Diet and functional diversity of birds in different rainforest transformation systems in Sumatra

Master Thesis

To gain the Master of Science degree (M.Sc.) in Tropical and International Forestry (TIF) at the Faculty of Forest Sciences and Forest Ecology, Georg-August-University Göttingen

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Zusammenfassung

Die Abholzung von Wäldern und die intensiver werdende Bewirtschaftung von Landschaften haben einen starken Einfluss auf die taxonomische und funktionelle Diversität von Flora und Fauna. Die Erforschung ökologischer Funktionen und Artenvielfalt in von Menschen dominierten Landschaften, trägt zu ihrem Schutz und zur nachhaltigen Entwicklung in den Tropen bei. Ich habe die Ernährung von Vögeln in mehreren Regenwald-Transformationssystemen in der Provinz Jambi auf Sumatra untersucht und miteinander verglichen. Von Vögeln erfüllte ökologische Funktionen resultieren hauptsächlich aus ihrer Ernährungsweise. Die Vögel wurden in Japannetzen gefangen und ihre Ausscheidungen in 32 Probeflächen in und um die Schutzgebiete „Bukit 12 Nationalpark“ und „Harapan Rainforest“ gesammelt. Die Probeflächen befanden sich in Sekundärwald, Kautschuk-Agroforstsystemen sowie in Kautschuk- und Ölpalmplantagen. Mithilfe von diagnostischen Bestandteilen wie Samen und Arthropoden-Fragmenten im Vogelsekret, konnte die Ernährungsweise gefangener Vogelarten bestimmt werden. Zusätzlich wurden Pollenkörner vom Schnabel nektarivorer Vögel untersucht und die von ihnen besuchten Pflanzenarten identifiziert. Aufgrund ihres bevorzugten Lebensraumes und ihrer Ernährung, wurden die Vögel in verschiedene Habitat-Gruppen und Nahrungsgilden eingeordnet. Um die Interaktionen zwischen Konsumenten und Ressourcen (Vögel und Arthropoden/Pflanzen) aufzuzeigen, wurden Nahrungs-Netzwerke erstellt und die Spezialisierung von Vogelarten und Netzwerken anhand von Indexen (*d’* und *H2’*) bestimmt. Dadurch konnten die trophischen Beziehungen zwischen Vögeln, Pflanzen und Arthropoden in den verschiedenen Transformationssystemen festgestellt und verglichen werden. Mit einer intensivierten landwirtschaftlichen Nutzung nahm die Diversität von Vogelarten ab und die Zusammensetzung von Vogelgemeinschaften änderte sich. Spezialisierte insektivore Vogelarten der Familien *Monarchidae*, *Muscicapidae* und *Timaliidae* verschwanden entlang des Transformations-Gradienten. Dagegen nahm die Zahl omnivorer Vogelarten der Familien *Columbidae, Dicaeidae* und *Pycnonotidae* innerhalb der Plantagen zu. Zudem ließen sich Unterschiede in ihrer Ernährung erkennen. Die am häufigsten konsumierten Früchte in den Plantagen stammten von unkrautartigen und invasiven Pflanzenarten wie *Melastoma malabathricum, Clidemia hirta* und *Clibadium surinamense*. Außerdem ließ sich auf den Konsum unterschiedlicher Arthropodenarten in den verschiedenen Habitaten schließen. Diese Ergebnisse deuten darauf hin, dass sich auch in Zukunft viele der im Wald lebenden spezialisierten Vogelarten nicht an die rasante Umwandlung natürlicher Habitate anpassen können und dass Vogelarten mit einer generalisierten Ernährungsweise im Vorteil sind.

Abstract

Deforestation and land-use change have strong impacts on taxonomic and functional diversity of aboveground animal biodiversity. Scientific research on diversity patterns contributes to efforts for conservation and sustainable development in the tropics. I examined the diet composition and associated ecological functions of understory birds in different rainforest transformation systems in the province Jambi in Sumatra. The ecological functions that birds provide (seed dispersal, predation and pollination) mainly result from their foraging behavior. Birds were caught in mist nets and dropping samples at 32 plots in and around "Bukit 12 National Park" and "Harapan Rainforest" were collected. The plots were located in secondary forest, jungle rubber, rubber plantations and oil palm plantations. By identifying material in the droppings such as seeds and arthropod fragments, it was possible to determine the diet composition for caught understory bird species. Additionally, pollen grains from the beak of nectarivorous birds were examined to identify the visited flowering plants. I classified the bird species into habitat groups and feeding guilds according to their preferred habitat and diet. I also created food networks to display the structure of consumer-resource interactions (birds - arthropods/plants) and determined the specialization of bird species and networks through the computation of indices *d'* and *H2'*. Thus, I could assess and compare the trophic relation between birds and consumed arthropods and plants in different rainforest transformation systems. With intensifying agricultural exploitation, bird species richness decreased and the bird community composition changed. Specialized insectivorous bird species from the families *Monarchidae, Muscicapidae* and *Timaliidae* disappeared along the gradient of transformation, whereas the number of omnivorous bird species from the families *Columbidae, Dicaeidae* and *Pycnonotidae* increased in the plantations. Furthermore, different diet compositions were observable. The majority of consumed fruits inside the plantations belonged to weedy and invasive plant species such as *Melastoma malabathricum, Clidemia hirta* and *Clibadium surinamense*. Moreover, different families and species of arthropods are likely to be consumed within the different habitat types. These results indicate that many specialized forest bird species are not able to adapt to the continuous conversion of formerly natural habitats and common bird species with a generalized foraging behavior are advantaged.

1. Introduction

1.1 Deforestation and landscape transformation in Indonesia

The increasingly rapid deforestation in tropical developing countries destroys unique forest habitats and releases large amounts of greenhouse gases, thus contributing to biodiversity loss and global warming (Margono et al. 2014). The tropical forests in South-East Asia are among the most species-rich in the world, but are also severely threatened by rapid population growth and the increasing demand for natural resources (N. Sodhi et al. 2005). Large areas formerly covered with tropical forest are cleared and converted to agricultural land to satisfy the needs of the population. This resulting biodiversity loss becomes even more severe, when the management of these agricultural areas is intensified (Donald 2004). Two of the most rapidly spreading crops in tropical regions are oil palms (*Elaeis guineensis*) and rubber trees (*Hevea brasiliensis*) and Indonesia is one of the top global producers of these crops (Clay 2004).

From 2000 to 2012, the total primary forest loss in Indonesia amounted to 6.02 Mha. Moreover, the annual primary forest loss in Indonesia (0.84 Mha in 2012) became even higher than in Brazil (0.46 Mha in 2012), the former leading country in tropical deforestation (Margono et al. 2014). The constant landscape transformation and land-use intensification (e.g. through pesticide application, fertilization, irrigation and crop breeding) supporting Indonesia's agro-industrial development, drastically changes natural habitats and threatens many animal and plant communities (Margono et al. 2012; Clough et al. 2009). The thriving oil palm industry is contributing to a large extent to the forest loss in the country (Beukema et al. 2007). Together, Indonesia and Malaysia produce 85 % (in 2011: 23.9 Mt and 18 Mt respectively) of the world's' palm oil (UNCTAD, 2012) and with both countries supporting the establishment of new industrial oil palm plantations, they will most likely stay the worlds' main palm oil producers in the future. According to UNCTAD (2012), it is Indonesia's goal to produce 40 Mt of palm oil per year by 2020, half of this amount exclusively for biofuel. Another major crop in Indonesia is the Brazilian rubber tree to produce natural latex. With 3.45 Mha in 2011, Indonesia is the country with the largest area under rubber cultivation in the world (UNCTAD, 2012).

1.2 Landscape transformation and bird conservation in Sumatra

In Sumatra, 70 % of the island's original forest cover was cleared by 2010 (Margono et al. 2012). The tropical lowlands of Sumatra are suitable for the cultivation of oil palm and rubber plantations and have been converted mostly to large monocultures (MacKinnon and Phillipps, 2012) of *Elaeis guineensis* and *Hevea brasiliensis*. A publication by Donald (2004) compared the biodiversity in natural forest habitats and plantations, asserting that oil palm plantations are very poor habitats for wildlife, which do not provide suitable environmental conditions for most species. For example, the author summarized a study from Danielsen and Heegard (1995) and stated that the conversion of forests to oil palm plantations in Sumatra resulted in simple and species-poor vertebrate communities of low conservation importance and with only few specialized species. Many bird species respond quickly to changes in habitat and climate, therefore, their presence or absence can be seen as an indicator for the ecological condition of natural habitats (Sodhi et al. 2005; Zakaria and Rajpar 2010). The loss of tropical forests, especially lowland forests, represents one of the greatest threats to the worlds' bird diversity (Aratrakorn et al. 2006; Birdlife International 2008). As a report of Birdlife International (2012) points out, 70 % of all threatened bird species have a high or medium dependence on forest. Less than 1 % of the bird species in the world prefer agricultural areas, but about one third of all bird species use such habitats from time to time (Sekercioglu 2012). The Sumatran Archipelago is home to 732 known bird species of which 29 species are endemic (Avibase: Lepage 2015). The large island has a comprehensive network of nature reserves and national parks, covering about 45.000 km² (10 % of the island), with the potential to protect almost all avian species. However, due to insufficient law enforcement, the continuous encroachment of the land by timber concessionaires and local farmers continues (MacKinnon and Phillipps, 2012). Land conversion, forest fires, selective logging, poaching, and fuel wood collection are degrading and changing the diverse ecosystems (MacKinnon and Phillipps, 2012), leading to a loss of biodiversity. According to Beukema et al. (2007) "bird species that are associated with the forest interior of primary and old secondary forest are most affected by habitat loss through large scale forest conversion in the Sumatran lowlands". Another threat to the avifauna of the region is the international and nationwide bird trade: many wild-caught species are popular songbirds that are kept in cages or traded for consumption (MacKinnon and Phillipps, 2012).

1.3 Functional diversity of birds

The concept of functional diversity associates species diversity to ecosystem functions through specific resource-use patterns (Tscharntke et al. 2008; Sodhi et al. 2010). Functional diversity drives ecosystem processes, ecosystem services and their resilience to environmental change (Laliberté and Legendre 2010). Scientists have proposed many ways to measure functional diversity and the possibilities are increasing rapidly. Generally, one measures the diversity of functional information (traits) as part of an organism's phenotype, which influences ecosystem processes (Petchey and Gaston 2006).

Birds are a taxonomically and functionally diverse group and they fulfill important ecosystem services such as pollination, pest control, seed dispersal and nutrient deposition (Sodhi et al. 2005; Sekercioglu 2012). The ecosystem services that birds provide mainly result from their foraging behavior (Wenny et al. 2011). A simple approach for classifying birds is based on their diet (e.g. omnivory, insectivory, nectarivory, frugivory, carnivory, granivory etc.), so the number of trophic groups (also called 'feeding guilds') can serve as a measure for functional diversity (Petchey and Gaston 2006; Flynn et al. 2009). For example, nectarivorous bird species pollinate dependent plant species, contributing to the exchange of unrelated genetic material between areas. Frugivorous bird species consume and disperse seeds, improve their germination and are responsible for the genetic exchange between areas. Moreover, they can contribute to the recolonization and restoration of disturbed ecosystems. Insectivorous bird species control insect populations and can serve as an alternative to pesticides as they reduce plant damage, what therefore can also be of great economic importance (Sekercioğlu et al. 2004). In order to understand the ecology of tropical bird communities, to improve conservation efforts and to trace the alteration of birds' ecosystem services, functional changes in bird communities from distinct habitats such as tropical lowland forests and agroforestry systems to homogenous plantations, are of great interest (Sekercioglu 2012; Wenny et al. 2011). A global analysis of avian ecological data conducted by Sekercioglu (2012) revealed that the conversion of forest land to agricultural land causes a shift to less specialized bird communities, which are mainly composed of common and widespread species. This development also leads to modified proportions of functional groups and can reduce ecosystem functions and services provided by birds in agricultural landscapes (Sekercioglu 2012). This classification of bird feeding guilds becomes even more significant, when finer functional differences (e.g. size and type of food) within those broad categories are also considered (Petchey and Gaston 2006). To display trophic interactions between birds and their food resources, the establishment of detailed food networks can therefore be a useful tool to comprehend functional differences in bird communities between forest and agricultural habitats. A study by Flynn et al. (2009) has shown that functionally distinct species (specialists) are much more vulnerable to extinction through agricultural intensification than functionally redundant species (generalists) that share similar ecological functions. Nevertheless, a decrease in species richness is not always accompanied by a loss of functional diversity (e.g. generalized bird species could fulfill all functions that extinct specialized bird species no longer provide in agricultural landscapes) and so the species richness is not necessarily a good indicator for functional diversity (Flynn et al. 2009).

1.4 Food networks

It is becoming increasingly important for ecologists and evolutionary biologists to study animal-plant interactions to understand ecological communities and to improve their management and conservation (Vázquez et al. 2009). An ecological community is composed of many different populations, which form a multi-layered entity and interact with each other in several ways (e.g. predation, seed dispersal, pollination, competition, parasitism etc.). This complex system can be displayed and analyzed by creating an ecological network, in which relationships and energy fluxes between certain species are linked (Carnicer et al. 2009). Food networks can show a large amount of coexisting species in specific consumer-resource interactions (Allesina and Pascual 2007) and they can be further described by computing a variety of indices (Dormann et al. 2009). To display the structure and quantity of who interacts with whom in the different transformation systems in Jambi province, I established food networks and linked bird species to their specific food resources. Furthermore, I chose to evaluate several related indices (*web asymmetry, niche overlap, d', H2'*) concerning the degree of specialization on species and network level.

1.5 Study area

The study is part of the Collaborative Research Centre (CRC) 990 named "Ecological and Socio-economic Functions of Tropical Lowland Rainforest Transformation Systems" (EFForTS). The aim of the CRC 990 is to examine the reasons and effects of the transformation of tropical lowland rainforest into agricultural landscapes in Sumatra, Indonesia and to provide information on how to combine both agricultural land-use and conservation strategies (CRC 990, 2014). The CRC 990 is a long-term collaboration between the University of Göttingen, the University of Jambi (UNJA), Bogor Agricultural University (IPB), Tadulako University (UNTAD) and the Indonesian Institute of Science (LIPI). (CRC 990, 2014)

Research was conducted in Jambi province, located in Central Sumatra. The climate of the region is moist-equatorial with an annual rainfall of about 3000 mm. The wet season lasts from October to April (> 200 mm rainfall per month) and the dry season from May to September. The yearly average temperatures range between a minimum of 22.5°C and a maximum of

31.4°C. The slightly undulating to flat terrain is covered mainly by well-drained soils, such as acid oxisols with a low fertility. (Beukema et al. 2007)

Our fieldwork took place in 32 plots (size 50 x 50 m) within two landscapes around Bukit 12 National Park and Harapan rainforest. In each of the two landscapes, 16 plots are situated – four in rubber plantations, four in oil palm plantations, four in jungle rubber systems and four in secondary forest (in the protected areas Bukit 12 National Park and Harapan Rainforest) to serve as reference sites (map: Fig.17 in the appendix).

Forest habitats that are composed of several strata and hold a high arthropod and plant diversity provide suitable microhabitats and serve as foraging and nesting site for many forest bird species (Urban & Smith, 1989). A jungle rubber system is a traditional smallholder agroforestry practice. Jungle rubber agroforests resemble secondary forest in their structure, can host a large number of food resources and therefore support species diversity in fragmented and degraded landscapes (Beukema et al. 2007). Although these agroforestry systems have been common in Jambi, they are currently being replaced by rubber and oil palm monocultures (Bennett et al. 2005). Due to the uniform structure in rubber and oil palm plantations and the frequent application of herbicides to remove all undergrowth, the bird species richness decreases significantly (Aratrakorn et al. 2006).

