EFFECTS OF ISOLATION ON TEMPORAL DYNAMIC OF INSECT COMMUNITY STRUCTURE AND PARASITIC HYMENOPTERA DIVERSITY IN CACAO AGROFORESTRY SYSTEMS AT THE MARGIN OF LORE LINDU NATIONAL PARK, CENTRAL SULAWESI

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BOGOR
2004
ABSTRACT


Effects of isolation on insect community structure as well as diversity and abundance of parasitic Hymenoptera in cacao agroforestry systems were studied between February 2003 and April 2003. The research focused on two main aspects: (Chapter IV) effects of isolation of agroforestry systems from remaining forest on temporal dynamic of insect communities in general, (Chapter V) temporal and spatial dynamic of parasitic Hymenoptera of cacao agroforestry system.

The research was conducted at the eastern margin of the Lore Lindu National Park in Palolo Valley (Donggala District, Central Sulawesi). Samplings were conducted at 16 sites belonging to two different habitat types (cacao agroforestry systems, natural forest sites). The 12 sampled cacao agroforestry systems were situated in different distances to the forest margin (10 to 2200 m). The cacao plantations were located in the vicinity of the villages Berdikari, Sintuwu and Nopu. Two additional cacao agroforestry system were situated inside the forest margin shaded by a cover of remaining natural forest trees. Two further sampled sites were selected inside the natural forest. Insects were sampled by treating single cacao tree crowns with a knock-down insecticide (Matador). At each study site 5 randomly selected trees were sampled. After spraying all individuals were collected from a large plastic sheet spread under the treated canopy. Individuals were transferred to plastic containers containing 70% alcohol before sorting and identification took place in the laboratory.

A total of 119,536 insect specimens were collected by spraying single cacao trees. Results showed that the most abundant orders were Hymenoptera, Collembola, Homoptera, Diptera, and Coleoptera. Insect communities on cacao trees changed significantly with artificial disturbance by insecticide on cacao habitats. Increasing isolation of small blocks of cacao plantation from nearest forest did not have effects on insect communities. While a strong temporal effects was found. Samples within spraying periods proved to be more to each other than samples belonging to different spraying periods.

On a small temporal scale, we found significant differences of abundance and species richness of parasitic Hymenoptera between samples from June and August 2001 indicating that the re-colonization of the sprayed cacao trees was still in process after 2 months. No differences in abundance and species richness were found between samples after a re-sampling of the same trees 1.5 years later. However, a significant difference with respect to the species composition indicated a pronounced temporal species turnover. Due to the long recovery period of communities of parasitic Hymenoptera the treatment of cacao trees with insecticides can significantly decrease the effectiveness of these important parasitoids to control herbivores in cacao agroforestry systems.
Habitat corridors that connect isolated cacao plantations can be recommended to increase the abundance and diversity of species within those cacao plantations through increases in rates of immigration.

Keywords: parasitic Hymenoptera, insect communities, diversity, habitat isolation, temporal dynamic
ABSTRAK


Pengaruh isolasi habitat terhadap struktur komunitas serangga serta keanekekraganaman dan kelimpahan Hymenoptera parasitika pada sistem agroforestri tanaman kacang di teliti antara bulan Februari 2003 dan April 2004. Penelitian dikonsentrasi pada dua aspek, yaitu (Bab IV) pengaruh isolasi sistem agroforestri tanaman kakao dari hutan pada komunitas serangga dalam konteks waktu, dan (Bab V) dinamika Hymenoptera parasitika dalam konteks waktu dan ruang pad agroforestri tanaman kakao.


Secara keseluruhan dikoleksi sebanyak 119,536 spesimen serangga. Hasil penelitian ini menunjukkan bahwa Hymenoptera, Collembola, Homoptera, Diptera, dan Coleoptera merupakan ordo yang paling melimpah. Aplikasi pestisida yang bisa dianggap sebagai gangguan buatan ternyata sangat mempengaruhi struktur komunitas serangga secara umum. Isolasi plot-plot perkebunan kakao dari hutan tidak mempengaruhi struktur komunitas serangga. Struktur komunitas serangga akan berubah sesuai dengan perbedaan waktu sampling.

Pengambilan contoh yang dilakukan pada jarak waktu yang sempit (6 minggu) sudah memberikan pengaruh yang signifikan pada kelimpahan dan kekayaan spesies Hymenoptera parasitika, yang berarti bahwa rekolonisasi masih berlangsung dalam waktu tersebut. Tidak terdapat perbedaan yang signifikan dalam kelimpahan dan kekayaan spesies pada pengambilan contoh dengan tenggang waktu 1,5 tahun pada pohon yang sama. Perbedaan waktu pengambilan contoh memberikan implikasi pada perubahan komposisi spesies yang menunjukkan adanya temporal species turnover. Aplikasi insektisida dengan tenggang waktu yang sempit akan menyebabkan penurunan jumlah spesies,
sehingga dapat berimplikasi pada keefektifan parasitoid dalam mengendalikan serangga herbivora di perkebunan kakao.

Habitat yang berfungsi sebagai koridor yang menghubungkan perkebunan kakao dengan hutan dapat disarankan untuk meningkatkan kekayaan spesies Hymenoptera parasitika melalui peningkatan laju migrasi.

Kata kunci: Hymenoptera parasitika, komunitas serangga, keanekaragaman, isolasi habitat, dinamika waktu.
SURAT PERNYATAAN

Dengan ini, saya menyatakan bahwa tesis saya yang berjudul “Effects of Isolation on Temporal Dynamic of Insect Community Structure and Parasitic Hymenoptera Diversity in Cacao Agroforestry Systems at the Margin of Lore Lindu National Park, Central Sulawesi” merupakan gagasan atau hasil penelitian saya sendiri dan belum diajukan dalam bentuk apapun kepada perguruan tinggi manapun. Semua data dan informasi yang digunakan telah dinyatakan dengan jelas dan diperiksa kebenarannya.

Bogor, October 2004

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EFFECTS OF ISOLATION ON TEMPORAL DYNAMIC OF INSECT COMMUNITY STRUCTURE AND PARASITIC HYMENOPTERA DIVERSITY IN CACAO AGROFORESTRY SYSTEMS AT THE MARGIN OF LORE LINDU NATIONAL PARK, CENTRAL SULAWESI

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A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science
At the Graduate School, Bogor Agricultural University
Study Program Entomology/Phytopathology

GRADUATE SCHOOL
BOGOR AGRICULTURAL UNIVERSITY
BOGOR
2004
Title of Thesis: Effects of Isolation on Temporal Dynamic of Insect Community Structure and Parasitic Hymenoptera Diversity in Cacao Agroforestry Systems at the Margin of Lore Lindu National Park, Central Sulawesi

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In 2001, he was accepted as a student of the Study Program of Entomology-Phytopathology, Graduate Program. At the same year, he married Lu’lu Agustina SP and blessed with a two-year old son (born in Bogor on October, 16, 2002), named Muhammad Islam Al-Ghifari.
Foreword

Many thanks to Allah SWT for blessing me to finish this thesis "Effects of isolation on temporal dynamic of insect community structure and parasitic Hymenoptera in cacao agroforestry systems at the margin of Lore Lindu National Park, Central Sulawesi". This thesis based on the research under the supervision of Dr. Damayanti Buchori, chairman of the advisory committee, Drs. Rosichon Hibaidillah, DIC, Mphil and Dr. Christian H Schulze, both are members of the advisory committee. Many thanks are expressed to all of them for their support of my MSc research, their valuable advice and many fruitful discussion.

I am grateful to Faculty of Agriculture, and the Head of the Plant Pest and Disease Department, Bogor Agricultural University (IPB), Dr. Damayanti Buchori. They gave me the opportunity to perform my study and to use the department's facilities. I also like to thank all lecturers of IPB for sharing their knowledge and experience.

I am also thankful to Prof. Dr. Teja Tscharntke, head of the Institute of Agroecology, University of Göttingen, Germany, for giving me the opportunity to join the STORMA's research. Special thanks to Dr. Christian H. Schulze and Drs. Rosichon Hibaidillah DIC MPhil for many fruitful discussions, supports, and the close collaboration over the whole time during my MSc project.

Special thanks are extended to Peka Indonesia and Wildlife Trust which have given me a fellowship for attending the Graduate School, Director of Balai Taman Nasional Lore Lindu, Palu - University of Tadulako - STORMA. Which gave me facilities to perform my research in Palu. I would like to say many thanks to Dr. Tukirin who gave me more information related to my research topic, to all Storma’s drivers, Ibu Rina, and to all my best friends (Mbak Adha, Hertab, Jalu, Nina, Dina, Ai, Atiek, Nita, Rahma, Shinta etc) who assisted and encouraged me to finish this research.

Finally, I would love to express my lovely thanks to my wife Lulu' Agustina-Gifa for their love, support, understanding, and patience as well as all of my families and friends. To my son Gifa for his missing in love during the time I conducted my research in Bogor and Palu.
I really expect that the information resulted from the research will be useful for many people and for the growth of science in the world.

Bogor, October 2004

Bandung Sahari
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CHAPTER I. INTRODUCTION

1.1. Background

Tropical rainforest harbors the highest diversity of life in terrestrial habitats (e.g. Wilson 1988). This is particularly true for many groups of insects, for example parasitic wasps (Quicke 1997), ants (Brühl 2001), moths (Beck & Schulze 2000; Beck et al. 2002) and butterflies (Schulze et al. 2004). In the past 100 years, large areas of this ecosystem are modified and converted, for example to agricultural land-use. In fact, human activities are increasingly considered as the main threat to biodiversity worldwide due to their impact on destruction, fragmentation and isolation of natural ecosystems (Kruess & Tscharntke 1994; Andren 1997; Steffan-Dewenter & Tscharntke 1999; Kruess & Tscharntke 2000; Rogo & Odulaja 2001; Klein et al. 2002b). Human activities may also negatively affect biotic interactions and ecosystem stability (Steffan-Dewenter & Tscharntke 1999). This is true since at high levels of disturbance species diversity declines because many species cannot reproduce fast enough to compensate for the increased mortality imposed by the disturbance (Wootton 1998; Lawton et al. 1998). Today, only a small fraction of the terrestrial environment is represented by undisturbed tropical rainforest and the remaining forests are only patchily distributed in most tropical landscapes (Rogo & Odulaja 2001).

Those conditions mentioned above have a tremendous implication for insect diversity and abundance that in turn are capable of influencing ecosystem dynamics. Insects play a very important role in maintaining and conserving ecosystem functions, as well as providing many critically important services through numerous mechanisms, such as decomposition of leaf litter, pollination, suppression of plant growth, and serving as prey for predators (Hamond & Miller 1998; Black et al. 2001). Additionally, insects serve as effective ecological indicators (e.g. Basset et al. 2004) and are well suited to monitor effects of landscape and land-use changes, habitat destruction and isolation, and habitat modification because they are abundant, species rich, and ubiquitous in occurrence (Bossart & Carlton 2002), and represent a substantial proportion of all terrestrial biodiversity (e.g. Groombridge 1992). Among the insects,
Hymenoptera, in particular the assemblage of parasitic species, are among the most species-rich and biologically diverse taxa (Mason & Huber 1993; Naumann 1991; Quicke 1997; Whitfield 1998), and arguably one of the most important insect groups by representing many species playing valuable roles in maintaining the diversity of natural communities (Quicke 1997). The majority of species develops as parasitoids of other insects and plays an important role in natural regulation of populations of herbivorous insect. Many species of parasitic Hymenoptera have been successfully used in biological control against agricultural pests (Noyes & Hayat 1984; Quicke 1997).

The rapid destruction of natural habitats may also causes the extinction of many species of parasitic wasps. In fact, this condition may lead to the situation where extinction precedes discovery by humans. Many groups of Hymenoptera are particularly sensitive to environmental disturbance, which makes their populations especially prone to extinction. One main reason may be their highly specialized life history. Since parasitic Hymenoptera represent a key factor regulating natural insect populations, their loss can result in a serious destabilization of natural ecosystems. Therefore, systematic, biological and ecological studies of parasitic wasps on the level of entire communities are essential for our understanding of interactions between different trophic levels and the maintenance of ecological stability.

