 4 metre) and location (centre, edge).

	landscape		height [m]		location		
	Harapan	**Bukit12**	**2**	**4**	**centre**	**edge**	**total**
a) Abundance							
Arthropods	34.09 ± 37.88	52.59 ± 60.09	26.74 ± 27.42	59.94 ± 62.52	43.71 ± 54.01	42.96 ± 47.97	43.33 ± 50.92
Arthropods (excl.Form.)	14.93 ± 15.47	15.3 ± 21.79	8.45 ± 8.82	21.78 ± 23.38	12.21 ± 12.59	18.01 ± 23.21	15.11± 19.84
Formicidae	19.16 ± 32.93	37.29 ± 52.13	18.29 ± 24.52	38.16 ± 56.27	31.5 ± 51.63	24.95 ± 35.78	28.23 ± 44.4
b) Species richness							
Arthropods	5.82 ± 3.22	5.86 ± 3.17	4.75 ± 2.62	6.93 ± 3.34	5.51 ± 3.17	6.18 ± 3.19	5.84 ± 3.18
Formicidae	2.64 ± 1.77	3.8 ± 2.04	2.91 ± 1.79	3.53 ± 2.14	3.29 ± 1.75	3.15 ± 2.21	3.21 ± 1.99
c) Decomposition							
Weight loss 2 month	1.44 ± 0.48	1.67 ± 0.53	1.68 ± 0.49	1.42 ± 0.52	NA	NA	1.55 ± 0.51
Weight loss 4 month	1.78 ± 0.5	1.89 ± 0.44	1.86 ± 0.44	1.82 ± 0.5	NA	NA	1.83 ± 0.47

Appendix 2 Linear mixed effect models

Appendix 2.1 Arthropod and Formicidae community

Table 4. Summary of statistics (model output tables) of linear mixed effects analyses of oil palm components: dry organic matter, height (2 metres, 4 metres), location (centre, edge), moisture content (%), epiphyte cover (1=low, 6=high), and ground cover (1=low, 3=high) on (a) total arthropod abundance (log+1), (b) arthropod abundance with Formicidae excluded (log+1), and (c) Formicidae abundance (log+1). Random effects: 1| plot/tree. Significant p-values (<0.05) are indicated in bold.

a) Arthropod Abundance

	numDF	denDF	F-Value	p-Value
(Intercept)	1	113	401.7174	**<.0001**
organic matter	1	113	15.9928	**0.0001**
height	1	113	17.7342	**0.0001**
location	1	113	0.4231	0.5167
moisture content	1	113	0.3069	0.5807
epiphyte cover	1	113	0.4172	0.5197
ground cover	1	113	0.2766	0.6000
epiphyte species richness	1	113	0.4038	0.5264

b) Arthropod abundance (Formicidae excluded)

	numDF	denDF	F-Value	p-Value
(Intercept)	1	113	994.5093	**<.0001**
organic matter	1	113	21.6781	**<.0001**
height	1	113	14.5869	**0.0002**
location	1	113	4.3922	**0.0383**
moisture content	1	113	0.0861	0.7698
epiphyte cover	1	113	0.9497	0.3319
ground cover	1	113	5.3653	**0.0223**
epiphyte species richness	1	113	0.0002	0.9878

c) Formicidae abundance

	numDF	denDF	F-Value	p-Value
(Intercept)	1	113	104.78174	**<.0001**
organic matter	1	113	5.75540	**0.0181**
height	1	113	5.58677	**0.0198**
location	1	113	5.16378	**0.0250**
moisture content	1	113	0.74124	0.3911
epiphyte cover	1	113	0.11845	0.2714
ground cover	1	113	0.17046	0.6805
epiphyte species richness	1	113	1.31356	0.2542

Table 5. Summary of statistics (model output tables) of linear mixed effects analyses of oil palm components: dry organic matter, height (2 metres, 4 metres), location (centre, edge), moisture content (%), epiphyte cover (1=low, 6=high), and ground cover (1=low, 3=high) on (a) arthropod taxon richness, and (b) Formicidae species richness. Random effects: 1| plot/tree. Significant p-values (<0.05) are indicated in bold.

a) Arthropod taxon richness

	numDF	denDF	F-Value	p-Value
(Intercept)	1	112	601.8491	**<.0001**
arthropod abund. (log + 1)	1	112	116.5770	**<.0001**
organic matter	1	112	15.5791	**0.0001**
height	1	112	0.2459	**0.0492**
location	1	112	3.8988	**0.0508**
moisture content	1	112	0.0056	0.9402
epiphyte cover	1	112	0.2869	0.5933
ground cover	1	112	8.9691	**0.0034**
epiphyte species richness	1	112	0.1738	0.7745

b)Formicidae species richness

	numDF	denDF	F-Value	p-Value
(Intercept)	1	112	459.4773	**<.0001**
Formicidae abund. (log +1)	1	112	83.6782	**<.0001**
organic matter	1	112	11.3171	**0.0011**
height	1	112	1.5224	0.2198
location	1	112	0.1322	0.7169
moisture content	1	112	4.8332	**0.0300**
epiphyte cover	1	112	1.7004	0.1949
ground cover	1	112	1.3898	0.2409
epiphyte species richness	1	112	0.1299	0.7192

