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**Assessment of insect biological diversity of various land use systems in the
Peruvian Amazon**

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Statutory declaration

I hereby certify that I have completed my thesis independently, only with the expert guidance of my thesis tutor doc. Ing. Bohdan Lojka Ph.D. and professional entomologist consultants.

I further declare that all data and information I have used in my thesis are stated in the references according to the citation rules of the Faculty of Tropical AgriSciences, CULS Prague, for writing theses in English, published in 2017.

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Abstract

During recent decades, all tropical regions have been under high demographic pressure. Increasing food and land demands results in forest conversion and high biodiversity losses due to the destruction of natural habitats of millions of animal species. This effect is more evident in the surroundings of fast-growing cities, for example in the Ucayali region of the Peruvian amazon. However agroforestry is perceived to be able to conserve biodiversity. The main objective of this study was to assess and compare insect species richness and diversity of five different ecosystems/land-use systems (primary forest, multistrata agroforestry, cocoa agroforestry, monoculture cropping, and degraded lands infested by weeds) and to determine the relationship between land-use intensity and the rate of biodiversity loss. The study was carried out in four villages in the surroundings of Pucallpa city. In all assessed ecosystems, insects were captured by Malaise and pitfall traps and sweeping nets, followed by determination of morphospecies. The data were evaluated using standardized indexes for bio-monitoring e.g. Shannon diversity index, Jackknife's species richness estimator, Sørensen's index of similarity, ANOVA, etc. In total, we captured 4,949 individuals of 756 morphospecies. The most abundant and species rich sites were located in primary forest followed by multistrata agroforestry systems. Agricultural fields with monocultures and weedy grasslands were found to have the lowest values of insect biodiversity. Species diversity was highest in the forest of Macuya, decreasing along an ecological gradient to multistrata agroforestry, with lower values in cocoa agroforestry, monoculture cropping, and weedy grasslands. The presented research also highlights qualitative data about lifestyle strategies of captured Hymenoptera: Aculeata insects, which have a wide diversity of social life strategies and which, according to the statistics, are not influenced by the type of ecosystem. The Amazon basin is not only diverse in insect species, but also in human native ethnicities, such as the Asheninka and Shipibo tribes. Therefore, we also compared ethno-entomological knowledge of small-scale farmers in the assessed area to people who live in a close relationship with the natural habitat – native indigenous tribes. Interestingly, people of the Asheninka tribe have the most conservative entomological knowledge, in comparison to people of the Shipibo tribe or of mestizo origin.

Key words: agroforestry, biodiversity reservoir, Neotropical insects, Peruvian rainforest

Abstrakt

V posledních desetiletích byly všechny tropické regiony vystaveny vysokému demografickému tlaku. Zvyšování požadavků na potraviny a půdu mělo za následek přeměnu lesů a vysoké ztráty biologické rozmanitosti způsobené ničením přírodních stanovišť milionů druhů zvířat. Tento efekt je patrnější v okolí rychle rostoucích měst, například v oblasti Ucayali v peruánské amazonii. Oproti klasickému hospodaření je agrolesnictví vnímáno jako schopné částečně biodiverzitu uchovat. Hlavním cílem této studie bylo posoudit a porovnat bohatost a diverzitu hmyzu pěti různých ekosystémů/systémů využívání půdy (primární les, multistrata agrolesnictví, agrolesnictví zaměřené na produkci kakaa, monokulturu a degradované zaplevelené půdy) a stanovit vztah mezi intenzitou využívání půdy a mírou ztráty biologické diverzity. Studie probíhala ve čtyřech obcích v okolí města Pucallpa.

Sběr hmyzu probíhal využitím Malaiseho pastí, zemních pastí, smýkací sítě, a následně určen do morfodruhů. Data byla vyhodnocena pomocí standardizovaných indexů pro bio-monitoring, např. Shannonův index diverzity, Jackknife index, Sørensenův index podobnosti, ANOVA apod. Celkem bylo určeno 4949 jedinců v 756 morfospecies. Nejvíce početné a druhově bohaté lokality byly nalezeny v primárním lese následované agrolesnickými systémy typu multistrata. Bylo zjištěno, že zemědělské plochy s monokulturami a zaplevelenými půdami mají nejnižší hodnoty biodiverzity. Hodnoty biodiverzity se snižovaly podél ekologického gradientu od lesního porostu, přes multistrata agrolesnictví, nižší hodnoty pak vykazovalo agrolesnictví s produkcí kakaa, monokultury a na samém závěru degradované půdy.

Tato studie také pracuje s kvalitativními údaji o životní strategii skupiny žahadlových blanokřídlých (Hymenoptera: Aculeata), která má široké spektrum sociálního chování. Na základě našich výsledků, není toto chování a strategie ovlivněno typem ekosystému.

Amazonská nížina je domovem mnoha etnických skupin jako například kmeny Asheninka a Shipibo. Zajímali jsme se o to, jaké znalosti o hmyzu mají farmáři ze zkoumaných lokalit ve srovnání s lidmi etnického původu, kteří žijí v těsném souladu s přírodou. Lidé kmene Asheninka zachovávají mnohem více znalostí o hmyzu než kmen Shipibo a farmáři.

Klíčová slova: agrolesnictví, rezervoár biodiverzity, neotropický hmyz, peruánský deštný prales

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Abbreviations and Acronyms

a.s.l.	above sea level, elevation
abb.	abbreviation
abund.	abundance
AFS	agroforestry system - multistrata type
CF	cacao agroforestry
CIDRA	Centro de Investigación y Desarrollo Rural
CIFA	Centro de investigación de fronteras amazonicas
e.g.	for example
FAO	The Food and Agriculture Organization
H	Hypothesis
H'	Shannon index of diversity
ICRAF	The World Agroforestry Centre
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales
ind.	individual/s
INRENA	Instituto Nacional de Recursos Naturales
IPCC	The Intergovernmental Panel on Climate Change
IUCN	The International Union for Conservation of Nature
m.sp.	morphospecies
MC	monoculture - annual crops
N	number of individuals
\bar{O}	average
PF	primary forest
S	Jackknife estimate of species richness
S'	Fisher's alpha diversity index
s	number of species
SENAMHI	Servicio Nacional de Meteorología e Hidrología
stand. dev.	standard deviation (statistics)
UNIA	Universidad Nacional Intercultural de la Amazonia
UNU	Universidad Nacional de Ucayali
W	weedy grasslands

1. Introduction

Over the last decade, we have used the word “biodiversity” more and more in the contexts of our lives, environmental protection, and sustainable management of natural resources. Biodiversity plays a central role in our lives: we depend upon plants and animal species for food, medicines and raw materials; the genetic resources contained within biodiversity hold the basis of our continued existence; and services provided by biodiversity and ecosystems help sustain our livelihoods and protect our health. Furthermore, there is no doubt that the beauty and variety of living species greatly improves the quality of our lives (Tucker et al. 2005). Worldwide efforts emphasize the need to conserve endangered ecosystems and biodiversity for subsequent generations. We should focus on places with the highest biodiversity losses to prevent their total destruction.

The rainforest of the Amazon basin is classified as a “biodiversity hot-spot” and it is a habitat for millions of plant and animal species. According to FAO (2016), the American forest covers 842 million ha (8,420,000 km²); however, large areas are deforested, degraded and changed to other types of land-use systems annually. South American rainforests suffered a deforestation level of about 4.0 million hectares per year in the period between 2000 and 2010 (FAO 2010). The highest peak of deforestation was in 2005, with more recent years experiencing a decreasing rate (FAO 2010; Mountinho 2009; Butler 2015). According to FAO (2016) the deforestation trend in South American tropical forests decreases in 2010-2015. The conversion of primary forests to other land uses (usually by slash-and-burn farming) threatens biodiversity and releases gases into the atmosphere that are associated with current changes in climate. On the other hand, forest conversion to other land-use systems based on tree growing, such as agroforestry, can foster economic development of tropical countries and provides a viable livelihood for many smallholder farmers. Exports of high value timber are an important source of foreign exchange, but logging roads provide access for human settlers to claim new lands and begin agricultural activities. Agricultural expansion, primarily by smallholders, is estimated to be the cause of at least 50% of the deforestation in Peruvian tropical forests (White et al. 2005).

The application of alternative farming systems could improve this situation. One potentially suitable and ecological system is agroforestry, which could be productive while conserving natural resources to a high degree. It is predicted that agroforestry systems can

be sustainable and work as a species reservoir (Van Schaik & Van Noordwijk 2002). They can also help with soil and forest restoration and to control troublesome weeds, as well as being very important for biodiversity conservation.

