Management of homegardens in Indonesian agricultural landscapes and its impact on invertebrate diversity and herbivore predation

M.Sc. Thesis

“Sustainable International Agriculture”

Specialisation in “Tropical Agriculture”

Faculty of Agricultural Sciences

Georg-August-University of Göttingen, Germany




By Manuel Toledo-Hernández

Matriculation number: 21170568

Supervisors:

1. Prof.Dr.TejaTscharntke
2. Dr.Yann Clough

Accomplished at the Department of Agroecology

Faculty of Agricultural Sciences

Georg-August-University, Göttingen

25. August 2014

Table of content

1. Abstract

Forest loss and landscape transformation and expansion can have serious impacts on biodiversity and associated ecosystem services, as well as on the livelihood of the local people. The high plant biodiversity and low intensity management in homegardens could play an important role in the preservation of biodiversity in modified landscapes, as well as ensure food security of low income households. In this study, I investigated the impact of smallholder ethnicity on homegarden components and the effect of these homegarden components on invertebrate communities (more specifically on hymenopterans) and on the predation rate of insect herbivores in Jambi province, Indonesia. In addition, I contrasted the invertebrate communities in homegardens with other important agricultural systems in the region. To determine the homegarden components and management practices driving invertebrate community composition and predation rate I completed crop inventories, measured the homegarden size, and interviewed the owners in 24 homegardens. Vane traps, pitfall traps and sweep netting were used to survey the invertebrate communities in 24 homegardens and four oil palm, intensive rubber and extensive rubber plantations.. The results show that Jambi local smallholders conducted a significantly smaller number of management practices than the Javanese smallholders, and on average Javanese transmigrants own larger homegardens than Jambi locals, but there is no difference on crop species richness between ethnic groups. None of the homegarden components affected invertebrate abundance, but number of management practices had a positive correlation with hymenopteran abundance and species richness. Additionally, increased crop species richness also had a positive influence on total hymenopteran abundance Herbivore predation rate was not affected by homegarden size and crop species richness, but predation

rate decreased with increasing the number of management practices. Finally, I found that larger homegardens have higher invertebrate abundance, and hymenopteran species richness and abundance than oil palm plantations, rubber plantations and jungle rubber. My results support the hypothesis that homegarden systems are important in promoting the conservation of beneficial organisms that provide important ecosystem services. Therefore, more attention should be given to understanding the importance of small scale agroecosystem as a hot spot of biodiversity in highly modified landscapes.

2. Introduction

Agricultural expansion is the principal cause of deforestation and forest degradation worldwide (Foley et al., 2005; Senior et al., 2013), and in developing countries, agriculture alone causes 73% of all deforestation (Hosonuma et al., 2012). Since the 1990s, deforestation in Indonesia has increased at an alarming rate (Hansen et al., 2009; Tscharntke et al., 2012) and a recent study from Margonaet. al. (2014) confirms that during 2000-2012, Indonesia surpassed Brazil in primary forest loss, ranking Indonesia as the country leader in tropical forest deforestation. The tropical lowland forest of Sumatra and Kalimantan in Indonesia are the principal regions affected by forest clearing with over 40% of the forest cleared in the past two decades (Hansen et al., 2009).

There is considerable research available establishing the negative impacts of landscape modification from agricultural expansion and deforestation on biodiversity and ecosystem services (e.g. Tscharntke et al., 2005; Priess et al., 2007; Deguines et al., 2014). The conversion of complex natural ecosystems to simplified agricultural systems negatively impacts species diversity and abundance, altering the species composition and ecological functions of many organisms (Flynn et al., 2009; Senior et al., 2013) which can lead to considerable changes in critical ecosystem processes. Invertebrates, which maintain key ecosystem services (Altieri, 1999; Foster et al., 2011) such as biological pest control, pollination of crops and decomposition processes (Zhang et al., 2007; Isaacs et al., 2008; Fayle et al., 2010) are particularly threatened. For example, Larsen et al. (2005) found that habitat loss by conversion to agriculture and further land intensification causes a decrease in bee abundance and species richness as well as the loss of key predators controlling seed-predators and herbivores; and Tylianakis et al. (2007) found that the structure of host-parasitoid food webs is altered by agricultural induced habitat modification. The reduction of ecosystem services can also compromise food security. For instance, 35% of global crop production depends on pollination services (Klein et al., 2007). The disappearance of all pollinators in the ecosystems can be translated to the loss of 3-8% of the world crop production (Deguines et al., 2014).

Homegardens are old-age traditional systems, particularly common in the tropics, characterised by a low intensity management and a high plant diversity (Kumar and Nair, 2004, 2007; Scales and Marsden, 2008). Homegardens contribute significantly to the household diet by producing a large varieties of products, and in times of food shortages, homegarden production represents an important source of food for low income families (Raintree and Warner, 1986; Marsh, 1998; Kumar and Nair, 2007), thus strengthening food security (Kumar and Nair, 2004). The homegarden's architecture often resembles the surrounding ecosystems by integrating characteristics observed in natural areas such as high plant biodiversity and a multistory combination of trees and plants (Mohri et al., 2013). Homegarden management typically consists of the use of local knowledge, the application of agro-ecological practices such as use of organic fertilisers, management of plant arrangements and structure to enhance crop-beneficial organisms and reduce pests and weed abundances, and minimal chemical inputs (Altieri, 1999; Mohri et al., 2013). A large web of ecological interactions are key for homegardens to contribute to sustainability and ecosystem services by providing habitats for crop-beneficial organisms, such as pollinators, pest-control predators and seed dispersers (Altieri, 1999; Mohri et al., 2013).

Despite the acknowledged importance of homegardens in providing ecosystem services, most of the studies conducted in these traditional systems are detailed descriptions and inventories of the crop diversity, plant arrangements, structure and socio-economic components (e.g. Trinh et al., 2003; Kehlenbeck and Maass, 2004; Kumar and Nair, 2007). There are few studies available investigating homegarden invertebrate communities and invertebrate ecological functions (Mohri et al., 2013) which are essential to understand the importance of homegardens as a provider of ecosystem services. For example, the impact of the smallholder ethnicity on the homegarden components such as homegarden size, management practices and crop diversity, and the influence of these components on the invertebrate communities are not yet understood in detail (Mohri et al., 2013). Additionally, it is important to evaluate the contribution of homegardens for preserving invertebrate communities in agriculture induced modified landscapes.

In this study, I investigated the impact of smallholder ethnicity on homegarden components and the effect of these homegarden components on invertebrate communities (more specifically, bee and wasp species richness) and on the predation rate of insect herbivores in Jambi province, Indonesia. In addition, I contrasted the invertebrate communities in homegardens with those found in three important agricultural systems of the region (oil palm plantations, rubber plantations, and jungle rubber). I hypothesize that homegardens are important agro-ecosystems for maintaining beneficial invertebrate communities in highly modified landscapes, and that the smallholder ethnicity could impact homegarden components and the variation in these homegarden components will influence invertebrate communities.

3. Methods

3.1. Study area

This study was conducted in two regions adjacent to two large forests (Bukit Duabelas National Park and Harapan rainforest) in the lowlands of Jambi province, Sumatra, Indonesia. Over the past decades, this region has experienced a rapid expansion of monocultures at the cost of forest and traditional cash-crop and subsistence agriculture (Hansen et al., 2009). Three predominant agriculture systems in the study area are oil palm plantations, intensive rubber (rubber) plantations and extensive rubber (jungle rubber).

In the study area, the population is dominated by two ethnic groups: Jambi local residents and Javanese transmigrants. The Javanese population in Jambi province represents the biggest transmigrant group of the region. Approximately 80% of all transmigrants in Jambi are originally from Java, who settled in Sumatra during 1980s as part of a set of governmental policies (transmigration programme) aiming to recruit farmers into the logging, rubber and oil palm sectors (Murdiyarso et al., 2002). In the study area, homegardens are a popular traditional farming systems carried out by both ethnic groups.

3.2. Study design

To investigate the relationship between social and ecological factors on homegarden components I selected 12 homegardens within three villages for each of the two regions where the study was conducted, giving a total of 24 homegardens and 6 villages investigated. To estimate homegarden size effects I chose two small (0-200 m^2) and two large (600-800 m^2) homegardens in each village: There was a minimum distance of 100 m between homegardens. To contrast homegardens with other agricultural systems that are important in the study area I selected four oil palm plantations, four rubber plantations and four jungle rubber sites in the Harapan rainforest region only. In this study I defined jungle rubber as secondary forests in which rubber trees are in between native vegetation, with minimal management. The plantations selected for my study are part of the research sites available for a broader project (CRC 990).

3.3. Homegarden owner interviews

I conducted semi-structured interviews with all of the owners of the selected homegardens to determine their ethnicity (local or Javanese) and the number of management practices they used in their homegardens (i.e. application of fertilizer, herbicide, insecticide, and hand weeding). The number of management practices was used to assign each homegarden a measure of management intensity between one and four, where one is if one management practice is used in a homegarden (e.g. only fertilizer is used) and four is for those homegardens where all types of management practices are conducted. To estimate the homegarden crop diversity, I recorded the presence of all plants with a socio-economic purpose for the homegarden owner, discarding ornamental plants. The crops were identified with the help of the owners and local assistants.