Appendix 2.2 Decomposition rate

Table 6. Summary of statistics (model output tables) of linear mixed effects analyses of oil palm components: dry organic matter, height (2 metres, 4 metres), moisture content (%), epiphyte cover (1=low - 6=high), ground cover (1=low - 3=high), arthropod abundance (Formicidae excluded), Formicidae abundance, arthropod taxon richness, Formicidae genus richness, and Formicidae abundance (predatory excl.) on (a) decomposition rate after 60 days, and (b) decomposition rate after 120 days in the centre plots. Random effects: 1| plot/tree. Significant p-values (<0.05) are indicated in bold.

a) decomposition rate after 60 days

	numDF	denDF	F-Value	p-Value
(Intercept)	1	32	6287.253	**<.0001**
organic matter	1	32	3.184	**0.0471**
height	1	32	1.563	0.2203
moisture content	1	32	6.434	**0.0163**
epiphyte cover	1	29	1.736	0.1980
ground cover	1	29	3.216	0.0833
epiphyte species richness	1	29	0.039	0.8457
arthropod abund. (log+1)	1	32	1.947	0.1725
Formicidae abund. (log+1)	1	32	0.146	0.7054
arthropod taxon richness	1	32	0.023	0.8804
Formicidae genus richness	1	32	0.192	0.6642
Formicidae abund. (pred. excl.)	1	32	0.482	0.4925

b) decomposition rate after 120 days

	numDF	denDF	F-Value	p-Value
(Intercept)	1	32	12313.570	**<.0001**
organic matter	1	32	0.001	0.9722
height	1	32	2.910	0.0977
moisture content	1	32	19.094	**0.0001**
epiphyte cover	1	29	1.528	0.2263
ground cover	1	29	7.376	**0.0110**
epiphyte species richness	1	29	0.008	0.9274
arthropod abund. (log+1)	1	32	4.134	0.2366
Formicidae abund. (log+1).	1	32	5.820	**0.0217**
arthropod taxon richness	1	32	1.455	**0.0504**
Formicidae genus richness	1	32	5.038	**0.0318**
Formicidae abund. (pred. excl.)	1	32	0.566	0.4575

Appendix 3 Barplots

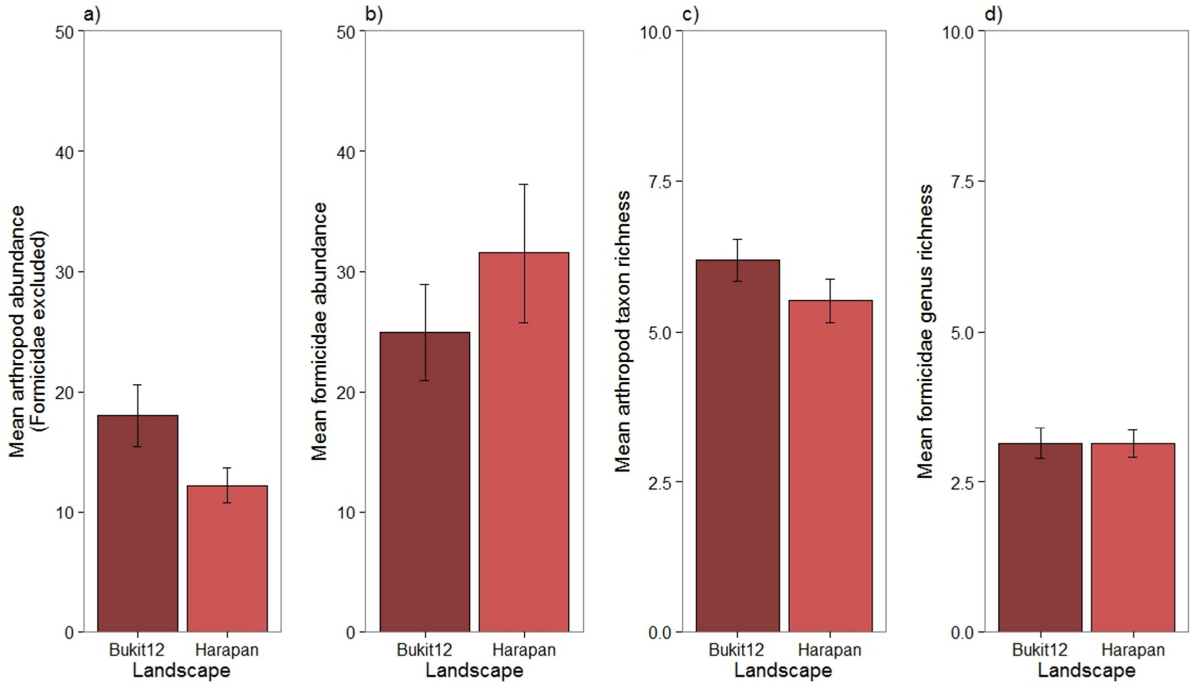

Figure 10. The relationship between the two landscapes (Bukit12, Harapan) and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae genus richness in oil palm plantation (n=160). The error bars indicate the standard errors.