Nowadays, biodiversity monitoring plays one of the most important roles in environmental investigation. It assumes that there are new ecological consequences in original ecosystems as well as in ecosystems disturbed by human activities. Complete data offers a good basis for environmental evaluation and aids in ecosystem and biodiversity conservation.

This research was focused on evaluating the impact of agroforestry systems on insect biodiversity. The work for this thesis was completed near Pucallpa city (Ucayali region) in the Peruvian Amazon in cooperation with The National University of Ucayali under the framework of the development project, “Sustainable management of natural resources in Peruvian Amazonia” carried out by the Faculty of Tropical AgriSciences of The Czech University of Life Sciences and financed by the official Czech Development Cooperation Program. The main objective of this research was to analyze insect biodiversity across various land-use systems and to determine the extent to which implementation of agroforestry practices could help biodiversity conservation in the Amazon.

2. Study background

2.1. Biodiversity

2.1.1. Definition and concept

The term "Biodiversity" was introduced to our vocabulary in the mid-1980s by Warren G. Rosen and the term has since grown steadily in popularity (Footitt & Adler 2009; Wilson 1988). There are various definitions of biodiversity. Some of them are simple, while others are very complex; but according to Wilson (1996), biologists are inclined to agree that it is, in one sense, everything. Biodiversity is defined as all hereditary based variation at all levels of organization: from the genes within a single local population or species, to the various species composing all or part of a local community, and finally to the communities themselves that compose the living parts of the multifarious ecosystems of the world. There are also opinions to define it as "species richness" (Fiedler & Jain 1992), but this is only one of the components of biodiversity – it is more than species diversity (Pielou 1977). Faith (2007) defines biodiversity as the variety of all forms of life, from genes to species, through to the broad scale of ecosystems. The most complex and clear definition is offered by DeLong (1996): "Biodiversity is an attribute of an area and specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of genetic diversity and the identity and number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount (e.g., abundance, biomass, cover, and rate) and structure of each. It can be observed and measured at any spatial scale ranging from microsites and habitat patches to the entire biosphere." The Convention on Biological Diversity (CBD 2018) defines biodiversity as the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

As stated above, there are many definitions of biodiversity, but we can generally distinguish three main categories. One category is genetic diversity, which refers to the diversity of genes within a single species and also between species. Another is species or taxonomic diversity, based of course on the different species/taxa contained within an

ecosystem. A third form of diversity is functional diversity, which refers to the various roles that different organisms play within an ecosystem, including the different roles of separate life stages of individual species (Silvert 2003). The definition according to IPCC (2002) highlights the importance of including all of the types of diversity and describes three main levels of biodiversity. (i) Genetic diversity, which is the rich diversity of genes within a species. Populations of the same species or genetically different individuals of one population belong to this group. Losses of species diversity are (in small populations) often caused by losses of genetic diversity. (ii) Species diversity means species richness and numerousness in a selected area. (iii) Ecosystem diversity is a complex evaluation of diversity according to societies and ecosystem parameters.

From another point of view, according to Whittaker et al. (2001), the total species diversity in a landscape (gamma diversity) is determined by two different things, the mean species diversity in sites or habitats at a more local scale (alpha diversity) and the differentiation among those habitats (beta diversity).

Monitoring of the biological diversity of an assessed area gives complete information about the living ecosystem and is very important for ecological, zoological and botanical research. It is the most important step in ecosystem description, management planning, and conservation.

Biodiversity patterns vary between regions. As has been already said, tropical rainforests possess the highest biodiversity; according to Myers (1992), tropical ecosystems contain more than half of all terrestrial species and some estimates are even as high as 90% (Young 2003). According to Schroth & Da Fonecsa (2004), there are suitable environmental conditions in the tropics around the world. These conditions allow for the occurrence of a large amount of plant and animal species. High diversity is generally attributed to: high ecosystem productivity, low environmental variance, consistent predation and competition, and differential speciation and extinction rates. That is why the tropical rainforests are classified as biodiversity hot-spots and reservoirs (Mountinho 2009). They also make crucial contributions to human well-being (Rashid 2003): they act as a fresh water reservoir, produce oxygen, and conserve many plant species that have medicinal uses, etc. Although these attributes tend to support high diversity in the tropics, it is important to note that there are significant intra-tropical variations in diversity and that lower-diversity regions do exist (Schroth & Da Fonecsa 2004). These regions are very often situated around cities, where the biodiversity decreases due to extensive land use changes. Therefore, biodiversity monitoring plays a very important role and is the first step towards biodiversity conservation.

2.1.2. Importance of biodiversity monitoring

According to Footit and Adler (2009) we cannot know all that we are losing if we do not know all that we have. That is why the monitoring of diversity is so important. Lindenmayer et al. (2011) states that effective biodiversity monitoring is critical to evaluate, learn from, and ultimately improve conservation practice. On the other hand, the same author offers a very interesting point-of-view defining barriers to biodiversity monitoring: many conservation programs have poorly articulated or poorly planned objectives which creates difficulties in measuring progress, contributing to design and implementation problems; longterm biodiversity monitoring is often poorly developed; appropriate institutional support is frequently lacking, including coordination and targeted funding for biodiversity monitoring; and appropriate standards to guide monitoring activities and make data available from these programs are missing. These barriers are more visible in developing countries where local students and researchers do not have many possibilities to publish their research and/or it is too expensive for them. This does not change the fact that more and more people and their research are focused on biodiversity measuring, understanding, and protection.

Understanding biological diversity in terms of the processes by which ecosystems and their components function – be it at community, species, population, or genetic levels – is critical to informing the sustainable use of land areas and the safeguarding of ecosystems for the benefit of future generations. Given that biological diversity is dynamic, continually evolving and changing in response to biotic and abiotic fluctuations and other environmental pressures, it is necessary to record in time and space its status quo (Camphausen 2004) and, subsequently, monitor that status quo in order to identify changes and assess their impacts. Such impacts may require intervention or mitigation measures to safeguard future conservation, including sustainable use, of biological diversity. Crucially important is the need to identify species present in areas of natural habitat ahead of any changes in land use in order to assess what diversity may be lost from a locality. This is particularly pertinent to tropical ecosystems, where levels of endemism tend to be higher than in more temperate regions and, consequently, the risks of species becoming globally extinct may be greater (Green et al. 2009).

Research on biodiversity is essential for helping the Amazonia implement the Convention on Biological Diversity (Noss et al. 1994) and to reach the specific target of halting loss of biodiversity in this unique ecosystem. Conservation of biodiversity has

become an important issue receiving national and international attention (Noss et al. 1994). The first step of biodiversity surveys is an estimation of diversity at one point in time and in one location. The second phase is monitoring biodiversity, or estimating diversity at the same location over multiple times, to draw inferences about changes (Wilson et al. 1996). Another level of biodiversity monitoring and evaluation is to compare various localities or ecosystems in the same time period. Biodiversity can be monitored on each level of ecological organization. All programs of biodiversity conservation are based on diversity studies. Recognizing and naming species allows information transference; however, high proportions of undescribed or unrecognizable species necessitate the use of terms such as ‘morpho-species’ in many ecological interpretations of diversity (New 2009).

In general, three main categories of measures are used to assess species diversity: (i) species richness indices, which measure the number of species in a sampling unit; (ii) species abundance indices, which have been developed to describe the distribution of species abundances; and (iii) species diversity indices that are based on the proportional abundances of species such as the Shannon and Simpson indices (Magurran 1988; Gaines et al. 1999).

Natural habitats together with sites that have already been modified by human activities are very important for assessments of biodiversity and can recommend the best possible alternatives for biodiversity conservation. Biodiversity monitoring in tropical land-use systems – including various land use systems such as agricultural, forestry, or agroforestry – is very important for the investigation of biodiversity reservoirs, biocorridors, and biodiversity conservation (species, habitats) in general.

2.1.3. Biodiversity in the Peruvian Amazon

The forests of Peru, situated in the western part of Amazonia, are the most species rich in the world (Alonso et al. 2001). The literature (Haffer 1969; Haffer 2008) explains this reality as the consequence of historical events since the Pleistocene when climatic conditions in the Amazon Basin changed: dry and humid periods cycled repeatedly.