3.4. Herbivore predation rate

In the homegardens I estimated the predation rates of insect herbivores using dummy caterpillar exposure (Richards and Coley, 2007; Faveri et al., 2008; Howe et al., 2009). The dummy caterpillars were made with green modelling clay (20 mm long x 5 mm diameter). I glued four caterpillars on up to four individuals of each of the three dominant crops in the homegardens on three different days. The three dominant crops determined from the crop survey were banana (*Musa sp.*), cassava (*Manihot sp.*), and chili (*Capsicum sp.*). The dominant crops were present in all homegardens but in some cases there were not four individuals present of each species. In practice this procedure resulted in a maximum of 144 (48 per day) and a minimum of 96 (32 per day) dummy caterpillars used in each homegarden. In all cases the first caterpillar was placed at least 20 cm above the ground and with 5 cm of a minimum distance between the caterpillars. The dummies were collected after 24 hours and marks such as bites, stings and scratches were counted for predation.

3.5. Invertebrate communities

The invertebrate communities in both the homegardens and the other agricultural systems were surveyed using three different sampling methods (blue/yellow vane, pitfall traps, and sweep netting) to increase the representation of the invertebrate communities sampled. Pitfall traps are a useful method for collecting surface-active invertebrates (Fisher, 1999; Ward et al., 2001), and blue/yellow vane traps and sweep netting are efficient for collecting flying invertebrates and invertebrates inhabiting the vegetation (Haddad et al., 2000; Stephen and Rao, 2007).

I randomly placed pairs of blue and yellow vane traps (n=4) as well as four pitfall traps (Stephen and Rao 2007) within the homegardens and within a 50 x 50 m area in the other agricultural systems. The vane traps were suspended one meter above the ground on plastic t-posts and the pitfall traps were deposited in soil pits 20 cm deep. The invertebrate samples in both trap types were collected after 24 hours. I conducted sweep netting sampling between 08:00-15:00 hours. Sweeps of 5 minutes duration were completed at four different transects (10 m length), with a minimum distance of three meters between transects. I conducted three repetitions for each of the three sampling methods.

The invertebrates collected were identified first to higher taxonomic groups. Subsequently I identified hymenopteran to suborders. With the exception of formicidae, all hymenopteran were further identified to family and morpho-species, and categorized to functional groups (parasitoids, predators, pollinators) using the Goulet and Huber (1993) identification key.

3.6. Statistical analysis

3.6.1. Determining the effect of the owner ethnicity on homegarden components, and the effect of homegarden components on invertebrates communities and herbivore predation rates

I tested (1) the influence of the owner ethnicity on homegarden components; and (2) the impact of the homegarden components on total invertebrate abundance, hymenopteran species richness and abundance (discarding formicidae), hymenopteran functional group (predators, parasitoids and pollinators abundance), and predation rate using Generalized Linear Models (GLMs) (Guisan et al., 2002). I hypothesized that differences in homegarden components induced by the owner ethnicity could have an effect on the invertebrate communities. Quasi-poisson distributions for over-dispersed data were used for counted data (absolute numbers of invertebrate and hymenopteran individuals, absolute number of hymenopteran morpho-species and absolute number of hymenopteran individuals sorted by functional groups) and a binomial distribution for proportion data (predation rate).To test if the individual pesticide use and landscapefactors affectpredation rate, and pesticide use impact invertebrate communities, thevariables were added to the GLM models.

To estimate the factors in the models with the highest likelihood of explaining the response variables I selected the significant p-values from the output table given by the GLM model. The factor with the smallest p-value ($p \leq 0.05$) in the model was considered with the highest likelihood to explain the response variable.The data in this section was analysed in R version 3.0.3 (R Development Core Team 2008).

3.6.2. Contrasting invertebrate community composition in homegardens and the main agricultural systems

To investigate the difference between invertebrate communities (total invertebrate abundance, hymenopteran species richness and abundance and hymenopteran functional group abundance) in the homegardens and oil palm, rubber and jungle rubber I conducted one-way ANOVA test to check for significant differences between the agricultural systems. When p-values ($p \leq 0.05$) given by the output table were significant, I performed a Multiple Comparison analysis to test for particular differences in invertebrate communities between the different systems. I conducted a Tukey's Honest Significant Difference test (HSD post-hoc test) to determine the pattern of difference between groups (Abdi and Williams, 2010). I hypothesised that invertebrate community composition would significantly differ between the different systems, and that the plant heterogeneity and low management intensity in homegardens could lead to a higher invertebrate diversity and abundance. The response variables were considered significantly different between the systems if the output table from the HSD test gave different alphabetic letters. I used the "agricolae" library package (R Development Core Team 2008) for the data analysis in this section.

4. Results

4.1. Invertebrate and hymenopteran communities in the study systems

A total of 5508 invertebrate individuals corresponding to 26 higher taxonomic groups were collected during the study (see Appendix 1). The five most abundant taxonomic groups that represented 83% of the total invertebrate abundance were Hymenoptera (1923), Collembola (1245), Coleoptera (886), Diptera (724) and Araneae (351). A higher number of taxonomic groups were sampled in the homegardens (26) than in the other agricultural systems altogether (17).

A total of 254 hymenopteran individuals were collected, representing 30 families (discarding Formicidae) and 113 morphospecies (Appendix 2). The five most abundant families represented 71% of the total hymenopteran abundance: Vespidae (67), Apidae (39), Nyssonidae (39), Anthophoridae (23) and Colletidae (12). The families with the highest number of morphospecies were Vespidae (27), Apidae (15), Nyssonidae (11), Ichneumonidae (9), Anthophoridae (8) and Sphecidae (7). In total 26 families and 88 morphospecies were sampled in the homegardens and 14 families and 25 morphospecies in total at the oil palm, rubber and jungle rubber sites.

The hymenopteran functional group with the highest representation in the samples was the predators with 109 individuals, followed by pollinators (84) and parasitoids (60). Only one individual from the family Megalodontidae was collected and categorized in the herbivore functional group (Appendix3).

4.2. The effect of smallholder ethnicity on homegarden components, and the impact of the homegarden components on invertebrate communities and herbivore predation rate

The ethnicity of homegarden owners did not explain variation in homegardens size (p-value= 0.10, Figure 1a, Appendix 4a) and crop species richness (p-value=0.85, Figure 1b, Appendix 4b). However, number of management practices did differ significantly between the two ethnic groups studied (p-value=0.01, Figure 1c, Appendix 4c). The number of management practices used in local smallholders homegardens was less than in the homegardens owned by smallholders of Javanese ethnicity (Figure 1c). In total, I found that both ethnic groups conduct up to four management practices (i.e. hand weeding, application of fertiliser, pesticide and herbicide).

The size of the homegardens did not explain the variation in invertebrate abundance (p-value=0.12, Figure 2a, Appendix 5a), hymenopteran abundance (p-value=0.39, Figure 2b, Appendix 5b), and hymenopteran species richness (p-value=0.65, Figure 3c, Appendix 5c). Also, the abundance of each of the hymenopteran functional groups studied was not influenced by the homegarden size: predator (p-value=0.86, Figure 2d, Appendix 5d), pollinator (p-value=0.38, Figure 2e, Appendix 5e), and parasitoid (p-value=0.66, Figure 2f, Appendix 5f).

Crop species richness in homegardens had no effect on total invertebrate abundance (p-value=0.52, Figure 3a, Appendix 5a), but there was a positive relationship between crop species richness and hymenopteran abundance (p-value=0.04, Figure 3b, Appendix 5b). However, crop species richness did not explain variation in hymenopteran species richness, although there is a trend of hymenopteran richness increases with crop species richness (p-value=0.08, Figure 3c, Appendix 5c). There was no variation in the functional groups abundance associated to crop richness: predator (p-value=0.08, Figure 3d, Appendix 5d), pollinator (p-value=0.20, Figure 3e, Appendix 5e), and parasitoid (p-value= 0.50, Figure 3f, Appendix 5f).

Besides to invertebrate abundance which it was not affected by the intensity of management (p-value= 0.16, Figure 4a, Appendix 5a), the variation in hymenopteran abundance (p-value=0.01, Figure 4b, Appendix 5b) and hymenopteran species richness (p-value=0.01, Figure 4c, Appendix 5c) could be explained by the number of management practices conducted in homegardens. The abundance in predator (p-value=0.04, Figure 4d, Appendix 5d) and parasitoid functional groups (p-value=0.01, Figure 4f, Appendix 5f) can also be explained by the management intensity in homegardens, however, this was not true for the pollinator functional group (p-value=0.63, Figure 4e, Appendix 5e).

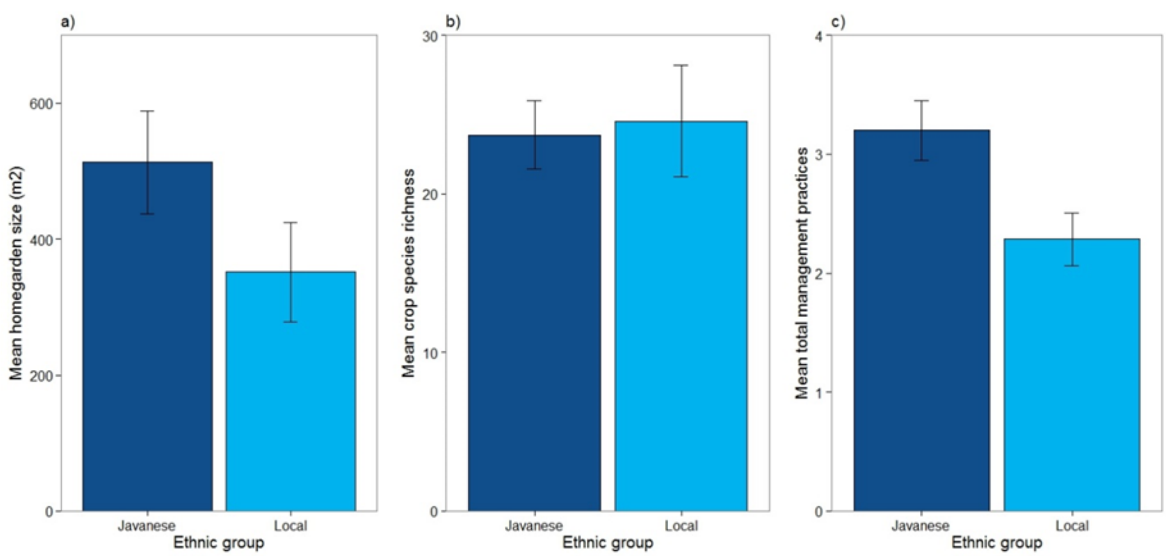

Figure 1. The relationship between owner ethnicity (Javanese or Local) on (a) homegarden size (large=600-800 m^2, small=0-200 m^2), (b) crop species richness, and (c) total number of management practices (n=24).The error bars represent the standard errors.