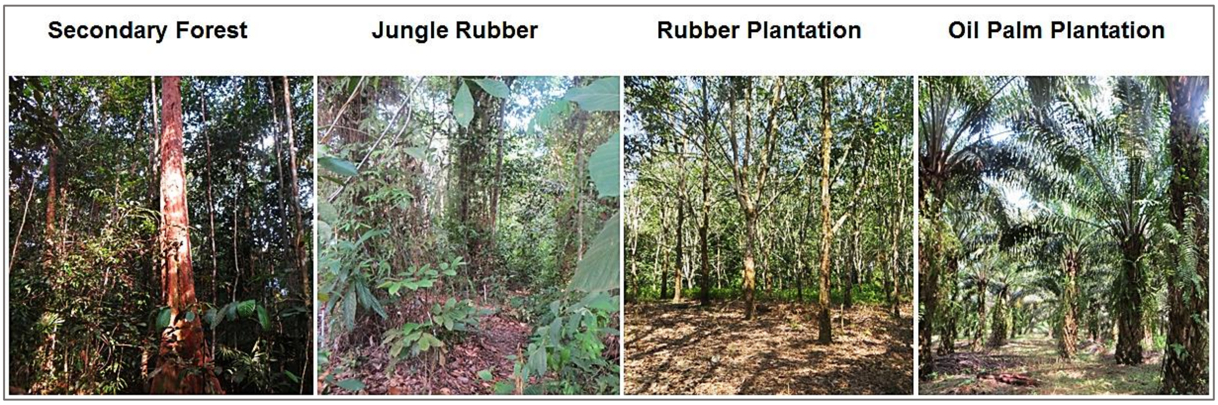

Figure 1: The rainforest transformation systems in Jambi province

1.6 Aim of the study

The purpose of this thesis is to describe human-induced landscape transformations with regard to the community composition, functional diversity and trophic specialization of birds in different habitat types. We collected and analyzed bird droppings to determine the diet composition and to derive the birds' ecological function. We also gathered claw tips and feathers from birds for stable isotope analysis to assess their trophic position within the complex food web through a different approach. Furthermore, we took pollen samples from nectarivorous bird species, to determine the plant species visited. Through these measures, we could assess and compare the organization of bird communities through their diet and understand their function in different habitat types.

I expected the available food resources to be most diverse in secondary forest and therefore, the bird abundance and diversity to be the highest inside this habitat. Furthermore, I hypothesized that the networks in these natural forest habitats are most specialized. In the jungle rubber agroforests, I expected a moderate variety of food resources and still a relatively high bird abundance and diversity. Moreover, I expected to find more specialized bird species in these forest and agroforest habitats, which strictly depend on certain environmental conditions and have a specialized diet, such as insectivorous, frugivorous and nectarivorous bird species. Within the homogeneous rubber and oil palm plantations, I expected a very limited availability and variety of food resources and therefore a lower bird abundance and species diversity. I also expected to catch a larger number of common bird species with a broad food spectrum and more generalized networks in these habitats. I hypothesized that generalized bird species are able to adapt more easily to transformed landscapes, whereas specialized bird species are clearly disadvantaged, when their usual food sources diminish due to habitat loss and land conversion.

2. Material and Methodology

2.1 Study design

Several standard techniques are used to sample birds: Bird calls often have unique acoustic signatures and therefore a direct way to explore the composition of bird communities, is the collection and analysis of avian sound recordings. As birds are heard more often than caught or observed, the analysis of sound spectrograms through suitable automatic call recognition software is an extremely valuable technique for monitoring bird diversity and abundance. This method is especially convenient to detect species that occur in dense vegetation or are difficult to observe in some other way (Sutherland 2004; Brandes 2008). Other bird monitoring methods are line or point transects, at which birds are recorded visually by qualified observers and their distance to a predetermined route or a certain plot is marked. These are flexible approaches and there are many suitable sampling design possibilities, which can be adapted to specific terrain conditions. However, the collected data is dependent on the observer's skill and data quality can be influenced by double-counting, visibility, foliage density and canopy cover (Sutherland 2004; Zakaria and Rajpar 2010).

The application of mist nets in avian studies is especially effective to detect small and shy bird species with secretive behavior and infrequent calls (Zakaria and Rajpar 2010). In general, mist nets are suitable for a wide range of bird species and as their installation is quite flexible, they can be applied in almost every terrestrial habitat. The captured birds are easily identified, ringed and the collection of specific samples is possible. With this procedure, biased bird identifications and double counting can be avoided. However, it requires a lot of experience to extract birds from mist nets unharmed and it is still a very stressful procedure for them (Sutherland 2004). Moreover, the method is very time-consuming and the transport and installation of the mist net equipment requires considerable efforts (Zakaria and Rajpar 2010). For my research, I chose to capture birds in the study area with mist nets. As Dunn et al. (2002) point out, "mist netting is an important technique for population monitoring, helping to assess species composition, relative abundance, population size and demography (productivity and survival)". Moreover, it is possible to collect data for other research purposes at the same time (Dunn et al. 2002). I collected bird droppings, pollen, claw tip and feather samples, which is not possible using other bird monitoring techniques. I focused on small to medium-sized understory birds and chose mist nets with 19 mm and 30 mm mesh size (NHBS, 2014). These nets have a height of 3.0 – 3.2 m and were set up 0.1 – 1.0 m above the ground, depending on the site conditions (slope, ground vegetation). To achieve a total net length of more than 100 m per plot (recommendation of Dr. Yeni Mulyani, personal communication, 10th April 2014), two 6 m-nets with 19 mm mesh size, two 18 m-nets with 30 mm mesh size and five 12 m-nets with either 19 mm or 30 mm mesh size (in total 108 m net length) were combined. We opened the mist nets at sunrise (approximately 6 AM) and closed them before sunset (approximately 5 PM), to avoid nocturnal birds or bats. During daytime, we closed the nets during rainfall or when temperatures were too high during the middle of the day to avoid bird mortality.

2.2 Fieldwork procedure

We carried out mist netting in Harapan landscape from 24th April 2014 to 20th May 2014 and in Bukit 12 landscape from 26th May 2014 to 21st June 2014. As we worked in two teams, we were able to collect data at two plots simultaneously. Data collection at each plot took place over a two-day period. Nets were checked every hour to reduce stress for the birds and to avoid them becoming more entangled with time. We extracted the birds from the nets and put them into clean paper bags to collect their droppings. We checked the ground below the net for droppings and feathers and collected possible fruit samples from the surroundings.

We kept the birds in paper bags for 20 to 40 minutes until they defecated and then we started with our measurements. The first step was to identify the species (MacKinnon and Phillipps 2012; Robson 2011) and to measure the bird's tarsus diameter to apply a fitting bird ring with its individual ID number (Bird rings provided by LIPI, the Indonesian Institute of Sciences). Next, we measured body mass, beak length, wing length, tail length and total length using the required equipment (see table 7 in the appendix). We collected all data according to a datasheet of the Indonesian Bird Banding Scheme (IBBS).

After completing the measurements, we took claw tip samples (1 – 2 mm according to bird size and claw length) from two toes with a nail clipper. We collected pollen from nectarivorous bird species with a strip of transparent cellophane tape from the upper and lower side of the bird's beak and their throat. We attached the tape onto a microscope slide, to conserve the pollen grains. After some final photographs for reference, we released the bird. We stored all collected samples either in zip lock bags or small centrifuge tubes, each sample labelled with the individual bird ring ID and plot ID. We conserved the droppings and the fruit samples with 70 % ethanol. As in (Pearson Ralph et al. 1985) we established a reference collection of arthropods, fruits and seeds, which could be found in and around the plots. Arthropods were collected from the jungle rubber, rubber and oil palm plots in the Harapan landscape with sweep-nets, beating trays and pitfall traps. The arthropods were separated into morphospecies and then identified to order or family level. The collected arthropods were fed to two cage birds (*Pycnonotus goiavier* and *Prinia familiaris*) and their droppings were analyzed under the microscope. This procedure allowed identification of arthropod parts of specific taxa, before the analysis of the bird droppings from the fieldwork. All arthropod fragments and seeds from the reference collection and from the fieldwork samples were photographed and a unique ID number for future reference and comparison was assigned.

2.3 Dropping analysis

The analysis of the bird droppings was conducted in the CRC 990 laboratory at the University of Jambi. First, the droppings were shaken inside the sample tubes for about 30 seconds to dissolve all the particles in the ethanol solution. The content was then poured from the sample tubes onto a glass plate and seeds and arthropod fragments were separated from other objects (e.g. feathers, sand and fruit parts) under the microscope. With the help of the reference collection, the seeds and arthropod fragments were identified to order level and if possible, family, genus or species level. The diagnostic parts were also counted. Some broken arthropod fragments could not be identified and a few samples contained only uric acid. All distinct fragment types (arthropod or seed) found in a dropping were assigned an ID number and photographed and this data was linked to the specific bird ID.

2.4 Stable isotope analysis

Analyzing the diet of birds based on their droppings reflects their diet in the few hours prior to collection and can be biased, for example through the fast digestion of soft-bodied prey (Pitocchelli et al. 1994). According to Hopkins & Ferguson (2012) the utilization and analysis of stable isotope data is an important tool to examine the foraging ecology of animals. As Pitocchelli et al. (1994) point out, stable carbon and nitrogen isotopes can reveal the birds' trophic position. I wanted to define the trophic position of birds in Jambi within their complex food web and draw conclusions about their diet. In avian studies, it is still common to collect samples of muscle, bone and blood tissue for an isotopic analysis (Bearhop et al. 2003), however, I wanted to apply a less invasive approach, so we collected claw tips and feather samples to derive the isotopic data. Claws and feathers provide information on bird diet and habitat selection on a temporal scale of a few weeks to several months before the sampling

(Bearhop et al. 2003). I have not yet been able to conduct an isotope analysis of the collected samples, as I did not receive a permit from the Indonesian Ministry of Research to export the samples to Germany. Therefore, I will not present any results concerning this topic in my thesis.

2.5 Pollen preparation and analysis

It is possible to distinguish pollen load from different plant species through diagnostic traits like the size of the pollen grain, the structure of the exine wall and the number and size of the apertures (COLOSS 2015). I prepared and analyzed the collected pollen samples in the palynology laboratory at Georg-August-University Göttingen. First, the cellophane tape was removed from the microscope slides and the glue of the tape was dissolved with ethanol in labelled plastic tubes. After one day, the residual tape was removed from the plastic tubes, centrifuged several times for five minutes at 3500 RPM and the supernatant was poured off into a beaker. Later the remaining fluid was moved into labelled Eppendorf tubes and I continued to centrifuge them for three minutes at 9000 RPM, until only a very small amount of concentrate was left. For dehydration, 1 ml of acetic acid (CH3COOH) was added into each sample and the content was mixed and centrifuged again for three minutes at 9000 RPM to separate the extract from the supernatant. Then, an acetolysis was conducted and 1 mL of the acetolysis solution (= 9:1 acetic anhydride ((CH3CO)2O) to concentrated sulphuric acid (H2SO4)) was added to each sample.

Afterwards, the open Eppendorf tubes were placed into a water bath for 10 minutes at 90 °C to start the chemical reaction and then the tubes were centrifuged again for three minutes at 9000 RPM to remove the supernatant. I washed the samples with distilled water once and centrifuged one more time to pour off the supernatant. I then placed the open Eppendorf tubes into an oven at 60 °C for one night to dry the samples. Subsequently, a few drops of glycerin were added to each sample and this mixture was preserved in paraffin wax on labelled moving slides to scan the pollen under the microscope. With the help of this procedure I wanted to determine, which flowering plant species were visited by nectarivorous bird species in the study area.

2.6 Statistical analysis

R statistical software (R Core Team 2014, Version 3.1.1) was used for the analysis and graphical visualization of the collected data. Mist-netting data are not suitable for detailed population and diversity analyses, therefore my statistical analysis focused on trophic networks.

I used R package *bipartite* (Dormann et al. 2014), which allows visualization of food webs (command: plotweb()). Moreover, this package can calculate a series of network and species indices, which are used to describe certain patterns in ecological food webs (e.g. *web asymmetry*, *niche overlap*). The focus of this package lies in webs that consist of two trophic levels like predator-prey-webs or pollination webs (= consumer - resource webs).

Nonmetric multidimensional scaling (NMDS) is one technique used to describe community similarity between samples. This multivariate analysis is a statistical tool to visualize the level of similarity or dissimilarity of individual cases of a dataset graphically within a coordinate system (McGarigal, 2000). I applied NMDS to display the composition of bird communities in the different transformation systems and to identify clusters of functionally similar bird species (R package *vegan* by Oksanen et al. 2015; command: metaMDS()).

To determine, if the functional variation (measured as amount and strength of trophic links) occurs at taxonomic or systemic level related to the type of transformation system, I applied two quantitative indices (*d'* and *H2')* to describe the degree of specialization of the “bird - food resource” interactions. The species-level measures of trophic functions can be compared to network-wide trophic measures to analyze, how generalized or specialized and how stable the food networks are. Interactions between consumers and resources were usually described in a simple qualitative way: is a certain interaction between two parties present or absent? This approach leaves out any further distinction regarding strong or weak interactions. A quantitative approach, with regard to interaction strength (number of seeds or arthropod parts) is superior to this common binary way (Blüthgen et al. 2006).

Both indices are based on the Shannon entropy and are mathematically related (Blüthgen et al. 2006). The first index *d'* describes the degree of interaction specialization at species level (computed with R package *bipartite*: command specieslevel()). This index is derived from the Kullback-Leibler divergence and calculates how strongly a species deviates from a random sample of interactions. It ranges from *d'*=0 for extreme generalization to *d'*=1 for extreme specialization (Blüthgen et al. 2006). The second index *H2'* works on network-level (R package *bipartite*: networklevel()) and describes the degree of specialization or partitioning between species in the entire network. The *H2'*-values are standardized between 0 and 1 for extreme generalization (maximum niche overlap) versus extreme specialization (maximum niche divergence) respectively (Dormann et al. 2009).

I tested whether the specialization on species and network level (*d'* and *H2'* respectively), the niche overlap and the web asymmetry is significantly different between the four different rainforest transformation systems and landscapes using linear mixed-effects models (LME) and Post-hoc analyses of comparisons of *H2'* means by land-use with Dunnett contrasts (glht() function from package *multcomp*). The type of transformation system (and landscape) was defined as the fixed effect and plot identity was included as a random effect to account for variation within the same habitat type (Crawley 2013). The LME were computed with the R package *nlme* (Pinheiro et al. 2013) and fitted with Maximum Likelihood (ML) to allow stepwise selection and model comparison with AIC scores.

3. Results

In the two landscapes Bukit 12 and Harapan, we caught 260 birds (Bukit 12: 157, Harapan: 103, retraps in total: 7) and identified 60 different bird species from 18 families. The families *Pycnonotidae* (62), *Columbidae* (50) and *Timaliidae* (35) were most abundant. The three most abundant bird species were *Chalcophaps indica* (48), *Arachnothera longirostra* (26) and *Pycnonotus plumosus* (18), 25 bird species were singletons (see table 3 in the appendix).

We were able to attach a bird ring with a unique ID to 240 birds; the other 20 recorded birds escaped and could not be included in our measurements and sampling. From the total amount of captured birds, 199 individuals could be identified as adults and 44 individuals were juveniles. We were unable to determine the age of 17 individuals, because they escaped too soon. According to the IUCN Red List, the status of 49 captured bird species is considered as "least concern" (LC) and 10 species are considered as "near threatened" (NT), mainly due to habitat loss (IUCN 2014).

We collected a total amount of 170 dropping samples (Harapan: 72; Bukit 12: 98), 174 claw tip samples (Harapan: 66; Bukit 12: 108), 167 feather samples (Harapan: 66; Bukit 12: 101) and 45 pollen samples from nectarivorous species (Harapan: 19; Bukit 12: 26). Overall, our mist nets were open for 656 hours (20.5 hours per plot). In Bukit 12, the nets were open for 314 hours and in Harapan, the nets were open for 341 hours. In Bukit 12, the net hours were less due to unsuitable weather conditions and time constraints, but in both cases, the invested amount of time and the total net hours conformed to the planning.

3.1 Distribution of bird habitat groups

I classified all captured bird species broadly into three habitat groups (based on Beukema et al. 2007) according to their preferred habitat in the lowlands and their level of association with the forest:

- Habitat group 1: *'Open woodland and cultivated areas'* = Species of open woodlands, low secondary growth, grasslands, inhabited and cultivated areas.
- Habitat group 2: *'Degraded and artificial forest types'* = Species mostly found along edges, in gaps or in the upper canopy of dense forest stands or in semi-deciduous, more open forest types. They occupy degraded secondary forests, tree plantations and clearings.
- Habitat group 3: *'Primary and old secondary forest interior'* = Species mostly associated with the primary and old secondary forest interior. Some are restricted to large, undisturbed forest tracts; others are more tolerant of human or natural disturbance and remain widespread in secondary forests.