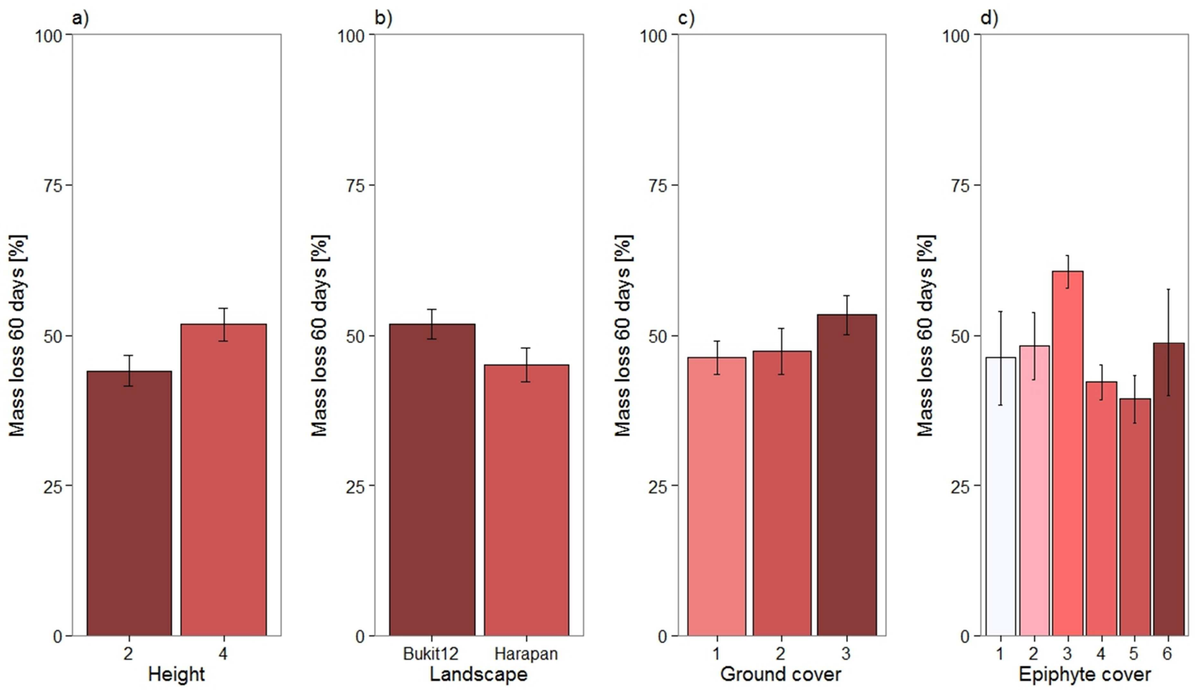

Figure 11. The relationship between mass loss [%] after 60 days and (a) height (2m, 4m), (b) landscape, (c) ground cover (1=low, 3=high) and (d) epiphyte cover (1= very low, 6= very high) of centred oil palm trees (n=80). The error bars indicate the standard errors.