Unfortunately, up till today, many natural habitats in the tropical zone have been already converted anthropogenically into a diverse spectrum of land-use systems. Therefore, at present most tropical landscapes are dominated by agroecosystems. In the old paradigm, land-use systems were categorized as modified ecosystems without conservation value and were categorized as a serious threat to biodiversity. However, as the world faces alarming rates of tropical forest loss, some agricultural systems tend to offer a glimmer of hope by maintaining at least a certain fraction of biodiversity (Perfecto et al. 1997; Rice & Greenberg 2000; Klein et al. 2002b; Beck et al 2002; Alkorta et al 2003). In particular many agricultural landscapes, which are managed under traditional culture techniques, are able to contribute significantly to biodiversity conservation (Moguel & Toledo 1999; Rizali et al. 2002; Perfecto et al. 2003). For example, it
was demonstrated that traditional agroforestry systems such as coffee and cacao cultivations established under a diverse layer of forest trees can maintain a high extent of tropical biodiversity (Moguel & Toledo 1999; Perfecto et al 1997; Rice & Greenberg 2000; Faminow & Rodriguez 2001; Klein et al 2002a; 2002b; 2003). It was also shown that the structural diversity of agricultural landscapes could have a strong impact on the diversity and abundance of natural enemies that occur within crops (Kruess & Tscharntke 1994; Fabian et al. 1999; Varchola & Dunn 1999; Marino & Landis 2000).

Cacao agroforestry systems, which are one of the most sustainable land-use system from a biodiversity-conservation perspective, are particularly abundant in the eastern parts of Indonesia. Cacao is still one of the most important cash crops and the best source of income for many farmers. In 2002, cacao plantations in Indonesia covered an area of 776,900 ha (Taher 2002). The main cacao production areas are located in South, Southeast, Central, and North Sulawesi (Martadinata 1998). In Central Sulawesi, cacao plantation can be found predominantly within and at the margin of tropical forest. Many insect species that are able to survive in forest remnants may interact with agroecosystems (Klein et al. 2002a). Consequently, a certain number of insect species usually typical for tropical forests can be expected to occur also in shaded cacao plantations (Schulze et al. 2004). Based on the hypothesis of island biogeography developed by MacArthur and Wilson (1967), for a certain assemblage of species forest remnants could act as mainland area and small cacao agroecosystem as islands colonized by a fraction of forest species. According to that hypothesis, cacao plantations closer to remaining forest should support higher insect species richness than ones situated in a larger distance to the forest. With respect to conservation, cacao plantations closer to forest margin therefore could play an important role as buffer zone for protected areas.

This study quantifies the spatial and temporal dynamic of (1) the structure of entire insect communities, and (2) species richness and composition of communities of parasitic wasps in cacao agroforestry systems situated in different distances to the forest margin.
The forest margin was represented more or less by the border of the Lore Lindu National Park. The forest within the area of the National Park could provide an important source area, while cacao agroforestry system may act for many species as sink. In this respect, cacao agroforestry system closer to the forest may have a higher insect diversity than cacao plantations located far away from the forest. Such kind of data on the diversity of natural enemies such as parasitic Hymenoptera, and effects of isolation of agroforestry systems on insect community structure are an important source of information to strengthen efforts in a high proportion of biodiversity in tropical landscapes. Furthermore, such data can be used by decision makers to develop landscape management programs, which intend to take into account conservation aspects.

In particular, this study addressed the following questions:

1. Does isolation of agroforestry systems from forest affect the structure of the entire insect community?
2. Does isolation of agroforestry systems from forest affect abundance and species diversity of parasitic Hymenoptera?
3. Does isolation of agroforestry systems affect the species composition?
4. Do cacao plantations contribute to the conservation of parasitic Hymenoptera diversity?

1.2. Objectives

The objectives of the study are:

1. To analyze effects of increasing isolation of agroforestry systems from remaining forest on the structure of insect communities in general and the abundance and species richness of parasitic Hymenoptera particularly.
2. To study effects of isolation on temporal dynamic of entire insect communities and the abundance as well as species richness of parasitic Hymenoptera.
3. To evaluate the conservation value of cacao plantations for Hymenoptera.
REFERENCES


CHAPTER II. LITERATURE REVIEW

2.1. Lore Lindu National Park: Functions and Status

The Lore Lindu National Park (LLNP) is located in Central Sulawesi, close to the junction where the four “arms” of the island meet. This protected area is one of the most important biological refuges of Sulawesi and contains large areas of remaining, still relatively untouched forests including lowland, lower and upper montane and heath forest (Whitten et al. 2002).

Officially declared as national park on October 5, 1993, its area amalgamated three existing reserves: the Lore Kalamanta Nature reserve, which was set aside for the protection of Sulawesi’s unique endemic fauna; the Lake Lindu Recreation and Protection Forest, established to protect the catchment area of the Palu Valley’s Gumbasa River irrigation scheme, and to develop tourism; and Lore Lindu Wildlife Reserve. According to the Decision Letter No 464/Kpts-II/1999, the park covers an area of 217,991.18 ha (Departemen Kehutanan 2002). LLNP is bordered by four distinct valleys, Palolo in the north, Napu in the east, Kulawi in the west and Bada in the south. The long straight western boundary formed by Kulawi Valley actually consists of a series of narrow valleys. This western rift boundary (also called the Fossa Sarasina) is following an active geological fault line. The area around the national park is dominated by coffee and cacao plantations, maize and paddy fields as well as fallow land.

The protected forest of LLNP is an important area for many endangered and/or endemic species. However, the forest also plays an important role in providing livelihood for local people living around the park and hold a crucial value in providing water for Palu City. Unfortunately, still today, forest destruction through illegal logging is taking place in many parts of the park. According to Adiwibowo and Shohibudin (2003), the widespread incidence of illegal logging in Central Sulawesi is most likely caused by three key factors: (1) the high level of demand for wood in the region sawmills and wood (carpentry) shops most of which are operating illegally in the Palu Valley; (2) the weakness of law enforcement, and (3) the ongoing issuance of transportation permits and
certified forestry products documents, which is not selective enough and additionally the documents are too easy to get.

Taking into account the situation mentioned above, the government has to take action to overcome this problems affecting seriously the conservation value of Lore Lindu National Park. This is not only a governmental responsibility, but also stakeholders have to take part in protecting the park against these unsustainable human activities.

2.2 Tropical Insect Communities and Species Richness

A total of ca. 1.7 million species is so far described with ca. 74% belonging to the taxon Animalia (Groombridge 1992). The highest number of animal species is represented by arthropods (84% of described animal species). Species diversity of most taxonomic groups is significantly increasing from the poles towards the equatorial region (e.g. Stevens 1989; Groombridge 1992; Blackburn & Gaston 1996). However, the fact that recent estimations of the global species richness are still extremely varying by ranging between 12.5 (Groombridge 1992) and 100 million species (Savage 1995) is emphasizing the existing lack of knowledge. Due to the high diversity of tropical rainforests, most likely more than 50% of the species are occurring on only 7% of the global land area (Myers 1992), that area which is covered by tropical rainforest.

Based on their samples from the rainforest canopy Erwin (1982; 1983) and Stork (1988) estimated that between 10 and 80 million arthropod species can be expected to live in this habitat; 5 to 20 times more species than described during the last 250 years of taxonomic research. Although other studies emphasized that the highest diversity on earth seems to be reached in the canopy layer of tropical rainforests (e.g. Stork 1988; 1991; Stork et al. 1997 but also see Schulze 2002), the true species richness in this habitat is still very speculative (see e.g. Stork 1993; May 1988; 1994).

Investigations of the insect fauna of tropical forest canopies using insecticide knockdown techniques has resulted in a significantly increased estimate of the number of insect species estimated to exist globally (Erwin 1982). A study on the insect fauna of the forest canopy in Borneo based on by fogging
samples showed that secondary forest had the highest number of insect species, while ants represented 61% of all collected specimens. (Chey et al. 1998).

2.3. Parasitic Hymenoptera in Tropical Landscapes: General Overview, Function, and Their Status in Ecosystems

2.3.1. General Overview of Tropical Parasitic Hymenoptera

About 56% of all species known globally are insects (MacDonald 2003). A large proportion of insects is comprised by Hymenoptera, particularly parasitic wasps (Quicke 1997; Whitfield 1998). According to the investigation of the World Conservation Monitoring Center (MacDonald 2003), Hymenoptera only represent about 7.7% of all known insect species. Therefore, Hymenoptera can be categorized, as one of the most diverse insect orders. Only the order Coleoptera, Lepidoptera and Diptera reaching a higher species- richness in terrestrial habitats throughout the world (Mason & Huber 1993; Whitfield 1998). There are currently over 115000 described species of Hymenoptera (Lasalle & Gauld 1993). At the species and ecosystem levels, Hymenoptera are among the most diverse and important of all organisms. Not only are Hymenoptera one of the most species rich insect orders, they are also incredibly diverse in the biology displayed by those species. Hymenoptera can be found in large numbers in almost any terrestrial ecosystem, and more importantly, they are responsible for a larger share interactions with other species in ecosystems than any other insect group. (Lasalle & Gauld 1993; Mason & Huber 1993; Quick 1997).

It was speculated that tropical communities of parasitic Hymenoptera (e.g. Ichneumonidae) might be not significantly richer in species than species assemblages recorded for from the temperate zone (e.g. Gauld 1987; Gauld & Gaston 1992; Rathcke & Price 1976). Several studies showed that species richness of several groups of parasitic Hymenoptera, especially for Ichneumonidae seems to decrease in the tropics (this may related to "nasty host hypothesis" by Gauld et al 1992). However, many studies in the tropical regions indicate that Hymenoptera are as diverse in the tropics as they are in temperate zones (Lasalle & Gauld 1993). This is true since Noyes (1989) recorded a higher species diversity of Hymenoptera in Sulawesi (tropical zone) compared to England.
(temperate zone) and studies by stork (1991) showed that in fogging samples from tree canopies in Borneo, Hymenoptera accounted for 27.8% of all arthropod individuals collected. Recent fogging samples from tree canopies of a Dipterocarp rainforest in East Malaysia proved that tropical Hymenoptera communities are as diverse as other tropical insect taxa when compared to temperate zone communities (Horstmann et al. 1999).

Unfortunately, until today, many natural habitats in the tropical zone have been already converted anthropogenically into a diverse spectrum of land-use systems. Therefore, nowadays most tropical landscapes are dominated by agroecosystems. The rapid destruction of natural habitats most likely causes also the extinction of many species of parasitic wasps. Actually, many species will become extinct before there was a chance to discover and describe them. Many groups of Hymenoptera are particularly sensitive to environmental disturbance, which makes their populations especially prone to extinction. Since parasitic Hymenoptera represent a key factor regulating natural insect populations, their lost can result in a serious destabilization of natural ecosystems.

2.3.2. Parasitic Hymenoptera and Biological Control

Parasitic wasps are questionably one of the most important insect groups. Many species play crucial roles in maintaining the diversity of natural communities (Clausen 1940; Huber 1993; Quicke 1997). Furthermore, Hymenoptera are also important for the balance and function of most ecosystems. Specifically, parasitic wasps play an important role in regulating populations of herbivorous and predatory insects in natural ecosystem (Clausen 1940; Noyes & Hayat 1984; Huber 1993; Godfray 1994). In agricultural ecosystems, parasitic Hymenoptera are capable to keep populations of herbivorous insect below an economic threshold. The release of parasitic wasps is often the most successful approach of controlling pest insects without excessive use of insecticides. Noyes & Hayat (1984) stated that the majority of insect species introduced to control pests are parasitic Hymenoptera. According to Goulet & Huber (1993), most of parasitic Hymenopetra are parasitoids. In biological control program, Hawkins et al. (1997), reported that among natural enemies (predator, parasitoid, or pathogen)
representing an important and ubiquitous source of herbivore mortality, parasitoids are the most important factor causing mortality of herbivores than do either predators or pathogens.