According to Haffer (2008), dryer climatic conditions in the Pleistocene led to the division of the Amazonian forest into various small forest islands among wide-open land of non-forested vegetation, such as savanna. The remaining forests worked as “refuge areas” for many forest species/populations. These populations began to deviate from each other due to

geographic isolation. Afterwards, during humid climatic periods, open land returned to forest, permitting the refuge area populations to extend their ranges. The same author mentioned that this scenario was probably repeated several times during the Quaternary period, causing the rapid differentiation of Amazonian forest fauna. This theory is based on the assumption that forest species originated from small populations that were isolated from their parent population and deviated by selection and chance. Most of this differentiation probably took place in refuge areas. We suppose that the tertiary ancestors of present Amazonian species may have speciated repeatedly during the Quaternary period, and that many connecting links may have disappeared due to extinction. A similar assumption may also apply to insects (Emsley 1965).

These forest refuges served as incubators of endemism. However, there are many factors (geographic, evolutionary, geologic, and climatic) that produced this diversity. Fine-scale habitat heterogeneity and intermediate levels of natural disturbance created many niches, which in turn led to higher diversity of organisms (Connell 1978; Fox 1979; August 1983; Brown 1987; Rossetti & Toledo 2006).

Recently, Peru was classified as one of the top seven mega-diversity countries of the world. It is estimated that there are more than 30,000 species of plants, of which 510 have been described as medicinal (Bushmann & Sharon 2009). Within class Insecta, we can find a large diversity of species, forms, behaviour, and ecological relationships. According to Fisher (1988), the Creator must have had an inordinate fondness for beetles. As many in the scientific community suppose, in the rainforest there are a lot of diverse species that we do not yet know and which will be extinct before we have the opportunity to describe them. As Godfray et al. (1999) states, understanding insect diversity in the humid tropics is one of the major challenges in modern ecology. Recent calculations that there may be more than 30 million species of insects on earth have focused attention on the magnitude of this problem and stimulated several new lines of research (although the true figure is now widely thought to be between five and 10 million species).

All living organisms in tropical forests form unique ecosystems with specific environmental conditions; however, the environment is rapidly deteriorating everywhere, including areas once thought to be remote, such as the Peruvian Amazonia. This ecological crisis is a global process that is generating much concern and discussion on environmental problems at a worldwide scale, especially on the destruction of habitats and the resulting unavoidable loss of species (Ugarte & Pacheco 2001).

2.1.4. Main reasons for biodiversity losses in the Peruvian Amazon

Biodiversity losses are generally caused by direct human activities and their ecological consequences, like habitat destruction. Empirical studies suggest that habitat loss has large and consistently negative effects on biodiversity (Fahrig 2003). Over the past few hundred years, humans have increased species extinction rates. There are approximately 100 well-documented extinctions of birds, mammals, and amphibians. Some 12% of bird species and 23% of mammals are currently threatened with extinction. In addition, 32% of amphibians are threatened with extinction (Millenium Ecosystem Assessment 2005). Currently, up to 300 species are endangered of extinction in Peru (Dallmeier & MacIver 2008). Biodiversity should be conserved on all levels, but mainly on an environmental level to protect natural habitats. The environment and its species are threatened by deforestation from logging, oil drilling, mining, gas extraction, expansion of farming land, extraction of other natural resources, and agriculture. Chemical spraying in order to eradicate coca plants is another source of deforestation that affects the local flora and fauna.

The human population of the Peruvian Amazon is increasing and this growth places incredible stress on ecosystems (Cincotta et al. 2000; Worldometers 2018), which causes huge modification of the environment. Destruction of natural habitats is the primary reason for the existing worldwide trend of decreasing biodiversity (Ehrlich 1988). The degree to which habitat loss translates into biodiversity loss (loss of species due to extinctions) often depends largely upon two factors: (1) the relative amount of habitat converted over time and (2) the nature of species distributions among patches of the habitat. For example, species which are widespread, common, and occur in a large fraction of habitat patches are less likely to be threatened with extinction due to habitat loss than are species which are endemic, rare, and occur in only a small fraction of patches (King 1998).

During the last three decades, the ecosystem of the Peruvian Amazon has been widely modified. Effects produced by logging to supply the demand for exotic woods with high commercial value constitute part of the environmental problem. Extractive process cause irreversible losses of natural habitats and genetic recourses, with secondary effects of fragmentation, losses of animals, and interruption of the food chain (IDEAM-FAO 2002).

Peruvian Amazonia has been systematically under high pressure for wood logging and agriculture development in recent decades. In the period before 1974, about 3,000 ha yr⁻¹ of forest was cleared. Deforestation rates shot up between 1974 and 1989, with rates near 20,000 ha yr⁻¹. Rates of deforestation due to logging were reduced by half in the 1990s, but

have continued to be substantial over the last several years (Hyman et al. 2002; Swallow et al. 2007; Oliveira et al. 2007).

A major proportion of deforestation in the country is now due to extensive agriculture, in which small-scale farmers slash and burn hundreds of hectares per year. Nonetheless, forests are the most visibly affected (Figure 1). Elgegren (2005) estimates the rate to be 149,631 ha per year for the period 1990-2000. According to Oliveira et al. (2007) there was an average deforestation rate in Peru of about 64,500 ha annually in the period from 1999 until 2005.

According to Latin American Post (2018), the largest deforestation in Peru was between 2001 and 2015 when the jungle lost around 2 million hectares in less than 15 years. The same source also indicates that the major deforestation activity was mostly in 2009 and 2014. According to MAAP (2018), in 2017 Peru decreased deforestation by 13% from the previous year.

Only a few logging companies are exporting legally. Goi (2017) in his article writes that despite efforts to combat the crime of illegal wood logging, an estimated 1,550 km² of forest are logged illegally in Peru every year. The Associated Press (2017) reported that 80% of timber exports from Peru are illegal. As we observed in the forest and small settlements in immediate proximity to the forest, the deforestation is not only caused by large wood-logging companies and illegal groups, but also by individuals or small groups of people who selectively cut down only large trees and rare woods and extract them from the forest. They then sell it to local dealers who falsify documentation and sell it on the market. For those people, this can be the only way to create regular income. It is very difficult to quantify how many trees are cut down annually by all these people; however, it is estimated that one such illegal logger can cut and sell up to 30 m³ of wood every month. Selling animal skins, teeth and jaws from hunting is additional small income for them; yet, it is a big loss for nature. Peru has improved its laws against illegal wood logging and the illegal market, but it needs more transparency to combat the omnipresent corruption.

In accordance to the Monitoring Project of the Andean Amazon (MAAP 2018), the causes of deforestation were logging, agriculture, livestock, illegal mining, infrastructure works, and illicit crops.