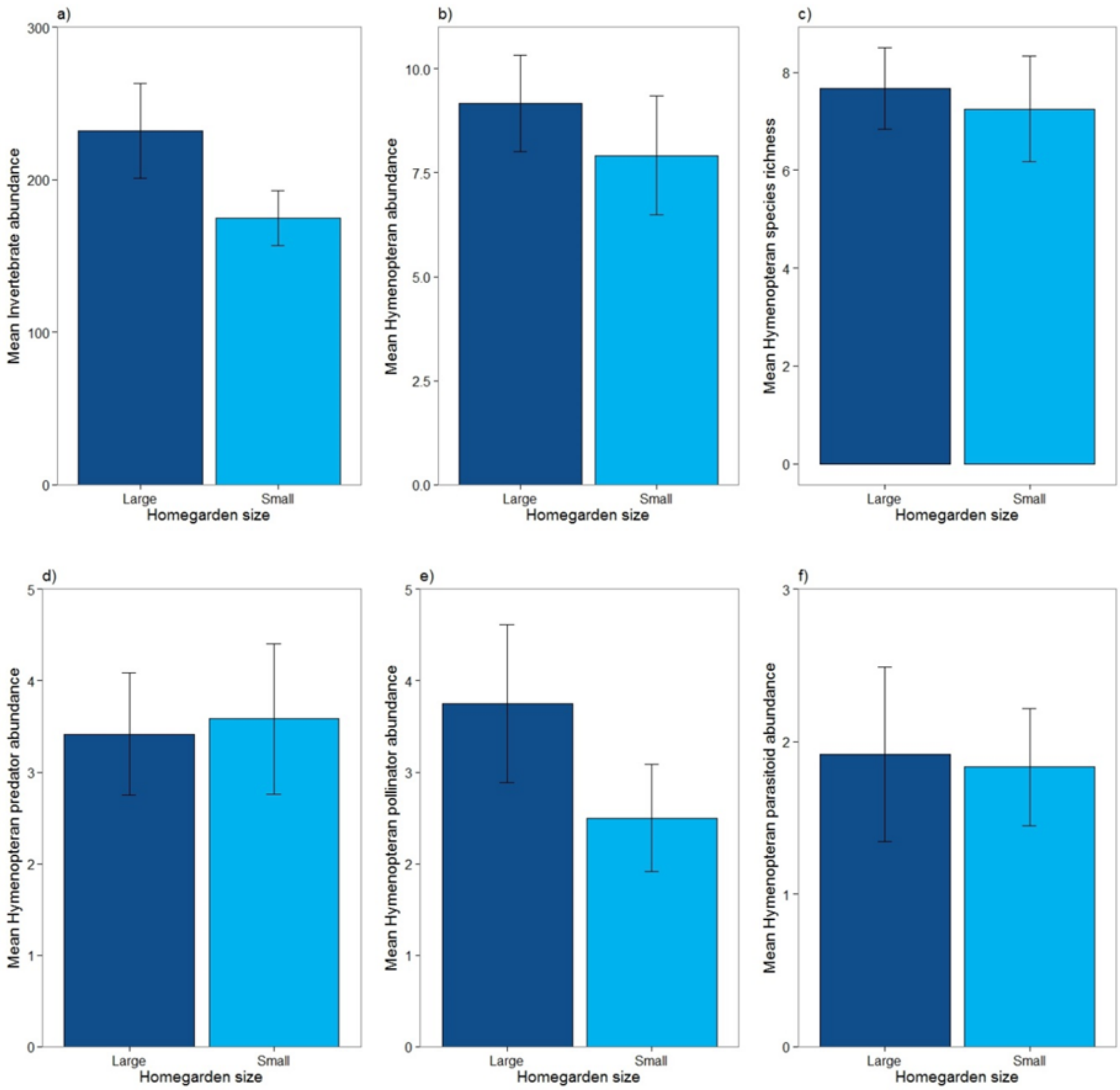

Figure 2. The relationship between homegarden size (large=600-800 m2, small=0-200 m2) and (a) invertebrate abundance, (b) hymenopteran abundance, (c) hymenopteran species richness, (d) hymenopteran predator abundance, (e) hymenopteran pollinator abundance and (f) hymenopteran parasitoid abundance in homegardens (n=24). The error bars indicate the standard errors.

When testing the effect of each management practice separately on the response variables I found that the application of fertilizer did not explain variation in total invertebrate abundance (p-value=0.08, Appendix 6a), hymenopteran abundance (p-value=0.32, Appendix 6b), and hymenopteran species richness (p-value=0.15, Appendix 6c). Nevertheless, fertilizers application did have a positive effect on the abundance of the predator functional group (p-value=0.03, Appendix 6d), though not on pollinator (p-value=0.65, Appendix 6e) and parasitoid abundance (p-value=0.36, Appendix 6f). The application of herbicide did not affect the invertebrate abundance (p-value=0.88, Appendix 6a), hymenopteran abundance (p-value=0.36, Appendix 6b), hymenopteran species richness (p-value=0.47, Appendix 6c), predator abundance (p-value=80, Appendix 6d), and pollinator abundance (p-value=0.76, Appendix 6e), but it did affect the abundance of the parasitoid functional group (p-value=0.02, Appendix 6f). Finally, the application of pesticide did not explain any variation in the invertebrate and hymenopteran community response variables (Appendix 6).

From a total of 2784 dummy caterpillars exposed in the homegardens, 372 had evidence of predation, which represents an overall predation rate of 13.3%. There was no significant variation in predation rate in response to homegarden size (p-value=0.25, figure 5a, Appendix 7) or crop species richness (p-value=0.29, Figure 5b, Appendix 7). However, there is a strong negative correlation between increasing number of management practices and predation rate (p-value=0.03, Figure 5c, Appendix 7).

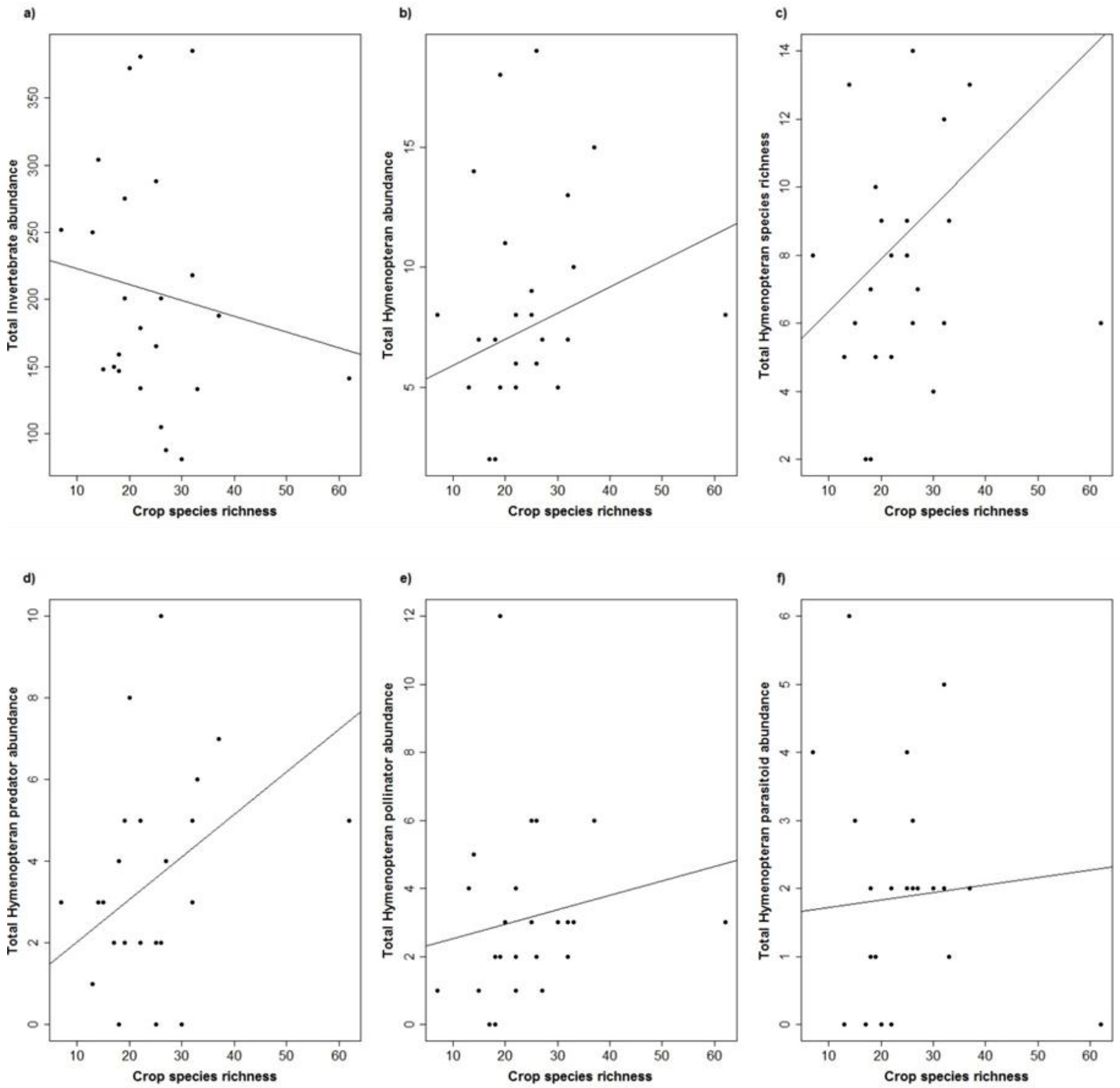

Figure 3. The relationship between crop species richness and (a) total invertebrate abundance, (b) hymenopteran abundance, (c) the hymenopteran species richness, (d) hymenopteran predator abundance, (e) hymenopteran pollinator abundance and (f) hymenopteran parasitoid abundance in homegardens (n=24).