Appendix 4 Boxplots

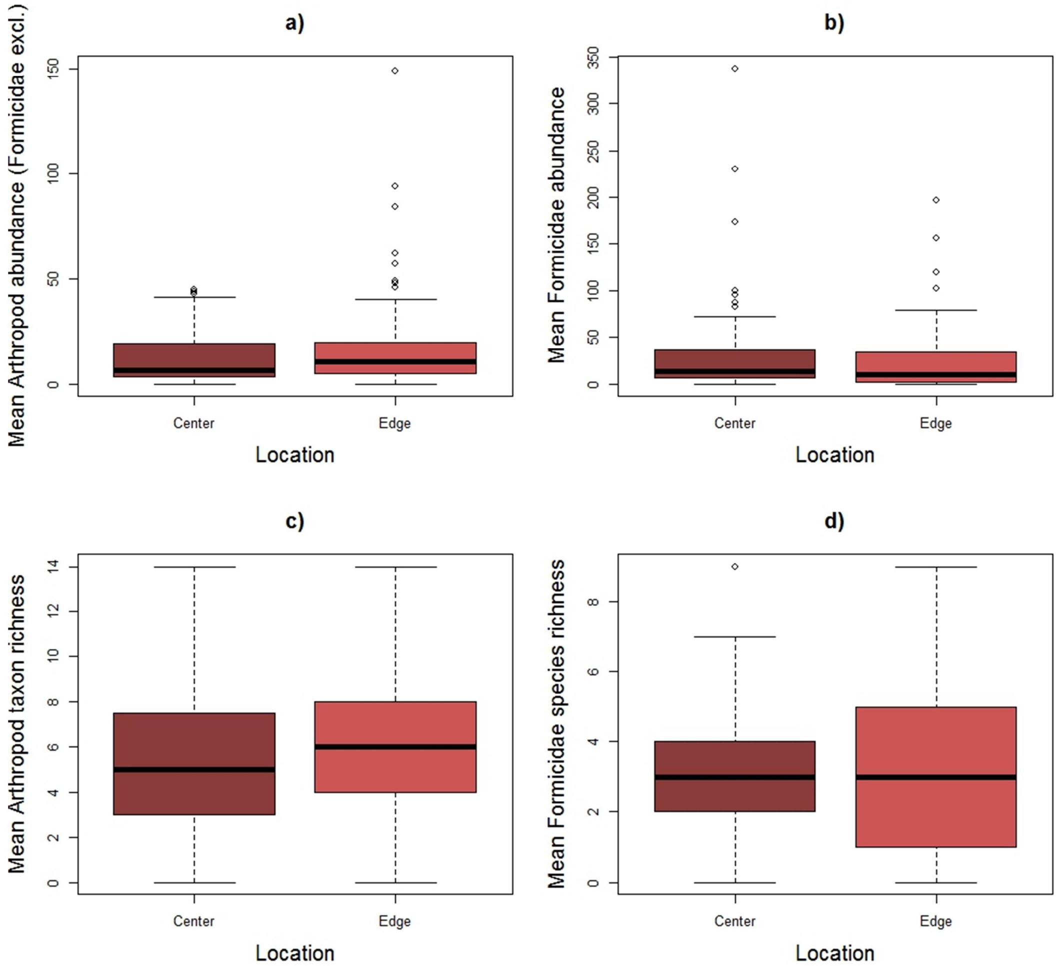

Figure 12. Relationship between location (centre, edge) of the sampled oil palm trees and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae species richness in oil palm (n=160).

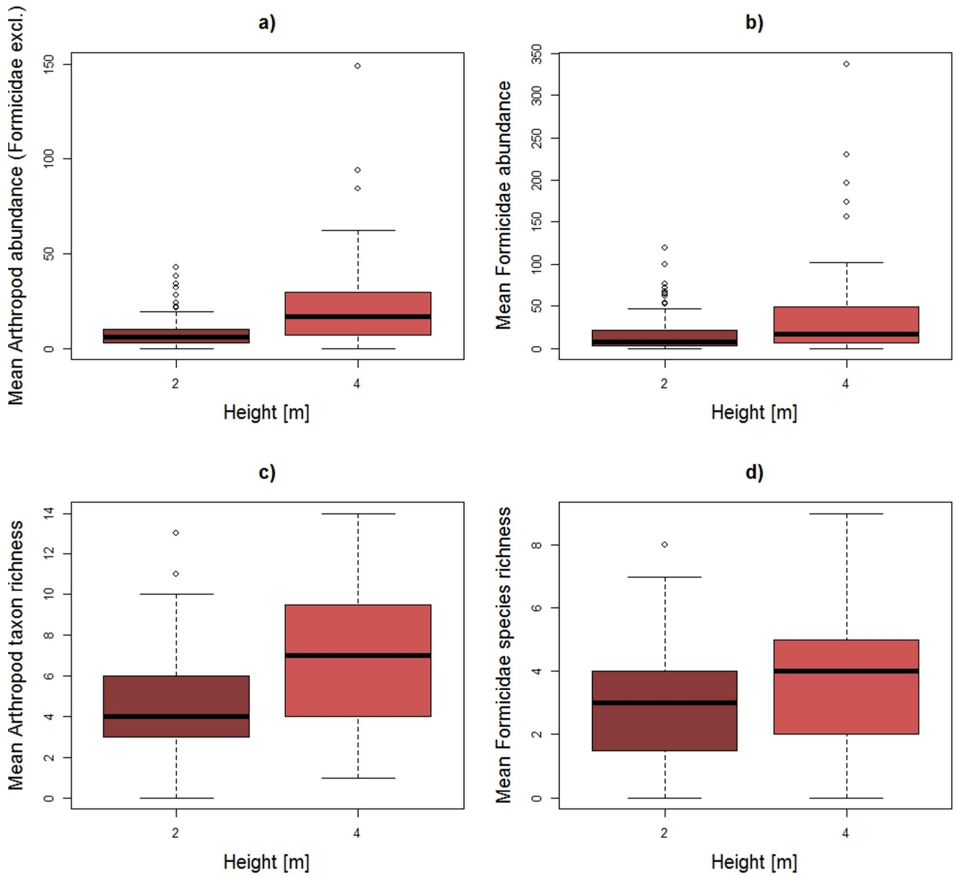

Figure 13. Relationship between height (2 metres, 4 metres) of the sampled oil palm trees and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae species richness in oil palm (n=160).