The two graphs (Fig. 2 and 3) display the relationship of birds to their preferred habitat. The birds classified as "Habitat group 1" do not occur within secondary forest, but mainly inside oil palm plantations (Harapan and Bukit 12) and rubber plantations (Bukit 12 only). The birds classified as "Habitat group 2" represent a major proportion of birds found within the plantations, most notably at Harapan landscape. A large proportion of forest birds ("Habitat group 3") were caught at jungle rubber and secondary forest plots and they rarely occurred at plantation plots, especially not in oil palm plantations.

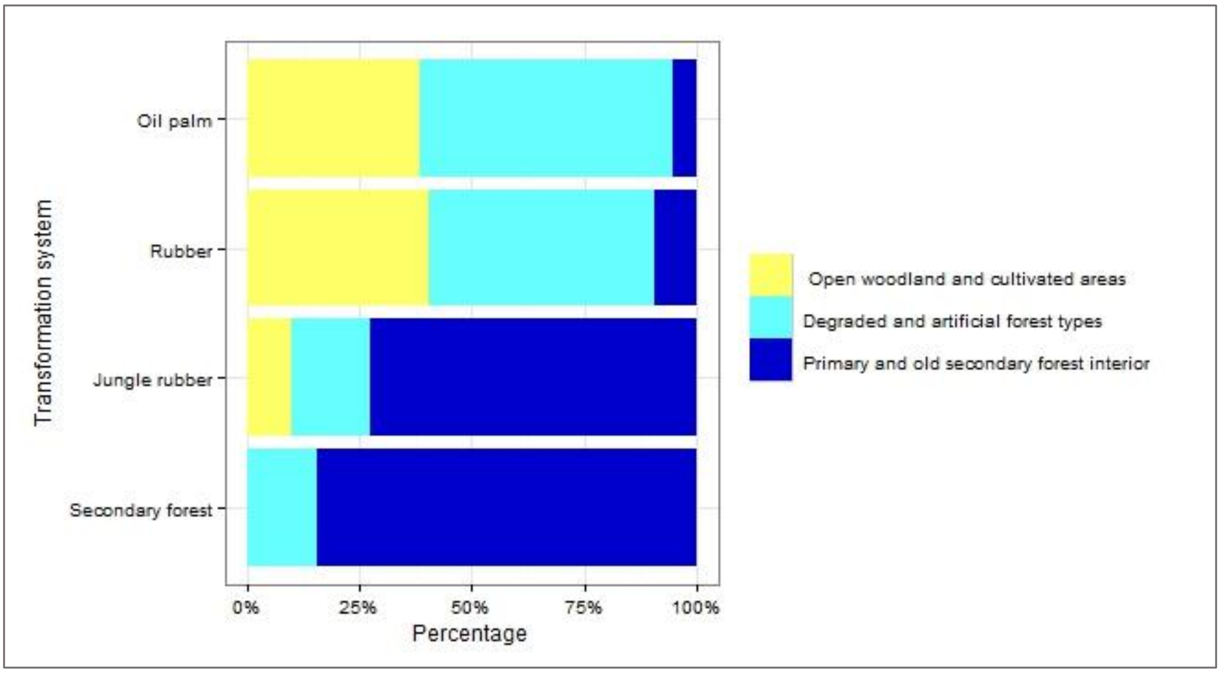

Figure 2: Bird habitat groups (1-3) in the transformation systems of Bukit 12 landscape

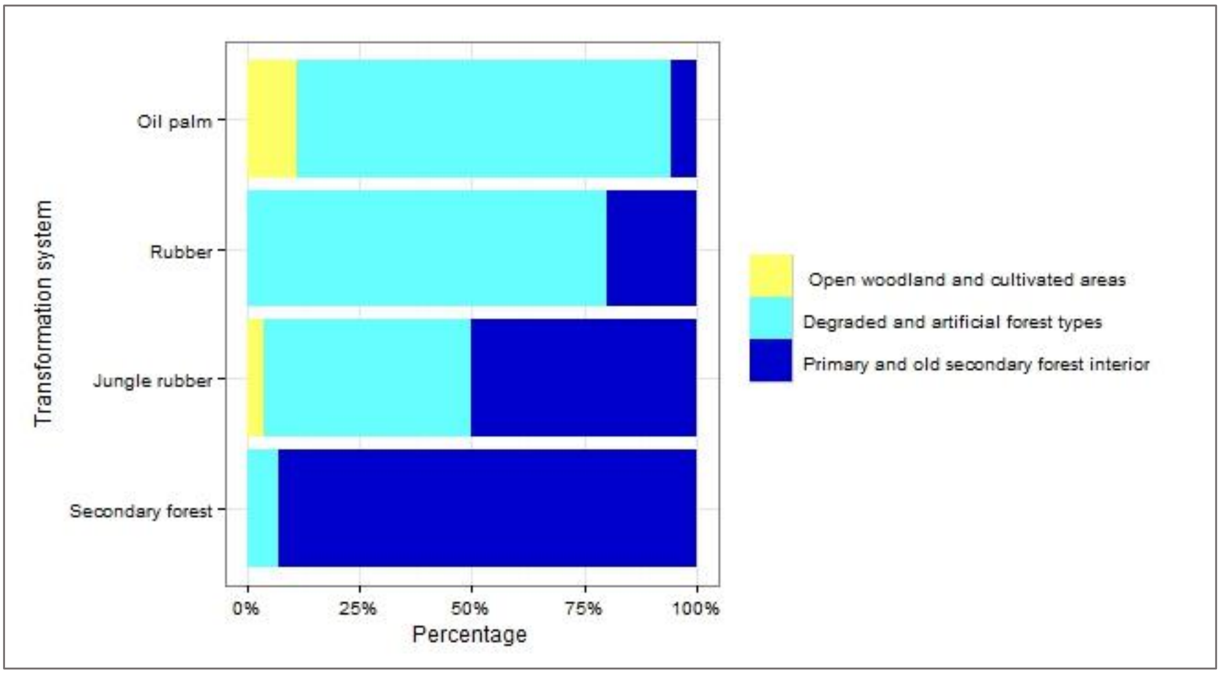

Figure 3: Bird habitat groups (1-3) in the transformation systems of Harapan landscape

3.2 Bird species richness

The total bird species richness in the different transformation systems of both landscapes amounted to 28 species within the secondary forest plots, 26 species within the jungle rubber plots and decreased to 19 species in the oil palm plots and 18 species in the rubber plots (Fig. 4). In Bukit 12, the bird species richness in the different transformation systems was 12 species in the secondary forest plots, but increased to 17 species in the jungle rubber plots, 17 species in the oil palm plots and 16 species in the rubber plots. In Harapan, the bird species richness in the different transformation systems was 22 species in the secondary forest plots, 18 species in the jungle rubber plots and decreased to 7 species in both the oil palm and rubber plots.

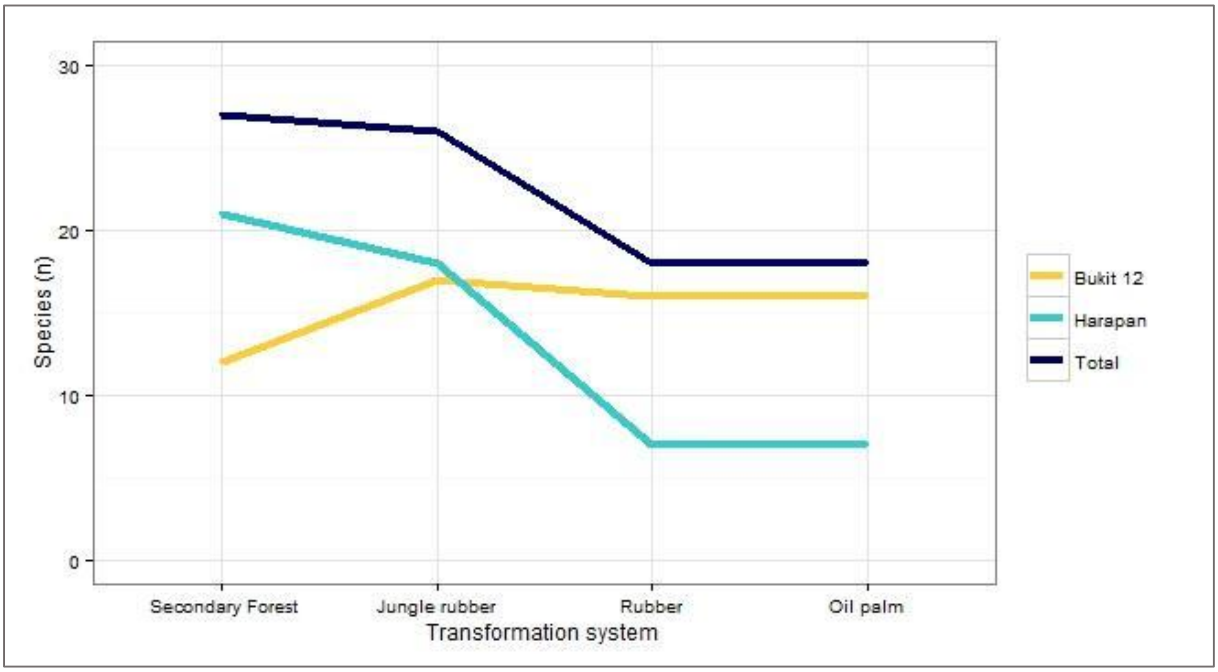

Figure 4: Bird species richness in the transformation systems of Jambi province by landscape and total

3.3 Non-metric multidimensional scaling

Through the generation of two-dimensional NMDS plots, I visualized similarities in bird communities between plots in Harapan and Bukit 12 in the four transformation systems. The NMDS plots clearly display the differences between bird communities in secondary forest and jungle rubber and bird communities in rubber and oil palm plantations (Fig. 5 and 6). In Bukit 12, there is a clear gap between the plots of secondary forest, jungle rubber agroforest and the plantations plots (Fig. 5). The bird communities are very different in the systems, but there is a remarkable overlap in the plantation plots. The differences in bird community composition between natural forest and plantations are striking. In Harapan, there is a large gap between the bird community of the four forest plots and the other plots inside jungle rubber, rubber and oil palm plantations (Fig. 6). The community composition of the latter non-forest plots is more similar and partly overlapping. In the majority of cases, it was not possible to identify arthropod fragments even to family level and the visualization of food resources at order level in NMDS plots was not meaningful; therefore, I did not analyze the trophic differences in bird communities with NMDS plots. I also did not catch enough individuals of the same species in all transformation systems to compare the diet of a particular bird species between them.

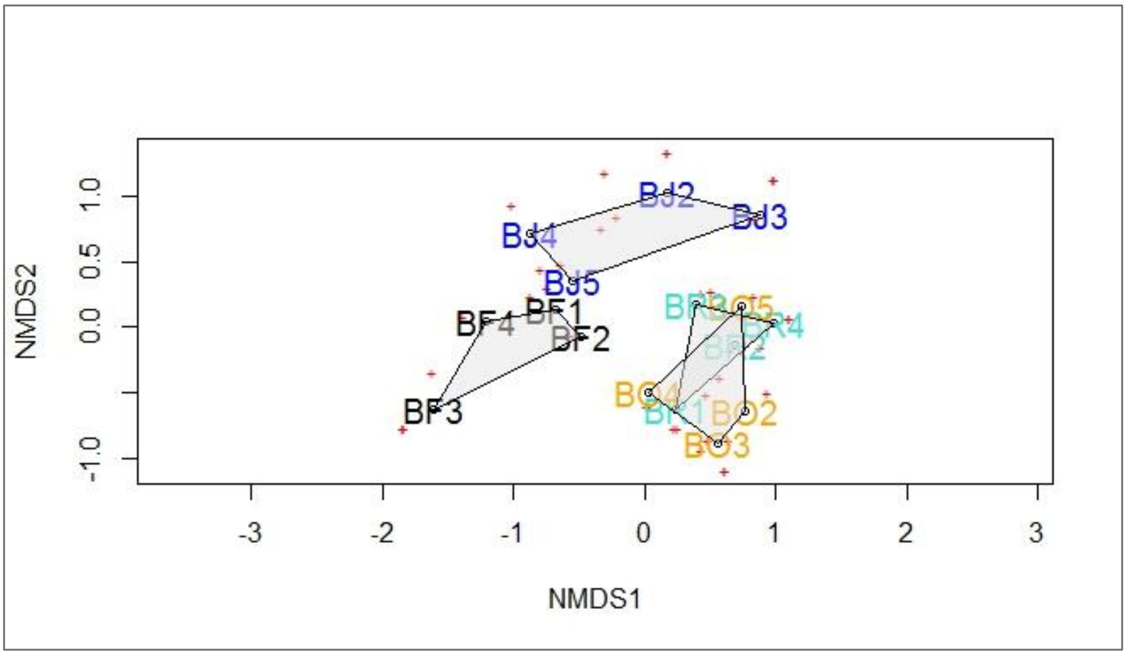

Figure 5: NMDS plot visualizing the different bird communities in the transformation systems of Bukit 12; forest (black),jungle rubber (blue), rubber (turquoise), oil palm (orange); bird species displayed as red crosses

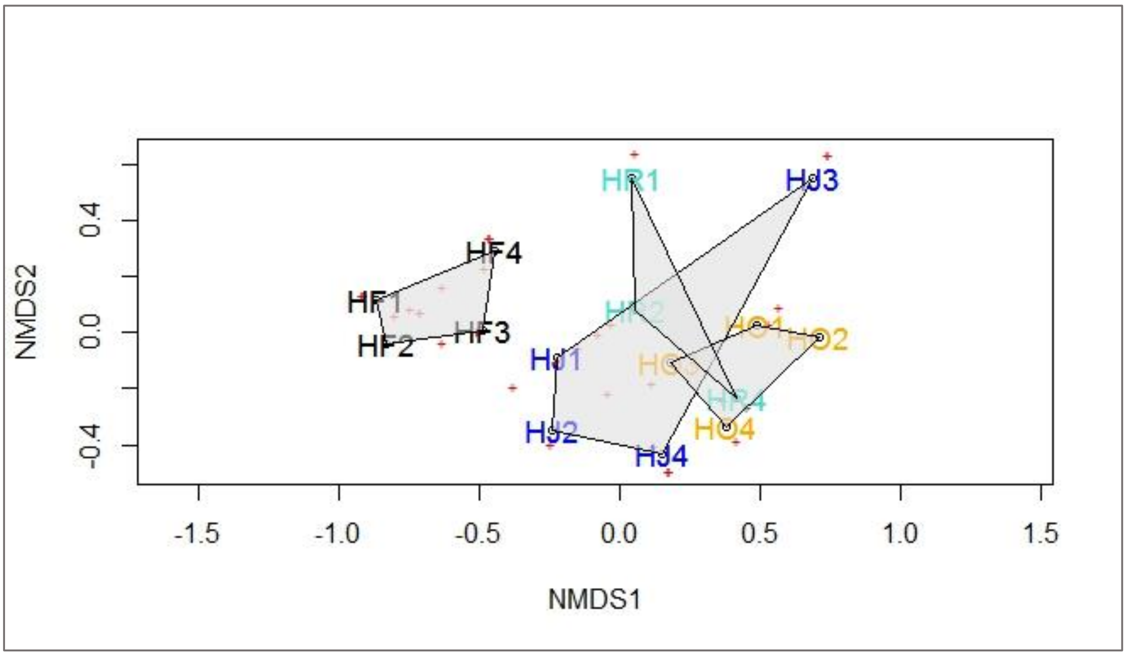

Figure 6: NMDS plot visualizing the different bird communities in the transformation systems of Harapan; forest (black),jungle rubber (blue), rubber (turquoise), oil palm (orange); bird species displayed as red crosses

3.4 Feeding guilds

According to their diet, I classified bird species into feeding guilds. As remarked by Komar (2006), shown by several scientific publications (Thiollay 1995; Wilman et al. 2014) and my own literature research, it is difficult to produce a uniform bird feeding guild classification because of different methodologies and the seasonality of underlying data. Due to this, bird species are placed in different feeding guild categories. Fig. 7 displays the proportion of each bird feeding guild in the four different transformation systems of Harapan and Bukit 12, based on the classification from distinct sources to show how variable the outcome may look. According to my own classification (based on Thiollay 1995 and HBW Alive 2015), it is clearly visible that the major proportion of omnivorous bird species have been caught in oil palm and rubber plantation plots (Fig. 7 a) and b)). The highest proportion of insectivorous bird species occurred in more natural habitats as jungle rubber and secondary forest. Moreover, the share of frugivorous and nectarivorous birds was much higher in these habitats than within the plantation plots. The carnivorous bird species (*Alcedinidae*) were rare, but caught in all transformation systems. The most noticeable difference to the feeding guild classification by Thiollay (1995) were bird species he considered as granivores. Bird species from the family *Columbidae* are all classified as granivores and therefore their proportion is high within the rubber and oil palm plantation plots. Through the analysis of droppings from *Chalcophaps indica* (*Columbidae*), arthropod parts and seeds from certain fruits could be identified as part of their diet, so I classified this species as omnivorous. Following the database of Wilman et al. (2014), more bird species were classified as frugivorous/nectarivorous although based on the classifications of Thiollay (1995) and I, they are omnivorous (e.g. species from the family *Pycnonotidae* feed on arthropods and fruits). Therefore, the proportion of this feeding guild seems to be higher within the plantation plots. Bird species, such as *Arachnothera longirostra* from the family *Nectariniidae*, have been classified as omnivores, although based on the classifications of Thiollay (1995) and I, they are nectarivores. For this reason, it seems as if no birds classified as frugivorous/nectarivorous occur in secondary forest at all and the proportion of omnivorous birds is higher or almost as high as within the rubber and oil palm plantation plots. My guild classification conforms to the latest information on bird diet from HBW Alive (2015) and is supported by older data of Thiollay (1995) for the most part. This classification supports the expectation that bird species with a generalized diet are not strictly dependent on specific food resources and therefore are most likely able to adapt to modifying landscapes. That is why they represent the major proportion in artificial rubber and oil palm plantations. On the other hand, bird species with a specialized diet tend to thrive in natural forest-like habitats.