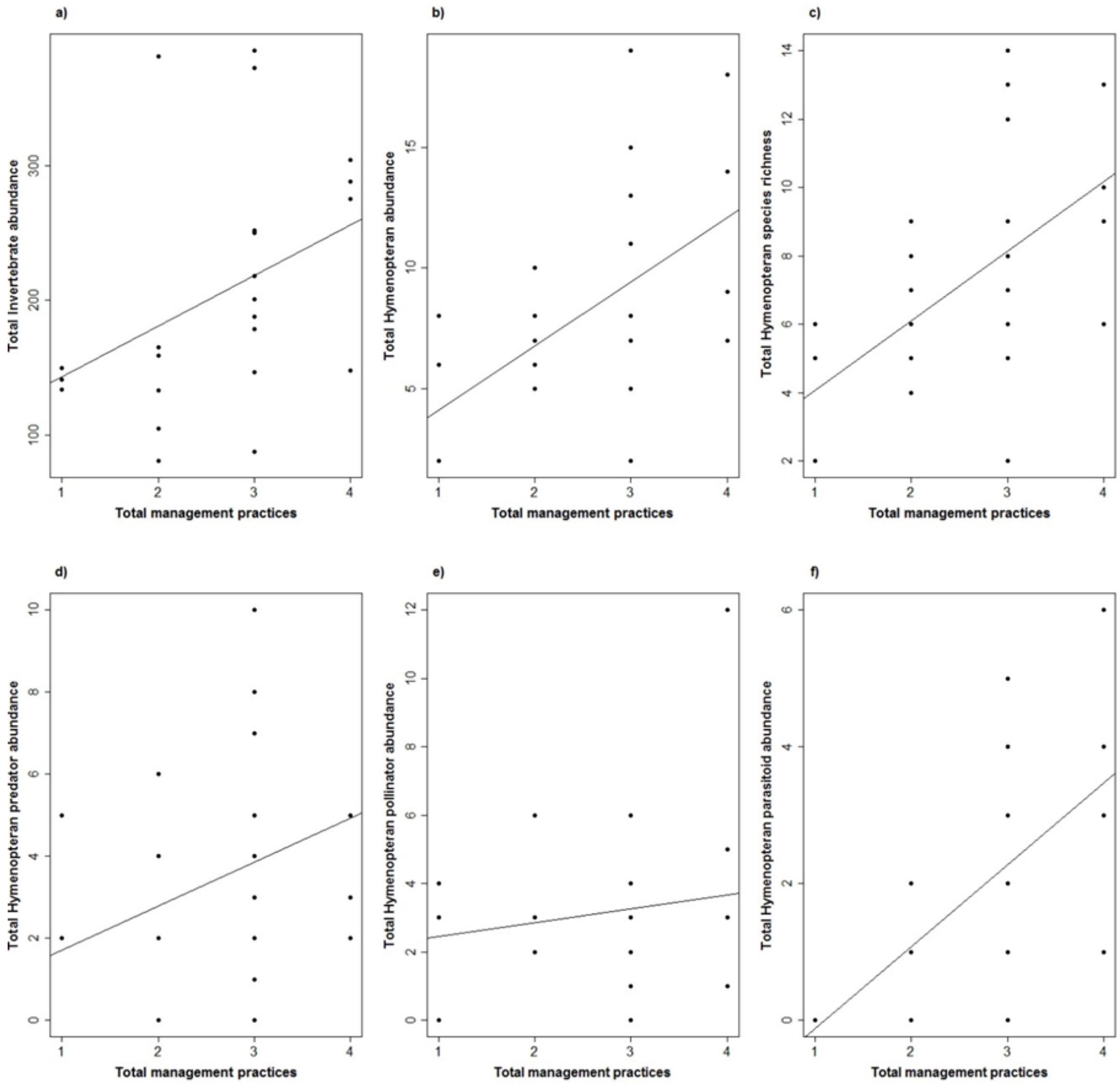

Figure 4. The relationship between number of management practices and (a) total invertebrate abundance, (b) hymenopteran abundance, (c) the hymenopteran species richness, (d) hymenopteran predator abundance, (e) hymenopteran pollinator abundance and (f) hymenopteran parasitoid abundance in homegardens (n=24). The error bars indicate the standard errors.

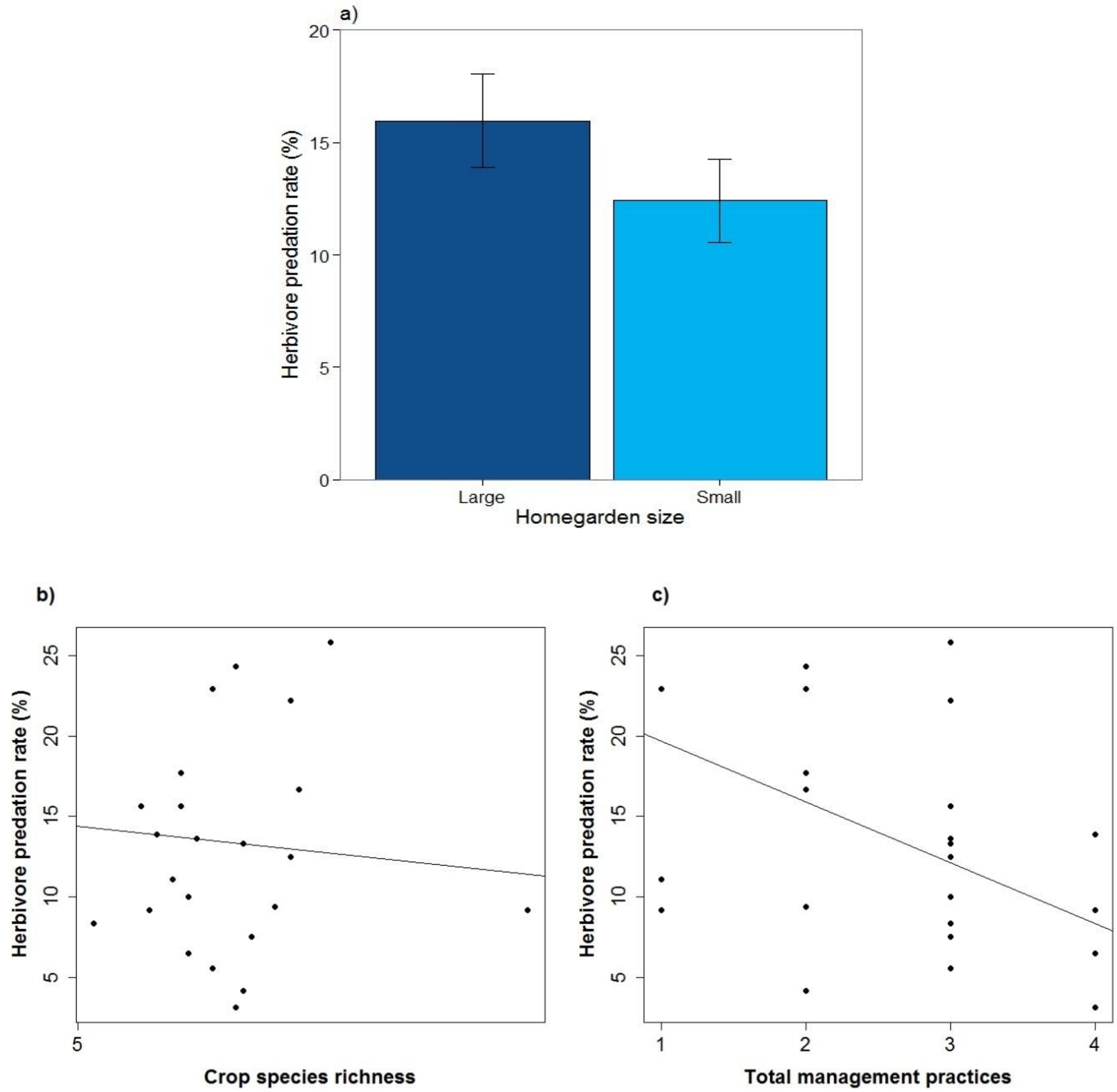

Figure 5. The effect of the (a) homegarden size (m2),crop species richness (b), and number of management practices on herbivore predation rate in homegardens (n=24). The error bars (a) indicate the standard errors.