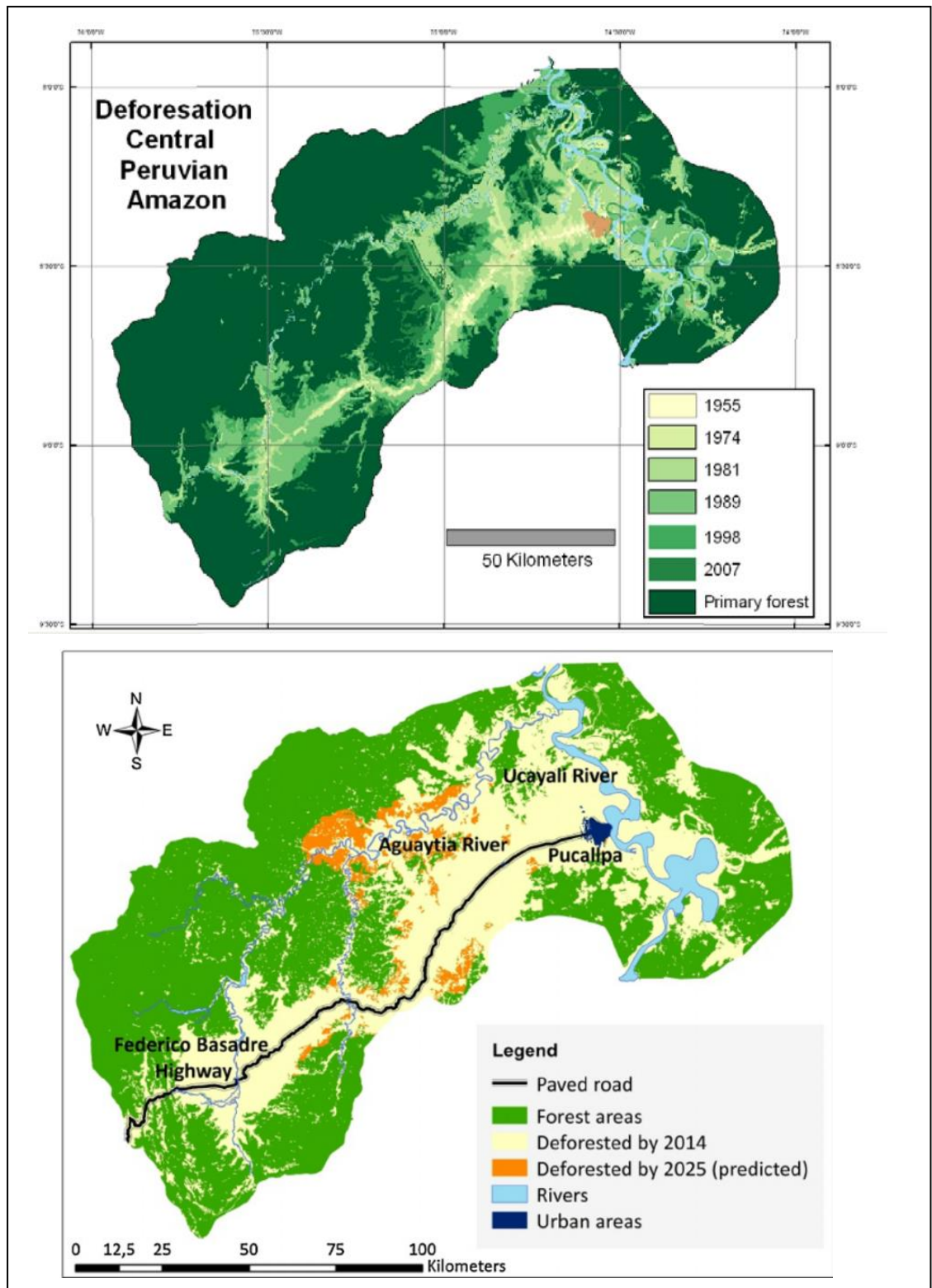


Figure 1. Deforestation in the Central Peruvian Amazon since 1955 with prediction until 2025 (Hyman & Fujisaka 2008; Bax et al. 2016).

Extraction of natural resources is the major economic driver in the Peruvian Amazon: timber, petroleum, and natural gas are the most important parts of the Peruvian

economy. Besides deforestation, petroleum and gas extraction are secondarily polluting the environment with lead and cadmium (Martínez et al. 2007). In the central Peruvian Amazon, the main production is based on cocoa (*Theobroma cacao* L.) plantation and oil palm *Elaeis guineensis* Jacq. Colombia and Peru have the highest percentage of growth in this sector in recent years, and these crops have become a dominant strategy for development in the Peruvian Amazon. Between 2000 and 2015, 40,000 hectares of old growth forest have been cleared for large oil palm plantations in Peru (Bennett et al. 2018) and much biodiversity has been lost establishing new cocoa and oil palm plantations. De Sy et al. (2015) published an interesting investigation about land use following deforestation in Central and South American countries from 1990 to 2005. Based on their results, the deforestation in Peru is mainly followed by smallholder crop agriculture and pastures. All agricultural activities, including slash-and-burn farming, are one of the main influences on habitat fragmentation. Socolar et al. (2017) has investigated small-scale farming in northern Peruvian Amazonia that results in high biodiversity losses of trees and birds. According to this author, small-scale farming must be regarded as a serious threat to the region's biodiversity. This pattern is visible in all densely fragmented environments. According to New (2009), forest fragmentation is one of the most important factors in biodiversity loss. The term "habitat fragmentation" is often used inconsistently and as a broad umbrella for many patterns and processes that accompany landscape change (Lindenmayer 2006). It is defined as a landscape-scale process involving both habitat loss and the breaking apart of habitat. It means modification of an environment when a large region of habitat has been broken down, or fragmented, into a collection of smaller patches of habitat. Fragmentation typically occurs when land is converted from one type of habitat to another. For example, a forest habitat may become fragmented when a road is built across the forest; the road splits a single, large, continuous patch of forest into two smaller patches, edge habitats. This process can benefit some species, but negatively affects many others. Edge effects are major drivers of change in many fragmented landscapes, but are often highly variable in space and time (Lawrance et al. 2007). Habitat fragmentation divides a population into two or more small parts. In time, in more sensitive species, this causes losses of genetic diversity and can result in the extinction of this species in a certain area or fragment. When the fragments of forest are big enough, some species can be conserved for a limited time, the fragments acting like islands among degraded land. Another way to conserve some species is to use alternative agricultural practices that are friendlier to the natural ecosystem such as agroforestry.

2.2. Agriculture in the Peruvian Amazon

2.2.1. Historical Amazonian agriculture

Human impacts on the Neotropical environment can be dated to the Anthropocene epoch, approximately 10,000 years ago, when megafauna was extinct. As published (Bush et al. 2015, Isandahl 2011), changes in fire frequency have been detected to originate approximately 8,000 years ago. Evidence of the first agriculture, planting of squash 9,000 years ago, was found in the northwestern Amazonian regions. Cultivation of maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz) in the Amazon Basin has been dated to 6,500 years ago. According to Bush et al. (2015), some archaeologists argue that between 2,000 and 500 years ago the Amazon Basin became a manufactured landscape. According to the Inga foundation (2018), seeds of the Inga tree (*Inga edulis* Mart.) were found in Peru thousands of years ago and probably formed an important part of the local economy. Major river corridors were probably influenced by human populations; however, land use in the wide areas between rivers remains a matter of debate (Bush et al. 2015; Urrego et al. 2013; Bush 2004).

Intermittently distributed in this tropical region are very nice living examples of ancient Amazonian agriculture, *terra preta* – anthropogenic dark soils. According to Glaser & Birk (2012) this is a highly fertile soil, containing up to 70 times more black carbon than surrounding soils. They are also known as Anthropogenic Dark Earths or *terra preta de Índio*, and, with high nutrient and soil organic matter formed by addition of charcoal, are perfect for agriculture. Nowadays, there is a great interest in these soils (Glaser & Birk 2012; Glaser et al. 2001) because they could serve as a model for promoting sustainable agricultural practices in the humid tropics. The majority of records of these soils are from Brazil (McMichael et al. 2014; Doughty et al. 2014; Mendes Barros et al. 2016); however, they also occur in the Columbian Amazon, Venezuela, and Peru (Sombroek et al. 2003), albeit rather rarely.

During work for this thesis, we did not observe any terra preta soils in the chosen localities; however, we did observe various land use systems on red Amazonian soils, such as intensive and extensive crop production, agroforestry, pastoral systems, and home gardens.

2.2.2. Agricultural practices in Peruvian Amazonia

The Peruvian Amazon holds a great diversity and store of natural resources; its forests and river system support the livelihoods of many people and animals and, therefore, drives much of the economy of tropical regions. In regards to location, soil quality, landscape shape, accessibility, and water sources various agricultural systems are used for intensive, extensive or self-subsistence production. According to Kobayashi (2004), there were around 260,000 ha of cultivated land and around 43,000 ha of pastures in the Peruvian Amazon. Those numbers rise every year due to an increase in traditional crop production in order to meet growing feed and food requirements and a growing expansion of new crops, mainly soya (*Glycine max* L.), oil palm, and sugarcane (*Saccharum officinarum* L.) (Pacheco 2012). The growing expansion of biofuel production for feedstocks has also stimulated the growth of the above-mentioned three crops (Pacheco 2012; ECLAC 2008).

The oil palm problem

The Peruvian Amazon, as well as other tropical forestlands, has a problem with deforestation for oil palm plantations. The cultural value of the lost forest and its biodiversity is much higher than the income from oil palm plantations. In recent years, oil palm plantations have been established on grasslands, but only on a few hectares. According to Pacheco (2012), oil palm productivity in the Peruvian Amazon is around 19 tons/ha, with 14,000 ha harvested in 2010. The main factors affecting yields are poor plantation management in the region and inadequate adaptation of varieties to specific agro-ecological conditions. Yields are growing through the use of agro-chemicals, which are now more accessible for local palm producers. Oil palm monocultures also change insect biodiversity due to a higher number of pests.

Monocultures

There are many monoculture fields mainly cultivated with cash crops such as sugarcane, maize, soya, cassava, and papaya (*Carica papaya* L.). Cocoa production also sometimes has a pattern of monoculture, but still mainly cultivated in polycultures with combination of shade and fruit trees. For all monocultures on nutrient-poor tropical soils, there is a serious problem with yield, which decreases very fast during the first 3-5 years of land use (Kleinman et al. 1995). After that, the land is converted into grassland or pasture. Rarely, farmers apply fertilizers (mainly in associated farmers/companies); however, in the assessed region, problems of old or lacking mechanization and the high cost of fertilizer (in

the required amounts) still remain. Farmers usually abandon depleted land, looking for another part of the forest to burn and crop.