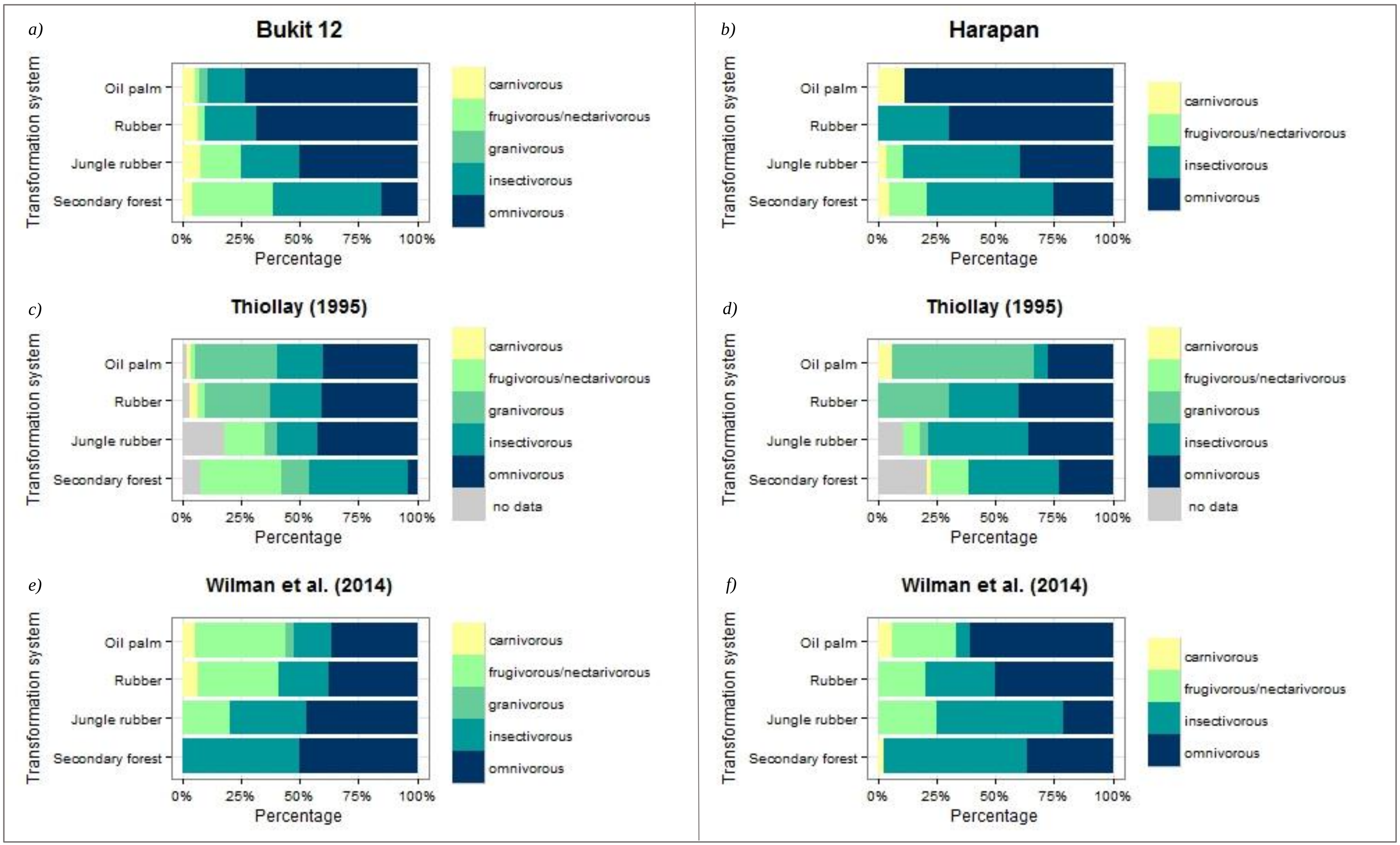

Figure 7: Classification of bird species into feeding guilds in Bukit 12 and Harapan according to a) and b) = own classification; c) and d) = Thiollay 1995; e) and f) = Wilman et al. 2014

3.5 Trophic relationships between birds and their food resources

Through the microscopic analysis of arthropod fragments, seeds and pollen grains, it was possible to identify a large variety of food resources consumed by birds in Jambi province. All arthropod fragments were identified to order level, a further identification almost never possible (the very common *Formicidae* family was an exception). The most frequent diagnostic arthropod parts were femur, mandible, tibia, head and leg. In general, the highest quantity of consumed arthropods belong to the orders *Hymenoptera* (1188 fragments) and *Coleoptera* (457 fragments). Less commonly consumed arthropods belong to the orders *Araneae* (24 fragments), *Hemiptera* (20 fragments) and *Dermaptera* (4 fragments). Rarely consumed arthropods were of the orders *Diptera* (2 fragments), *Orthoptera* (1 fragment), *Lepidoptera* (1 fragment), *Acarina* (1 fragment) and *Psocoptera* (1 fragment).

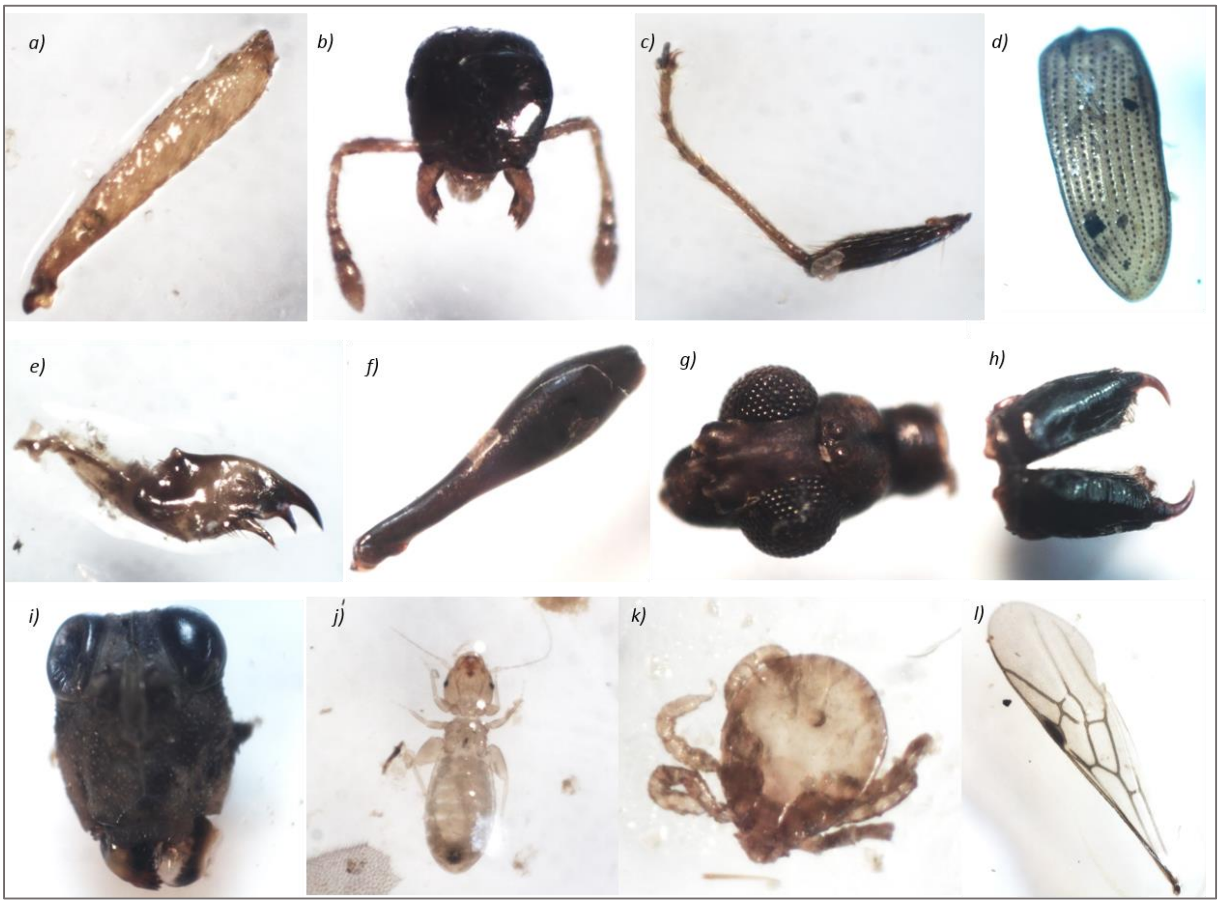

Figure 8: Selected pictures of arthropod fragments a) Hymenoptera (tibia), b) Formicidae (head), Hymenoptera (leg), d) Coleoptera (elytra), e) Coleoptera (mandible), f) Coleoptera (femur), g) Hemiptera (head), h) Araneae (chelicera), i) Orthoptera (head), j)Psocoptera (body), k) Acarina (body), l) Hymenoptera (wing)

The majority of seeds were identified to species and at minimum, they were identified to family level. The highest quantity of seeds came from the two plant species *Melastoma malabatricum* (3442 seeds) and *Clidemia hirta* (2751 seeds). Less commonly consumed seeds came from the species *Urophyllum arboreum* (313 seeds), *Trema orientalis* (38 seeds), *Clibadium surinamense* (15 seeds), *Lantana camara* (1 seed) and *Scleria ciliaris* (1 seed). Other seeds, which could not be ascribed to a certain plant species, belong to the families *Actinidiaceae* (56 seeds), *Euphorbiaceae* (46 seeds), *Phyllanthaceae* (30 seeds), *Poaceae* (23 seeds), *Moraceae* (18 seeds), *Anacardiaceae* (15 seeds), *Myrtaceae* (2 seeds), *Lauraceae* (1 seed) and *Rutaceae* (1 seed).

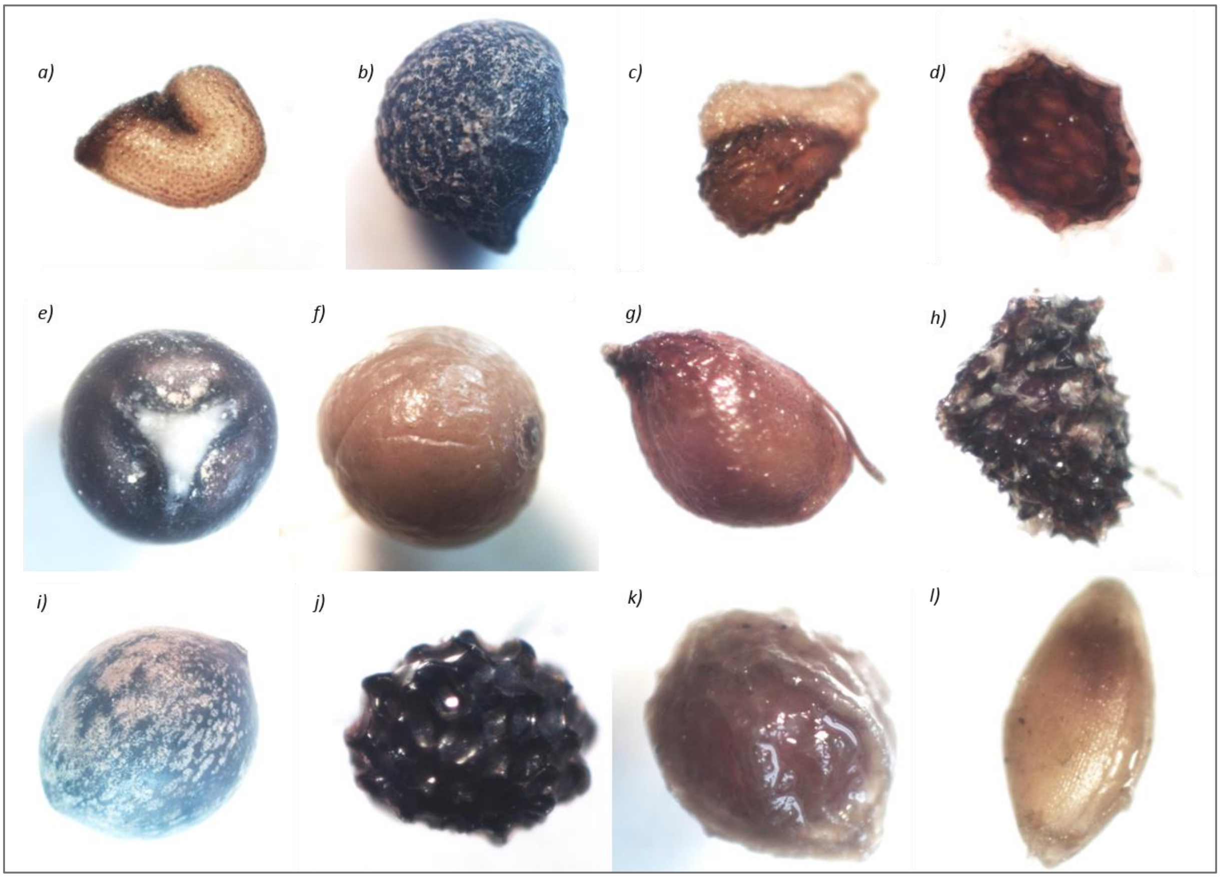

Figure 9: Selected pictures of seeds a) Melastoma malabathricum (Melastomataceae), b) Macaranga sp. (Euphorbiaceae), c) Clidemia hirta (Melastomataceae), d) Urophyllum arboreum (Rubiaceae), e) Scleria ciliaris (Cyperaceae), f) Schinus sp. (Anacardiacea), g) Ficus sp. (Moraceae), h) Saurauia sp. (Actinidiaceae), i) Lycea sp. (Lauraceae), j) Actinidiaceae, k) Trema orientalis (Ulmaceae), l) Poaceae

Pollen grains from the bird species *Arachnothera longirostra*, *Dicaeum trigonostigma*, *Hypogramma hypogrammicum* and *Prionochilus percussus* - caught in different transformation systems, were identified. These pollen grains belong to the plant families *Apocynaceae, Arecaceae, Euphorbiaceae, Fabaceae, Lamiaceae, Loranthaceae, Moraceae, Myrtaceae, Pandanaceae, Poaceae* and *Rubiaceae*. Unfortunately, the processing of the pollen slides resulted in a loss of material. Therefore, the data are incomplete and I cannot use the actual quantity of identified pollen grains for the networks.