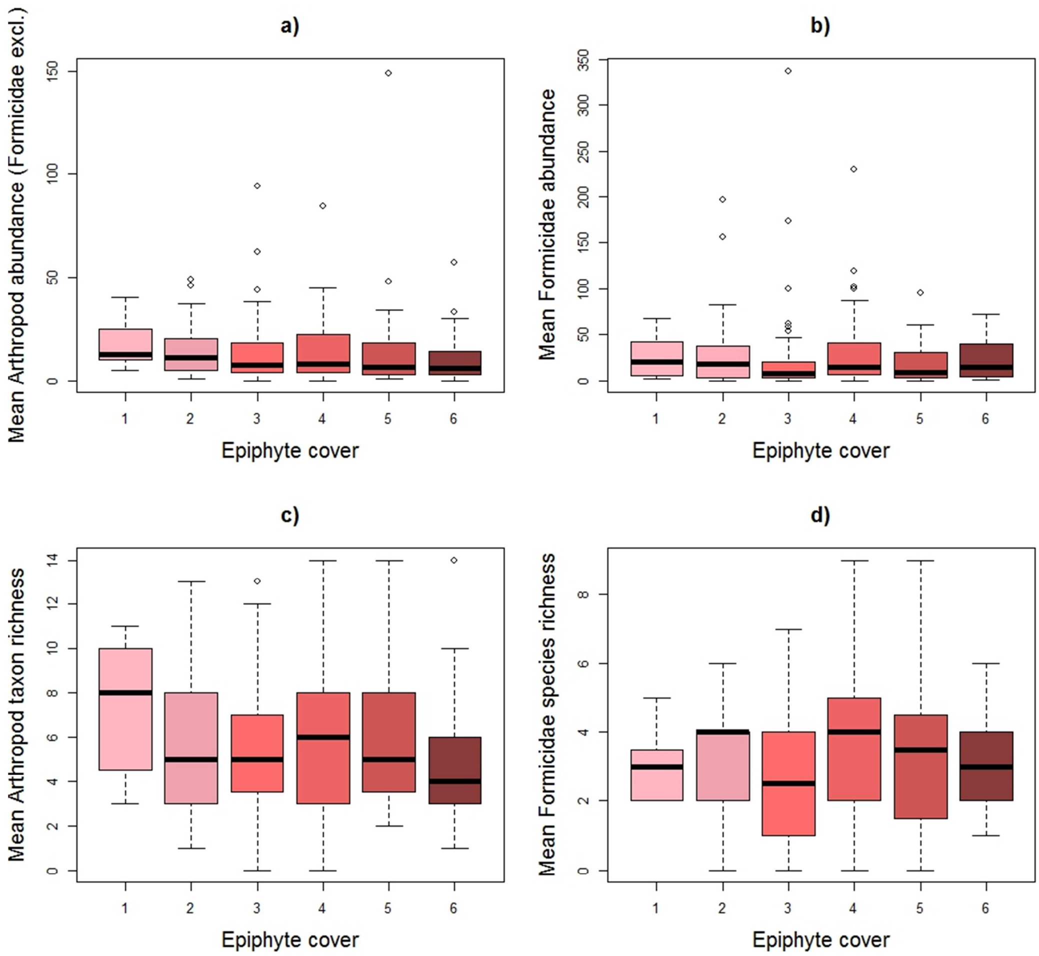

Figure 14. Relationship between epiphyte cover (1=low, 6=high) and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness and (d) Formicidae species richness in oil palm (n=160).