Shifting cultivation (slash-and-burn farming)

In the past, the original peasants of the Amazonian region were using a similar type of cropping (slash-and-burn); however, they did so in a way that was friendlier to the environment. The land was used mainly by small-scale farmers who practiced shifting cultivation or slash-and-burn farming; it remains a dominant agricultural system in tropical forests (Socolar et al. 20017; Takasaki 2011). According to Nair (1993), shifting cultivation was originally a concept of short-term cropping with a subsequent long fallow period, which permits soil restoration, forest regrowth, and management over time (Takasaki 2011; Fujisaka & White 1998). In this system, the time of cultivation is usually much shorter than the period of regeneration (lying fallow). The farmer abandons the land to repeat the slash-and-burn process on another plot, and so forth. After years, the farmer returns to the original place, where the cycle closes.

An increasing population and higher food demands has caused a shortening of the fallow period and consequently a lower rate of soil and vegetation restoration. Changes in the soil from clearing and burning results in a sharp increase in available nutrients; therefore, the first crop plantation benefits considerably. Afterwards, the soil becomes less and less productive and crop yields decline (Lojka 2011); the fields are overrun by weeds and this together motivates the farmer to slash and burn another part of the rainforest or cut down young secondary forest growing on a previous crop plot. There are also some rare exceptions: some farmers employ land clearing without any burning and some cultivators are purely migratory and do not use any cyclical method on a given plot. In any case, it is a cycle of irreversible land cover modification. The greater the food demand, the more highly visible is the devastation of the original natural ecosystems. After 2-3 years of plantation, the non-rentable field is converted to pasture or abandoned land. Takasaki (2011) and Meyers (1992) also state that shifting cultivation is highly associated with changes in the above ground vegetation of the tropics and causes multiple environmental problems like soil degradation and biodiversity losses (Socolar et al. 2017). The shifting cultivation method also conflicts with various conservation efforts, such as maintaining protected areas and reforestation.

In Peruvian Amazonia, we frequently observe slash-and-burn fields of annual staple crops such as rice (*Oryza sativa*), cassava (*Manihot esculenta*), plantain (*Musa* sp.), and maize (*Zea mays* L.), which are frequently planted for the farmer's subsistence and sale at

local markets. Also, various local fruits and citrus are found very frequently in this zone. Around Pucallpa, the average farm is about 22 ha in total area, with 2 ha per year under cultivation, 4 ha in different stages of managed secondary forest, 5 ha in managed primary forest, 10 ha in pastures, and the remainder in home gardens and boundary planting (Sotelo-Montes & Weber 1997). In 2011, region Ucayali counted with approximately 21,500 farmers working on 19,100 km² of farmland under various land-use systems (Agenda Agraria Ucayali 2013). Farmers also have to compete with weeds, which quickly infest degraded lands and pastures. The most frequent problematic weed is the *Imperata* genus forming green savannah. *Imperata cylindrica* (L.) Beauv. is recognized as the worst weed of south eastern Asia and already covers as much as 25 million of hectares of moist savannah in West Africa; it is now beginning to threaten South America, particularly the Amazon Basin (Garrity et al. 1997; Estrda and Flory 2015). *Imperata* is distributed throughout South America, Central America, Mexico, the West Indies, and the United States. It is an erect, tufted perennial grass with rhizomes, up to 100 cm tall. It is abundant and weedy in South American tropic lowlands and it prefers habitats with low altitudes, as well as sandy and humid soils. It is a weed of waste places and perennial crops (Krausová 2008).

In Peruvian part of Amazon Basin it grows on open deforested areas and degraded lands. *Imperata* (also locally called cashausha) is one of the biggest problems for local farmers in Peru. Mac Donald (2010) describes this weed as very fast growing, aggressive, and very troublesome. Frequent fires are used to suppress it, but after fire the weed develops even faster (Rusdy 2017). It is not good fodder for animals. Cattle do not ingest it well (rarely, they can ingest young weed outgrowths). The chemical method of combating this weed is effective, but the chemicals are not friendly to other vegetation and cause biodiversity losses as well. Furthermore, the chemicals are expensive, resulting in accessibility issues for poor farmers. *Imperata* is shade intolerant (MacDicken et al. 1996): use of shade trees in an agroforestry design is the most promising method for small-scale farmers to control these grasslands. This method increases species diversity and provides soil restoration.

Agroforestry systems

Agroforestry is a modern name for land-use systems that combine tree and crop plantation. It is defined by the International Center for Research in Agroforestry (ICRAF, 1993) as a collective name for land-use systems and technologies, in which woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used in the same land management unit as agricultural or temporal sequence.

For example Leakey (1996) considers Agroforestry as “a dynamic, ecologically based, natural resource management system that, through the integration of trees in rangeland, diversifies and sustains production for increased social, economic and environmental benefits.” Relatively poor small scale farmers find in Agroforestry such optimization of crop and animal production using multipurpose trees in combination with domestic animals and fishery. Modern methods of agroforestry allow for maintained and increased soil fertility and positive microclimates. There are three main types of agroforestry systems: (1) agro-silvicultural, using crops and trees including shrubs; (2) silvopastoral, based on pasture animals and trees; and (3) agro-silvopastoral, which combines the two previous systems. There are also other types of agroforestry using multipurpose trees, agriculture and trees, aquaculture and trees, apiculture, etc.

Agroforestry holds great promise for the development of sustainable food production in the Amazon Basin, where it is used in its improved form. According to De Jong (1995) there are various agroforestry systems practiced in the Peruvian Amazon near the Ucayali River, where we can observe multistrata agroforestry, multilayer tree gardens, plantation crop combination, tree hedges, trees on pastures, intercropping, trees and crops for fuel and fodder, and homegardens.

In the Peruvian Amazon, the systems mostly combine fruit trees with fast growing trees planted for timber production. The Guaba tree (*Inga edulis*) is used by many small-scale farmers as a pilot tree for new agroforestry plots, as it provides shade, improves soil condition, and forms a good base for other economically more important species (for wood and fruit production). In lowland terrains along the Ucayali River, use of guaba, bolaina blanca (*Guazuma crinita*) and capirona (*Calycophyllum spruceanum*) in combination with plantains (*Musa* sp.), carambola (*Averrhoa carambola*) and various palm species is very common (personal observation). In elevated terrains in the Ucayali region, trees of *Inga* with cacao (*Theobroma cacao*), fruit and timber trees are planted. The composition of plant species depends on the locality, on economic factors, and on market opportunities for the farmer. Adoption of agroforestry by local people depends on various factors. According to Olujide and Oladele (2011) farmers must be able to accomplish them safely, efficiently, and with tools already available to them. Agroforestry practices must be friendly to farmers, their budgets, and the land. As previously stated, agroforestry increases the amount of nutrients in the soil and provides a good microclimate for vegetation. With improving soil and vegetation conditions we can expect higher biodiversity too, but it depends on various factors (Altieri et al. 1984; Kruess and Tschardtke 2002). According to Puri and Panwar

(2007), if natural forest is cleared to make way for agroforestry practices, there will be a loss of biodiversity; yet, a similar practice, established on degraded land, might bring about an increase in biodiversity. In other words, the impact on biodiversity will be a function of what land use agroforestry replaces. If agroforestry practices are situated close to existing natural forests, they may benefit from the forest's biodiversity: animals, birds and insects will be readily available to invade. Moreover they can serve as a buffer zones around natural ecosystems.

So, if there is no original primary or secondary forest vegetation in a relatively close distance to an agroforestry plot, being invaded by wildlife from outside becomes difficult and it takes a long time. As was mentioned before, degraded lands and pastures in the Pucallpa zone are expanding and thus increase the distance of new agroforestry plots to original vegetation. However, as Puri and Panwar (2007) state: in some situations agroforestry practices may have a positive impact on biodiversity. When the vegetation has already been destroyed or seriously damaged - for example, by unsustainable agriculture or overgrazing – tree plantations under agroforestry practices may help to restore some biodiversity, either by sheltering relics of the original flora and fauna and allowing them to proliferate, or by creating a new ecosystem, albeit with a different mix of species from the one which originally occupied the site. The most common species in agroforestry are birds, small vertebrates, and invertebrates (spiders and insects). Schroth et al. (2004) identified and discussed three roles of agroforestry in biodiversity conservation on a landscape scale: (1) providing supplementary secondary habitat for species that tolerate a certain level of disturbance; (2) reducing the rates of natural habitat conversion in certain cases; and (3) creating a more benign and permeable 'matrix' between habitat remnants (as compared to less tree-dominated land uses), which may support the integrity of these remnants and the conservation of their populations (McNeely & Schroth 2006). Traditional agroforestry practices have huge potential in supporting biodiversity conservation. The use of agroforestry technologies mitigates biodiversity loss and provides opportunities for improving diversification and the range of livelihood options for rural households (Kalaba et al. 2010; Akinnifesi et al. 2008).