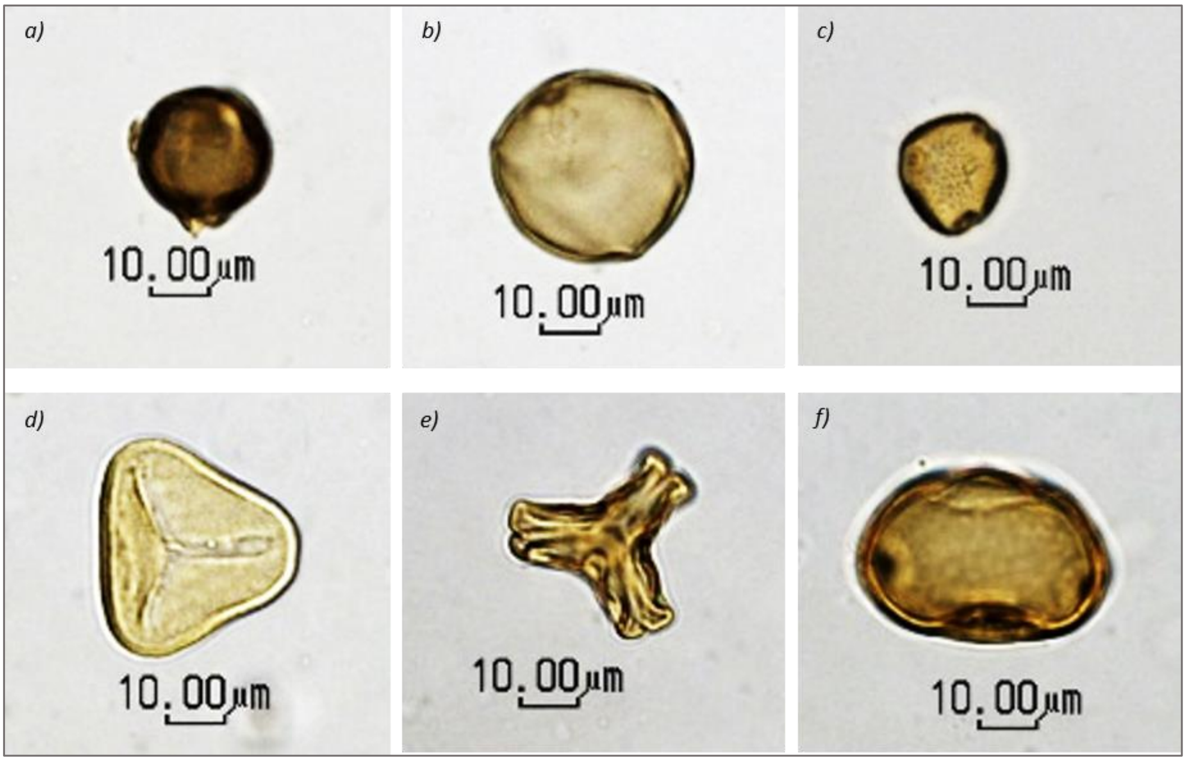

Figure 10: Selected pictures of pollen a) Fabaceae, b) Poaceae, c) Randia sp. (Rubiaceae), d) Elaeis guineensis (Arecaceae), e) Loranthaceae, f) Parsonsia sp. (Apocynaceae)

The quantity of consumed arthropod parts and seeds mirror the frequency of arthropods and plants (fruits/seeds) that are consumed by the examined bird species in Jambi province. The created food networks provide a more detailed look at the trophic relationship between the sampled bird species and their food resources in secondary forest (Fig. 11), jungle rubber (Fig. 12), rubber (Fig. 13) and oil palm (Fig. 14). The calculation of several indices (*web asymmetry, niche overlap, d' and H2'*) allows further interpretation of these networks (bird species and food resources are listed in table 4 and 5 in the appendix).

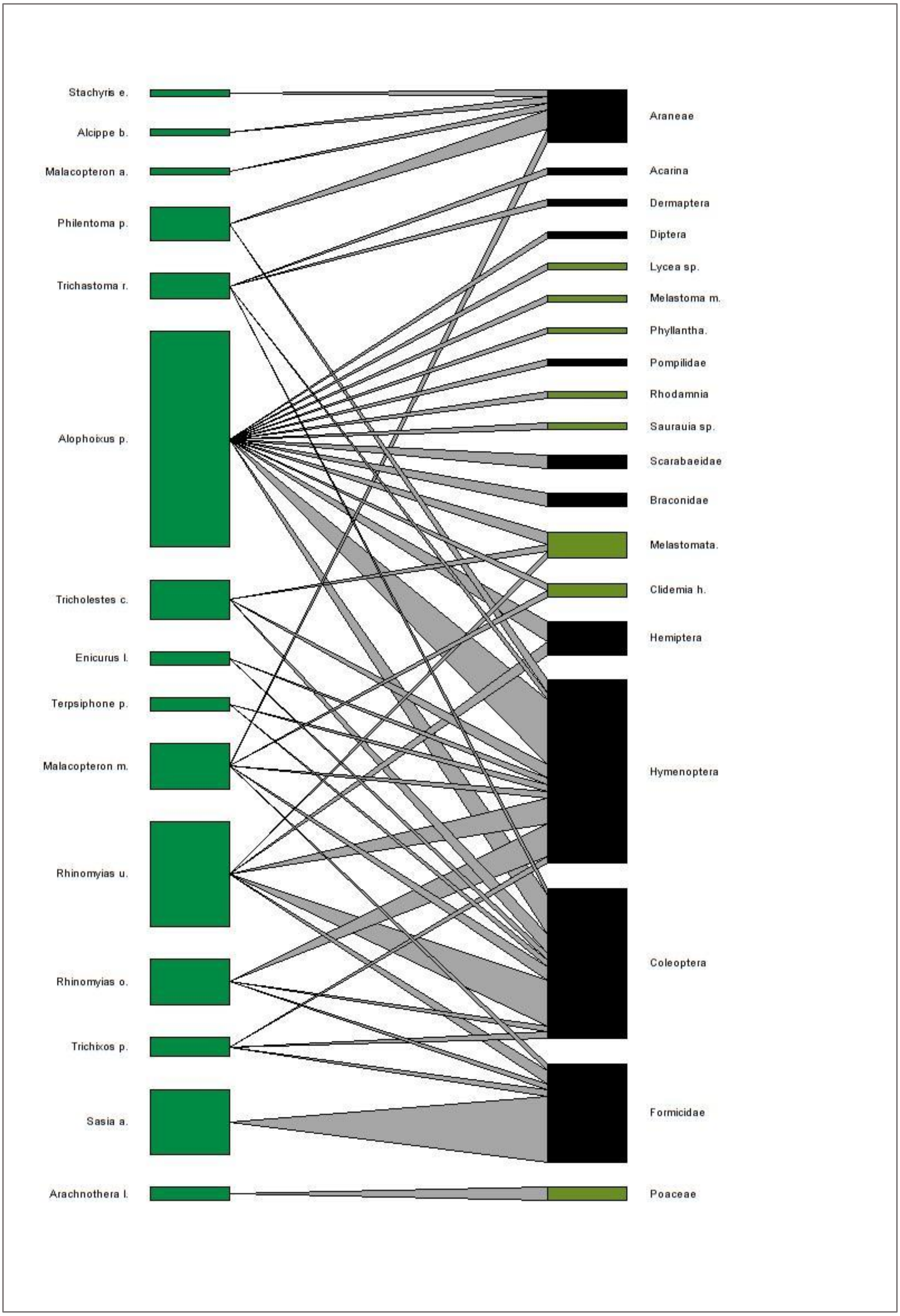

Figure 11: Ecological food network of secondary forest habitat (Bukit 12 and Harapan combined); bird species displayed on the left are linked to their identified food resources displayed on the right (arthropods in black, plants in olive green)

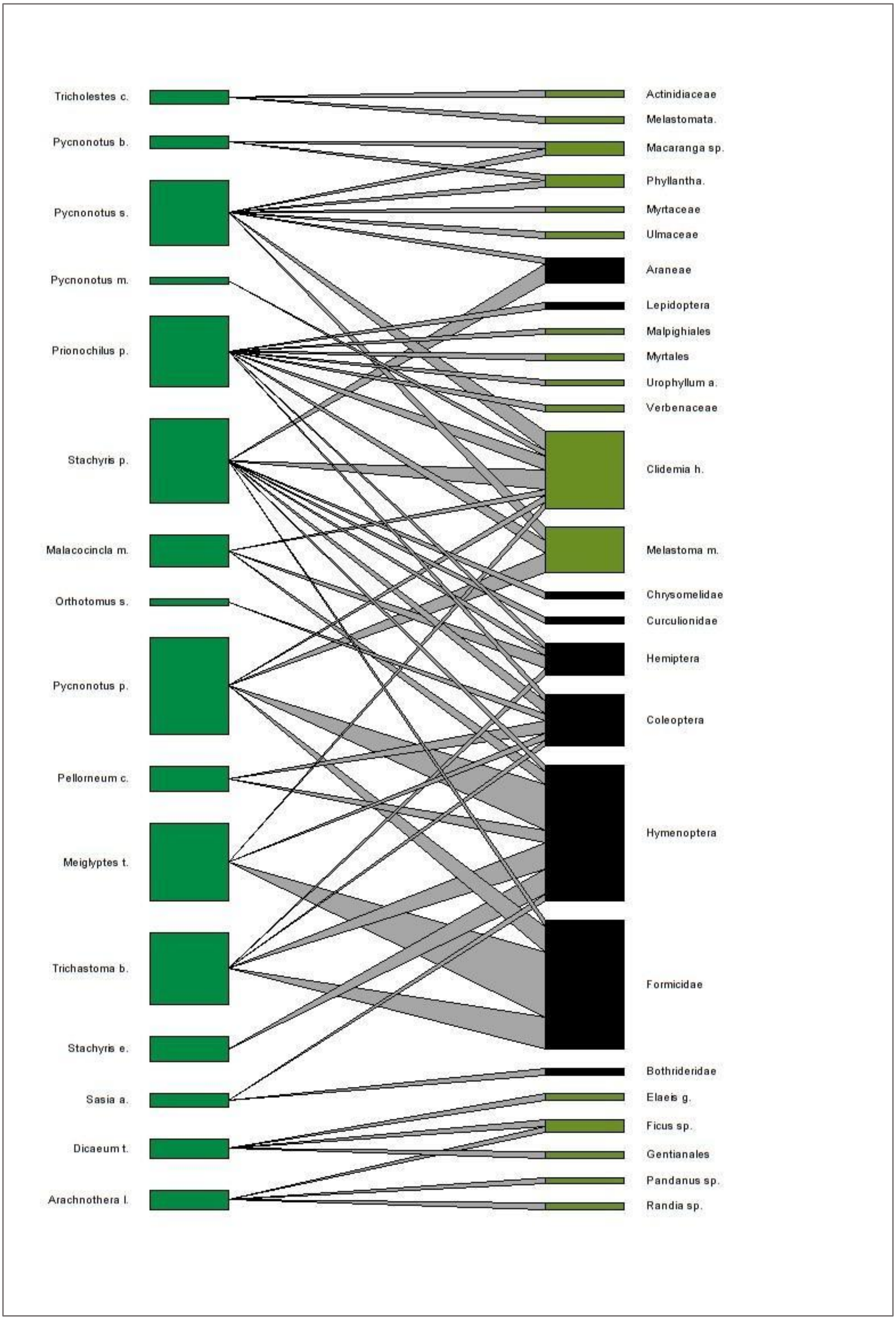

Figure 12: Ecological food network of jungle rubber habitat (Bukit 12 and Harapan combined); bird species displayed on the left are linked to their identified food resources displayed on the right (arthropods in black, plants in olive green)

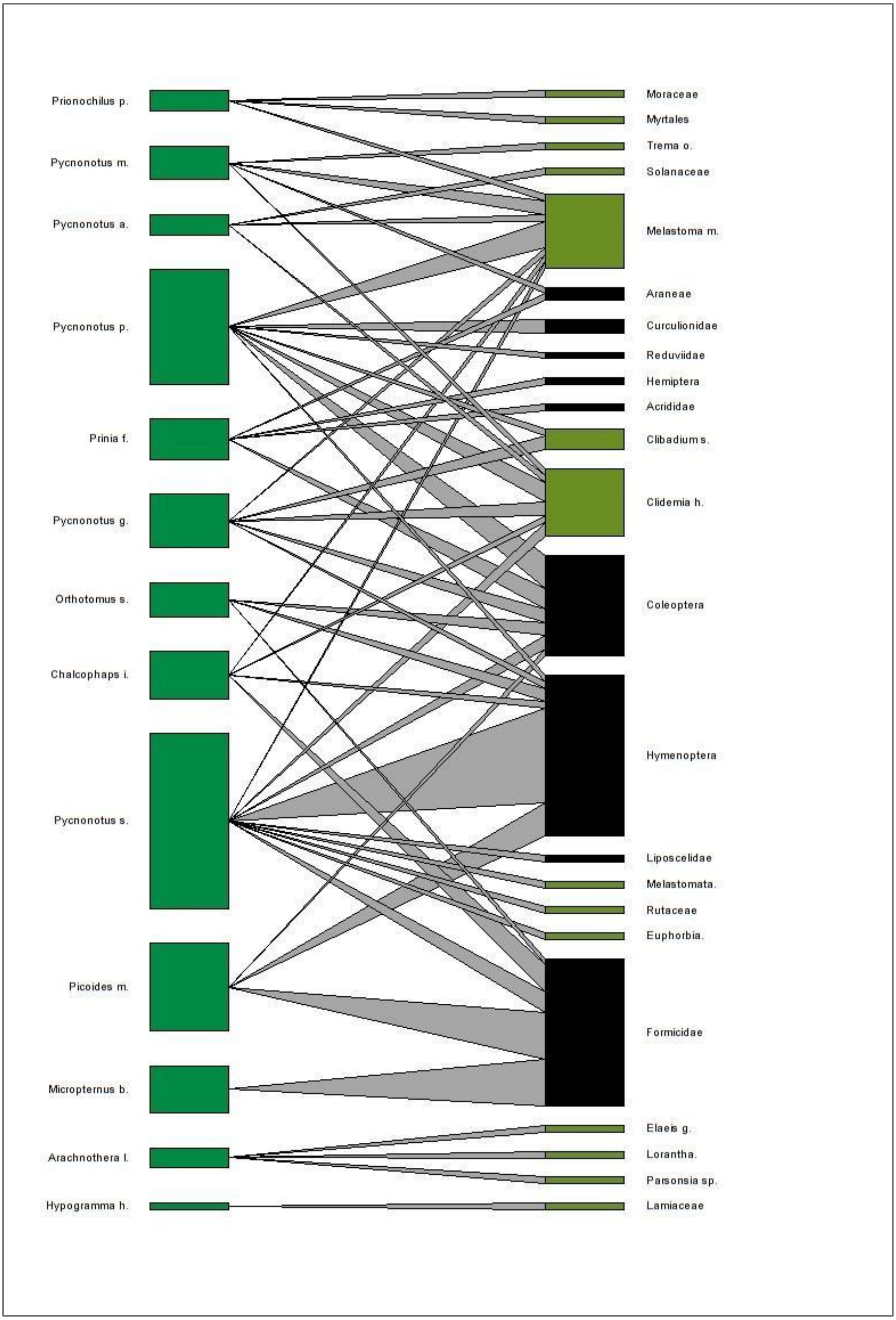

Figure 13: Ecological food network of rubber habitat (Bukit 12 and Harapan combined); bird species displayed on the left are linked to their identified food resources displayed on the right (arthropods in black, plants in olive green)