4.3. Comparison of invertebrate and hymenopteran community composition in homegardens and the predominant agricultural systems

Total invertebrate abundance (p-value=0.002, Appendix 8a), hymenopteran abundance (p-value=0.01, Appendix 8b), hymenopteran species richness (p-value=0.001, Appendix 8c) were all significantly higher in the large homegardens than in the oil palm, rubber and jungle rubber sites investigated (Figure 6a-c). However, small homegardens invertebrate abundance, hymenopteran abundance and species richness were not significantly different than the other studied agricultural systems (Figure 6a-c).

I found that for the hymenopteran functional groups there were no significant differences in predator (p=0.2, Appendix 8d) and parasitoid (p=0.3, Appendix 8f) abundance in homegardens compared with the predominant agricultural systems (Figure 6d, Figure 6f). However, abundance in pollinators (p-value=0.0.5, Appendix 8e) was significantly higher in large homegardens than in the small homegardens and in the other agricultural systems (Figure 6e). Abundance of pollinators was not significantly different between small homegardens and oil palm, rubber and jungle rubber plantations (Figure 6e).

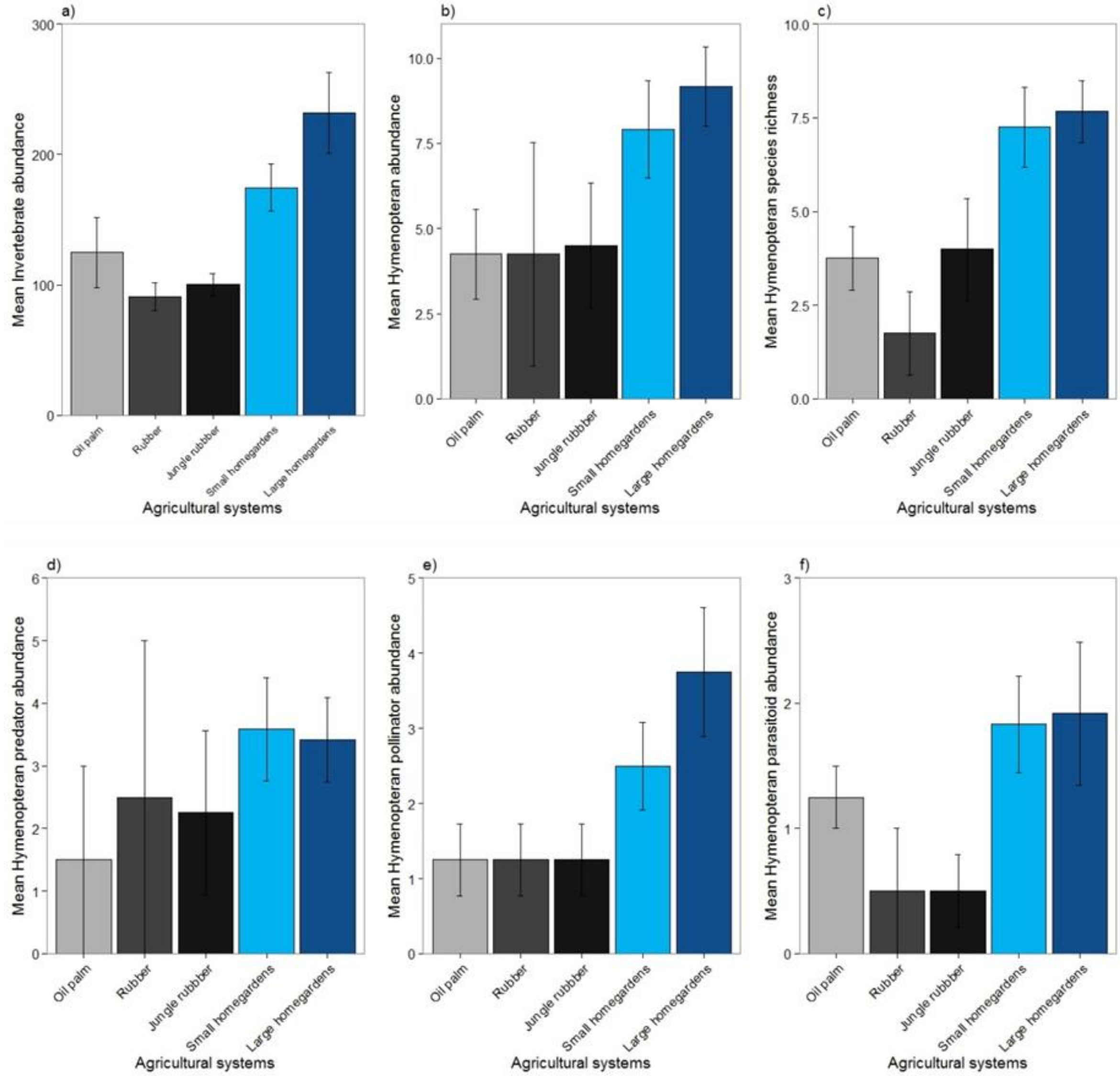

Figure 6. Comparison of the (a) invertebrate abundance, (b) hymenopteran abundance, (c) hymenopteran diversity, (d) hymenopteran predators, (e) hymenopteran pollinators and (f) hymenopteran parasitoids in large homegardens (600-800 m2), small homegardens (0-200 m2), oil palm and rubber plantations, and jungle rubber. The error bars indicate the standard errors.

5. Discussion

5.1. The effect of the owner ethnicity on homegarden components

In this study I found that the ethnicity of smallholders influences components observed in homegardens. In particular, I found that Jambi local smallholders conducted a significantly smaller number of management practices than the Javanese smallholders and although, there was no significant difference in homegarden size between ethnic groups, on average Javanese transmigrants own larger homegardens than Jambi locals, and a larger sample size may have yielded a significant result. Taken together, the significantly higher number of management practices and tendency of increased homegarden size within Javanese owned homegardens suggests a general trend towards increased intensification within Javanese transmigrants owners compared with Jambi locals. These findings are supported by previous studies that have also found variation in homegarden components and management in relation to the ethnicity of the owners (Trinh et al., 2003; Vazquez-Garcia, 2008). For example, Trinh et. al. (2003) found that variation in plant species composition, structure and function of homegardens in Vietnam are related to differences between ethnic groups; for instance he found that the Tho minority group tends to conduct less intensive management than the Kinh majority. However, ethnicity is only one of many important factors that can cause variation in homegarden composition and intensity of management, such as the geographical location, availability of resources, the particular preferences of the smallholders, and the distance to markets (Jose and Shanmugaratnam, 1993; Kumar and Nair, 2007; Mohri et al., 2013). The similarity of crop species richness between ethnic groups observed in this study for example could be due to plant resource availability and the similarity in the geographic location (e.g. climate, altitude) of the homegardens surveyed. Many of the smallholders interviewed usually exchanged seeds, seedlings and plant material between neighbouring homegardens (pers. comm.). Additionally, studies have suggested that management intensity in homegardens is usually associated with the economic importance a smallholder gives to their homegardens (Kumar and Nair 2007). Generally, homegardens oriented for cash-crop production are more intensively managed than those oriented for self-consumption (Kumar and Nair, 2007). In the case of the homegardens I studied, the majority of smallholders keep homegardens for self-consumption as a strategy for food security, and the surplus is shared with the relatives and neighbours (pers. comm.). Nevertheless, a few of the smallholders interviewed, particularly of Javanese ethnicity sell surplus to the nearby local markets to generate extra income, which may have resulted in the intensification of their homegardens, by increasing the number of management practices conducted, and an expansion of land under cultivation.

5.2. The impact of the homegarden components on the invertebrate communities and herbivore predation rate

The homegarden components investigated in this study had varying influences on overall invertebrate communities and hymenopteran communities alone. For instance, none of the homegarden components tested affected invertebrate abundance, but certain components did affect hymenopteran abundance, richness and specific functional groups. In particular, management intensity had a positive correlation with hymenopteran abundance and species richness and more specifically hymenopteran predator and parasitoid abundance. Increased crop diversity also has a positive influence on total hymenopteran abundance. It was hypothesized that larger homegardens would have a higher abundance and diversity of plant resources and thus habitats available for a higher number of invertebrate taxa

(Siemann et al., 1998; Scherber et al., 2006)in contrast to homegardens with smaller size.However, surprisingly, homegarden size did not influence any of the measured invertebrate variables. Studies suggest that cropdiversity in homegardensis not always associated with the homegarden size, but with other social factors such as the particular interests of smallholder(Trinh et al., 2003; Márquez and Schwartz, 2008). The number of nesting places for hymenopteran prey organisms, as well as the flower resources for foraging bees could be associated with the homegarden crop species richness, and these components might be particularly attractive to certain groups of hymenopteran, such as bees and wasps, which could explain the variation in hymenopteran abundance, but not in invertebrate abundance and hymenopteran species richness, in relation to the homegarden crop species richness.