Agroforestry can be used to maintain wild biodiversity, but there must be realized with the application of adaptive management approaches for example: to recognize local knowledge and practices and incorporate research and monitoring naturally. Investigation provides information feedback to the management system. Maintaining diversity in the approaches to management of agroforestry systems, based on natural resource management,

will provide the best foundation for adapting to changing economic, social, and climatic conditions (McNeely & Schroth 2006).

Another type of agroforestry system for food production or small-scale land use is homegardens, which are small, but very diversified, common, and important in Peruvian Amazonia. Homegardens are not just for ornamental purposes, rather they serve as a special and complex type of agroforestry plot, with a high diversity of plants that have important productive purpose. They originate through specific selections made by farmers to provide the products they consider to be important for their subsistence and livelihood (Kumar & Nair 2007).

As we have observed, homegardens in farmland are more open and are used mainly for fruit production in combination with medicinal plants and shade trees or hedgerows. These gardens provide easy daily access to plants of a given crop that normally grow at a far distance from the house. Homegardens in town and city environs are of smaller size, but are more stratified for the production of spices, medicinal plants, vegetables, fruit trees, and ornamental plants. Our observations are supported by various case studies of the Peruvian Amazon region (Kumar and Nair 2007; Wezel and Ohl 2007). Homegardens in the Peruvian Amazon include various species according to the dweller's preferences; however, those most frequently used include: coconut palm (*Cocos nucifera* L.), mango (*Mangifera indica* L.), citruses, and *Inga* sp. These are followed by: pineapple (*Ananas comosus* (L.) Merr.), bijao (*Calathea* sp.), noni (*Morinda citrifolia* L.), camu camu (*Myrciaria dubia* Kunth) (McVaugh), cocona (*Solanum sessiliflorum* Dunal), medicinal plants, and spices.

3. Role of insects in tropical ecosystems

Insects are the world's most diverse group of animals, inhabiting all types of habitats and playing major roles in the function and stability of terrestrial and aquatic ecosystems. The tropical regions of the world house the greatest concentration of insect species. One hectare of Amazonian rainforest contains more than 100,000 species of arthropods (Erwin 2004), of which roughly 85% are insects (May 1998).

They are significant component of complex food chains and play irreplaceable role in the development of ecosystems. There are many herbivore, predator, parasite, and decomposer species in the forest: each group plays its own part in the ecosystem and representatives are well adapted to the environment. According to specific adaptations, close interactions have developed between insects and the rainforest: those species that are more closely tied to the forest are more sensitive to frequent forest disruptions and transformations. Most of the insect species that have lived have gone extinct before they had a scientific description.

It is necessary to understand, that insects are closely associated with our lives and affect the welfare of humanity in various ways. At the same time, a large number of insect species, including those we have no knowledge of, continue to become extinct or eradicated from local habitats worldwide (Footitt & Adler 2009). They form the biological foundation for all terrestrial ecosystems; they cycle nutrients, pollinate plants, disperse, maintain soil structure and fertility, control populations of other organisms, and provide a major food source for other taxa (Majer 1987). Generally, they can be regarded as planet feeders. Insects also play an important role in ecosystem stability, acting as ecosystem engineers, predators, hosts, prey, and parasitoids, which are involved in natural and practical control of insects. In the past decades, there have been several reviews of how insects, in particular herbivores, can affect ecosystem function (Weisser & Siemann 2004).

3.1. Insect pests and beneficial species

Insect pests are the most economically important group of insects in all agro-ecosystems. They cause losses of green foliage above ground and fruit yields of annual and perennial plants, even trees. The trees are attacked by leaf eaters in the nursery, termites and root grubs during the early establishment stage in the field, and other pest groups such as sap-suckers, gall formers, stem borers, pod or fruit borers, and seed eaters perpetually during

the later stages (Rao 2000). Interestingly, less than 1-2% of phytophagous insects that are potential pests ever achieve the status of even a minor pest (DeBach 1974). However, those species that are well adapted or more tolerant can become major pests with problematic or even devastating effects on tropical extensive agriculture and small-scale farmers. Every massive outbreak of some phytophagous species can negatively affect the stability of wildlife populations (Martin et al. 2006). We observe pest outbreaks mainly on plantations of taxonomically related plants. Damages are mostly caused by phytophagous beetles or ants (etc.); however, negative effects can also be caused by insects other than leafeaters. For example, brown planthoppers can cause huge damage to plantations by transmitting plant viruses. Major pests in agriculture are non-native species, introduced into a new ecosystem, usually without their natural biological control agents (Pimentel 2002).

Various species or families of insects are beneficial for plantations and for the ecosystem in general. Many Hymenoptera species are natural control and also biological control species of several pests. Ants are examples of good ecosystem engineers, having wide scale mutualisms with plants and honey producing Hemipterans, fungi, and antibiotic bacteria (Janzen 1966; Batra 1967; Currie et al. 1999). For example, leaf cutter ants (*Atta* sp.) are often recognized as pests when they cut and take out up to a half of the leaf cover of tropical citrus trees; however, they evidently also play an important ecological role through their long-distance transport, redistribution, and concentration of nutrients for plants growing near their nests. They also improve the physical and chemical conditions of the soil (Sternberg et al. 2007; Baumann et al. 1997). Honeybees, which have a great impact on human socio-economic situations, have a very specific and important role in agro-ecosystems, acting as excellent pollinators worldwide (Klein et al. 2007). Bees are part of the Aculeata group, which has a wide variety of interesting lifestyle strategies.

3.1.1. Importance of *Aculeata*, their lifestyle and sociality

Aculeata is a very numerous and important subclade of Hymenoptera. This group includes the bees and ants and all of the eusocial Hymenopterans. Within these groups, we can find a great diversity of species, adaptations, life strategies, and several types of sociality. According to Michener (2000), females of solitary bee species construct their own nests and provide food for the offspring; she has no help from other bees and usually dies or leaves the nest before maturation of her offspring. Linsley (1958) says that many solitary bees take

pollen only from certain kinds of plants, but are very efficient pollinators of the plants that they frequent. As the literature shows (Gathmann & Tschardtke 2002), this type of bee lifestyle is not dependent on colony formation and all female energy is invested into her own offspring. Sub-social bee females feed and care for offspring rather than merely storing food for them. Michener (2000) defines a colony as a group consisting of two or more adult females, irrespective of their social relationships, living in a single nest. However, not all bees that live in colonies are eusocial. Keller (2003) recognizes two main types of social organization. In communal species, several females of the same generation join together to start a colony. Within colonies, all females contribute more or less equally to reproduction. In some species, groups of cohabiting females may be sisters, and if there is a division of labour within the group, then they are considered semisocial.

In eusocial species, a division of labour exists - a single female (the queen) initiates a colony and sociality emerges when the daughters (workers) help their mother (Michener 2000; Le Féon et al. 2015). Cuckoo bees, which are cleptoparasitic, have an interesting lifestyle strategy. Cleptoparasitism is a relationship in which the young of one bee species develops by feeding on the food stored for the young of another species (Rozen JG 1991). The term can also be used to describe the stealing of nest material or a complete nest burrow (Michener 2000).

Aculeata comprises diverse insects with various food habits, which have a large influence on the ecosystem. Many aculeate hymenoptera species are predatory, hunting caterpillars, spiders, flies, grasshoppers, leafhoppers, etc.; therefore, they are able to regulate the population of some insect species. All adults are pollinators of flowers and trees because they feed on nectar. Pollination is important for natural ecosystems, including tropical farmland.

Bees (Aculeata: Apidae) are insects commonly used in agroforestry by small-scale farmers. The most important activity of bees, in terms of benefits to humans, is their pollination of natural vegetation. Wild bees have now become even more important as pollinators than in the past: for example, representatives of genus *Osmia* and *Megachile*. In many countries, populations of wild bees have been seriously reduced by human activity (Grossman 2013).