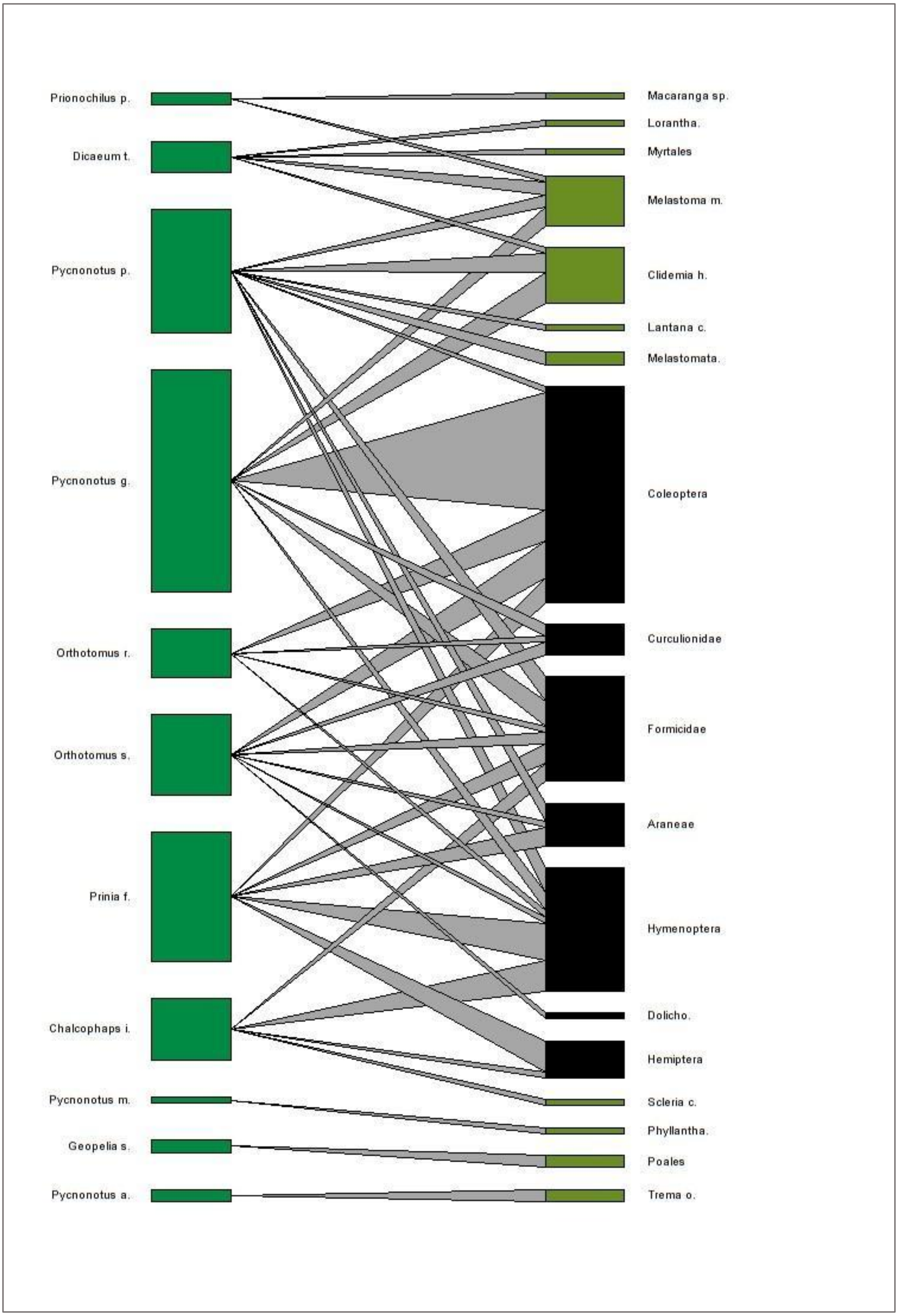

Figure 14: Ecological food network of oil palm habitat (Bukit 12 and Harapan combined); bird species displayed on the left are linked to their identified food resources displayed on the right (arthropods in black, plants in olive green)

The secondary forest network (Fig. 11) displays 15 bird species on the higher trophic level (left) and 19 resource types on the lower trophic level (right), the jungle rubber network (Fig. 12) 17 bird species and 26 resource types, the rubber network (Fig. 13) 13 bird species and 23 resource types and the oil palm network (Fig. 14) 11 bird species and 18 resource types. I combined the data of Bukit 12 and Harapan to provide more detailed networks for all four transformation systems. The networks can be considered as asymmetric, as there are more resources on the lower trophic level than bird species on the higher trophic level (Dormann et al. 2014). When comparing all systems, secondary forest has the least web asymmetry. The niche overlap describes the similarity in interaction pattern between species of the same level and values near 0 indicate no common use of niches, while 1 indicates a perfect niche overlap (Dormann et al. 2009). The niche overlap index for secondary forest indicates a higher niche overlap compared with jungle rubber, rubber and oil palm (see table 1).

*Table 1: Overview of computed network indices (HL = higher level; LL = lower level), * indicate significance of difference to reference system (secondary forest) based on linear mixed-effects model*

Indices	Secondary forest	Jungle rubber	Rubber	Oil palm
Nr. of species HL	15	17	13	11
Nr. of species LL	19	26	23	18
Web asymmetry	-0.12	-0.21	-0.28	-0.24
Niche overlap HL	0.35	0.15	0.21	0.17
Niche overlap LL	0.44	0.13	0.13	0.15
Mean *d'*	0.51	0.67	0.45	0.56
H2'	0.52	0.73	0.83*	0.92**

3.6 Indices of bird specialization (*d'* and *H2'*)

To find out at which level the specialization (measured as amount and strength of trophic links) resides, at species or network level related to the type of transformation system, the two indices *d'* and *H2'* were computed (table 6 in the appendix). The species-level measures of trophic functions can be compared to network-wide trophic measures to analyze how generalized or specialized and how stable the different food networks are. Based on the consumer - resource interactions presented in food networks, I calculated the index *d'*. The mean values of the *d'*-index for the 8 secondary forest and jungle rubber plots are *d'*=0.51 and *d'*=0.67 respectively, which can be interpreted as intermediate to moderately high specialization of bird species. The mean value for rubber (only 5 plots considered) was *d'*=0.45 and for oil palm (only 5 plots considered) *d'*=0.56, which can be considered as intermediate as well. There is quite large variability concerning the bird species specialization within the transformation systems (Fig. 15). In Bukit 12, the *d'*-values of the plots BF3 and BF4 in secondary forest indicate a very low species specialization, whereas the plots BF1 and BF2 indicate a much higher specialization (see table 4 in the appendix). A similar pattern can be observed within the jungle rubber plots: the low values of BJ3 and BJ5 indicate a low specialization of bird species and the high values at BJ2 and BJ4 indicate a rather strong specialization. In Harapan, the variability between the plots in secondary forest and jungle rubber is not as extreme as in Bukit 12. The values for HF3 and HF4 indicate a fairly low specialization of bird species and the values for HF1 and HF2 indicate a high specialization. In jungle rubber, the values for HJ2 , HJ3 and HJ4 indicate a very high species specialization and only the value for HJ1 indicates less specialized species interactions. In Bukit 12, the values within rubber plantations range between very low at BR3 and moderately high at BR4, which can also be considered as a quite large variability. In Harapan, only one value was produced, indicating for an intermediate specialization. The values for the plots in oil palm plantations are the least diverse. In Bukit 12, they range from intermediate at BO4 to moderately high at BO2, which also indicates a moderate to high species specialization. For Harapan, only two values for the plots HO3 and HO4 could be produced, which indicate a large variability from moderately high to low specialization.

Based on the consumer - resource interactions presented in food networks, I also calculated the index *H2'* for the entire networks. The produced values represent the specialization of bird communities for all plots from the landscapes Bukit 12 and Harapan. The mean values of *H2'*=0.52 for secondary forest (7 plots considered) and *H2'*=0.73 for jungle rubber (8 plots considered) can be interpreted as a moderate to high network specialization. The mean values of *H2'*=0.83 for rubber (only 5 plots considered) and *H2'*=0.92 for oil palm (only 5 plots considered) are much higher and indicate an extreme network specialization. Due to insufficient data, R could not produce *H2'*-values for 7 plots, so they are also missing in the following graph (Fig. 16). Again, I could detect a large variability between the plots in secondary forest and jungle rubber. In Bukit 12, the networks of the plots BF3 and BF4 are much generalized, whereas the value of from BF2 indicates an extreme specialization. The four jungle rubber plots in Bukit 12 show a similar variability, as the values for the plots BJ3 and BJ5 are very small and the *H2'*-values for BJ2 and BJ4 are high. The secondary forest and jungle rubber plots in Harapan also show very different degrees of specialization. In secondary forest, the network specialization ranges from moderately low in HF4 to very high in HF2. Different from Bukit 12, the network specialization of all jungle rubber plots in Harapan is quite high, regarding the values of HJ1, HJ2 and HJ3. Within the rubber and oil palm plantation plots, the variability among the plots is much smaller. The four rubber plots in Bukit 12 show a high network specialization with an intermediate value in BR2 and a very high value in BR3. There are no

H2'-values available for three out of four rubber plots in Harapan, but the high value for HR4 also suggests a very high network specialization. The presented *H2'*-values for all oil palm plots in Bukit 12 and Harapan suggest a very high network specialization, as they are high at BO3 and very high at HO3 and HO4. As the *d'*- values, the *H2'*-values were very diverse and unexpectedly high for the plantation plots.

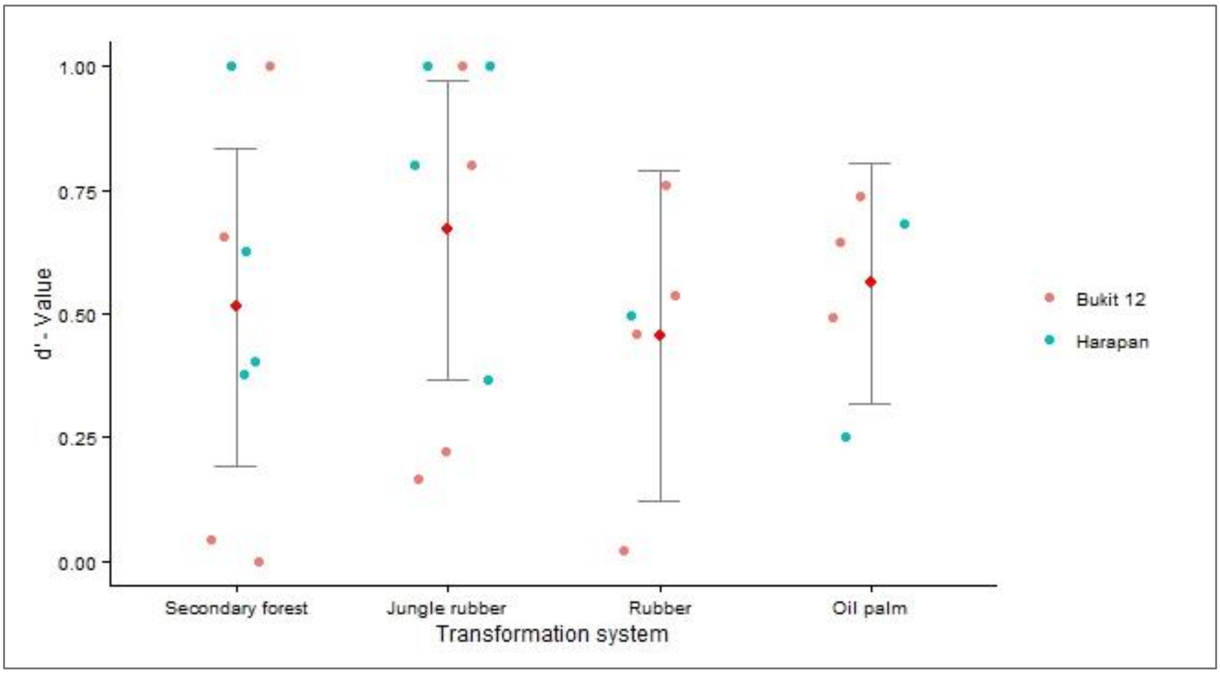

Figure 15: d'- index per plot / per transformation system / per landscape; error bars (grey) with means (red)

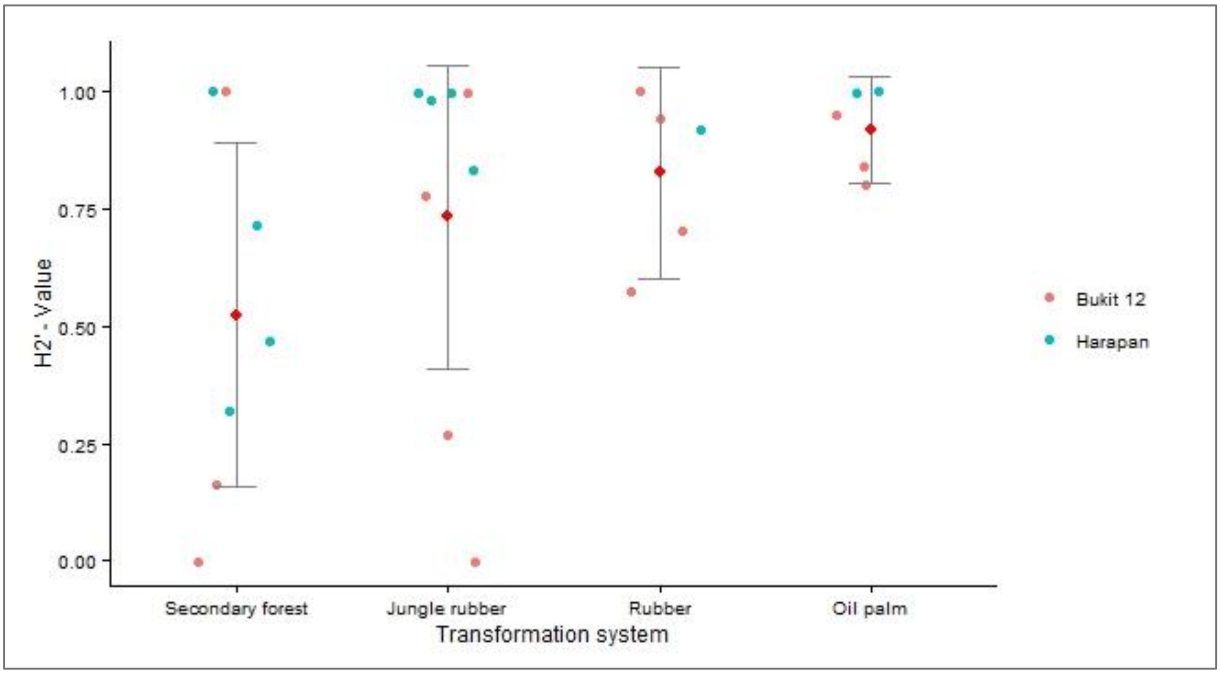

Figure 16: H2'- index per plot / per transformation system / per landscape; error bars (grey) with means (red)

3.7 Linear mixed-effects models (LME)

The constructed LME account for fixed land-use and landscape effects on computed indices (*d'*, *H2', web asymmetry* and *niche overlap*) and random plot effects. To determine whether trends differed between landscapes, I compared the Akaike's Information Criterion (AIC) of models with/without landscape and with/without interactions as explanatory factor. Lower AIC values indicate a higher model quality (better trade-off between model fit and model complexity) and were used for model selection (Crawley 2013). For the *H2'* index, the stepwise model selection (stepAIC function) starting with the full model reached a minimum AIC score of 18.06 after the interaction between landscape and land-use was dropped. This corresponded to the same model with the lowest AIC score among the manually constructed models with all factor combinations. So the LME with landscape and land-use as explanatory variables and without interaction (*'H2' ~ landscape + landuse')*, was selected as the best model for predicting the *H2'* index. The *p*-values of 0.1490 (jungle rubber agroforests), 0.0341 (rubber plantations) and 0.0192 (oil palm plantations) show that the network specialization differs significantly (at $p < 0.05$) in the plantations compared to secondary forest (see table 2). Post-hoc analyses comparing *H2'* means by land-use with Dunnett contrasts confirm this trend (see table 3). When running a stepwise AIC model selection on the full models (including land-use system, landscape and interactions) for indices *d', web asymmetry* and *niche overlap*, it became clear that they are not significantly influenced by land-use or landscape and the constructed models were not better than the null model.

*Table 2: Summary of best H2' LME model, AIC score=18.06, * for significance*

LME: *'H2'~landscape+landuse'*	**Value**	**Std. Error**	**DF**	**p-value**
Forest Bukit 12	0.3681	0.1315	20	0.0111
Forest Harapan	0.2714	0.1229	20	0.0392
Land-use jungle rubber	0.2288	0.1524	20	0.149
Land-use rubber	0.4051	0.1781	20	0.0341*
Land-use oil palm	0.4416	0.1734	20	0.0192*

*Table 3: Comparisons of H2' means by land-use (Dunnett contrasts); * for significance*

Linear Hypotheses:	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
System: Jungle rubber - Secondary forest == 0	0.2288	0.1363	1.678	0.2961
System: Oil palm - Secondary forest == 0	0.4416	0.1551	2.847	0.0169*
System: Rubber - Secondary forest == 0	0.4051	0.1593	2.543	0.0408*
Landscape: Harapan - Bukit 12 == 0	0.2714	0.11	2.467	0.0501

4. Discussion

The monitoring of bird community composition, bird species abundance and their diet in different habitats is extremely important in order to examine population trends and define the main causes of bird diversity loss in human-modified landscapes (Sekercioglu 2012; Zakaria and Rajpar 2010). My results demonstrate a decrease in bird species richness and a changing bird community composition with intensifying agricultural exploitation in Jambi province, which is conform to findings of Prabowo (2014). Furthermore, differences in bird diets and differing degrees of specialization could be observed.