Although the response of hymenopteran communities to management intensity was positive rather than negative as hypothesised, it is possible that the application of crop residues as fertiliser, which it was the main fertiliser source used in the study sites (pers. comm.), could have a positive effect on the hymenopteran species richness and abundance. For instance, the management of the organic matter by the application of crop residues may enhance natural enemy populations (Landis et al., 2000), especially of predators and parasitoids, since their prey could benefit from the use of the organic matter. For example, Yardım and Edwards (2003) found that the abundance in pest-predators is affected differently by the application of organic and chemical fertilisers in tomatoes; he found larger populations of aphid pests and Anthocorid predators in plantations where organic fertiliser was applied rather than chemical fertilisers. Furthermore, the use of fertiliser is aimed to improve soil fertility and thus enhance plant growth, which might have a positive impact on invertebrate abundance due to more plant resources being available for herbivore prey (Landis et al., 2000), and this interaction could have positive effect on hymenopteran communities. Although, strategies to control weeds are expected to negative impact invertebrate communities since plant resources are removed from the system, the owners of the homegardens surveyed tended to target weeds by conducting hand weeding rather than by applying chemical compounds. The management of weeds, in contrast to their complete removal in agricultural systems may enhance the composition of beneficial organisms (Marshall et al., 2003), for example, hand weeding could beless destructive for invertebrate habitats than herbicide application since smallholders select the undesirable weeds they want to remove, allowing other plants to establish and grow.To further understand the relationships between management and hymenopteran communities seen in this study the details of management practices used would need to be investigated more thoroughly, for example type, amount and frequency of inputs as well as time invested were not included in our simple measure of management intensity and these are all important components of management intensity.

My results showed that herbivore predation rate is not affected by homegarden size and crop species richness, but predation rate decreased with increasing the number of management practices. The use of certain inputs such as pesticide and herbicide application and weeding can alter prey abundance, through the reduction of their population by direct impact of the management (pesticide) (Landis et al., 2000), and the decrease of plants resources and invertebrate habitats (herbicide, weeding) (Marshall et al., 2003). These factors could have a direct impact on predator abundance and consequently, predation rate. To increase the understanding of the importance of homegarden invertebrate predators controlling pests it would be necessary to conduct further studies that estimate herbivory rates.

5.3. Comparison of invertebrate and hymenopteran community composition in the studied agricultural systems

There are numerous studies that emphasise that invertebrate diversity and abundance loss is associated to landscape transformation due to agriculture and its consequences (e.g. Fayle et al., 2010; Foster et al., 2011; Senior et al., 2013), such as the simplification of agro-ecosystems, the use of high amounts of external chemical inputs and habitat fragmentation (Landis et al., 2000; Isaacs et al., 2008; Flynn et al., 2009). In this study I found highly significant differences in invertebrate abundance, and hymenopteran diversity and abundance between large homegardens and oil palm plantations, rubber plantations and jungle rubber. This could be associated with the complexity of homegardens, such as higher plant biodiversity and relatively low intensity management conducted compared with the plantation systems. Homegardens can also resemble the surrounding natural ecosystems which could be a possible reason for invertebrates finding homegardens attractive habitats. The opposite is true in highly intensively managed agro-ecosystems such as oil palm and rubber plantations where commonly, plant diversity is low and the amount of pesticides and herbicides used to control pest and weeds is high. Other studies have found similar results, for example Rahman et. al. (2012) found that soil invertebrate diversity and abundance in Indian homegardens is higher than in intensive annual cropping systems and monoculture plantations. Interestingly, I did not observe significant variation in overall invertebrate abundance between oil palm, rubber and jungle rubber sites. I expected that jungle rubber, which is less intensively managed than monoculture plantations, would be asite more suitable for invertebrate communities than oil palm and rubber and therefore have higher invertebrate abundance. However, this finding also strengthens my hypothesis that homegardens are important habitats for preserving invertebrate communities in disturbed landscapes, although my results also suggest that for homegardens to be effective, attention should be given to the homegarden components, and recommendations on the management strategies should be provided to the owners.

6. Conclusions

In this study I observed that there are relationships between the ethnicity of smallholders and components of homegardens, the strongest of which is that number of management intensity is more likely to be higher in homegardens with Javanese owners. Furthermore, I found that intensity of management and crop species richness influence invertebrate communities, and predation rates are affected only by the management intensity. Taken together, these results could suggest that the ethnicity of smallholders is indirectly impacting invertebrate communities through the type of homegardening the different ethnic group practice, which shows the importance of taking social factors into consideration when conducting studies evaluating ecological components of homegardens. However, other important factors affecting invertebrate communities that should be considered are the vegetation composition of homegarden surrounding landscapes (e.g. urban settlements, secondary forest and plantations), as well as the composition of non-crop species within the homegardens, such as ornamental plants, that could be attractive to certain invertebrate organisms, neither of which were measured in this study. The comparison of homegarden invertebrate communities with three of the important agricultural systems in the area determined that homegardens are crucial agro-ecosystems for enhancing invertebrate abundance and hymenopteran diversity and abundance in highly modified agricultural landscapes, such as the tropical lowlands of Jambi, Indonesia. Practicing homegardening by smallholders is a strategy that not only contributes to strengthening food security of vulnerable households, but also promotes the conservation of beneficial organisms that provide important ecosystem services for food production and human welfare. Therefore, more attention should be given to understanding the importance of these traditional small-scale systems as hotspots for preserving biodiversity in the tropics.

7. References

Abdi, H., & Williams, L. J. 2010. Tukey's honestly significant difference (HSD) test. Encyclopedia of Research Design. Thousand Oaks, CA: Sage, 1–5.

Altieri, M. A. 1999. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment, **74**:19–31.

Collaborative Research Centre 900 (CRC990): Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems (Sumatra, Indonesia), URL http://www.uni-goettingen.de/en/study-site/416784.html

Deguines, N., Jono, C., Baude, M., Julliard, R., & Fontaine C. 2014. Large-scale trade-off between agricultural intensification and pollination. Frontiers in Ecology and the Environment, **12**:212–217.

Faveri, S. B., Vasconcelos, H. L., & Dirzo, R. 2008. Effects of Amazonian forest fragmentation on the interaction between plants, insect herbivores, and their natural enemies. Journal of Tropical Ecology, **24**:57-64.

Fayle, T. M., Turner, E. C., Snaddon, J. L., Chey, V. K., Chung, A. Y., Eggleton, P., & Foster, W. A. 2010. Oil palm expansion into rain forest greatly reduces ant biodiversity in canopy, epiphytes and leaf-litter. Basic and Applied Ecology, **11**:337–345.

Fisher, B. L. 1999. Improving inventory efficiency: a case study of leaf-litter ant diversity in Madagascar. Ecological Applications, **9**: 714–731.

Flynn, D. F., Gogol-Prokurat, M., Nogeire, T., Molinari, N., Richers, B. T., Lin, B. B., Simpson, N., Mayfield, M. M., & DeClerck, F. 2009. Loss of functional diversity under land use intensification across multiple taxa. Ecology Letters, **12**: 22–33.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, L. C., Ramankutty N., & Snyder P. K. (2005). Global consequences of land use. Science, **309**: 570-574.

Foster, W. A., Snaddon, J. L., Turner, E. C., Fayle, T. M., Cockerill, T. D., Ellwood, M. F., Broad, G. R., Chung, A. Y. C., Eggleton, P., Khen, C. V., & Yusah, K. M. 2011. Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. Philosophical Transactions of the Royal Society B: Biological Sciences, **366**:3277–3291.

Goulet, H., & Huber, J. T. 1993. Hymenoptera of the world: an identification guide to families. Research Branch, Agriculture Canada.

Guisan, A., Edwards Jr, T. C., & Hastie, T. 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological Modelling, **157**:89–100.

Haddad, N. M., Haarstad, J., & Tilman, D. 2000. The effects of long-term nitrogen loading on grassland insect communities. Oecologia, **124**:73–84.

Hansen, M. C., Stehman, S. V., Potapov, P. V., Arunarwati, B., Stolle, F., & Pittman, K. 2009. Quantifying changes in the rates of forest clearing in Indonesia from 1990 to 2005 using remotely sensed data sets. Environmental Research Letters, **4**:034001.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., & Romijn, E. 2012. An assessment of deforestation and forest degradation drivers in developing countries. Environmental Research Letters, **7**:044009.

Howe, A., Lövei, G. L., & Nachman, G. 2009. Dummy caterpillars as a simple method to assess predation rates on invertebrates in a tropical agroecosystem. Entomologia Experimentalis et Applicata, **131**:325–329.

Isaacs, R., Tuell, J., Fiedler, A., Gardiner, M., & Landis, D. 2008. Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants. Frontiers in Ecology and the Environment, **7**:196–203.

Jose, D., & Shanmugaratnam, N. 1993. Traditional homegardens of Kerala: a sustainable human ecosystem. Agroforestry Systems, **24**:203–213.

Kehlenbeck, K., & Maass, B. L. 2004. Crop diversity and classification of homegardens in Central Sulawesi, Indonesia. Agroforestry Systems, **63**:53–62.

Klein, A.-M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences, **274**:303–313.

Kumar, B. M., & Nair, P. R. 2004. The enigma of tropical homegardens. Agroforestry Systems, **61**:135–152.

Kumar, B. M., & Nair, P. R. 2007. Tropical homegardens: a time-tested example of sustainable agroforestry (Vol. 3). Springer.

Landis, D. A., Wratten, S. D., & Gurr, G. M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology, **45**:175–201.

Larsen, T. H., Williams, N. M., & Kremen, C. 2005. Extinction order and altered community structure rapidly disrupt ecosystem functioning. Ecology Letters, **8**:538–547.

Margono, B. A., Potapov, P. V., Turubanova, S., Stolle, F., & Hansen, M. C. 2014. Primary forest cover loss in Indonesia over 2000-2012. Nature Climate Change.

Márquez, A. R. C., & Schwartz, N. B. 2008. Traditional home gardens of Petén, Guatemala: Resource management, food security, and conservation. Journal of Ethnobiology, **28**:305–317.

Marsh, R. 1998. Building on traditional gardening to improve household food security. Food Nutrition and Agriculture, 4–14.