Apids (bees), another commonly known Aculeata, are a cosmopolitan, widely distributed insect group with many benefits for people and nature. The Apidae family is a morphologically and bionomically very diverse group, having a range of body sizes and varied lifestyles, including solitary, communal and eusocial strategies. They even live as

nest and social parasites. In the assessed localities, we mostly found individuals of tribe Meliponini - a large eusocial group of the Apidae family. They are closely related to common honey bees, carpenter bees, orchid bees, and bumblebees. This group is frequently represented by podgy, densely hairy species with pollen baskets located on the hind tibia, which are adapted to transport pollen, plant resins (propolis) or soil. Most interestingly, this group is stingless. They possess a stinger; yet, it is highly reduced and cannot be used for defense. Meliponini usually nest in hollow trunks, tree branches, underground cavities, or rock crevices, but they have also been encountered in wall cavities. When the nest is disturbed, bees attack using painful bites. Some species of this genus are kept by small-scale farmers to produce honey and to sell (divided bee colonies).

Diverse lifestyle-strategies are also observed in other groups, e.g. Halictidae; small to medium-sized bee species, mostly dark, often metallic in color. Females are very podgy, contrary to very slim males. Halictidae mainly nest in soil; however, in the tropics, there are also species that nest in rotted wood. Most species have solitary nests arranged in expansive nesting aggregations with all types of social behavior from communal to primitively eusocial. According to Macek et al. (2010), some species are nest parasites (cuckoo bees).

Nest parasitism can also be observed in Megachilids. This group includes nesting species as well as nest parasites. Nesting species choose various types of nesting substrate to build their nests, such as soil or wood; others construct nests in stems, a wide variety of natural cavities, snail shells, or the abandoned nests of other insects. Most species use an impermeable material made of saliva to protect the inner layer of nest tunnels. Those Megachilids who parasitize, do not develop an apparatus to gather pollen because their larvae feed on provisions from the host species (cleptoparasitism). A cleptoparasitic female ovoposits in an unfinished host nest; her larvae then destroy the host larva or egg and develop on host provisions.

Aculeate insects even display predatory behavior, which can be observed in a broad range of Crabronid species. This family is as diverse in body size and shape as it is in lifestyle. Adults are good hunters. Prey, mainly insects and spiders, are paralyzed first and then transported to the larvae. Most species are specialized for one (or two) types of prey. Depending on the size and weight of the prey, adults provide enough food for their young with one or up to dozens of prey individuals. Adults normally feed on sugar nectar or suck the hemolymph of prey. In our samples, there were various Crabronids, including those of genera: *Nysson*, *Gorytes*, *Liris*, *Oxybellus*, *Tachytes* and *Trypoxylon*.

Nysson is a Holarctic genus of cleptoparasitic wasps in the family Crabronidae. Over 100 species are known. *Nysson* females enter host nests and ovoposit under the wings of the prey (paralyzed leafhoppers) before the host ovoposits its own ovum. The parasite develops faster and destroys the host first, finishing its development on host provisions. Its host species are mainly representatives of the *Gorytes* genus: this genus includes small through middle-sized species living in a wide variety of habitats with sandy or clayish subsoils. They often build multi-chamber nests in soil with short branches and divisions terminated by small chambers. Adults hunt all stages of leafhoppers (Cercopidae, Cicadellidae, Fulgoridae) and also visit various flowers, mainly of the Apiaceae family.

Other interesting Crabronids, are species of the *Liris* genus that like xerothermic biotopes with sandy soils where they establish a one-chamber nest using the abandoned nests of solitary bees. *Liris* also make improvements to their nests to prevent parasitism, lengthening the tunnels up to 2 m. Adults hunt and paralyse small forest crickets and collocates them into the chamber (up to 7 pc. of prey). Larvae develop on the provisions of prey bodies.

Members of the *Oxybelus* genus, which nest in simple or multi-chambered soil nests, can also be found in the same biotope. Adults hunt Diptera during flight and then transport it to the nest impaled on their stinger. Larvae develop on the body of the prey (Hamm & Richards 1930; Peckham et al. 1973). Males of some species defend the nest against competitor males and/or parasites.

Hunting behavior has also been described (Bohart et al. 1976; Piek 2013; Alock 2007) in the *Tachytes* and *Tachysphex* genera. Both are solitary predatory wasps, hunting short-horned and long-horned grasshoppers and sometimes crickets, which they transport in flight to the nest. Prey individuals that are too large for them to fly with are dragged across the ground.

Another genus belonging to the Crabronid family is *Trypoxylon*, which is interesting for its defending behavior. Females establish a nest in various types of natural cavities; for example, in stems or in abandoned beetle tunnels. They are found in broad nesting aggregations. Females often usurp the nest of other females of the same species. To protect the next generation, males defend nests against other females. The nest often consists of 8 chambers, each one supplied with up to 50 paralyzed spiders. Larvae develop on the body of the prey. Development of this species is very fast – no more than one week.

Another family frequently found in our samples was Mutillidae, often called velvet ants, who parasitize bees and wasps. After mating, the female looks for a host nest, which is

usually a ground-nesting bee or wasp. Then, the female colocates one egg next to each larva or pupa. The larvae develop as ectoparasitoids of the host. Sometimes they kill the host's larvae or pupa.

A cosmopolitan but predominantly tropical family is Pompilidae, containing over 5,000 species. Pompilids are normally black, sometimes iridescent blue or green, and often exhibit integumental markings of brighter colors. This family is commonly known as the spider wasps because each larva typically develops in a nest cell on a single (paralyzed) spider host. According to Macek et al. (2010) most species are solitary, although several mud-nesting species are communal. Nests are made in preexisting cavities, are dug into the soil, or are made of mud or masticated leaf material. The larvae of some species develop as ectoparasites of active spiders. Some species are cleptoparasitic on other spider wasps.

Emeralds among wasp species are the Chrisids (fam. Chrysididae), which prefer open, hot, predominantly sandy or clayish biotopes where most of their hosts nest. They feed on plant nectar or lymph of Aphids (Macek et al. 2010). Larvae are nest parasites, or ectoparasites, of solitary wasps and bees. Some species are specialized for certain host groups, for example those who nest in stems or branches.

Bethylidae is a very interesting cosmopolitan family, its highest diversity being in tropical regions; they are ectoparasitoids of larvae and occasionally of pupae of Coleoptera and Lepidoptera, mostly in concealed situations (Finnamore & Brothers 1993). The host is usually paralyzed (temporarily or permanently), or sometimes killed, with a single (or multiple depending on the size of the host) sting from the female. The female drags the paralyzed larva to a sheltered place (in the case of free living hosts) or utilizes the host's shelter (in the case of concealed hosts) and oviposits one or several eggs (depending on host size) on the surface of the host (Macek et al. 2007).

The Vespidae family is very large and diverse, so only the two most frequently sampled groups, Eumeninae and Polistinae, will be discussed. Eumeninae wasps, also called real solitary wasps, are diverse in their nest building strategies. Recent literature (Macek et al. 2010) concludes that the different species may either use existing cavities (such as beetle tunnels in wood, abandoned nests of other Hymenoptera, or even man-made holes like old nail holes, screw shafts on electronic devices) that they modify to some degree or they construct their own nests, which can be underground or exposed. The nest may have one or several individual brood cells. The most widely used building material is mud made of a mixture of soil and regurgitated water, but many species use chewed plant material instead.

Most species are predatory, hunting caterpillars and larvae of various insect species, which are used as provisions for developing larvae. Adults feed on floral nectar.

According to Macek et al. (2010), the Polistinae are eusocial wasps, closely related to the more familiar yellow jackets, but placed in their own subfamily, containing four tribes; with some 1100 species in total, it is the second-most diverse subfamily within the Vespidae. Most species are tropical or subtropical. They are also known as paper wasps, but some Epiponine wasps (e.g. *Polybia sp.*) build their nests out of mud. Polistinae hunt mainly Diptera. Adults chew the prey, preparing a special pulp to feed the larvae.

Sphecidae are also called digger wasps because most species dig to build nests in soil. They may also establish nests in natural cavities (cracks in rock, hollow branches, or plant stems). Adults are predators of spiders and other insects (cockroaches, grasshoppers, mantis, butterfly caterpillars, and hymenoptera larvae). Adults feed on nectar.

There are also non-nesting aculeate species; for example, the Tiphiidae family. The adults feed on pollen and nectar. Interestingly, they do not construct nests because they are ectoparasitoides on larvae of terrestrial beetles (Macek et al. 2010; Bouček 1956). Adult females seek their host (a wide variety of beetle larvae of the Scarabaeidae, Tenebrionidae and *Cicindela* genera) in soil, following odour prints. Spines on their middle and hind legs aid in digging. The host is temporarily paralyzed by one sting or many and the female lays her egg on the host. The larvae develop by feeding on host lymph.