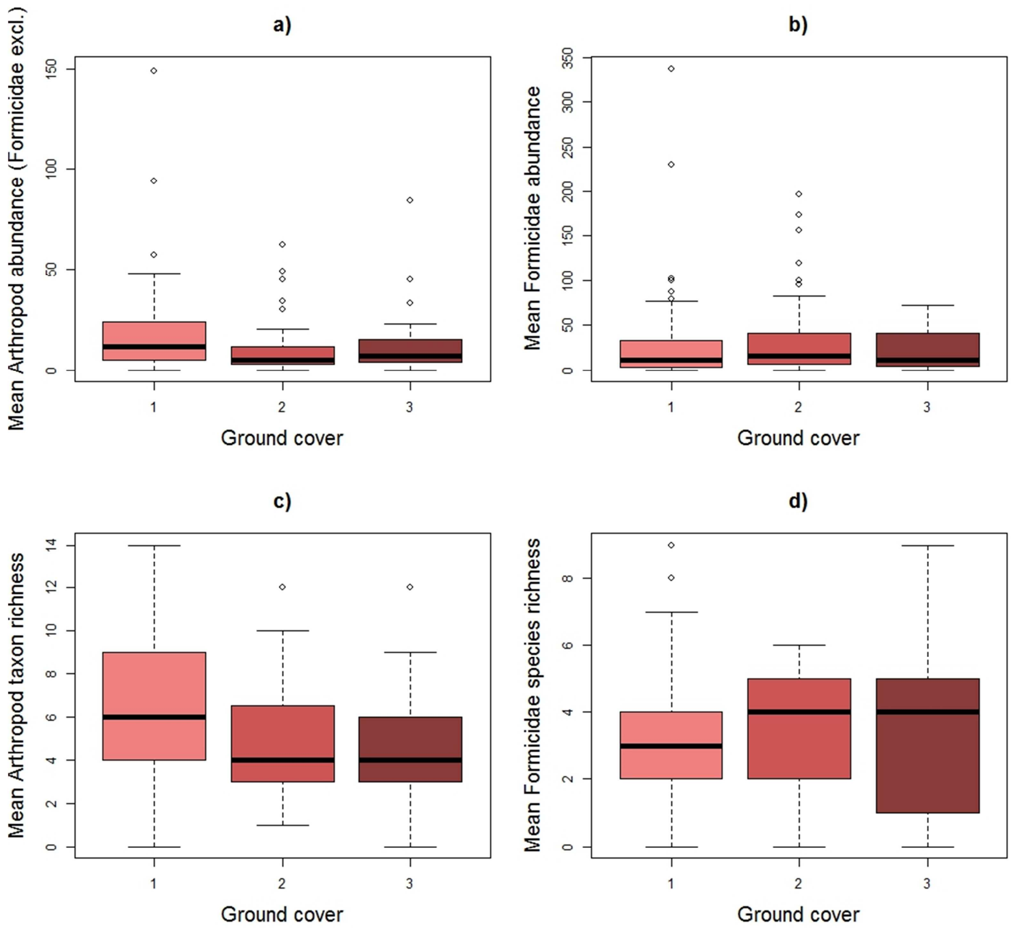

Figure 15. Relationship between ground cover (1=low, 3=high) and (a) arthropod abundance (Formicidae excluded), (b) Formicidae abundance, (c) arthropod taxon richness, and (e) Formicidae species richness in oil palm (n=160).

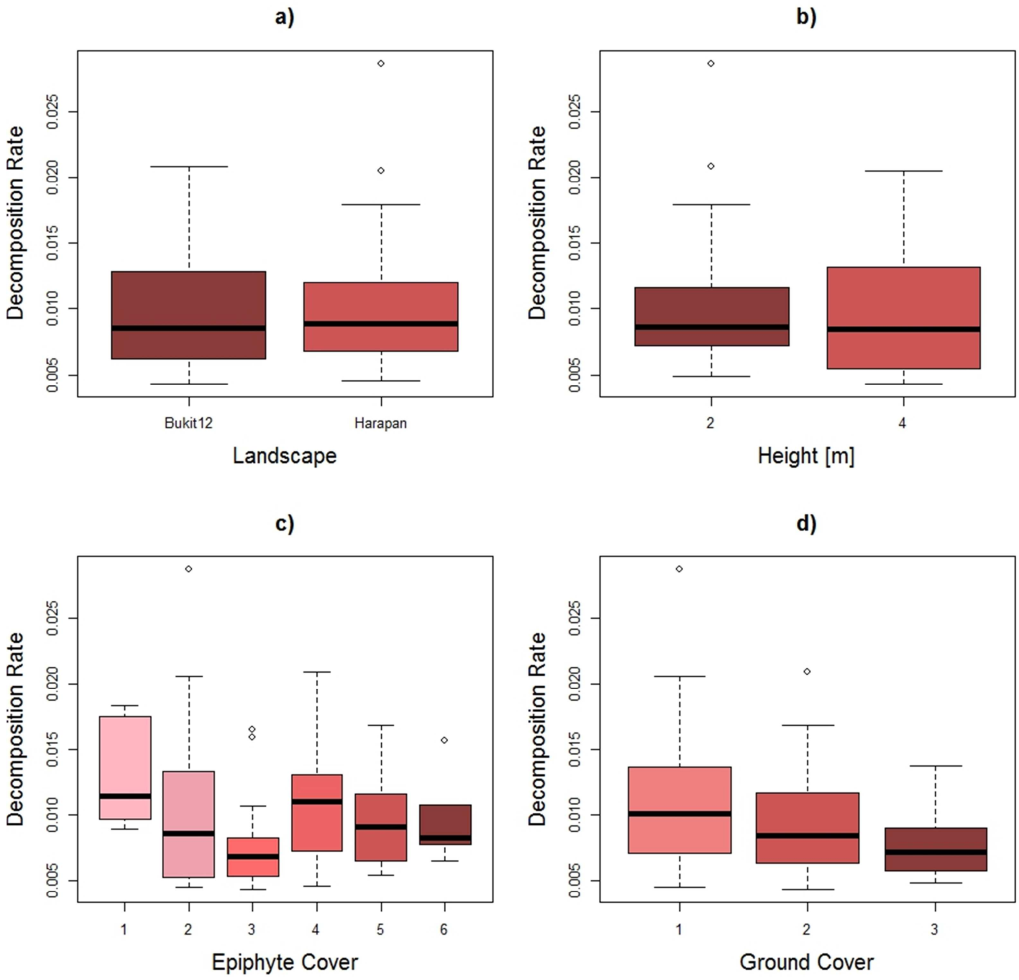

Figure 16. Relationship between decomposition rate after 120 days and (a) landscape (Bukit12, Harapan), (b) height (2 metres, 4 metres), (c) epiphyte cover (1=low, 6=high) and (d) ground cover (1=low, 3=high) in oil palm (n=80).