4.1 Landscape transformation changes bird communities

The distribution of bird habitat groups (Fig. 2 and 3) implies a different bird community composition between the rainforest transformation systems. Only very few bird species that are associated with the primary and old secondary forest interior (Habitat group 3) have been caught within rubber and oil palm plantations. Instead, the bird communities in the plantations were mostly composed of species with an association to open woodland and cultivated areas or degraded artificial forest types (Habitat groups 1 and 2). The NMDS plots (Fig. 5 and 6) emphasize the distinct bird communities in forests and modified habitats. A striking difference between bird communities in natural forest-like habitats and plantations is the disappearance of species from the families *Monarchidae, Muscicapidae* and *Timaliidae,* which all consume exclusively arthropods, e.g. from the orders *Araneae, Coleoptera* and *Hymenoptera*. Apparently, the rubber and oil palm plantations are not suitable habitats for these bird families and are therefore avoided. One major difference between the bird communities in rubber and oil palm plantations is the absence of woodpeckers (*Picidae*) in oil palm plantations. In Sumatra, this insectivorous arboreal bird family is mainly feeding on arthropods (e.g. *Formicidae*) at the bark of trees and decaying wood (HBW Alive, 2015). As also mentioned by Edwards et al. (2013), bark foragers do not persist in oil palm plantations, because their specific resource base of bark-dwelling arthropods has disappeared and oil palm trunks possibly cannot substitute for that. Nevertheless, their demands seem to be fulfilled in rubber plantations, as they can forage on arthropods at the bark of rubber trees. Furthermore, no nectarivorous birds (*Nectariniidae*) such as sunbirds and spiderhunters occurred within oil palm plantations due to the absence of suitable flowering epiphytes, shrubs or tree species. The bird diversity of Jambi province decreased drastically along the transformation gradient, however, the trends in the two landscapes Bukit 12 and Harapan were quite different from each other (Fig. 4), which conforms findings of Prabowo (2014) and Darras (unpublished data, 2015). In Harapan, the bird species richness declined with an increasing human-induced landscape modification, which confirms my expectations. In Bukit 12, the trend was unusual due to the low species richness in secondary forest and higher species richness in the jungle rubber agroforests and plantations. The bird abundance in the understory of the forest plots of Bukit 12 National Park was very low, what could be caused by certain edge effects and inefficient control of poaching by local people, known to occur in these parts of the national park. The relatively high bird abundance in the plantation plots was possibly caused by the presence of undergrowth or spillover effects due to their relative proximity to small patches of secondary forest and jungle rubber agroforests. As confirmed by Komar (2006) and demonstrated by my comparison of feeding guild classifications (Fig. 7) based on data from different sources (Thiollay 1995, Wilman et al. 2014 and my own literature review based on Thiollay and HBW Alive 2015), it proved to be difficult to produce a uniform bird feeding guild classification. It becomes obvious that the classification of feeding guilds can only serve for rough orientation, but as no uniform information and categories for every bird species exist, I would consider them as quite subjective and arbitrary. However, following the feeding guild classification based on my own literature review, it was possible to get an idea about the preferred diet of birds and the ecological functions that are related to it. Within rubber and oil palm plantations, functions such as pest predation, seed dispersal and pollination were mainly fulfilled by functionally similar omnivorous bird species (e.g. *Dicaeidae*, *Pycnonotidae*). On the other hand, in secondary forest and jungle rubber these functions were mostly fulfilled by more specialized birds categorized as insectivorous (e.g. *Monarchidae, Muscicapidae, Timaliidae)* and nectarivorous species (*Nectariniidae)*. Frugivorous bird species such as parrots and hornbills (*Psittaculidae, Bucerotidae*) were occasionally observed in or above the canopy of forest habitats, but it was not possible to collect data concerning these bird species through mist netting.

4.2 Food networks and bird specialization

Detailed ecological food networks can give more specific information about the diet of birds. The food networks (Fig. 11 - 14) for each rainforest transformation system of Bukit 12 and Harapan combined, visualize the amount and strength of trophic links between the examined bird species and their food resources. As birds have the ability to fly and can quickly switch between different habitat types, the food remains in their droppings and the pollen grains on their beak do not necessarily correspond to the environment they were caught in. This could be the case, especially, when a landscape is comprised of a mosaic-like pattern of small-scale land-use systems and natural forest habitats. Moreover, diverse ecological and evolutionary processes operating along a wide range of temporal scales (Carnicer et al. 2009) are building such network patterns. On a short-time scale, communities vary in their composition due to birth, death, migration and dispersal and therefore it has to be considered that the number and strength of interactions can be influenced by such processes (Carnicer et al. 2009; Vázquez et al. 2009). The bird communities in transformed systems are not formed because of long-term evolution, but mainly by human-induced landscape modification.

The established food networks can be considered as asymmetric, as there are more resources on the lower trophic level than bird species on the higher trophic level (Dormann et al. 2014). In comparison to the other food networks for jungle rubber, rubber and oil palm, the secondary forest network is the most balanced (see table 1). It is also stated by Carnicer et al. (2009) and previous studies (Vásquez and Aizen 2004; Bascompte, et al. 2006) that interactions in ecological networks "tend to be asymmetric, in both the number of links per species and the strength of the reciprocal effects". Moreover, it was remarked that it is characteristic for such networks to have most interactions concentrated on few species, which strongly influence other species (Carnicer et al. 2009). This is also the case in the regarded food networks, were generalized birds such as *Alophoixus phaeocephalus* in forest, *Prionochilus percussus* in jungle rubber, *Pycnonotus simplex and Pycnonotus plumosus* in rubber and *Pycnonotus plumosus* and *Pycnonotus goiavier* in oil palm seem to be very dominant over the other species.

The *niche overlap* value is the highest for the secondary forest network and the values for jungle rubber, rubber and oil palm are smaller (although differences are not significant), because less ecological niches are present within these moderately to highly disturbed habitats in which they are more isolated from each other (see table 1). In secondary forest, more coexisting bird species in various ecological niches are present and therefore, the use of resources can be more diverse and tends to overlap more frequently. This drives competition and therefore specialization, leading to such enhanced species diversity in tropical forests (Cody, 1974). As Cody (1974) elaborates, bird species can only coexist in the same habitat, when their use of resources differs to a minimal degree (e.g. different foraging behavior, taking food at different heights or feeding sites). For these reasons, he also explains that the stomach contents of birds can show a great diet overlap, although bird species might be feeding in different ways or places (Cody, 1974). As mentioned by (Konopik et al. 2014), the niche breadth of bird communities is narrowing with an increasing modification of tropical landscapes, which explains a less frequent overlap of ecological niches in disturbed agroforests and plantations.

The computation of the *H2'* index considers both the upper and lower trophic level (birds and food resources) of the respective network. Comparing the mean *H2'*-values between the different transformation systems can be misleading at first. The lower value for secondary forest suggests that forest networks are less specialized than plantation networks (Fig. 16), results that are contradicting my expectations. As Dormann et al. (2009) states, the *H2'* index is sensitive to an asymmetry in network dimensions, when networks are small (< 50 species in both levels) and that is the case for the networks I generated. This is why I interpret these values with caution. In secondary forest and jungle rubber habitats, a larger variety of ecological niches and food resources is available for birds than in more disturbed agroforests and plantations. There are more foraging options (higher arthropod and plant diversity) in these natural forest habitats and the amount and strength of links between certain bird species and their food resources can be more numerous and diverse. This leads to a smaller *H2'*-value, which actually suggests a lower specialization. On the other hand, the availability and diversity of food resources in monocultures like rubber and oil palm plantations is possibly quite limited. For this reason, the *H2'*-value for those networks is larger and the food consumption of birds seems to be more specialized, as they do not have many options.

In comparison to *H2'*, the computed *d'*-values only consider the specialization of the upper trophic network level (birds). The *d'*-values for secondary forest and rubber plantations seem to be marginally lower than for jungle rubber and oil palm plantations. However, there are no clear differences between the mean *d'*-values of the four transformation systems (Fig. 15), so this index cannot indicate for more or less specialized bird species. Again, the higher diversity and availability of food resources in natural habitats and their limitations inside the plantations could influence the bird specialization and produce this unexpected effect. Because of the low bird abundance in many rubber and oil palm plantation plots, it was not possible to compute *d'*-values for 6 plots and *H2'*-values for 7 plots and so they could not be taken into account in the interpretation.

4.3 Variations in bird diet composition

I wanted to examine whether the diet of particular bird species varies between different transformation systems, but as not enough individuals of the same species occurred in all rainforest transformation systems, such a comparison was not possible. Again, this proves the different bird community composition between the examined habitat types. In all forest, agroforest and plantation habitats, many bird species consumed arthropods from the orders

Hymenoptera (e.g. *Formicidae*) and *Coleoptera*. The quantity of other consumed arthropods was much lower. The exceptional dominance of *Hymenoptera* and *Coleoptera* could be biased through their hard chitin exoskeleton, which often cannot be completely digested by birds (Wong 1986). Soft-bodied prey such as *Lepidoptera* caterpillars or *Diptera* larvae probably were completely digested and were rarely detected in the droppings. In general, a more detailed identification to family (or genus/species) level was rarely possible, but I hypothesize that different families (or genera/species) of *Hymenoptera* and *Coleoptera* are consumed by birds in different habitat types. This assumption is based on findings of several studies about a decreasing arthropod diversity and changing arthropod community composition in tropical plantations (e.g. by Turner and Foster 2009). Unpublished data about arthropod diversity and community composition in Jambi by Drescher (2015) show (ant diversity in rubber/oil palm decreased 50 % compared to forest/jungle rubber) that these changes also happen in Jambi province. A study about arboreal ant diversity in oil palm plantations in Malaysia conducted by Pfeiffer et al. (2008) revealed a similar trend with a significantly lower ant species diversity in oil palm plantations (40 arboreal ant species recorded), compared to natural rainforest (280 arboreal ant species recorded). Another study about subterranean and understory beetle diversity in Malaysia conducted by Chung et al. (2000) detected a much lower abundance, species richness and a distinct beetle community composition in oil palm plantations due to a lower plant species richness and canopy cover, less leaf litter and a frequent application of pesticides compared to *Acacia* plantations and primary forest sites.

Strikingly, the highest quantity of distributed seeds within the oil palm and rubber plantations stem from the plant species *Melastoma malabathricum* and *Clidemia hirta*, both considered as widespread weeds in industrial plantation crops, the latter originally from the Neotropics and invasive in tropical South-East Asia (International Institute of Tropical Forestry, 2009). Another invasive plant species from the Neotropics that frequently occurs in the plantations is *Clibadium surinamense*. Birds facilitate the fast propagation of these plant species in and outside of plantations (Marthy 2014) and as they are very competitive, they can affect the yield and possibly suppress the development of native plant species, even in natural ecosystems.

4.4 Methodological limitations

There are several efficient research methods available to examine bird population trends and as previously performed by Pearson Ralph et al. (1985), Sodhi et al. (2005) and Zakaria and Rajpar (2010), I chose the application of mist nets to study the bird communities and their diet in Jambi province. According to Sutherland (2004), the return of mist netting is poor in relation to the required effort, as it is unlikely to catch a large part of the avifauna. This confirms what I experienced during my fieldwork in Jambi. The 32 plots in Bukit 12 and Harapan were predefined by the CRC 990 and it was not possible to choose more suitable areas to establish mist nets (e.g. close to streams or ecotones). In both landscapes, one factor for the bird scarcity could be the lack of ground vegetation in some of the oil palm and rubber plantation plots, due to the application of herbicides (personal observation). When vegetation below the canopy is absent, birds have no reason to fly low to search for food and mist nets were not a useful tool. Other reasons could be edge effects, as many plots were located close to roads or near the forest edge (Sutherland 2004). During fieldwork, it was convenient that the majority of plots were easy to access, but bird species in accessible areas are also more likely to be trapped by poachers. Within Bukit 12 National Park, where the abundance of understory birds was surprisingly low, the limitations of mist netting were especially remarkable. As suggested by Sutherland (2004), one measure to improve these conditions and make mist-netting more effective would be the provision of baits close to the mist nets, but it would bias the outcome. Setting up mist nets higher above the ground could be another option to catch more birds in the canopy. Moreover, an extensive preliminary bird survey in the sampling area would be necessary to detect suitable mist netting spots, which are more independent from already predefined sample plots. Furthermore, as recommended by Sodhi et al. (2005) and Zakaria & Rajpar (2010, mist netting should be combined with other suitable monitoring techniques as point counts to gather additional data and these methods were already used in the frame of other CRC 990 studies (Prabowo 2014).

Studies about bird diet can answer many questions, especially to compare the consequences for ecosystem services and functionality in a changing environment (Sekercioglu 2012). As proposed by Pearson Ralph et al. (1985), the analysis of bird droppings can be useful to identify approached food resources through the identification of arthropod fragments and seeds. The identification of arthropod and plant remains from the droppings is more difficult than from stomach content gained through stomach flushing or emetics (Major 1990, Robinson et al. 1982), but it is far less harmful for the birds. However, a preliminary reference collection of potential food resources is essential for a reliable identification of droppings (Sutherland 2004). The collection of pollen grains from the beak of birds can expand data concerning the food resources of nectarivorous bird species. However, to collect the pollen with adhesive tape and attach it on a microscope slide as proposed by Feinsinger (1992), did not prove to be a suitable technique, if an acetolysis is required to facilitate the pollen identification afterwards. During the preparation and processing of the pollen tapes in the laboratory, a presumable large quantity of pollen grains got lost, probably because of an insoluble type of glue. A better method could be the utilization of synthetic cotton swabs, which are wiped along the birds' beak and then preserved in sample tubes with 70 % ethanol until further processing in the laboratory.

As the diet can vary throughout the year and the day, between sites and even between individuals, it is important that this variability is reflected by the sampling design (Sutherland 2004). The collection of bird dropping samples in Hawaii by Pearson Ralph et al. (1985) lasted from 1976 to 1981. To capture as much information about the varying food resources of certain bird species as possible and create a complete picture, repeated sampling throughout a longer period of time (one year or more) would be necessary, but was impossible in the frame of this study. Our sampling effort of approximately two months fieldwork was sufficient to gain knowledge about the diet of bird communities in different habitats in the province Jambi.

4.5 Generalists tend to replace specialists in transforming landscapes

My findings that bird species richness decreased and the bird community composition changed with intensifying agricultural exploitation are conform with those of Aratrakorn et al. (2006), Sekercioglu (2012) and Prabowo (2014) and indicate that a large number of species formerly present in the area cannot adapt to the conversion of forests to simplified agricultural monocultures. As Sekercioglu et al (2002) and Tscharntke et al. (2008) found out, forest understory insectivores are considered to be disproportionately sensitive to habitat and landscape modification. More generalized insectivores and species with a broader diet are less affected than habitat-specialized insectivores (Clough et al. 2009).

The process of land conversion results in a decreasing bird diversity and altered proportions of functional groups by replacing specialized bird species with restricted ranges and a high conservation status with common generalist species (Aratrakorn et al. 2006; Sekercioglu 2012). The study by Aratrakorn et al. (2006) stated that the bird species richness was significantly greater where undergrowth was allowed to regenerate beneath the crop trees and that is also how I explain the relatively high species richness and bird abundance within some of the rubber and oil palm plantation plots in Bukit 12. Differences in bird abundance and species richness between plantation plots with and without undergrowth were definitely noticeable (personal observation). As suggested by Clough et al. (2009), forest proximity is another critical factor that influences the composition of bird communities in human-modified landscapes. They state that the species richness of forest specialists decreases rapidly, the larger the distance from the forest edge gets. According to Thiollay (1995), the number of large canopy frugivores and understory insectivores greatly decreased in plantations in Sumatra compared to natural forests nearby. It is also confirmed by Tscharntke et al. (2008) that functionally important species are only able to survive in agricultural land-use systems within tropical mosaic landscapes, when they are connected to natural habitats. This was noticeable during my fieldwork, when the bird abundance and species richness was higher at plantation plots located next to forest remnants or jungle rubber agroforests (personal observation) than in plots located in large homogeneous plantation areas. This shows that the mosaic-like landscape in Jambi, still composed of many different habitat patches such as small-scale plantations, agroforests and remaining degraded forests, strongly influences the composition of bird communities and bird abundance. These observations will be examined more closely as more detailed land-use maps from the Jambi province will be released at the end of February 2015.