Marshall, E. J. P., Brown, V. K., Boatman, N. D., Lutman, P. J. W., Squire, G. R., & Ward, L. K. 2003. The role of weeds in supporting biological diversity within crop fields*. Weed Research, **43**:77–89.

Mohri, H., Lahoti, S., Saito, O., Mahalingam, A., Gunatilleke, N., Hoang, V. T., Hitinayake, G., Takeuchi, K., & Herath, S. 2013. Assessment of ecosystem services in homegarden systems in Indonesia, Sri Lanka, and Vietnam. Ecosystem Services, **5**:124–136.

Murdiyarso, D., Noordwijk, M. V., Wasrin, U. R., Tomich, T. P., & Gillison, A. N. 2002. Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra. Journal of Vegetation Science, **13**:429–438.

Priess, J. A., Mimler, M., Klein, A.-M., Schwarze, S., Tscharntke, T., & Steffan-Dewenter, I. 2007. Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems. Ecological Applications, **17**:407–417.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R project.org/

Rahman, P. M., Varma, R. V., & Sileshi, G. W. 2012. Abundance and diversity of soil invertebrates in annual crops, agroforestry and forest ecosystems in the Nilgiri biosphere reserve of Western Ghats, India. Agroforestry Systems, **85**:165–177.

Raintree, J. B., & Warner, K. 1986. Agroforestry pathways for the intensification of shifting cultivation. Agroforestry Systems, **4**:39–54.

Richards, L. A., & Coley, P. D. 2007. Seasonal and habitat differences affect the impact of food and predation on herbivores: a comparison between gaps and understory of a tropical forest. Oikos, **116**:31–40.

Scales, B. R., & Marsden, S. J. 2008. Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factors influencing them. Environmental Conservation, **35**:160–172.

Scherber, C., Mwangi, P. N., Temperton, V. M., Roscher, C., Schumacher, J., Schmid, B., & Weisser, W. W. 2006. Effects of plant diversity on invertebrate herbivory in experimental grassland. Oecologia, **147**:489–500.

Senior, M. J., Hamer, K. C., Bottrell, S., Edwards, D. P., Fayle, T. M., Lucey, J. M., Mayhew P. J., Newton, R., Peh, K. S.-H., Sheldon, F. H., Stewart, C., Styring, A. R., Thom, M. D. F., Woodcock, P., & Hill, J. K. 2013. Trait-dependent declines of species following conversion of rain forest to oil palm plantations. Biodiversity and Conservation, **22**:253–268.

Siemann, E., Tilman, D., Haarstad, J., & Ritchie, M. 1998. Experimental tests of the dependence of arthropod diversity on plant diversity. The American Naturalist, **152**:738–750.

Stephen, W. P., & Rao, S. 2007. Sampling native bees in proximity to a highly competitive food resource (Hymenoptera: Apiformes). Journal of the Kansas Entomological Society, **80**:369–376.

Trinh, L. N., Watson, J. W., Hue, N. N., De, N. N., Minh, N. V., Chu, P., Sthapit, B. R., & Eyzaguirre, P. B. 2003. Agrobiodiversity conservation and development in Vietnamese home gardens. Agriculture, Ecosystems & Environment, **97**:317–344.

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer J., & Whitbread, A. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biological Conservation, **151**:53–59.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. 2005. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecology Letters, **8**:857–874.

Tylianakis, J. M., Tscharntke, T., & Lewis, O. T. 2007. Habitat modification alters the structure of tropical host–parasitoid food webs. Nature, **445**:202–205.

Vazquez-Garcia, V. 2008. Gender, ethnicity, and economic status in plant management: Uncultivated edible plants among the Nahuas and Popolucas of Veracruz, Mexico. Agriculture and Human Values,**25**:65–77.

Ward, D. F., New, T. R., & Yen, A. L. 2001. Effects of pitfall trap spacing on the abundance, richness and composition of invertebrate catches. Journal of Insect Conservation, **5**:47–53.

Yardım, E. N., & Edwards, C. A. 2003. Effects of organic and synthetic fertilizer sources on pest and predatory insects associated with tomatoes. Phytoparasitica, **31**:324–329.

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. 2007. Ecosystem services and dis-services to agriculture. Ecological Economics, **64**:253–260.

Appendices

Appendix 1

Total invertebrate abundance in the studied agricultural systems in, classified to the higher taxonomic groups.

Agricultural systems	**Acarina**	**Araneae**	**Blattodea**	**Diptera**	**Chilopoda**	**Collembola**	**Coleoptera**	**Crustacea**	**Dermaptera**	**Diplura**	**Hemiptera**	**Homoptera**	**Hymenoptera**	**Isopoda**	**Isoptera**	**Lepidoptera**	**Mantodea**	**Mollusca**	**Myriapoda**	**Neuroptera**	**Odonata**	**Orthoptera**	**Phasmatodea**	**Protura**	**Psocoptera**	**Thysanoptera**	**Unidentified**	**Total**
Small homegardens (n=12)	6	138	5	270	2	642	426	1	1	1	108	26	880	0	26	29	0	12	2	1	8	140	0	1	1	6	54	2786
Large homegardens (n=12)	12	135	2	275	2	350	284	0	2	3	84	52	726	9	20	16	2	0	2	0	21	100	2	0	0	7	53	2159
Oil palm (n=4)	3	33	1	48	1	139	46	0	5	0	14	13	129	0	0	9	0	0	1	0	2	57	2	0	0	0	1	228
Rubber (n=4)	1	31	0	58	0	38	60	0	0	0	28	2	96	0	0	1	0	0	0	0	5	31	0	0	0	3	9	175
Jungle rubber (n=4)	4	14	3	73	1	76	70	0	0	0	10	6	92	0	0	30	0	0	0	0	6	10	1	0	0	1	4	160
Total	26	351	11	724	6	1245	886	1	8	4	244	99	1923	9	46	85	2	12	5	1	42	338	5	1	1	17	121	5508

Appendix 2

Total hymenopteran abundance in the studied surveyed agricultural systems, classified to families (discarding Formicidae).

Agricultural system	Anthophoridae	Apidae	Austroniidae	Braconidae	Ceraphronidae	Chalcididae	Colletidae	Crabronidae	Ctenoplectridae	Dryinidae	Eucharitidae	Halictidae	Ichneumonidae	Leucospidae	Megachilidae	Megalodontidae	Megaspilidae	Melittidae	Mymaridae	Nyssonidae	Perilampidae	Platygastridae	Pompilidae	Rhopalosomatidae	Scelionidae	Scoliidae	Sphecidae	Tiphiidae	Trichogrammatidae	Vespidae	Total
Small homegardens (n=12)	7	14	1	0	1	0	5	1	2	1	0	1	1	1	1	0	1	0	3	14	0	1	0	0	2	0	6	0	4	28	95
Large homegardens (n=12)	13	21	0	0	0	1	5	2	0	0	0	4	4	1	0	0	0	2	2	10	0	1	1	1	2	2	6	2	0	29	109
Oil palm (n=4)	3	1	0	0	0	1	1	0	0	0	1	0	0	0	0	1	0	0	1	4	1	0	0	0	1	0	0	0	0	2	17
Rubber (n=4)	0	2	0	1	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	4	17
Jungle rubber (n=4)	0	1	0	0	0	1	1	0	0	0	1	0	2	0	0	0	0	0	0	5	0	0	0	0	0	0	0	1	0	4	16
Total	23	39	1	1	1	5	12	3	2	1	4	5	7	2	1	1	1	2	6	39	1	2	1	1	5	2	12	3	4	67	254

Appendix 3

Total hymenopteran abundance (discarding Formicidae) in the studied agricultural systems, classified to functional groups.

Agricultural systems	**Predators**	**Pollinators**	**Parasitoids**	**Herbivores**	**Total**
Small homegardens (n=12)	43	30	22	0	95
Large homegardens (n=12)	41	45	23	0	109
Oil palm (n=4)	6	5	5	1	17
Rubber (n=4)	10	2	5	0	17
Jungle rubber (n=4)	9	2	5	0	16
Total	109	84	60	1	254

Appendix 4

Summary of statistics (model output tables) of GLM for the effect of homegardens owner ethnicity (origin) on (a) homegarden size (m^2), (b) crop richness, and (c) management intensity. Significant p-values (<0.05) are indicated in bold.

a) Homegarden size (m^2)

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.3571	0.1314	10.332	**<0.001**
origin	0.4946	0.2936	1.685	0.106

b) Homegarden crop richness

	Estimate	Std. Error	t-value	p-value
(Intercept)	25.4429	6.831	3.725	**0.0011**
origin	-0.8714	4.554	-0.191	0.85

c) Homegarden management intensity

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.3714	0.5035	2.724	**0.0124**
origin	0.9143	0.3356	2.724	**0.0124**

Appendix 5

Summary of statistics (model output tables) of GLM for the effect of the homegarden components: homegarden size, crop richness, and management intensity, on (a) invertebrate abundance, (b) hymenopteran abundance, (c) hymenopteran diversity, (d) hymenopteran predators, (e) hymenopteran pollinators, and (f) hymenopteran parasitoids. Significant p-values (<0.05) are indicated in bold. Pesticide application variable was added in the model.