Appendix 5 Scatterplots

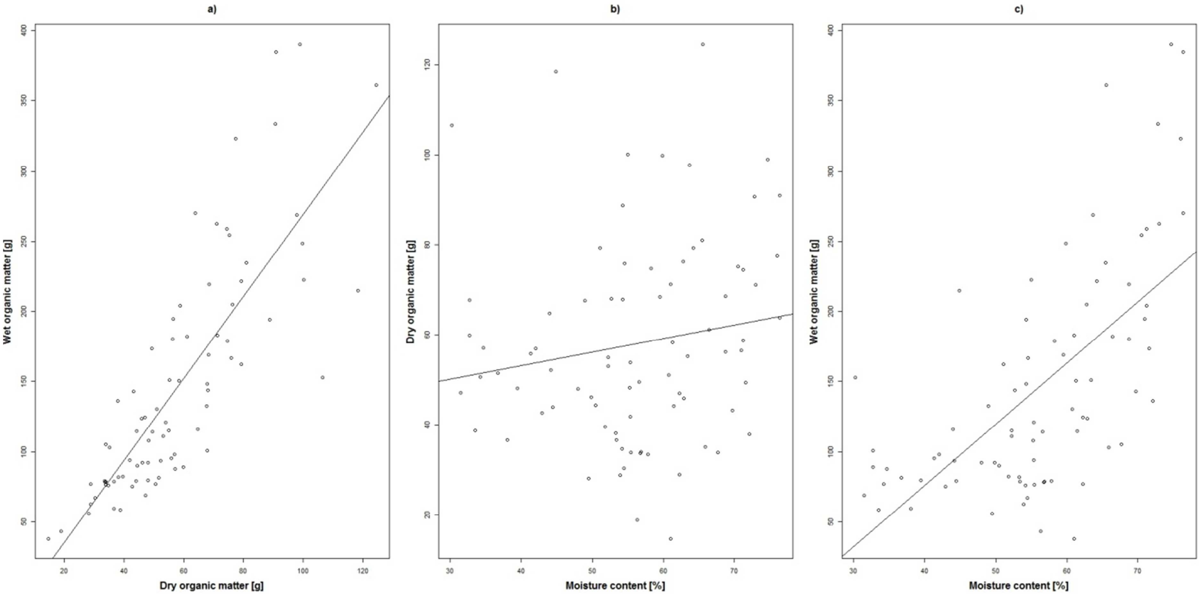

Figure 17. The relationship between (a) wet organic matter and dry organic matter, (b) dry organic matter and moisture content, and (c) wet organic matter and moisture content in oil palm (n=160).