Among the parasitic wasps, Ichneumonidae and Braconidae are most important families frequently encountered to attack a wide variety of e.g. lepidoptera caterpillars, sawfly larvae, as well as larvae and adults of beetles etc. (Clausen 1940). In the last 20 years, many families of parasitic Hymenoptera has been successfully used in agricultural field to control pest population, one of which are the release of Encarsia formosa (Aphelinidae) to control Bemisia argentifolii (Homoptera) (Hoddle et al. 1997). In Indonesia, the release of Diadegma semicalasum (Ichneumonidae) to control diamondback moth in Sumatera, Sulawesi, and Java was successfully performed (Sastrosiswojo 1996). Several studies also showed that the release of egg parasitoid Trichogrammatidae significantly decreased pest population in agricultural field (Nurindah & Bindra 1989), Nurindah et al (1993). Herlinda (1995), dan Marwoto & Supriyatin (1999).

2.3.3. Morphological Characters of Hymenoptera.

Hymenopterans live in virtually all terrestrial and freshwater habitats and play numerous ecological roles (Whitfield 1998). Although the order Hymenoptera represents a morphologically diverse group of insects, there are many characteristics that unite it as a monophyletic group. First, all Hymenoptera have membranous wings [Exceptions with reduced or absent wings: wing-less fig wasps, ant workers and soldiers], much like many primitive insects. However, their venation is much simpler. The base of the forewing is covered by a small roundish sclerite (plate) called the tegula and the fore and hindwings are connected by small hooks called hamuli. Although all of these characters help distinguish winged Hymenoptera from other insects, they do little good for the numerous species with rudimentary or absent wings. A more technical character shown only in the Hymenoptera is that the first segment of the abdomen is fused with the last segment of the thorax. In more advanced Hymenoptera, which possess a strong constriction between the first and second abdominal segment, the
first segment is referred to as the propodeum. Therefore, the strong constriction separates not the thorax from the abdomen, but the thorax plus the first abdominal segment (the mesosoma) from the rest of the abdomen (the metasoma). This combination of characters should allow anyone to differentiate between Hymenoptera and any other insects. It is important to note that Hymenoptera also have a holometabolous development (complete metamorphosis). An overview on Hymenoptera morphology can be found in Mason & Huber (1993).

2.4. Island Biogeography and Habitat Isolation

MacArthur and Wilson (1967) developed an equilibrium model of island biogeography that offered predictions about the number of species present on an island. They stated that islands that are close to continents tend to have a higher species richness than islands located far away from continents. Proximity of islands to the mainland largely influences immigration rates. Furthermore, islands that are near to the mainland more likely receive colonists by jump dispersal than islands far away from the mainland. Based on this hypothesis, islands that are situated far away from the mainland area tend to have lower species richness. Low species richness on isolated islands was documented by many studies. For example, in Venezuela, butterflies species inhabiting isolated island was lower than in mainland area (Shahabudin & Terborgh 1999). The species richness of birds in isolated patches of montane forest in Venezuela, Colombia, and Ecuador decreases with distance from the main chain of the Andes Mountains (MacDonald 2003).

In terrestrial habitat, islands biogeography hypothesis were adapted into ecological islands concept, where natural habitat may act as source for many species and agricultural fields that are situated at its margin may act as a sink. Extensions and modifications of the island biogeography hypothesis provided the basis for predicting effects of increasing isolation of natural habitats located within the cultivated landscape on species communities. In the last five years, several studies on the effects of isolation on insect species have been conducted in tropical landscapes (e.g. Klein et al. 2002). Generally, agroecosystems causing a complex landscape mosaic consisting of many different crop and non-crop
habitats (Marino & Landis 2000). Isolation of agro-ecosystems from natural habitats may affect species richness and community structure. Klein et al. (2003) reported that the number of social bees in coffee plantations decreased significantly with increasing distance to nearest forest. In an isolation experiment with two self-incompatible annuals plants, Steffan-Dewenter & Tscharntke (1999) found that fruit set decreased with increasing distance to remaining natural habitat. The quality and connectivity of the agricultural landscape matrix, including the distance to species-rich habitats, appears to be important for species richness and plant animal interactions (Steffan-Dewenter et al 2002).

2.5. Cacao Agroforestry Systems and Conservation of Insect Diversity

Tropical landscapes are mostly dominated by agroecosystem, but unfortunately the potential value of agro-ecosystems for the survival of species is often ignored (Klein et al. 2002; Weibull et al. 2003). This is true since many conservation efforts focus on natural habitats, while only little attention has been paid to the potential value of agroecosystems for conservation of species. For many years conservationists believed that agricultural systems are not capable of contributing to the maintenance of biodiversity. This opinion is supported by facts that most modern agroecosystems differ dramatically from primeval landscapes from which they derived (Marino & Landis 2000). However, in the last decade many studies showed that agricultural systems can at least donate to the conservation of a certain proportion of species (Perfecto et al 1997; Moque & Toledo 1999; Rizali et al 2002; Klein et al. 2002). This suggests that agroecosystems have to be taken into account for the conservation of biological diversity on a landscape scale.

Cacao agroforestry systems are one agricultural system, which may contribute to the conservation of species and promises a glimmer of hope for maintaining at least a certain proportion of tropical biodiversity outside protected areas. Basically, cacao (Theobroma cacao L.) agroforestry systems are cacao cultivations with other planted, naturally grown or remaining forest trees which are used to provide a vegetation layer shading the cacao trees (Rice & Greenberg 2000; Klein et al. 2002). Such shade management systems varies significantly in
terms of complexity and diversity of the upper canopy layer. This also can be seen in coffee system where the crops are cultivated between other planted trees. According to Rice & Greenberg (2000), there are three basic cacao shade management systems that may contribute differently to the conservation of species: (1) *Rustic Cacao* (characterized by planting cacao under thinned primary or older secondary forest tree layer), (2) *Planted Shade* (ranges from traditional polycultures through commercial plantations with a single emergent tree species providing shade). (3) *Technified cacao* (no shade component).

Cacao farms that are characterized by a diverse shade canopy are capable of supporting higher levels of biological diversity than most other tropical crops (Rice & Greenberg 2000). This may be caused by the high structural and floristic complexity of the shade tree layer. This is particularly true since many studies revealed that cacao agroforestry systems that are managed under diversified systems are capable of maintaining a high proportion of the local biodiversity (particularly insect diversity: Rice & Greenberg 2000). Also coffee plantations that are managed under a diverse layer of shade trees can contribute to the conservation of biodiversity (Perfecto et al 1997, Faminow & Rodriguez 2001).
REFERENCES

Blackburn TM & Gaston KJ. 1996. A sidways look at patterns in species richness, or why there are so few species outside the tropics? Biodiv Letters 3: 44-53.


Table 3.1. Information on the sampled study sites. Cacao plantation situated in the vicinity of the villages Nopu, Sintuwu, and Berdikari are indicated by the letters N, S, and B, respectively. Plantations inside the forest margin are indicated by MS and K, respectively and are indicated by F.

<table>
<thead>
<tr>
<th>No.</th>
<th>Sites code</th>
<th>Coordinates*</th>
<th>Altitude [m a.s.l.]</th>
<th>Distance to forest [m]</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N2</td>
<td>S 01011.23'E 120005.18'</td>
<td>650</td>
<td>150</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>2</td>
<td>N3</td>
<td>S 01011.24'E 120004.99'</td>
<td>650</td>
<td>50</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>3</td>
<td>N4</td>
<td>S 01011.36'E 120004.95'</td>
<td>650</td>
<td>0</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>4</td>
<td>N5</td>
<td>S 01011.42'E 120004.62'</td>
<td>650</td>
<td>100</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>5</td>
<td>N6</td>
<td>S 01011.76'E 120003.83'</td>
<td>650</td>
<td>100</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>6</td>
<td>S1</td>
<td>S 01009.33'E 120003.25'</td>
<td>600</td>
<td>2200</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>7</td>
<td>S2</td>
<td>S 01010.45'E 120003.52'</td>
<td>600</td>
<td>800</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>8</td>
<td>S3</td>
<td>S 01009.72'E 120003.22'</td>
<td>600</td>
<td>1500</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>9</td>
<td>S5</td>
<td>S 01009.87'E 120002.52'</td>
<td>600</td>
<td>250</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>10</td>
<td>B1</td>
<td>S 01009.72'E 120008.02'</td>
<td>700</td>
<td>500</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>11</td>
<td>B4</td>
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<td>150</td>
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</tr>
<tr>
<td>12</td>
<td>B5</td>
<td>S 01011.2'E 120005.09'</td>
<td>700</td>
<td>900</td>
<td>Cacao with planted shade trees</td>
</tr>
<tr>
<td>13</td>
<td>F1</td>
<td>S 01011.70'E 120005.65'</td>
<td>690</td>
<td>-200</td>
<td>Forest</td>
</tr>
<tr>
<td>14</td>
<td>F2</td>
<td>S 01011.85'E 120004.71'</td>
<td>740</td>
<td>-150</td>
<td>Forest</td>
</tr>
<tr>
<td>15</td>
<td>MS</td>
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<td>0</td>
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</tr>
<tr>
<td>16</td>
<td>K</td>
<td>S 01011.11'E 120003.50'</td>
<td>770</td>
<td>0</td>
<td>Cacao with natural forest trees</td>
</tr>
</tbody>
</table>

*measured by using a GPS (Garmin GPS 12)
CHAPTER III. STUDY AREA AND STUDY SITES

3.1. Study area

The study was carried out in Central Sulawesi at the north eastern margin of Lore Lindu National Park (LLNP), close to Palu, the capital of the province Central Sulawesi (Figure 3.1 and 3.2). The total area of the park is approximately 217,991 ha (Departemen Kehutanan 2002).

Figure 3.1. Map showing the position of Lore Lindu National Park in Sulawesi.
The area of LLNP is located at an altitude between 500 and 2600 m a.s.l. Seasonal temperatures range from 17 to 35°C and relative humidity from 77 to 85% (see Klein et al. 2002). Highland areas are significantly cooler, as the temperature decreases 6°C every 1,100m. Heaviest rainfall occurs during the northern monsoon lasting from November to April. However, there is no pronounced wet and dry season. The average annual rainfall of the park varies locality-specific between 2000 and 4000 mm, highest values are reported from the southern part of the park. The border of the margin of the national park is characterized by extensively managed agroforestry systems dominated by cacao and coffee.

Study sites were selected in Palolo Valley in the vicinity of the villages Nopu, Sintuwu and Berdikari, which are all located in the sub-district Palolo (district Donggala). While the valley floor is dominated by cacao plantations and paddy fields, the slopes at both sites of the valley are covered by forest disturbed to a different extent. Although recent logging activities affected seriously large
forest areas at the margin of the park (Adiwibowo & Shohibudin 2003), the western slopes belonging to the LLNP are still partly covered by natural forest.

3.2. Study sites

Insect sampling was conducted at 16 sites (minimum size 0.5 ha per site) belonging to two different habitat types, cacao agroforestry systems (5-10 years old) and natural forest sites. Twelve studied cacao agroforestry systems located in the vicinity of the villages Berdikari, Sintuwu and Nopu were situated in different distances to the forest margin (10 to 2200 m, see Table 1). Two additional cacao agroforestry systems situated inside the forest margin shaded by a cover of some remaining natural forest trees. Two further sampled sites were selected inside the natural forest. All study sites are situated at an altitude between 600 and 770 m a.s.l. The exact locations of general information on each study site is provided by Table 3.1 and Figure 3.3.