5. Conclusion

Continuous forest loss and landscape fragmentation define the future of forest bird communities in the lowlands of Sumatra and bird species with a particular foraging behavior that are highly dependent on specific food resources are affected the most (Lambert and Collar 2002). With the conversion of forests to commercial rubber and oil palm plantations, species-rich and range-restricted bird communities are replaced by species-poor bird communities with extensive ranges and of lower conservation concern (Aratrakorn et al. 2006).

The proportions of generalized (omnivores) and specialized (e.g. insectivores, nectarivores) bird feeding guilds in the examined transformation systems are contradicting the computed *d'* and *H2'* indices. According to my feeding guild classification, the major proportion of omnivores occurred in oil palm and rubber plantation plots. The highest proportion of insectivores occurred in jungle rubber agroforest and secondary forest. Moreover, the proportion of frugivores and nectarivores was higher in these forest-like habitats than within the artificial plantation plots. On the other hand, the computed *d'*-values do not indicate different degrees of bird specialization and the *H2'*-values show a higher network specialization in the plantations than within forest and agroforest habitats. As I stated, these values are influenced by the variability or the limitation of offered food resources in these different transformation systems. Bird species thriving in rubber and oil palm plantations were able to adapt their demands to changing environmental conditions, because of their generalized food spectrum (omnivory). In contrast to that, many specialized forest bird species cannot adapt their demands, are not able to cope with the degradation of forest habitats and therefore disappear along the gradient of transformation. With the continuous degradation of complex forest habitats and landscape transformation, network stability is likely to decrease due to forms of cascading extinctions. The stronger the dependence of highly specialized bird species on certain plant or arthropod species (and vice versa), the more likely are they threatened by changing environmental conditions. If certain key species with a high amount of trophic links disappear from a network, other species that are depending on them are affected as well. In summary, I found that many forest bird species are not able to adapt to the rapid conversion of formerly natural habitats and more common bird species with a generalized diet are advantaged. This development will continue to change the composition of bird communities in the future, especially when industrial large-scale rubber and oil palm monocultures replace small-scale plantations and jungle rubber agroforests and forest habitats become rare and more isolated. Only the maintenance of more heterogeneous landscapes through the integration of forest remnants into rubber and oil palm plantations can prevent the continuous loss of bird diversity and functionality. For example, the incorporation of large fruits trees within newly established plantations (Maas 2013) and the creation of biological corridors to connect isolated forest fragments (Beier and Noss 1998) could contribute to the preservation of specialized forest bird species. Farmers should be encouraged to include such measures in their plantation management, for example through incentives like payments for ecosystem services (Wunder 2005). These measures would also stabilize the provision of valuable functions such as pest control and could be very advantageous for farmers (Maas, 2013). Other options to increase oil palm yields and therefore to reduce the pressure to clear new land for plantations could be selective breeding and the development of hybrid crosses between African and American oil palm species. Through such measures, the oil palm yield in Costa Rica is three times above the global average (Clay 2004). Such strategies should be backed by an increased protection of non-agricultural habitats (Niesten and Rice 2004; Aratrakorn et al. 2006). The protection of forest habitats against poaching should be improved and wildlife trade inhibited by efficient measures of law enforcement.

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Appendix

Table 4: List of bird species (2nd column corresponds to food networks Fig. 11-14) and families, species abundance (Abd.), IUCN Red List Status (NT="near threatened", LC="least concern"), feeding guilds and habitat groups (1:" Open woodland and cultivated areas", 2: "Degraded and artificial forest types", 3: "Primary and old secondary forest interior")

Species (Birdlife International)	Species short	Family	Abd.	Status (IUCN)	Feeding guild	Habitat group
Actenoides concretus	Actenoides c.	Alcedinidae	2	NT	carnivorous	3
Alcedo meninting	Alcedo m.	Alcedinidae	4	LC	carnivorous	3
Alcippe brunneicauda	Alcippe b.	Pellorneidae	1	NT	omnivorous	3
Alophoixus phaeocephalus	Alophoixus p.	Pycnonotidae	9	LC	omnivorous	3
Anthreptes singalensis	Anthreptes s.	Nectariniidae	1	LC	nectarivorous	2
Arachnothera longirostra	Arachnothera l.	Nectariniidae	26	LC	nectarivorous	3
Blythipicus rubiginosus	Blythipicus r.	Picidae	1	LC	insectivorous	3
Cacomantis merulinus	Cacomantis m.	Cuculidae	1	LC	insectivorous	1
Ceyx erithaca	Ceyx e.	Alcedinidae	3	LC	carnivorous	3
Chalcophaps indica	Chalcophaps i.	Columbidae	48	LC	omnivorous	2
Dicaeum trigonostigma	Dicaeum t.	Dicaeidae	6	LC	omnivorous	2
Enicurus leschenaulti	Enicurus l.	Muscicapidae	1	LC	insectivorous	3
Geopelia striata	Geopelia s.	Columbidae	1	LC	granivorous	1
Halcyon smyrnensis	Halcyon s.	Alcedinidae	3	LC	carnivorous	1
Hemipus hirundinaceus	Hemipus h.	Campephagidae	1	LC	insectivorous	2
Hypogramma hypogrammicum	Hypogramma h.	Nectariniidae	6	LC	omnivorous	3
Hypothymis azurea	Hypothymis a.	Monarchidae	1	LC	insectivorous	3
Lacedo pulchella	Lacedo p.	Alcedinidae	1	LC	carnivorous	3
Macronous gularis	Macronous g.	Timaliidae	2	LC	insectivorous	2
Macronous ptilosus	Macronous p.	Timaliidae	1	NT	insectivorous	3
Malacocincla malaccensis	Malacocincla m.	Timaliidae	7	NT	insectivorous	3
Malacopteron albogulare	Malacopteron a.	Timaliidae	1	NT	insectivorous	3
Malacopteron cinereum	Malacopteron c.	Timaliidae	3	LC	insectivorous	3
Malacopteron magnirostre	Malacopteron m.	Timaliidae	6	LC	insectivorous	3
Meiglyptes tukki	Meiglyptes t.	Picidae	1	NT	insectivorous	3
Micropternus brachyurus	Micropternus b.	Picidae	2	LC	insectivorous	2
Mixornis gularis	Mixornis g.	Timaliidae	2	LC	insectivorous	2
Orthotomus atrogularis	Orthotomus a.	Cisticolidae	1	LC	insectivorous	2
Orthotomus ruficeps	Orthotomus r.	Cisticolidae	2	LC	insectivorous	2
Orthotomus sericeus	Orthotomus s.	Cisticolidae	7	LC	insectivorous	3
Pachycephala simplex	Pachycephala s.	Pachycephalidae	1	LC	insectivorous	3
Pellorneum capistratum	Pellorneum c.	Pellorneidae	2	LC	insectivorous	3
Philentoma pyrhoptera	Philentoma p.	Muscicapidae	6	LC	insectivorous	2
Picoides moluccensis	Picoides m.	Picidae	1	LC	insectivorous	1
Prinia familiaris	Prinia f.	Cisticolidae	4	LC	insectivorous	2
Prionochilus maculatus	Prionochilus m.	Dicaeidae	1	LC	omnivorous	2
Prionochilus percussus	Prionochilus p.	Dicaeidae	9	LC	omnivorous	2
Pycnonotus atriceps	Pycnonotus a.	Pycnonotidae	2	LC	omnivorous	1
Pycnonotus aurigaster	Pycnonotus au.	Pycnonotidae	2	LC	omnivorous	2
Pycnonotus brunneus	Pycnonotus b.	Pycnonotidae	1	LC	omnivorous	2
Pycnonotus erythrophthalmus	Pycnonotus e.	Pycnonotidae	1	LC	omnivorous	1
Pycnonotus goiavier	Pycnonotus g.	Pycnonotidae	13	LC	omnivorous	2
Pycnonotus melanicterus	Pycnonotus m.	Pycnonotidae	6	LC	omnivorous	1
Pycnonotus plumosus	Pycnonotus p.	Pycnonotidae	18	LC	omnivorous	3
Pycnonotus simplex	Pycnonotus s.	Pycnonotidae	8	LC	omnivorous	3
Rhinomyias olivaceus	Rhinomyias o.	Muscicapidae	2	LC	insectivorous	3

Rhinomyias umbratilis	Rhinomyias u.	Muscicapidae	5	NT	insectivorous	2
Sasia abnormis	Sasia a.	Picidae	5	LC	insectivorous	3
Sitta frontalis	Sitta f.	Sittidae	1	LC	insectivorous	3
Stachyris erythroptera	Stachyris e.	Timaliidae	3	LC	insectivorous	3
Stachyris maculata	Stachyris m.	Timaliidae	1	NT	insectivorous	3
Stachyris poliocephala	Stachyris p.	Timaliidae	5	LC	insectivorous	2
Streptopelia bitorquata	Streptopelia b.	Columbidae	1	LC	granivorous	1
Streptopelia chinensis	Streptopelia c.	Columbidae	1	LC	granivorous	3
Terpsiphone paradisi	Terpsiphone p.	Monarchidae	1	LC	insectivorous	2
Todiramphus chloris	Todiramphus c.	Alcedinidae	1	LC	carnivorous	3
Trichastoma bicolor	Trichastoma b.	Pellorneidae	2	LC	insectivorous	3
Trichastoma rostratum	Trichastoma r.	Pellorneidae	1	NT	insectivorous	3
Trichixos pyrropygus	Trichixos p.	Muscicapidae	1	NT	insectivorous	3
Tricholestes criniger	Tricholestes c.	Pycnonotidae	2	LC	omnivorous	3

Table 5: List of identified arthropods and plants in the bird droppings (last column corresponds to food networks Fig. 11-14), empty rows mean no further identification

Organism	**Order**	**Family**	**Genus**	**Species**	**All ID short**
Arthropod	Acarina				Acarina
Arthropod	Araneae				Araneae
Plant	Arecales	Arecaceae	Elaeis	Elaeis guineensis	Elaeis g.
Plant	Asterales	Asteraceae	Clibadium	Clibadium surinamense	Clibadium s.
Arthropod	Coleoptera				Coleoptera
Arthropod	Coleoptera	Bothrideridae			Bothrideridae
Arthropod	Coleoptera	Chrysomelidae			Chrysomelidae
Arthropod	Coleoptera	Curculionidae			Curculionidae
Arthropod	Coleoptera	Scarabaeidae			Scarabaeidae
Arthropod	Dermaptera				Dermaptera
Arthropod	Diptera				Diptera
Arthropod	Diptera	Dolichopodidae			Dolicho.
Plant	Ericales	Actinidiaceae	cf. Saurauia	Saurauia sp.	Saurauia sp.
Plant	Ericales	Actinidiaceae			Actinidiaceae
Plant	Gentianales	Rubiaceae	Nauclea		Gentianales
Plant	Gentianales	Rubiaceae	Urophyllum	Urophyllum arboreum	Urophyllum a.
Plant	Gentianales	Rubiaceae	Randia		Randia sp.
Arthropod	Hemiptera				Hemiptera
Arthropod	Hemiptera	Reduviidae			Reduviidae
Arthropod	Hymenoptera				Hymenoptera
Arthropod	Hymenoptera	Braconidae			Braconidae
Arthropod	Hymenoptera	Formicidae			Formicidae
Arthropod	Hymenoptera	Pompilidae			Pompilidae
Plant	Lamiales	Verbenaceae			Verbenaceae
Plant	Lamiales	Lamiaceae			Lamiaceae
Plant	Lamiales	Verbenaceae	Lantana	Lantana camara	Lantana c.
Plant	Laurales	Lauraceae	cf. Lycea	Lycea sp.	Lycea sp.
Arthropod	Lepidoptera				Lepidoptera

Plant	Malpighiales	Rubiaceae			Malpighiales
Plant	Malpighiales	Euphorbiaceae	Macaranga		Macaranga sp.
Plant	Malpighiales	Euphorbiaceae			Euphorbia.
Plant	Malpighiales	Phyllanthaceae			Phyllantha.
Plant	Myrtales	Melastomataceae			Melastomata.
Plant	Myrtales	Melastomataceae	Clidemia	Clidemia hirta	Clidemia h.
Plant	Myrtales	Melastomataceae	Melastoma	Melastoma malabathricum	Melastoma m.
Plant	Myrtales	Myrtaceae			Myrtales
Plant	Myrtales	Myrtaceae	Rhodamnia	Rhodamnia sp.	Rhodamnia sp.
Arthropod	Orthoptera	Acrididae			Acrididae
Plant	Pandanales	Pandanaceae	Pandanus		Pandanus sp.
Plant	Poales	Cyperaceae	Scleria	Scleria ciliaris	Scleria c.
Plant	Poales	Poaceae			Poales
Arthropod	Psocoptera	Liposcelidae			Liposcelidae
Plant	Rosales	Moraceae	Ficus	Ficus sp.	Ficus sp.
Plant	Rosales	Ulmaceae	Trema	Trema orientalis	Trema o.
Plant	Santalales	Loranthaceae			Lorantha.
Plant	Sapindales	Rutaceae			Rutaceae
Plant	Solanales	Solanaceae			Solanaceae
Plant	Urticales	Moraceae			Moraceae
Plant	Urticales	Moraceae	Ficus	Ficus sp.	Ficus sp.

Table 6: List of computed H2' and d'- indices per plot, transformation system and landscape

Landscape	Transformation system	Plot	*H2'*	*d'*
Bukit 12	Secondary forest	BF1	NA	1
Bukit 12	Secondary forest	BF2	1	0.65655808
Bukit 12	Secondary forest	BF3	0	0
Bukit 12	Secondary forest	BF4	0.1590507	0.04200486
Bukit 12	Jungle rubber	BJ2	1	1
Bukit 12	Jungle rubber	BJ3	0.2672729	0.16432722
Bukit 12	Jungle rubber	BJ4	0.7783152	0.80166759
Bukit 12	Jungle rubber	BJ5	0	0.22049664
Bukit 12	Rubber	BR1	0.7007815	0.53755029
Bukit 12	Rubber	BR2	0.5740382	0.45936402
Bukit 12	Rubber	BR3	1	0.01926945
Bukit 12	Rubber	BR4	0.9426509	0.75857724
Bukit 12	Oil palm	BO2	0.8394126	0.73753106
Bukit 12	Oil palm	BO3	0.8016400	0.64404152
Bukit 12	Oil palm	BO4	0.9500833	0.49303541
Bukit 12	Oil palm	BO5	NA	NA
Harapan	Secondary forest	HF1	0.7145585	0.62431520
Harapan	Secondary forest	HF2	1	1
Harapan	Secondary forest	HF3	0.4680807	0.37795259
Harapan	Secondary forest	HF4	0.3204017	0.40319402
Harapan	Jungle rubber	HJ1	0.8341015	0.36657864
Harapan	Jungle rubber	HJ2	1	1
Harapan	Jungle rubber	HJ3	1	1
Harapan	Jungle rubber	HJ4	0.9806534	0.80055837
Harapan	Rubber	HR1	NA	NA
Harapan	Rubber	HR2	NA	NA
Harapan	Rubber	HR3	NA	NA
Harapan	Rubber	HR4	0.9196286	0.49596108
Harapan	Oil palm	HO1	NA	NA
Harapan	Oil palm	HO2	NA	NA
Harapan	Oil palm	HO3	1	0.68051801
Harapan	Oil palm	HO4	1	0.25052656

Table 7: List of mist netting and bird banding equipment

Item	**Amount**
Mist nets:	
6x3,0 m (19mm)	4
9x3,2 m (30mm)	4
12x3,0 m (19mm)	4
12x3,2 m (30mm)	12
18x3,2 m (30mm)	4
Wooden poles	100
Rope	100
Precision scales:	
100 g	2
500 g	2
1000 g	2
Tools:	
Calipers (dialMax)	2
Wing ruler (300 mm)	2
Tail ruler	4
Strand cutter	4
Net repair kits	2
Circlip pliers	2
Banding pliers (big)	2
Banding pliers (small)	2
Bird rings:	
size 2,0 mm	200
size 2,3 mm	200
size 2,8 mm	200
size 3,0 mm	200
size 4,0 mm	300
size 4,5 mm	200
size 5,5 mm	100
size 6,35 mm	100
size 7,0 mm	50
size 8,0 mm	50

Figure 17: Map of the study area showing the two landscapes Bukit 12 and Harapan and plot locations (CRC 990)

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Statutory declaration

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

Date: ____________________ Signature: ____________________