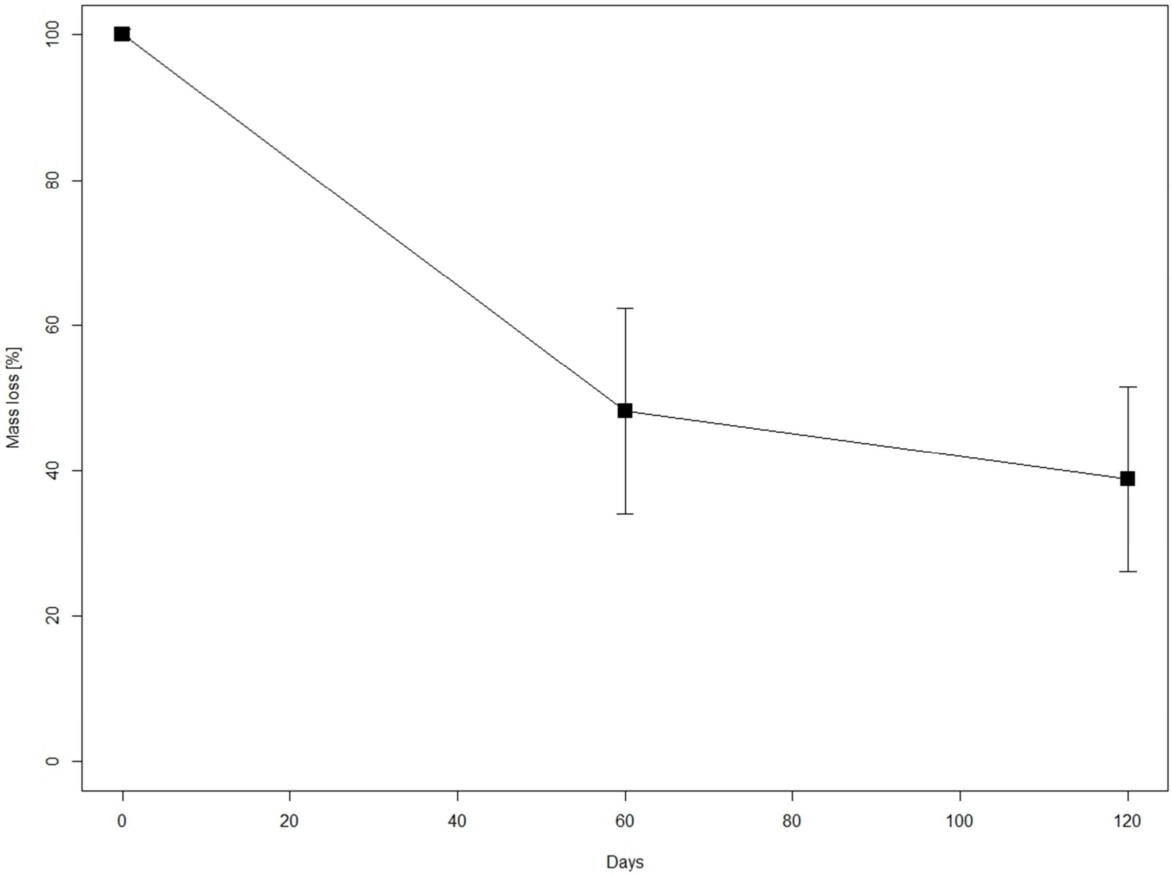

Figure 20. Mean mass loss [%] of litter bags during the time period. Error bars indicate the standard deviation.

Appendix 6 Pictures

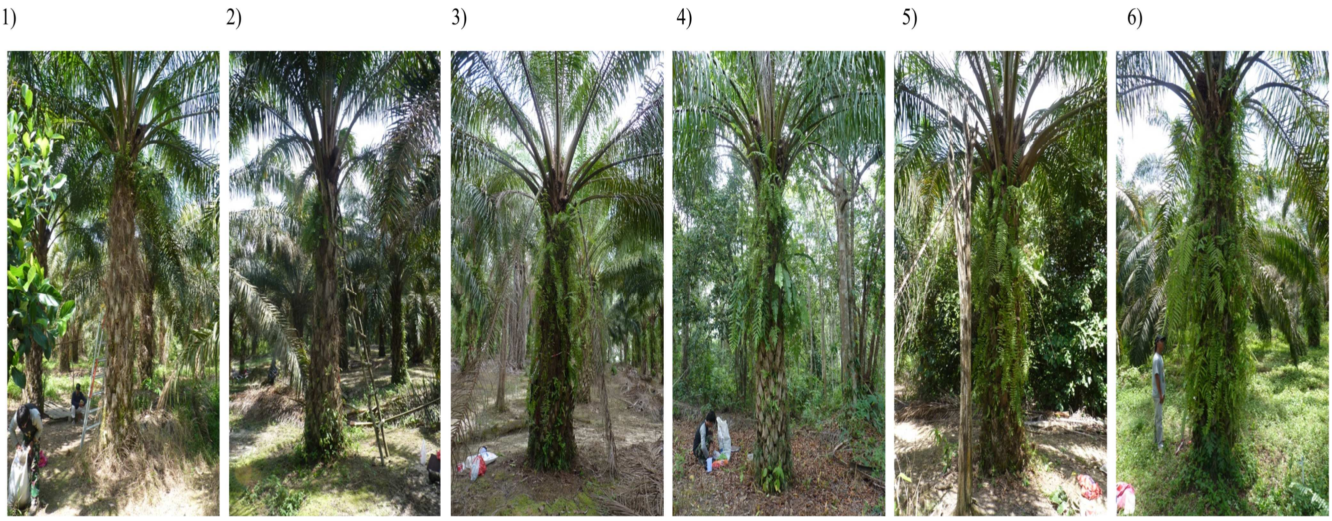

Figure 21. Epiphyte cover scala: (1) 0-15%, (2) 16-30%, (3) 31-50%, (4) 51-65%, (5) 66-80%, and (6) = 81-100% trunk cover.

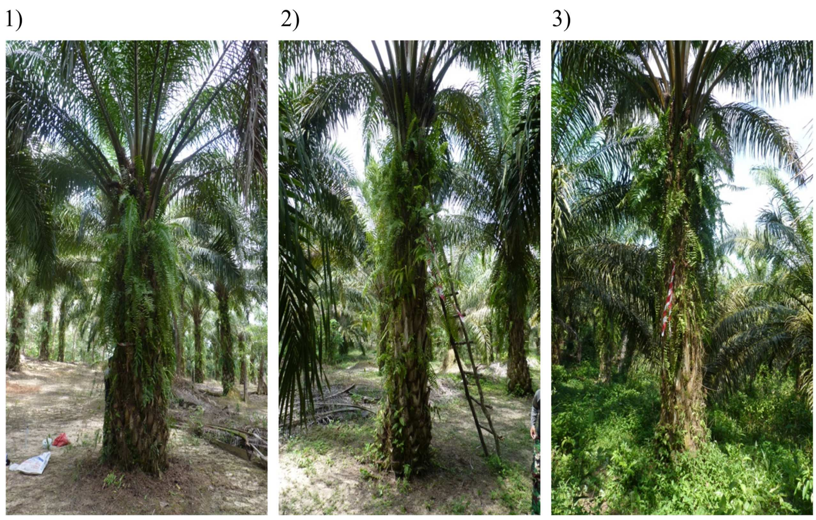

Figure 22. Ground cover scala: from (1) 0-35%, (2) 36-65%, (3) 66-100% ground cover.

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time of my studies without calling my leisure activities of traveling and celebrating into question.

Statutory declaration

I herewith declare that I composed my thesis submitted independently without having used any other sources or means than stated therein

Date:_______________________ Signature:______________________