![Figure 3.3 Map of study area at Palolo Valley showing the 18 study sites (marked as circle).](image-url)
REFERENCES


CHAPTER IV. EFFECTS OF HABITAT ISOLATION ON 
TEMPORAL DYNAMIC OF INSECT COMMUNITIES IN 
CACAO AGROFORESTRY SYSTEMS

Abstract

Effects of habitat isolation on insect community structure in cacao plantations were studied between February and March 2003. The objectives of this research were to analyze effects of increasing isolation of agroforestry systems from remaining forest on the structure of insect communities in general and their dynamic. Samplings were conducted at 16 sites belonging to two different habitat types (cacao agroforestry systems, natural forest sites) in Palolo valley at the eastern margin of Lore Lindu National Park (Central Sulawesi). The twelve sampled cacao agroforestry systems were situated in different distances to the forest margin (10 to 2200 m). The cacao plantations were located in the vicinity of the villages Berdikari, Sintuwu and Nopu. Two additional cacao agroforestry systems were situated inside the forest margin shaded by a cover of remaining natural forest trees. Two further sampled sites were selected inside the natural forest. Insects were sampled by treating single cacao tree crowns with a knock-down insecticide (Matador). At each study site five randomly selected trees were sampled. A total of 119,536 insect specimens were collected by spraying single cacao trees. Results showed that the most abundant orders were Hymenoptera, Collembolla, Homoptera, Diptera, and Coleoptera. Insect communities on cacao trees changed significantly with artificial disturbance by insecticide on cacao habitats. Increasing isolation of small blocks of cacao plantation from nearest forest did not have effects on insect communities. While a strong temporal effects was found. Samples within spraying periods proved to be more to each other than samples belonging to different spraying periods.

4.1. Introduction

Human activities in managing and exploiting natural resources cause the disturbance, isolation, and fragmentation of natural habitats. These kinds of habitat modification can have a tremendous negative impact on biodiversity (Kruess & Tscharntke 1994; Andren 1997; Steffan-Dewenter & Tscharntke 1999; Kruess & Tscharntke 2000; Rogo & Odulaja 2001; Klein et al. 2002), and also may alter and affect ecological processes in natural ecosystems. Unfortunately, today large areas of tropical forest, the most diverse ecosystem on earth, have been transformed into highly disturbed habitats. However, most biodiversity studies that attempted to measure the response of species to habitat disturbance only concentrated on different regimes of disturbance of the remaining natural
ecosystem while only little attention has been paid on modified habitats such as agricultural land-use systems. Since many species (especially insects) that are able to survive in forest remnants may interact with agroecosystem (Klein et al. 2002), the value of these habitats for conservation should not be neglected. In the last five years, several studies have proved that some agricultural landscapes, which are managed under traditional culture techniques, are able to contribute significantly to biodiversity conservation (Moguel & Toledo 1999; Rizali et al. 2002; Perfecto et al. 2003). Particularly, cacao agroforestry systems may contribute substantially to the conservation of species and promises a glimmer of hope for maintaining biodiversity in modified ecosystems (Rice and Greenberg 2000).

In Central Sulawesi, Indonesia, cacao trees are planted in and around forest remnants. This also applies for the margin of Lore Lindu National Park in Central Sulawesi. Since the forest at the margin of the national park may act as source for many species, cacao plantations that are situated at its margin may act as a sink. It can also be expected that distance of forest may then affects the diversity and colonization rate of forest species on to the agroforestry system. As in other agricultural systems, pest and diseases in cacao plantations are commonly controlled by pesticide, which are important factors in limiting cacao productivity. In turn, those kinds of disturbances may affect ecological processes and species community in the ecosystem, including insects.

Many insects are particularly sensitive to environmental disturbance. For this reasons and because insects are abundant, species-rich, and ubiquitous in occurrence, they have been widely used as biological indicators to monitor effects of landscape and land-use changes, habitat destruction and isolation, and habitat modification (Bossart & Carlton 2002). Because insects represent a substantial proportion of the entire terrestrial biodiversity, their response to disturbance should be of importance (Basset et al. 2004). Therefore, this study quantifies effects of increasing cacao plantation isolation on the structure of insect communities.
4.2. Methods

4.2.1. Insect Sampling

At each study site (see Chapter III) insects were sampled between February and March 2003 by spraying individual tree crowns with a knockdown insecticide, an approach commonly used to survey arthropod communities of tree canopies (e.g. Basset 2001; Chey et al. 1998; Floren & Linsenmair 1997; Floren et al. 1998; Stork 1987; Wagner 1998, 1999). Usually, the fog is generated by a thermal pulse-jet engine and then rises into the tree canopy (e.g. Adis et al. 1998). Insects getting into contact with the chemical are killed or rendered in trays (Chey et al. 1998). However, for small trees such as cacao trees the treatment of single canopies by spraying them with an insecticide (Matador 25 EC with 25g/l Lamda sihalotrin as active ingredient) proved to be sufficient (see Hosang 2004).

The spraying of tree canopies was conducted between 07:00-10:00 am. Plastic sheets (2 x 2.60 m) were spread under cacao tree canopies to collect the insects falling down from the canopy. Insects were collected from the plastic sheet after 30 min and transferred to small plastic containers with 70% alcohol. Sorting of all samples and identification took place in the laboratory of Tadulako University (Palu) and Bogor Agricultural University.

To quantify the temporal dynamic of insect communities, the samples from February-March 2003 (spraying-3) were compared with samples from the same sites obtained in June 2001 (spraying-1) and August 2001 (spraying-2) (see Hosang 2004). At each studied cacao plantation, five cacao trees were selected along a 100 m transect reaching from the edge of the plantation towards its center. At the two additional forest sites, we selected 5 trees along a 100 m transect which had a height and shape similar to that of sampled cacao trees. In total 60 cacao trees (12 sites x 5 trees ) outside the forest were sampled in each sampling period. In contrast to those cacao plantations, the cacao plantations inside forest and the forest sites were only sampled in February-March 2003.

4.2.2. Sorting of Insect Specimens

Insect samples, which were preserved in plastic microtube filled with 70% alcohol, were brought into the laboratory for sorting them to order level.
Identification of insect orders was done by referring to standard references such as Borror et al. (1982) and Naumann (1991)

4.2.4. Statistical analyses

To calculate first-order jackknife estimates, we used the computer program of Colwell (2000) by not shuffling individuals among samples within species and randomizing samples 50 times. Pearson correlations, Spearman rank correlations, Pearson chi² test, multidimensional scaling, Scheffé test and one-way ANOVA were performed using Statistica 5.1 (StatSoft 1997). The computed ANOVA was always of a one-way type. Means are given with standard deviation if not mentioned otherwise. Scheffé test was used for multiple comparisons of means. If necessary, data were log- or square root-transformed to achieve normal distribution.

For quantifying the similarity of different samples, we pooled the samples from the five trees sprayed per plantations. As measure of similarity we calculated the frequently used NESS index (e.g. Grassle & Smith 1976; Beck et al. 2002). All orders were defined as individual units. The NESS index avoids problems of other commonly used similarity measures related to size and incompleteness of samples (Wolda 1981). NESS values indicate normalized estimates of shared species (or in this study: orders) if random samples of size \( m \) were drawn from two communities. For \( m=1 \) the NESS index is equivalent to Morisita’s index and thus sensitive to the commonest species, while the contribution of ‘rare’ species is increasing with rising \( m \). We present NESS values for \( m=100 \), which therefore should be also strongly influenced by the presence (or absence) of rare, in this study, orders. NESS values were calculated by a computer program provided by S. Messner (pers. comm.).

Based on NESS values we performed non-linear multidimensional scaling (MDS) which led to a two-dimensional projection of distances between the sites (see Cox & Cox 1994, Pfeifer et al. 1998). MDS has two advantages for application in ecology: (1) In contrast to other ordination methods with more stringent model assumptions, results are robust under a wide range of conditions (Minchin 1987). (2) Any measure of similarity such as NESS index values can be
used for ordination. Two-dimensional MDS-plots were considered sufficient, since the first two dimensions accounted for 95.6% of the entire raw stress (a measure of explained variance in MDS analyses). Moreover, visualization in a Shepard diagram (Pfeifer et al. 1998) revealed a good data fit (not shown).

4.3. Results

4.3.1. Insect Communities in Cacao Agroforestry Systems

In total we sampled 119,536 insect specimens belonging to 18 orders by treating 70 cacao canopies three times with a knockdown insecticide (Exception: sites K and MS were only sprayed once). The three most abundant insect orders were Hymenoptera with 73,485 individuals (61.48% of total) (Formicidae contributing 98% of all collected Hymenoptera), Collembola and Homoptera. Other taxonomic groups such as Diptera, Coleoptera and Orthoptera represented only a minor fraction of the total number of collected insect specimens (Table 1). Other orders (Trichoptera, Ephemeroptera, Mantodea, Phasmatodea and Isoptera) were even represented by fewer specimens (see Table 4.1).

At the two forest sites a total of 2,389 insect specimens belonging to 18 orders were sampled from 10 trees (5 at each site). The most abundant orders were Hymenoptera, Collembolla, Coleoptera, Diptera, and Orthoptera. The abundance ranking differed slightly from the one found for cacao plantations, especially for Coleoptera (see Fig. 4.1). However, the Pearson Chi² test (orders with less than 10 specimens in each of the both samples were pooled) did not indicate a significant difference between the abundance distribution of orders between cacao plantation and forest sites (χ²=195.00, df=182, p=0.24). The Spearman rank correlation even showed a highly significant relationship between the abundance of orders between both sites (r=0.94, n=18 p<0.0001). However, Hymenoptera compared to all other collected insect specimens showed a significantly higher abundance in cacao plantations compared to the forest (2 x 2 table Chi²-test: p<0.0001). The same could be proved for Coleoptera (2 x 2 table Chi²-test: p<0.0001).
Table 4.1 Abundance of different insect orders recorded in cacao plantations. Numbers of specimens represent data pooled for all 14 sampled cacao plantations in Palolo Valley.

<table>
<thead>
<tr>
<th>Order</th>
<th>Number of specimens</th>
<th>Proportion of total [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hymenoptera</td>
<td>73,485</td>
<td>61.48</td>
</tr>
<tr>
<td>Collembola</td>
<td>24,776</td>
<td>20.73</td>
</tr>
<tr>
<td>Homoptera</td>
<td>9,848</td>
<td>8.24</td>
</tr>
<tr>
<td>Diptera</td>
<td>3,153</td>
<td>2.64</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>2,743</td>
<td>2.29</td>
</tr>
<tr>
<td>Orthoptera</td>
<td>1,937</td>
<td>1.62</td>
</tr>
<tr>
<td>Thysanoptera</td>
<td>1,109</td>
<td>0.93</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>767</td>
<td>0.64</td>
</tr>
<tr>
<td>Psocoptera</td>
<td>644</td>
<td>0.54</td>
</tr>
<tr>
<td>Hemiptera</td>
<td>505</td>
<td>0.42</td>
</tr>
<tr>
<td>Blatodea</td>
<td>326</td>
<td>0.27</td>
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<td>Dermaptera</td>
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<td>0.03</td>
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<tr>
<td>Trichoptera</td>
<td>36</td>
<td>0.03</td>
</tr>
<tr>
<td>Ephemeroptera</td>
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<td>0.02</td>
</tr>
<tr>
<td>Mantodea</td>
<td>8</td>
<td>0.06</td>
</tr>
<tr>
<td>Phasmatodea</td>
<td>8</td>
<td>0.01</td>
</tr>
<tr>
<td>Isoptera</td>
<td>3</td>
<td>0.003</td>
</tr>
</tbody>
</table>
Fig. 4.1. Relative abundance of orders in cacao plantation and forest samples. Ranking of orders on x axis by decreasing abundance in cacao plantation samples.

4.3.2. Temporal dynamic of insect community structure.

Pearson’s correlation confirmed that there was a significant relationship between first and third spraying with respect to the abundance of orders, while samples of the second spraying were not significantly correlated to the number of specimens belonging to different orders from the first spraying, but proved to be significantly related to the third spraying (see Table 4.2). Significant relationship indicate that community structure based on abundance of order was close to similar between spraying periods.
Table 4.2. Relationships between the three different spraying periods with respect to the total number of specimens belonging to the recorded orders. \( r = \) Pearson’s correlation coefficient, \( p = \) level of significance. Significant correlations are marked in bold. \( n = \) total number of recorded orders in the two compared samples.

<table>
<thead>
<tr>
<th>Spraying-2</th>
<th>Spraying-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spraying-1</td>
<td>( r=0.33, n=17 )</td>
</tr>
<tr>
<td></td>
<td>( p=0.15 )</td>
</tr>
<tr>
<td>Spraying-2</td>
<td>( r=0.66, n=18 )</td>
</tr>
</tbody>
</table>

The mean number of insect orders recorded from individual cacao plantations was significantly related to the sampling period (ANOVA: \( F_{2,33}=14.65, p<0.0001, n=36 \)). While no significant difference could be found between first and third spraying, a significantly fewer number of orders was recorded during the second spraying period (Fig. 4.2). Mean number of insect orders recorded during the second spraying period was significantly lower than in spraying-1 and spraying-3, respectively.