a) Invertebrate abundance

	Estimate	**Std. Error**	**t-value**	**p-value**
(Intercept)	51.765	96.677	0.535	0.599
size	57.622	35.774	1.611	0.124
crop richness	-1.181	1.807	-0.654	0.521
m. intensity	37.541	26.271	1.429	0.169
pesticide	90.381	45.7	-0.138	0.892

b) Hymenopteran abundance

	Estimate	**Std. Error**	**t-value**	**p-value**
(Intercept)	0.17432	0.55828	0.312	0.7583
size	0.18157	0.20658	0.879	0.3904
crop richness	0.02215	0.01044	2.122	**0.0472**
m. intensity	0.40039	0.15171	2.639	**0.0162**
pesticide	-0.07584	0.2639	-0.287	0.7769

c) Hymenopteran species richness

	Estimate	**Std. Error**	**t-value**	**p-value**
(Intercept)	0.4242	0.517045	0.82	0.4221
size	0.086642	0.191326	0.453	0.6558
crop richness	0.017654	0.009666	1.826	0.0836
m. intensity	0.365243	0.140502	2.6	**0.0176**
pesticide	-0.091196	0.244411	-0.373	0.7132

d) Hymenopteran predators

	Estimate	Std. Error	t-value	p-value
(Intercept)	-0.02164	0.72065	-0.03	0.9764
size	-0.04449	0.26667	-0.167	0.8693
crop richness	0.02428	0.01347	1.803	0.0874
m. intensity	0.42516	0.19583	2.171	**0.0428**
pesticide	-0.52586	0.34066	-1.544	0.1392

e) Hymenopteran pollinators

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.10412	0.66728	0.156	0.878
size	0.21905	0.24692	0.887	0.386
crop richness	0.01624	0.01248	1.302	0.209
m. intensity	0.08679	0.18133	0.479	0.638
pesticide	0.33026	0.31543	1.047	0.308

f) Hymenopteran parasitoids

	Estimate	Std. Error	t-value	p-value
(Intercept)	-0.375687	0.60309	-0.623	0.5407
size	-0.096727	0.223166	-0.433	0.6696
crop richness	0.007749	0.011275	0.687	0.5002
m. intensity	0.46707	0.163884	2.85	**0.0102**
pesticide	-0.043238	0.285086	-0.152	0.881

Appendix 6

Summary of statistics (model output tables) of GLM for the effect of the individual management practices: fertiliser , herbicide), and pesticide, on (a) invertebrate abundance, (b) hymenopteran abundance, (c) hymenopteran diversity, (d) hymenopteran predators, (e) hymenopteran pollinators, and (f) hymenopteran parasitoids. Significant p-values (<0.05) are indicated in bold.

a) Invertebrate abundance

	Estimate	Std. Error	t-value	p-value
(Intercept)	4.7887	0.1943	24.64	**<0.001**
fertiliser	0.4041	0.2211	1.827	0.0826
herbicide	0.0296	0.194	0.153	0.8803
pesticide	0.2071	0.172	1.204	0.2427

b) Hymenopteran abundance

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.5391	0.2601	5.918	**<0.001**
fertiliser	0.2964	0.2959	1.001	0.329
herbicide	0.24	0.2596	0.925	0.366
pesticide	0.2789	0.2302	1.212	0.24

c) Hymenopteran species richness

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.4277	0.2283	6.253	**<0.001**
fertiliser	0.3836	0.2598	1.477	0.155
herbicide	0.1645	0.2279	0.722	0.479
pesticide	0.2108	0.2021	1.043	0.309

d) Hymenopteran predators

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.90466	0.29698	3.046	**<0.001**
fertiliser	0.75698	0.33793	2.24	**0.03661**
herbicide	-0.07398	0.29643	-0.25	0.80546
pesticide	-0.26717	0.26289	-1.016	0.32163

e) Hymenopteran pollinators

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.09549	0.28901	3.791	**0.00115**
fertiliser	-0.15001	0.32886	-0.456	0.6532
herbicide	0.08596	0.28847	0.298	0.76879
pesticide	0.42523	0.25583	1.662	0.11207

f) Hymenopteran parasitoids

	Estimate	Std. Error	t-value	p-value
(Intercept)	0.2753	0.2437	1.13	0.272
fertiliser	0.2554	0.2773	0.921	0.368
herbicide	0.5835	0.2433	2.399	**0.0263**
pesticide	0.4104	0.2157	1.902	0.0716

Appendix 7

Summary of statistics (model output tables) of GLM for the effect of the homegarden components: homegarden size, crop richness, and management intensity, on herbivore predation rate. Significant p-values (<0.05) are indicated in bold. Pesticide application and the landscapesurveyed regions variables were added in the model.

	Estimate	Std. Error	t-value	p-value
(Intercept)	-0.87466	0.48569	-1.801	0.088501
size	0.19347	0.16626	1.164	0.259756
crop richness	-0.01101	0.01027	-1.071	0.298104
m. intensity	-0.27844	0.12538	-2.221	**0.039436**
pesticide	0.0879	0.2317	0.379	0.708867
landscape	-0.84048	0.17439	-4.82	**<0.001**

Appendix 8

Summary of statistics (model output tables) of one-way ANOVA for the effect of the study agricultural systems (group): large homegardens (600-800 m^2), small homegardens (0-200 m^2), oil palm and rubber plantations, and jungle rubber, on (a) invertebrate abundance, (b) hymenopteran abundance, (c) hymenopteran diversity, (d) hymenopteran predators, (e) hymenopteran pollinators, and (f) hymenopteran parasitoids. Significant p-values (<0.05) are indicated in bold.

a) Invertebrate abundance

	Df	Sum Sq	Mean Sq	f-value	p-value
(Intercept)	1	557540	557540	111.82	**<0.001**
group	1	57262	57262	11.48	**0.00264**
Residuals	22	109696	4986	——	——

b) Hymenopteran abundance

	Df	Sum Sq	Mean Sq	f-value	p-value
(Intercept)	1	1001	1001	58.696	**<0.001**
group	1	116.8	116.8	6.846	**0.0158**
Residuals	22	375.2	17.1	——	——

c) Hymenopteran species richness

	Df	Sum Sq	Mean Sq	f-value	p-value
(Intercept)	1	672	672	93.04	**<0.001**
group	1	96	96	13.3	**0.00142**
Residuals	22	158.9	7.2	——	——

d) Hymenopteran predators

	Df	Sum Sq	Mean Sq	f-value	p-value
(Intercept)	1	192.67	192.67	24.436	**<0.001**
group	1	11.88	11.88	1.506	0.233
Residuals	22	173.46	7.88	——	——

e) Hymenopteran pollinators

	Df	Sum Sq	Mean Sq	f-value	p-value
(Intercept)	1	84.38	84.38	18.294	**<0.001**
group	1	43.16	43.16	9.357	**0.005751**
Residuals	22	101.47	4.61	——	——

f) Hymenopteran parasitoids

	Df	Sum Sq	Mean Sq	f-value	p-value
(Intercept)	1	63.38	63.38	29.378	**<0.001**
group	1	2.17	2.17	1.004	0.327
Residuals	22	47.46	2.16	——	——

Acknowledgements

Firstly, I would like to thank my supervisors Prof.Dr.TejaTscharntke and Dr.Yann Clough for all the valuable support and advice throughout my Master thesis. Thank you very much for the chance you gave me to work within the CRC990 project. I've gained invaluable experiences due to this opportunity.

This work was possible thanks to the financial support of the Department of Agroecology at the University of Göttingen.

I'm deeply indebted to Lisa Denmead for all the input and time invested while supervising my work, of which the final outcome she totally is innocent. Thank you Lisa for the advices and help during the field work and writing this document, the movies and music, the innumerable "*oleholeh*", and thank you for being a friend.

I thank Kevin Darras for his help during my short internship in 2013 that eventually opened the chance for accomplishing my Master thesis within the BO9 project. I´m also thankful for the comments and recommendation you gave me on my thesis.

Numerous people have helped me during my stay and field work in Indonesia. I'm thankful for all the administrative support given by Dr. Rika Raffiudin. I thank the CRC990 staff in Jambi and Göttingen, and the BO9 assistants Patrick, Winda, Rico, Derly and Juwita for their valuable support. Penelitian ini tidak akan pernah mungkin terjadi tanpa pemilik homegarden dan keluarga mereka. Saya sangat berhutang budi pada mereka atas kesediaannyauntuk berpartisipasidalam penelitian saya, serta untuk kebaikan dan keramahan mereka. Terima kasih banyak!I would like to thank my "*GotongRoyong*" friends for their patience and great experiences we lived together during my time in Jambi.

Quisiera darles particularmente las gracias a mis amigos en Göttingen por estos últimos tres años de innumerables anécdotas y por su apoyo moral durante la escritura de este documento.

Ich möchte meiner deutschen Familie danken: Oma Gerda, Friedemann, Margit, Julika, Bärbel & Mitzi, Norbert und Rita &Harald. Danke für eure Unterstützung und Ratschläge und dafür, dass ihr dieses Land zu meinem zweiten Zuhause gemacht habt. DankeOmaGerdafür die reichhaltigeBewirtungmitRouladen.

No podría estar más agradecido a mi Abuela Griselda, mis padres Ernesto y Raquel, a mi hermana Rubí y mi cuñado Moisés, porque de maneras distintas siempre han estado ahí apoyándome para conseguir mis metas. Así mismo, quisiera reconocer el impulso que mis tíos Héctor y Laura me dieron en las primeras etapas de mi formación personal y académica, y que ahora van rindiendo frutos. ¡Gracias familia!

Finalmente quisiera agradecer a mi compañera de vida Marieke. Gracias por tu apoyo y comprensión durante este proceso de titulación. Gracias por tu paciencia cuando no estoy. Y gracias por ser mi compañera de aventuras. ¡Muchasgraciasporsertú y estarconmigo!

Statutory declaration

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

Date: ______________________ Signature: ______________________