In contrast, one way ANOVA did not indicate that the mean number of insect specimens was affected by the sampling period (ANOVA: \( F_{2,33}=2.78, p=0.12, n=36 \)) (Fig. 4.3). One-way ANOVA test proved that mean number of insect specimens sampled per plantation for five of the six most abundant orders recorded from individual cacao plantation was significantly affected by the sampling periods (see Table 4.3).
Fig 4.2 Mean number of insect orders recorded per plantation during the three different spraying periods. Significant differences between spraying periods are indicated by different letters (Scheffé test).

Fig 4.3 Mean number of insect specimens recorded per plantation during the three different spraying periods.
Table 4.3. Mean number of insect specimens per plantation of the six most abundant orders recorded during the three different spraying periods. Significant differences between spraying periods are indicated by different letters (Scheffé test). (n=12 for all spraying periods).

<table>
<thead>
<tr>
<th>Order</th>
<th>Mean number of specimens ± SD during three different spraying periods</th>
<th>One-way ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spraying-1</td>
<td>spraying-2</td>
</tr>
<tr>
<td><strong>Collembola</strong></td>
<td>16.65±12.09</td>
<td>246.25±133.83</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td><strong>Orthoptera</strong></td>
<td>11.97±5.10</td>
<td>5.09±3.75</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td><strong>Coleoptera</strong></td>
<td>15.30±6.99</td>
<td>9.27±3.52</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>B</td>
</tr>
<tr>
<td><strong>Homoptera</strong></td>
<td>111.58±263.84</td>
<td>20.77±13.60</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td><strong>Diptera</strong></td>
<td>16.15±7.73</td>
<td>8.84±4.34</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>B</td>
</tr>
<tr>
<td><strong>Hymenoptera</strong></td>
<td>747.17±1032.51</td>
<td>101.48±62.49</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>
4.3.3 Effect of isolation on temporal dynamic of insect community in cacao plantation

To analyze if the temporal change of the community structure is related to the distance of cacao plantations to the forest margin, coefficient of variation were used. Coefficients of variation as a measurement for the abundance dynamic of insect were not significantly related to distances of plantations from nearest forest. (Spearman's rank correlation: r=-0.24, n=12 p=0.45)

![Graph showing relationship between coefficient of variation (CV) and distance from nearest forest (m)].

Fig. 4.4. Relationship between coefficient of variation (CV) of mean number of insects recorded during three different spraying period and distance of cacao plantation from nearest forest.

4.3.4 Dynamic of insect community structure: time, space or habitat specific patterns?

Based on NESS values I performed non-linear MDS. The resulting two-dimensional MDS plot is indicating that the abundance structure of insect orders in single cacao plantations is strongly influenced by time but not by isolation of cacao plantations (Fig. 5). This was confirmed by a conducted ANOVA. It proved that values (extracted from the MDS plot) of both dimensions were significantly affected by the spraying period (Dim 1: \( F_{2,33}=4.42, p=0.02 \); Dim 2: \( F_{2,33}=9.03, \)
p<0.001), but not by habitat type (forest, plantations at the forest margin, plantations not attached to the forest margin) (Anova; Dim 1: F_{2,37}=2.20, p=0.13; Dim 2: F_{2,37}=0.31, p=0.74).

![Two-dimensional scaling plot based on NESS indices (m=100) calculated for the insect samples from three different spraying period.](image)

**Fig. 4.5.** Two-dimensional scaling plot based on NESS indices (m=100) calculated for the insect samples from three different spraying period.

### 4.3.4. Relationship between different orders

Abundance patterns of one group of insects in an ecosystem may affect another group of insects, for example a significant relationship can be expected between the abundance of predators and herbivores in a habitat. Pearson's correlation confirmed that several groups of insects in cacao plantations such as Coleoptera and Lepidoptera, non-formicid Hymenoptera and Lepidoptera as well as non-formicid Hymenoptera and Coleoptera were strongly correlated with respect to their abundance (see Table 4.4).
Table 4.4. Relationship between different orders of the last spraying

<table>
<thead>
<tr>
<th></th>
<th>Coleoptera</th>
<th>Collembola</th>
<th>Diptera</th>
<th>Ants</th>
<th>Hymenoptera formicid</th>
<th>non</th>
<th>Thysanoptera</th>
<th>Lepidoptera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleoptera</td>
<td>r=0.52</td>
<td>r=0.19</td>
<td>r=0.13</td>
<td>r=0.78</td>
<td>r=0.23</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=0.04</td>
<td>p=0.47</td>
<td>p=0.62</td>
<td>P=0.00</td>
<td>P=0.39</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collembola</td>
<td>r=0.16</td>
<td>r=0.30</td>
<td>r=0.57</td>
<td>r=0.22</td>
<td>r=0.39</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=0.56</td>
<td>p=0.30</td>
<td>p=0.02</td>
<td>p=0.22</td>
<td>p=0.14</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>r=0.47</td>
<td>r=0.47</td>
<td>r=0.57</td>
<td>r=0.21</td>
<td>r=0.43</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=0.07</td>
<td>p=0.07</td>
<td>p=0.02</td>
<td>p=0.43</td>
<td>p=0.43</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ants</td>
<td>r=0.04</td>
<td>r=0.24</td>
<td>r=0.12</td>
<td></td>
<td></td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=0.89</td>
<td>p=0.38</td>
<td>p=0.66</td>
<td></td>
<td></td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hymenoptera non ants</td>
<td>r=0.51</td>
<td></td>
<td></td>
<td>r=0.80</td>
<td>p=0.00</td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thysanoptera</td>
<td></td>
<td>p=0.04</td>
<td>p=0.00</td>
<td></td>
<td></td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepidoptera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n=14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Pearson's correlation coefficient $r$ the number of pairwise comparisons as well as the level of significance $p$ is given for all correlations. Significant correlations are marked in bold.
4.4. Discussion

4.4.1. Structure of insect communities: Cacao agroforestry systems vs. forest

In this study, Hymenoptera, Collembola, Homoptera, Diptera, Coleoptera, and Orthoptera represented the dominating insect orders. Chey et al. (1998) found Coleoptera, Hymenoptera, Diptera, Orthoptera dominating fogging samples from a forest in North Borneo. Also a study from rainforest in the Western Ghats, South India (Srinivasa et al. 2004) found a similar pattern. Coleoptera, Diptera and Hymenoptera again represented dominating insect orders of samples collected by fogging.

Although the general pattern of abundance of insect orders in spraying samples from tree canopies appears to be relatively stable, our study showed that the relative abundance of orders differed prominently between forest and cacao plantations with respect to Hymenoptera and Coleoptera. Particularly, the significantly higher abundance of insects in cacao agroforestry systems has important ecological implications by most likely influencing the strength of interactions between trophic levels. Basset (1991) reported that arthropod densities in tropical forest canopies maybe most strongly influenced by microclimatic conditions, which certainly differ more pronounced between forest and cacao plantation due to the prominent differences in vegetation structure. Srinivasa et al. (2004) documented that the community composition of the most abundant tree species strongly influences the composition of arthropods. This may to explain differences of insect communities between agroforestry systems and forest, which are dominated by completely different trees and particularly show a very different tree species richness (Schulze et al. 2004).

The heterogeneity between forest sites is more complex than in cacao plantations. Higher structural habitat diversity may provide a higher diversity of basal resources and therefore most likely support a higher diversity of insects communities (Hunter 2002), which additionally show a significant change of species composition in response to changes in structural vegetation diversity and microhabitat characteristics (Perfecto et al. 2003). Also Chey et al (1998) argued that a higher diversity of tree species composition and forest architecture should support larger and more complex insect communities.
This study did not find a significant decrease of arthropod numbers in cacao plantations with increasing isolation from the forest (potential source habitat). This may be caused by the specific condition in cacao plantations such as the presence of shaded trees and a well-developed leaf litter layer that can support insects species richness. Cacao farms with a diverse layer of shade trees support higher levels of biological diversity than most other tropical crops (Rice & Greenberg 2000).

4.4.2. Temporal dynamic of insect population in cacao plantations

This study did not find either a significant decrease of insect numbers in cacao plantations with increasing isolation from the forest (potential source habitat) or a change of the temporal abundance dynamic related to the extent of isolation of plantations from the forest. Samples only differed between the spraying periods independent of habitat isolation. Abundance of the total number of insects was lower during the second sampling period compared to the first and third spraying, respectively. This pattern was also shown for Hymenoptera, Coleoptera, Diptera, Orthoptera but not Collembola, which reached the highest abundance during the second spraying period. However, it is doubtful if Collembola were not just stick on the wet plastic sheet spread under the treecrowns by jumping to the sheet from the surrounding leaf litter.

The smaller mean number of insect orders and specimens recorded per cacao plantation during the second sampling period is most likely still an effect related to the initial treatment of tree-crowns by insecticides. The recovery of the insect communities was still not finished when the spraying was repeated 1.5 months after the first spraying. That the recovery of insect communities can last several months is also documented by other studies (Stork & Hammond 1997; Horstmann et al. 1999; see also Chapter V of this thesis).
4.4.3. Order-specific or general patterns?

The data indicate that abundance variation of insect orders between plantations does not necessarily have to be congruent but may show pronounced differences between taxonomic groups. However, it has to be emphasized that not a single correlation coefficient reached a negative value indicating an inverse trend of abundance variation between orders. This perhaps indicates that abundance variation of individual orders in general is underlined by a similar set of abiotic and/or biotic factors. Inverse trends between taxonomic groups could be also hardly found by other studies comparing environmental effects on the species richness of different taxonomic groups (e.g. Lawton et al. 1999, Schulze et al. 2004).

4.5. Conclusions

Studies on insects of tropical forest canopies using knockdown insecticide techniques resulted in a significant increase of our understanding of the ecology and biodiversity of this community (e.g. Noyes 1989, Horstmann et al. 1999). Insects play a crucial role in the interaction of plants with their environment and form an important link in most terrestrial food webs. Therefore, studies on insect diversity from tree canopies also are an important step in our understanding of agroforestry systems such as cacao plantations.

Overall, Hymenoptera, Coleoptera, Orthoptera, and Homoptera appeared to be the most dominant orders that could be found in the canopy layer of cacao plantations in Central Sulawesi. Artificial disturbance, for example pesticide application is capable of affecting the structure and abundance of insect communities in a sustainable way over a period of most likely several months.

The abundance structure of insect communities on the level of orders did not prove to be significantly affected by the distance of cacao plantation from nearest forest, while spraying samples from the forest itself showed a significant difference with respect to two dominant groups, Hymenoptera and Coleoptera.

Particularly, the significant decrease of the abundance of Hymenoptera after treatment of cacao trees with insecticides, which was still significant after 1.5 months, has most likely a strong effect on the foodweb in cacao plantation.
because the order Hymenoptera represent several important functional groups such as predators (ants), parasitoids (parasitic wasps) and pollinators (bees).
REFERENCES


Floren A & Linsenmair KE. 1997. Diversity and recolonisation dynamics of selected arthropod groups on different tree species in a lowland rain forest in Sabah, Malaysia with special reference to Formicidae. *S.* 344-


CHAPTER V. TEMPORAL AND SPATIAL DYNAMIC OF PARASITIC HYMENOPTERA OF CACAO AGROFORESTRY SYSTEMS

Abstract

In cacao agroforestry systems, an increasing distance from remaining forest may play not only an important role for modifying diversity and abundance of insects but also for the population dynamic. The objective of this study was to evaluate such effects on parasitic Hymenoptera assemblages along a gradient of increasing isolation of cacao agroforestry systems from remaining forest represented by the eastern margin of the Lore Lindu National Park in Palolo Valley (Central Sulawesi, Indonesia). Additionally to cacao canopies in 14 selected cacao plantations, the tree crowns of small understory forest trees were sampled. At each site, five trees were selected and Hymenoptera were collected from the canopies by treating them with a knock-down insecticide. Twelve cacao plantations were sampled tree times (June 2001, August 2001, February/March 2003) to study the temporal dynamic of communities of parasitic wasps. On a small temporal scale, we found significant differences of abundance and species richness of parasitic Hymenoptera between samples form June and August 2001 indicating that the re-colonization of the sprayed cacao trees was still in process after 2 months. No differences in abundance and species richness were found between samples after a re-sampling of the same trees 1.5 years later. However, a significant difference with respect to the species composition indicated a pronounced temporal species turnover. Due to the long recovery period of communities of parasitic Hymenoptera the treatment of cacao trees with insecticides can significantly decrease the effectiveness of these important parasitoids to control herbivores in cacao agroforestry systems.

5.1. Introduction

The increasing demand of the growing human population for land causes a continuing loss of natural habitats, and an increasing fragmentation and isolation of the remaining habitat remnants throughout the world (Henle 2004). Some insect groups appear to be negatively affected by fragmentation and isolation, and, therefore, suffering significant population declines or even local, regional or global extinction. Not until Mac Arthur & Wilson (1967) formulated their ideas of islands biogeography, did it become generally recognized that stochastic extinctions of island populations are a normal and pervasive ecological process. Based on the equilibrium theory of island biogeography, species numbers on
islands can be described as a function of island area and isolation. With respect to species conservation, it is important to know which species will be particularly affected by increasing isolation from available source areas. Effects of isolation on species diversity were already documented by many studies, for example for butterflies (Shahabudin & Terborgh, 1999).

Extensions and modifications of the island biogeography hypothesis provided the basis for predicting effects of increasing isolation of natural habitats located within the cultivated landscape on species communities. Modified ecosystems, such as agricultural habitats, are getting more and more isolated from remaining natural habitats that may act as important source areas for insects colonizing cultivated areas (sinks). The increasing rarity and isolation of natural habitats may negatively affect species richness abundance, and community structure of species assemblages of adjacent cultivated areas, as well as ecological services (Steffan-Dewenter & Tscharntke 1999; Kruess & Tscharntke 2000). For example, Steffan-Dewenter & Tscharntke (1999) found that the number of seeds per fruit and per plant decreased significantly with increasing distance from nearest grassland for both mustard and radish. Additionally, they reported that increasing isolation of small habitat islands resulted in both decreased abundance and species richness of flower visiting bees. Other studies showed that species richness of parasitoids and parasitism decreased significantly within a few hundred meters from the source area (Kruess & Tscharntke 1994, 2000). In tropical landscapes, several studies found that the distance from forest is known to affect the diversity of pollinators (Klein et al. 2002), and the number of social bee species, which showed a pronounced decrease with increasing distance to the forest (Klein et al. 2002).

Unfortunately, only few studies investigated effects of habitat isolation on parasitic Hymenoptera. Since parasitic Hymenoptera plays an extremely important role in regulating herbivorous insects in the agricultural landscape, studies on effects of isolation could provide information for managing agricultural landscapes. Until today, research on parasitic Hymenoptera in agro-ecosystems concentrated mostly on studying parasitoids attacking particular native as well as exotic pest species. However, data on the change of diversity, abundance and
species composition of parasitic Hymenoptera in relation to habitat fragmentation and isolation is very limited.

Specific information on effects of isolation on parasitic Hymenoptera can provide important implications for maintaining a high extent of diversity by developing more effective conservation strategies in our increasingly fragmented landscape. Therefore, this study focused on assemblages of parasitic Hymenoptera in cacao plantations located in different distances to forest, that potentially could act as important source area for species colonizing the adjacent cultivated landscape.

Particularly, the following questions are addressed:

1. Are abundance and species richness of parasitic Hymenoptera in cacao plantations negatively affected by increasing isolation from the forest?
2. Does the temporal dynamic of species communities change in relation to an increased isolation of cacao plantations from the forest?
3. Which taxa are most vulnerable to extinction in highly isolated agroforestry systems?

5.2. Methods
5.2.1. Sampling

Twelve cacao plantations at varying distances (10–2200m) to remaining forest (represented by Lore Lindu National Park), two cacao plantations inside the forest and two forest sites were selected. Hymenoptera were sampled from five cacao trees per cacao plantation and from five forest trees at each forest sites. Selected forest trees had a size and shape similar to that of cacao trees. Fogging of tree canopies with knockdown insecticides was found to be an excellent method for sampling canopy arthropods in tropical forests (Adis et al. 1998). Fogging of tree canopies seems to be also particularly successful for sampling the Hymenoptera fauna tropical tree crowns (Noyes 1989). Insects coming into contact with the chemical are killed or rendered in trays (e.g. Adis et al. 1998, Chey at al. 1998). However, for small trees such as cacao trees the treatment of single canopies by spraying them simply with an insecticide (Matador 25 EC with
25g/l *Lambda sialotrin* as active ingredient) proved to be sufficient in this study (See also Hosang 2004)

The treatment of single tree canopies was conducted between 07:00-10:00 am. In advance plastic sheets (2 x 2.60 m) were spread under the tree canopies to collect the arthropods falling down. After 30 min insects were collected from the plastic sheet and transferred to small plastic tubes filled with 70% alcohol. Sorting and identification of samples were conducted in the laboratories of Tadulako University at Palu and Bogor Agricultural University.

To quantify the temporal dynamic of communities of parasitic Hymenoptera in cacao plantations, single tree crowns were threatened with insecticide three times. The first fogging was performed in June 2001, the second in August 2001 and the third in February/March 2003. The two forest sites were only fogged once in March 2003. At each study site, five cacao trees were selected along a 100 m transect in cacao plantations reaching from the edge of the plantation towards its center. In total 80 trees were sampled in each sampling period.

### 5.2.2. Sorting and Identification

First, insect samples were sorted to orders level. Then only parasitic Hymenoptera were identified to families and sorted to morphospecies. Identification of parasitic wasps to families was conducted by using the family identification key of Goulet & Huber (1993).

### 5.2.3. Statistical analyses

Statistical analyses of the data were performed using the software Statistica for Windows 5.5 (Statsoft 1997). If necessary, logarithmic or square root-transformations variables were used to achieve normal distribution of data. Pearson's correlations were conducted when data proved to be normally distributed, otherwise Spearman rank correlations were used (Sokal & Rohlf 1995). Analysis of variance (ANOVA) was used to test for differences between two or more groups.
5.3. Results

A total of 1,276 Hymenoptera specimens (excluding ants) belonging to 37 families and 345 morphospecies were collected by three times spraying at the 16 selected sites (exceptions: site K, MS, F1 and F2; only sprayed once). The most important group of non-formicid Hymenoptera were parasitic wasps which represented 1,201 specimens (94.12% of all collected specimens) and 302 species. In contrast, aculeate Hymenoptera only represented a minor fraction of about 75 specimens belonging to 43 species (12.46% of total species). Abundance and species richness of families of parasitic Hymenoptera were highly correlated (Fig. 5.1). This indicates that the species assemblages are still very incompletely surveyed.

Fig. 5.1. Relationship between abundance and species richness of families of parasitic Hymenoptera sampled in individual cacao plantations. Spearman rank correlation: r=0.96, n=25 p<0.001.

That the species inventories are still very incomplete is also indicated by the species accumulation curve calculated for all samples. Not only are the numbers of recorded species still increasing but also the total number of species estimated by Chao1 and Jackknife1 still showed a pronounced increase (Fig. 5.2).
Fig. 5.2 Species accumulation curve (recorded species) and Chao 1 and Jackknife estimates on the total number of expected species for the assemblage of parasitic Hymenoptera species in the study area. Calculations are based on 40 samples (1 sample = species assemblage recorded during one spraying of 5 trees per site) from different habitats (forest, forest margin and cacao plantation) from three different sampling periods (Juni 2001, August 2001, February/March 2003).

At the two forest sites, a total of 143 specimens belonging to 84 species were collected. This represents 27.81% of all recorded species and 36.68% of the species total recorded during the third spraying. By taking into account that only two forest sites were sampled but 14 cacao plantations, these data indicate that forest contribute substantially to the species richness of parasitic Hymenoptera.

With respect to abundance of single families Encyrtidae (21% of total), Braconidae (15%) and Platygastridae (13%) were the three most abundant (Fig. 3a), while in terms of species richness the family Encytrtidae was replaced by Braconidae (Fig. 5.3b).
Fig. 5.3 Relative abundance (a) and species numbers (b) of individual families of parasitic Hymenoptera collected at the margin of Lore Lindu National Park by spraying individual crowns of cacao trees outside (12 sites, 3 spraying periods) and inside the forest (2 sites, 1 spraying period) as well as small forest trees (2 sites, 1 spraying period). Families, which were rare or represented only by a small number of species, were pooled ("others").

5.3.1 Temporal dynamic of overall species richness

Overall, 862 specimens of Hymenoptera (excluding ants) were collected from 12 cacao agroforestry systems during the three spraying periods (site M, K, F1, F2 excluded). About 93.27% of the specimens represented parasitic
Hymenoptera, belonging to 25 families and 275 species. The superfamilies Platygastridea, Chalcidoidea, and Ichneumonoidea were most abundant.

In the first and second samples, there were 323 specimens belonging to 182 species and 188 specimens belonging to 93 species, respectively. In the third collection, 363 specimens belonging to 171 species were collected in February/April 2003. A total of 126 species (45.82% of recorded species total) could be found only during one of the three spraying periods. Around 45 species were only recorded during the first spraying (24.73% of recorded species total), 28 species during the second spraying (30.11%), and 53 species during the third spraying (30.99%).

Table 5.1 shows the species numbers of single families and its proportion in the three different spraying periods. The species numbers of several families including Agaonidae, Aphelinidae, Braconidae, Ceraphronidae, Eucharytidae, Eucoilidae, Evanidae, Platygastridae, Signiphoridae, and Torymidae collected in the second spraying period was extremely decreased. Compared to the first and third spraying, the families Aphelinidae, Braconidae, Ceraphronidae, Eucoilidae, and Platygastridae showed a lower species richness during the second sampling period (compare Tab. 5.1).

To produce smooth species accumulation curves for each spraying period, sampling units (=individual plantations) were randomized 50 times. The species accumulation curves (Fig.5.4) indicated that species richness of spraying-2 samples was extremely low compared to samples from the first and third spraying period. That all species accumulation curves showed a steep increase indicates that species inventories are still very incomplete. Extrapolations on the total expected species richness estimated by Chao1 and Jacknife1 showed that the recorded species represent between 56% and 62% of the total number of expected species (324 and 292) for the 1st sampling period, 32.75% and 39.51% (expected total: 287 and 162 species) for the 2nd, and 43.96% and 63.10% for the 3rd sampling period (expected total: 289 and 271 species) (Table 5.2).
Table 5.1 Number of species per family that were collected three times from 12 selected cacao plantation

<table>
<thead>
<tr>
<th>No</th>
<th>Family</th>
<th>Number of species collected from three spraying periods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spraying-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>∑ species</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total</td>
</tr>
<tr>
<td>1</td>
<td>Agaonidae</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Aphelinidae</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Braconidae</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>Ceraphronidae</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Chalcididae</td>
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</tr>
<tr>
<td>6</td>
<td>Cynipidae</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Diapriidae</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>Elymidae</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Encyrtidae</td>
<td>25</td>
</tr>
<tr>
<td>10</td>
<td>Eucharitidae</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Eucolidae</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>Eulophidae</td>
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</tr>
<tr>
<td>13</td>
<td>Eupelmidae</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>Eurytomidae</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Evaniidae</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Ichneumonidae</td>
<td>7</td>
</tr>
<tr>
<td>17</td>
<td>Megasphilidae</td>
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</tr>
<tr>
<td>18</td>
<td>Mymaridae</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>Mymmaromatidae</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>Platygastridae</td>
<td>11</td>
</tr>
<tr>
<td>21</td>
<td>Pteromalidae</td>
<td>4</td>
</tr>
<tr>
<td>22</td>
<td>Scelionidae</td>
<td>22</td>
</tr>
<tr>
<td>23</td>
<td>Signiphoridae</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>Torymidae</td>
<td>3</td>
</tr>
<tr>
<td>25</td>
<td>Trichogrammatida</td>
<td>1</td>
</tr>
</tbody>
</table>
Fig. 5.4  Species accumulation curves for parasitic Hymenoptera sampled by spraying in 12 cacao plantations (5 sampled trees per plantation)

Table 5.2. Species richness of parasitic Hymenoptera recorded and estimated by Chao1 and Jacknife1 extrapolation method (Colwell 2000) for the three different sampling periods.

<table>
<thead>
<tr>
<th>Sampling period</th>
<th>Recorded species</th>
<th>Total species numbers estimated by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Chao1</td>
</tr>
<tr>
<td>1st spraying</td>
<td>182</td>
<td>324 (56 %)*</td>
</tr>
<tr>
<td>2nd spraying</td>
<td>94</td>
<td>287 (32.75 %)*</td>
</tr>
<tr>
<td>3rd spraying</td>
<td>171</td>
<td>389 (43.96 %)*</td>
</tr>
</tbody>
</table>

* Values in brackets represent the proportion of recorded species with respect to the estimated numbers

Spearman rank correlation indicated a significant relationship between first and third spraying period with respect to species numbers recorded for single plantations, while samples of the second period were not significantly correlated to species numbers of samples from the first and third fogging respectively (Table
5.3. The relationship between first and third fogging period with respect to the numbers of species recorded for single plantations is shown in Fig. 5.

Table 5.3. Relationship of species richness of parasitic Hymenoptera between the three spraying periods

<table>
<thead>
<tr>
<th></th>
<th>Spraying-2</th>
<th>Spraying-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spraying-1</td>
<td>r=0.50</td>
<td>r=0.67</td>
</tr>
<tr>
<td></td>
<td>p=0.09</td>
<td>p=0.02</td>
</tr>
<tr>
<td>Spraying-2</td>
<td>-</td>
<td>r=0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p=0.27</td>
</tr>
</tbody>
</table>

$r$ = Spearman rank correlation coefficient, $p$ = level of significance, $n$ = 12 plantations. Significant correlations are marked in bold.

Fig.5.5. Relationship between species numbers of parasitic Hymenoptera recorded from single plantations during first and third spraying period ($n$=12 sampled plantations). For results of Spearman rank correlation see Table 5.3.

5.3.2 Effects of habitat isolation on communities of parasitic Hymenoptera

For studying effects of isolation of cacao plantations from the forest margin, only samples from the last spraying period were used. Recorded species numbers and the mean number of specimens per tree found for single plantations
were not significantly correlated with the distance of the plantations to the forest margin (Spearman rank correlation; species numbers: $r=-0.411$, $p=0.14$; specimens/tree: $r=-0.518$ $p=0.057$). Both, the number of species as well as the abundance of parasitic Hymenoptera decreased with increasing distance to the forest margin. The highest species richness was found inside the forest and at the forest margin. However, differences between groups of habitats did not proved to be significant (see Fig. 5.6).

![Box plot showing mean number of species](image)

**Fig 5.6** Mean number of recorded parasitic Hymenoptera species ± SD (box) and SE (whisker) in cacao agroforestry system located in different distances to the nearest forest: $F_{4,11} = 2.07$, $p = 0.153$, $n= 16$. Numbers below the whiskers indicate the number of sampled sites.

Sørensen indices were used to quantify the similarity of species composition between sampled sites. The two-dimensional scaling plot based on these Sørensen indices is indicating a pronounced change of the species composition between (1) forest sites and cacao plantations inside the forest margin, (2) cacao plantations close to the forest margin and (3) cacao plantations located in a distance of more than 100m from the forest (Fig. 5.7).
Fig. 5.7. Two-dimensional scaling plot based on Soerensen indices for measuring similarity of species composition between single sampling sites. F: forest sites; FM: cacao plantations inside forest margin; Distances represent degree of isolation of cacao plantations from the forest margin. Connecting lines indicates defined groups of habitats.

This is emphasized by a one-way ANOVA testing for effects of the defined groups of sampling sites on the scores extracted from the two-dimensional scaling plot (Fig. 5.7). Dimension 1 values were significantly affected by habitat type (ANOVA: $F_{3,12}=16.61$, $p<0.001$). Species composition significantly differed with respect to dimension 1 values extracted from the two dimensional scaling plot between forest sites and cacao plantations in a distance of more than 100m to the forest margin. Additionally, a significant difference was found between cacao plantation close to the forest and located in a distance of >100 to 500m from the forest (Fig. 5.8). Dimension 2 values did not prove to differ significantly affected between habitat types (ANOVA: $F_{3,12}=0.41$, $p=0.75$).
5.3.3 Effects of isolation on temporal dynamic of parasitic Hymenoptera

The coefficient of variation used as measurement for the abundance dynamic of parasitic Hymenoptera was not significantly affected by habitat type and/or isolation of cacao plantations from the forest (one-way ANOVA: $F_{3,12} = 2.29$, $p = 0.129$, $n = 16$; for defined habitat groups see Fig. 5.9). However, there was a pronounced trend of decreasing abundance fluctuation with increasing distance of plantations from the forest (see Fig. 5.9).
Fig. 5.9. Mean coefficient of variation (CV) of abundance of parasitic Hymenoptera ± SD (box) and SE (whisker) at forest sites and cacao plantations inside as well as cacao agroforestry system located in different distance to the forest. Forest sites: n=2; plantations at forest margin (0-50 m): n=4; plantations close to forest (>50-250 m): n=5; plantations far from forest (500-2200): n=5.

The two-dimensional scaling plot based on Sørensen indices comparing samples of individual plantations from the three different spraying periods indicates, that there is a temporal species turnover between the first two spraying periods and the last one (Fig. 5.10). Although sampling period did not have an effect on Dimension 2 values (ANOVA: F_{2,33}=1.02, p=0.370) extracted from the two-dimensional scaling plot based on Soerensen indices (Fig. 5.10), Dimension 1 values were significantly affected by spraying period (ANOVA: F_{2,33}=5.43, p=0.009). The third spraying differed obviously from both other spraying periods, however, only the difference between the means of the second and third spraying reached a significant level (Fig. 5.11).
Fig. 5.10. Two dimensional scaling plot based on Sørensen indices for measuring similarity of species composition between single cacao plantations and fogging periods. Samples from different spraying periods are connected by lines.

Fig. 5.11. Means of Dimension 1 values (extracted from two-dimensional scaling plot, Fig. 5.9) for the three different spraying periods demonstrating a significant temporal species turnover of parasitic wasp assemblages. Different letters indicate significant differences between means (Scheffé test).
To test if the change in species composition between spraying periods was related to the isolation of cacao plantations, we tested if Soerensen indices quantifying the similarity of species composition between spraying periods are correlated with the distance of the plantations to the forest. Spearman rank correlations confirmed that Soerensen indices were not related to the distance of cacao plantations from nearest forest (see Table 5.4).

<table>
<thead>
<tr>
<th>Distance</th>
<th>Spray-1 vs spray-2</th>
<th>Spray-1 vs spray-3</th>
<th>spray-2 vs spray-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>r = -445</td>
<td>r=0.158</td>
<td>r=0.04</td>
<td></td>
</tr>
<tr>
<td>p=0.147</td>
<td>p=0.623</td>
<td>p=0.902</td>
<td></td>
</tr>
<tr>
<td>n=12</td>
<td>n=12</td>
<td>n=12</td>
<td></td>
</tr>
</tbody>
</table>

r = Spearman rank correlation coefficient, p = level of significance, n = 12 plantations.

5.4 Discussion

5.4.1 Communities of parasitic Hymenoptera in Central Sulawesi

Only few studies so far quantified species richness and community structure of tropical communities of parasitic Hymenoptera (e.g. Horstmann et al. 1999, Frankl-Sperber et al. in press). In our samples from Central Sulawesi the superfamilies Chalcidoidea, Platygastroidea, and Ichneumonoidea represented the most abundant families of parasitic Hymenoptera. According to Frankl-Sperber (in press) also in cacao plantations in Bahia (Brazil) these taxa were very abundant. However, Noyes (1989), who used fogging for surveying canopy arthropods, found Ichneumonidae only poorly represented or even absent from samples from tropical forests in North Sulawesi. Compared with our study from Central Sulawesi, the lower species richness found by Noyes (1989) is certainly related to a smaller sample size. But compared to samples of Ichneumonidae from other regions such as Northern Borneo (Horstmann et al. 1999) also the samples are very poor in species. However, our surveys failed to reach a high completeness of the species inventory. Even after three times of sampling in different habitats the accumulative number of parasitic Hymenoptera species is
still showing a pronounced increase with increasing sampling effort. Additionally, it has to be mentioned that a large number of parasitic Hymenoptera in the tropics appears to be night-active only (e.g. Horstmann et al. 1999). These species were not covered by the sampling method because spraying was conducted between 7:00 and 10:00 only. Also parasitic Hymenoptera restricted to microhabitats such as the leaf litter and upper soil layer (e.g. Horstmann et al. 1999) were not recorded by the collecting method. Therefore, the samples only represent a fraction of the total fauna of parasitic Hymenoptera, which can be expected to occur in a cacao plantation.

According to Frankl-Sperber et al. (in press) the proper management of shade tree diversity plays a vital role in maintaining the sustainability of cacao agroforestry production systems in the tropics and, concurrently, will maintain high biodiversity values in these locations. This factor may also be partly responsible for the lower values of species richness found in cacao plantations in Central Sulawesi, which are characterized by a low species richness of shade trees (Schulze et al. 2004).

5.4.2 Parasitic Hymenoptera: forest vs. cacao plantations

Comprehensive studies covering a wide variety of taxonomic groups clearly documented that generally forest modification and transformation to land-use systems have a negative effect on diversity and species richness (Lawton et al. 1998, Schulze et al. in press), although changes in species richness of single taxonomic groups do not reflect such anthropogenic disturbance (e.g. Schulze & Fiedler 2003). For parasitoid communities, Marino & Landis (2000) mentioned the scarcity of adult food sources, appropriate microclimates or alternate hosts as important reasons for a reduced abundance, diversity and species richness in agricultural landscapes. The data for parasitic Hymenoptera showed an effect of anthropogenic disturbance on species richness. At forest sites a higher number of species was recorded than at cacao plantations. However, the difference did not prove to be significant. Higher species richness inside and at the edge of the forest compared to cacao plantations far away from forest is most likely related to a more diverse assemblage of hosts for parasitic Hymenoptera (Noyes 1989).
Beck et al. (2002) documented that a decrease of plant diversity has a high potential to predict changes of moth diversity along a gradient of habitat disturbance. Frankl-Sperber et al. (in press) recorded a relationship between species richness of shade trees and the number of parasitic Hymenoptera species. Therefore, the decrease of plant diversity in cacao plantations compared to forest sites at the margin of Lore Lindu National Park as documented by Schulze et al. (2004) for understorey plants and trees is certainly related to a significant decrease of herbivores acting as potential hosts for parasitic Hymenoptera. For this reason, a decrease in species richness can be expected also for the parasitic wasps.

Although in our study the change of species richness from forest to cacao plantations was not as pronounced as expected, a significant change could be recorded for the species composition of parasitic wasp assemblages. A very similar pattern was found for dung beetles by Shahabuddin et al. (in press.)

5.4.3 Temporal dynamic of parasitic Hymenoptera communities

Only very few studies on temporal dynamics of tropical insect communities were conducted so far (Hosang 2004, Fiedler & Schulze in press). Climatic fluctuations are one important factor modulating dynamics of insect populations. In South-east Asia particularly ENSO has a strong effect on abundance and species richness of insect communities (e.g. Cleary & Genner 2004). However, also variation of climatic parameters (such as temperature and rainfall) on an annual scale can play an important role, even in so-called non-seasonal areas such as the equatorial regions.

On a small temporal scale, we found significant differences of abundance and species richness of parasitic Hymenoptera between samples form June and August 2001 indicating that the re-colonization of the sprayed cacao trees was still in process after 2 months. Re-fogging experiments of rainforest trees in East Malaysia conducted by Horstmann et al. (1999) showed that the re-colonization of fogged trees remains incomplete even after 7-19 months demonstrating that the recovery time of at least a certain part of the arthropod fauna of rainforest trees is significantly longer than previously assumed by Stork & Hammond (1997).
No differences in abundance and species richness were found between samples after a re-sampling of the same trees 1.5 years later indicating that in cacao plantations the re Colonization of the treated tree crowns was finished. However, a significant difference with respect to the species composition indicated a pronounced temporal species turnover.

5.4.4 Effects of habitat isolation on parasitic wasps

Several studies on effects of habitat fragmentation and isolation on insect communities were conducted recently (e.g. Steffan-Dewenter & Tscharntke 1999; Brühl 2001; Sanchez & Parmenter 2002; Klein et al. 2003). However, particularly data on the effects of isolation on parasitic wasps can have important implications for landscape management, which should target the maintenance of species-rich parasitoid communities with a high potential to control outbreaks of pest insects.

The data indicate that remaining forest has a significant effect on parasitic Hymenoptera communities. Compared to cacao plantations not attached to the forest margin and far away from remaining forest, at forest sites and plantations inside the forest margin higher species numbers and a more pronounced temporal dynamic (with respect to the abundance of parasitic wasps) of parasitic Hymenoptera could be recorded. However, while these changes failed to reach a significant level, a significant difference was found with respect to the species composition. While plantations inside the forest margin did not prove to have a parasitic wasp fauna differing from forest sites, plantations in a distance of less than 100m from the forest margin proved to have species compositions intermediate between sites inside or close to the forest and far away (>250m) from the forest margin. That result indicates that the forest play an important role as source area for cacao plantations attached or close to the forest margin, which act as sink. It appears that already plantations in a distance of more than 250m from the forest margin cannot be successfully colonized by a larger number of forest species. However, to prove this, future studies have to analyze in detail the biology and landscape distribution of selected parasitic Hymenoptera species and its hosts.
5.5 Conclusions

The three key results of this study are: (1) The transformation of forest to agroforestry systems such as cacao plantations has a strong effect on the species composition of parasitic Hymenoptera. (2) For plantations of more than 250m away from the forest the later habitat is only of a minor importance as source area for re-colonization of cacao plantations by parasitic Hymenoptera. (3) After the treatment of cacao tree-crowns with insecticide first still after 2 months the species community did not recover and was characterized by a significantly lower species richness.

The data on parasitic Hymenoptera indicate that cacao plantations have a strong potential to act as buffer zone habitat at the margin of the Lore Lindu National Park. Surprisingly, although highest species numbers were recorded in the forest and plantations at the forest margin, even plantations in larger distances to the forest margin did not prove to differ significantly with respect to the number of recorded species but were characterized by a different assemblage of parasitic Hymenoptera species. Without a better knowledge on the insect host species used by parasitic wasps occurring in cacao plantations it is not possible to discuss the origin of parasitoids today colonizing such kind of anthropogenic habitats.

Due to the long recovery period of communities of parasitic Hymenoptera, the treatment of cacao trees with insecticides can significantly decrease the effectiveness of these important parasitoids to control herbivores in cacao agroforestry systems. Therefore, any kind of insecticide applications should be avoided or at least not conducted without a detailed monitoring of the impact on the diversity of parasitoids and their hosts.

Due to (1) the pronounced effect of land-use on species composition and (2) the long recovery period after treating tree-crowns with insecticide parasitic Hymenoptera proved to be a extremely useful bioindicator taxa for monitoring effects of anthropogenic disturbance on biodiversity.
REFERENCES


Shahabuddin, Schulze CH & Tscharntke T (in press): Changes of dung beetle communities from rainforests towards agroforestry systems and annual cultures in Sulawesi (Indonesia). *Biodiv Conserv*. 


CHAPTER VI. SYNTHESIS

6.1 The importance of cacao plantations for maintaining insect diversity.

In Central Sulawesi, Indonesia, cacao trees are planted in and around forest remnants. This also counts for the margin of Lore Lindu National Park in Central Sulawesi. The Lore Lindu National Park is well recognized as local biodiversity hotspot and nominated as Biosphere Reserve Site by UNESCO in recognition of its biological, physical and cultural interest (Whitten et al. 2002). Unfortunately, most biodiversity studies that attempted to measure the response of species to habitat disturbance only concentrated on different regimes of disturbance of the remaining natural ecosystem while only little attention has been paid on modified habitats such as agricultural land-use systems (especially cacao agroforestry systems). Since many species (especially insects) that are able to survive in forest remnants may interact with agroecosystem (Klein et al. 2002), consequently, a certain number of insect species usually typical for tropical forests can be expected to occur also in shaded cacao plantations (Schulze et al. 2004). The value of these habitats for conservation should not be neglected. This is particularly true since many studies revealed that cacao agroforestry systems that are managed under diversified systems are capable of maintaining a high proportion of the local biodiversity (particularly insect diversity: Rice & Greenberg 2000). In fact, cacao plantations in and around forest remnant of LLNP are situated in various distances to forest. An increasing distance to the forest margin can play an important role for insect diversity in agroforestry systems by decreasing the likelihood for forest species to reach such secondary habitats. A corridor linking cacao plantations to forest may contribute to the conservation of insect species. Corridors that connect isolated habitat will increase the abundance and diversity of species within the plantations through increases in rates of immigration (Hunter 2002).
6.2. Forest modification and transformation: ecological implications on species diversity and abundance of insects in cacao plantation

It has become a common issue that large areas of natural ecosystems (e.g. forest) are modified and converted, into agricultural land-use. This also counts for Central Sulawesi, especially for Lore-Lindu National Park. For many years, parts of natural forest in this National Park have been transformed into cacao plantations. Comprehensive studies covering a wide variety of taxonomic groups clearly documented that generally forest modification and transformation to land-use systems have a negative effect on diversity and species richness (Lawton et al. 1998, Schulze et al. 2004). The data for parasitic Hymenoptera and Coleoptera showed an effect of anthropogenic disturbance on species richness and abundance. At forest sites a higher number of species was recorded than at cacao plantations. Lower number of species of parasitic Hymenoptera in cacao plantations may be due to a smaller number of available hosts species (Noyes 1989). In contrast, a higher number of ants as recorded in cacao plantations than at forest sites. The significantly higher abundance of Hymenoptera (represent by ants) in cacao agroforestry systems has important ecological implications by most likely influencing the strength of interactions between trophic levels. Hosang (2004) did not find that number of ants in cacao plantations located far away from forest margin was different. This may be caused by a generally higher number of prey and a lower number of other predators in cacao plantations than in forest, since forest may support a higher diversity of prey and other predators but not abundance.

6.3. Parameter limiting the abundance of insect communities and species number of parasitic Hymenoptera in cacao plantations.

Several parameters may play an important role for limiting the abundance and species diversity of insect in cacao plantation. For maintaining continuously an abundance and species richness on a relative high level, a constant availability of food, host/prey, space, and appropriate habitat should be the important prerequisites. Basset (1991) reported that arthropod densities in tropical forest canopies maybe most strongly influenced by microclimatic conditions, which are
certainly very different more pronounced between forest and cacao plantation due to pronounced differences in vegetation structure. Srinivasa et al. (2004) documented that the community composition of the most abundant tree species strongly influences the composition of arthropods. This may therefore also should have a strong potential to explain differences of arthropod communities in agroforestry systems and forest, which are dominated by completely different trees and particularly show a very different tree species richness (Schulze et al. 2004).

For parasitoid communities, Marino & Landis (2000) mentioned the scarcity of adult food sources, appropriate microclimates or alternate hosts as important reasons for a reduced abundance, diversity and species richness in agricultural landscapes. The decrease of plant diversity in cacao plantations compared to forest sites at the margin of Lore Lindu National Park as documented by Schulze et al. (2004) for understorey plants and trees is certainly related to a significant decrease of herbivores acting as potential hosts for parasitic Hymenoptera. For this reason, a decrease in species richness can be expected also for the parasitic wasps.

6.4. Effects of habitat isolation on insect communities in cacao plantations

In Central Sulawesi, cacao trees are planted in and around forest remnants. Since the forest at the margin of the national park may act as source for many species, cacao plantations that are situated at its margin may act as a sink. Additionally, it can be expected that an increased isolation of individual plantations may negatively affect diversity and colonization by forest species. Our data on parasitic Hymenoptera showed an effect of increasing distances from nearest forest on species richness and abundance, but particularly on species composition. Although, statistical analyses did not prove a significant difference, highest species number of parasitic Hymenoptera were recorded at forest sites, lowest species numbers at plantations far away from the nearest forest. However effects of isolation of agroforestry systems from the forest on insects cannot be generalized. The response of species richness and abundance towards habitat isolations is differing between insect taxa. Hosang (2004) showed that habitat
isolation did not have a significant effect on the number of dominant ants in cacao agroforestry systems. In contrast, several other studies found a significant effects of habitat isolation on several groups of insect (Klein et al. 2002, 2003; Steffan-Dewenter 1999).

6.5. Temporal dynamic of insect communities: implication on sampling design

Not all orders show a prominent temporal variation of abundance. The data for insect communities indicated that abundance data for single taxonomic groups cannot be used to predict the abundance of others. However, a strong temporal effect was found with respect to species composition of parasitic Hymenoptera. Those information has important implications for sampling design. Insect samples collected at different times could be strongly biased due to the prominent temporal species turnover recorded by this study.

6.6. Cacao plantation management: Its implication on species diversity

Since the decrease of species richness of parasitic Hymenoptera could be extremely affected by plant species diversity, recommendation on increasing plant species richness in cacao plantations should be considered. According to Frankl-Sperber et al. (in press) the proper management of shade tree diversity plays a vital role in maintaining the sustainability of cacao agroforestry production systems in the tropics and, concurrently, will maintain high biodiversity values in these locations. This factor may also be partly responsible for the lower values of species richness found in cacao plantations in Central Sulawesi, which are characterized by a low species richness of shade trees (Schulze et al. 2004). This study showed that cacao plantations far away from nearest forest did not support the maintainance of species diversity of parasitic Hymenoptera. However since agricultural landscape has a potential for insect conservation, I recommend to create corridors between cacao plantations and forest margin. This corridor could maintain a higher the rate of migration of species between cacao plantations and forest.
REFERENCE


CHAPTER VII. GENERAL CONCLUSION

Studies on insects of tropical forest canopies using knockdown insecticide techniques resulted in a significant increase of our understanding of the ecology and biodiversity of this community. Insects play a crucial role in the interaction of plants with their environment and form an important link in most terrestrial food webs. Therefore, studies on insect diversity from tree canopies also are an important step in our understanding of agroforestry systems such as cacao plantations.

Overall, Hymenoptera, Coleoptera, Orthoptera, and Homoptera appeared to be the most dominant orders that could be found in the canopy layer of cacao plantations in Central Sulawesi. The case study on parasitic Hymenoptera collected in cacao plantations showed that even with an extremely high sampling effort, we could not reach a complete species inventory. Artificial disturbance, for example pesticide application is capable of affecting the structure and abundance of entire insect communities as well as parasitic Hymenoptera in a sustainable way over a period of most likely several months.

Different variables (abundance/species richness) used to measure the effect of isolation on insect communities yielded different result and pattern. The abundance structure of insect communities on the level of orders did not prove to be significantly affected by the distance of cacao plantation from nearest forest, while spraying samples from the forest itself showed a significant difference with respect to two dominant groups, Hymenoptera and Coleoptera. Meanwhile, our data on parasitic Hymenoptera indicate that cacao plantations are situated far away from nearest forest did not support high species diversity of parasitic Hymenoptera. Forest was predicted to contribute the species richness recorded in cacao plantations.

Based on the result of this research, I recommended to consider temporal variation in designing insect biodiversity research. With respect to insect conservation in cacao agroforestry system, I suggested to create corridors connecting cacao plantations and forest to increase the rates of immigration. Plant diversity should be increased to maintain species diversity of parasitic
Hymenoptera that have a potential to control herbivorous insect in cacao agroforestry systems.
Appendix 1 Sample of Hymenoptera aculeata.

Bethylidae

Appendix 2 Samples of Hymenoptera parasitica.

Braconidae

Eucoilidae

Eulophidae