As there is a large diversity of species of bees and other stinger Hymenoptera, there is also a wide diversity of habits and life-styles within this group. Each of these strategies has its advantages and disadvantages.

3.2. Impact of insects on the ecosystem

Belowground biodiversity, or soil macrofauna, is the second component of land-use system biodiversity (Bardgett et al. 2005). According to the European Commission ED ENV (2010) soil macrofauna have an important role, helping to regulate the physical-chemical processes that affect soil productivity. Termites, ants and earthworms are three important groups. The stage of land use within a slash-and-burn system affects invertebrate communities. Ayuke et al. (2009) confirms that for intensive land uses, such as continuous cropping, macrofauna numbers are significantly reduced. However, some diversity levels can increase after agricultural use. From the perspective of ecosystem balance, one of the most significant insect group is ants. Ants are spread across the world and have adapted to different conditions and vegetation structures. Ants (Formicidae) represent a significant family of the Hymenoptera order. Hölldobler & Wilson (1990) estimate there are about 15,000 species of ants living on Earth. The highest amount of endemic genera can be found in Neotropical and African regions (Bolton 1994). Ants live in heavily populated, well-organized colonies that are protective of their territory. Ants are among the most important taxons living in the Amazon Basin. Estimation made by Hölldobler & Wilson (1990) says that one third of the entire animal biomass of the Amazonian rain forest is composed of ants and termites; more than 8 million ants and 1 million termites live on one hectare of soil. Ants are essential components of ecosystems because they act as ecosystem engineers and play an important role in the invertebrate biodiversity of agricultural land use systems (Krausová 2008).

Two main types of ants can be observed in the ecosystem: soil ants and canopy ants. Soil ants represents different trophic levels for example leaf-cutter and harvester ants as primary consumers; predators and mellivors as secondary consumers (Jones et al. 1994). Ants also improve soil conditions changing the physical and chemical properties of the soil by nest constructing. They can increase its drainage and aeration properties through the formation of underground galleries. Ants are experts in organic matter transformation and incorporation of nutrients through food storage, aphid cultivation, and the accumulation of feces and corpses (Brian 1978). Furthermore, ants help accumulate nutrients because they bury organic matter deep in the soil, in their special galleries that also act as water reservoirs. Leaf-cutters are special group of ants which is frequently classified as pests. *Atta* ants can cause a large amount of damage to crops and tree foliage. Its impact on the ecosystem can be also positive because they bury high amount of organic matter deep into

the soil structure, providing nutrition for tree roots. In effect, by changing the characteristics of soil, ants provide better conditions for vegetation development and, in this way, they also enrich habitats for other organisms. These changes depend on ant colony size as well as temporal and spatial distribution (Krausová 2008). Predatory ants can be classified as natural control of pest populations, which can be a benefit to agroforestry ecosystems.

3.2.1. Insects as natural and biological control

Many phytophagous insect species are classified as pest species, but in small abundances they do not have an economic impact on production. However, in greater abundance, these species can become pests with a large impact on local agriculture and devastating effects. Estimating the damage done by pest species to small-scale agroforestry farmers depends on various factors (Krausová 2008). Natural control is the phenomenon of plant and animal regulation by their natural enemies. In the case of pest insect and mite control, the major natural enemies are other insects (known as entomophagous) or microorganisms (the entomopathogens). The entomophagous group comprises both predators and parasitoids (Sampaio et al. 2009). Insects can also control weeds and parasitical plants. The presence of different herbivores in an agroforestry system may encourage predators to remain when their main prey is rare. Prey densities that fall below a certain threshold may cause emigration of natural enemies from an area (Singh 1995). In tropical regions, there are a huge diversity of pests and also natural enemies – natural controllers. As a brief example, there is a rich diversity of Hymenoptera families that are important biological controllers, such as Ichneumonidae, which utilize a diverse array of insects and arachnids as their hosts and play an essential role in the normal functioning of most ecosystems, underlining the need to inventory their diversity. Ichneumonids have been used successfully as biocontrol agents and, given the largely undocumented fauna, there is huge potential for their utilization in managed biocontrol programs (Gupta 1991). A typical predatory family is Sphecidae, in which females sting and paralyze other arthropods that are then taken to cells where they serve as food for larvae (Frank et al. 1995). There are many other Hymenoptera species serving as biocontrol agents. Beetles (Coleoptera) can function very well in biological control. For example, Coccinellids, the most widespread and abundant predators in many agricultural regions, are known to have the strongest impact on aphid and jassid species (Hodeck & Honek 1996). Both predator and pest species can also be used as indicators of biodiversity or ecosystem condition.

3.3. Insects as biodiversity indicators

Biological indicators – commonly abbreviated as “bioindicators” – are species, groups of species, or other taxonomic units that can be used to measure some feature of the environment. In cases where they are used to measure the health, state, or condition of the environment, they are referred to as environmental or ecological indicators (McGeoch 1998). Species biodiversity indicators are studied and monitored to determine the status of and trends in species biodiversity at global, regional and national scales (IUCN 2008). They are used for presenting and managing complex information in a simple and clear manner, which is also very important in the case of mega-diverse ecosystems such as the tropical forest. Insects are a very suitable group to use as biodiversity indicators for many reasons, including: their close relationship with the environment and vegetation cover; their sensitivity to humidity changes and habitat disruption; their fast reproduction cycles; and their large number of ecological interactions. Furthermore, they are easy and inexpensive to collect. Insects serve in monitoring significant positive and negative biodiversity impacts as well as in informing and reporting on the approach taken for biodiversity conservation at a strategic level. If the ecosystem is relatively equilibrated, the abundance of insect species, especially phytophagous insects, does not change significantly overtime; however, any significant change in their abundance will immediately imply an increase or decrease in their primary plant resources, their habitat, or their enemies (Brown 1997).

According to Footitt and Adler (2009), dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) are useful indicators of the effects related to the transformation of a locality from natural habitat to farmland. Consequences are primarily related to the modification of natural vegetation (Estrada & Coates-Estrada 2002; Halffter & Arellano 2002) and the loss of indigenous mammals, particularly large monogastric species that produce large fibrous droppings. Relative naturalness can be categorized by surveying differences in dung-beetle assemblages between natural ecosystems and disturbed farm habitats (Footitt & Adler 2009). However, in Bos et al. (2007), for example, dung beetles do not show a significant response to forest conversion because most species at the forest sites were also able to survive in agroforestry systems. A better response was represented using Hymenoptera: bees and wasps. These results highlight the importance of species choice (type of species and its ecological interactions) in investigations that use bioindicators. Bioindicators can be used to

measure the conservation potential of modified areas, such as monoculture agriculture, pastures, and agroforestry.

We have briefly outlined the role of insects in agro-ecosystems found in the Peruvian Amazon, such as monocultures, pastures and agroforestry, but how exactly does insect biodiversity vary among these ecological niches? Crops grown in conventional monoculture systems often suffer from severe pest problems. This is usually attributed to the nature of the cropping system. Monoculture reduces a complex natural plant system to a single-species community. This can lead to decreased insect diversity and can promote rapid population growth of a single, or very few, insect species (Stamps & Linit 1997). On the other hand, in poly-species plantations, there is an increase in plant and insect diversity, which promises different proportions of all insect species with a supposed lower occurrence of pest species. Andow (1991), in studies of 287 species of insect herbivores, reports a lower density of these insects in polycultural systems than in monocultural cropping for approximately 52% of the studied species. Moreover, only 15% had higher densities. In monocultures in the Peruvian Amazon, there are mainly: beetles, such as Chrysomelids; Hymenopterans represented by the Vespidae family; and Hemipterans. Diversity is normally low, but with a large number of specimens in each species. Conversely, agroforestry systems may offer an alternative way for agricultural land to support insect diversity. Scientists and policy makers are becoming increasingly aware of the role agroforestry plays in conserving biological diversity in both tropical and temperate regions of the world (Shibu 2009). There are many authors focused on the problem of insects in agroforestry and the conservation of insect biodiversity (for example McNeely 2004; Harvey et al. 2006), describing agroforestry systems as habitats for species that can tolerate a certain level of disturbance, which helps to reduce the rates of natural habitat conversion by providing a more productive, sustainable alternative to traditional agricultural systems (thoses that may involve clearing of natural habitats; Shibu 2009). According to Stamps and Linit (1997), abundant trees in agroforestry also satisfy non-nutritional arthropod needs, such as sites for mating, oviposition, hiding, resting, and aestivation. Andow (1991) determined that arthropod responses to polycultures and herbivore species are more abundant in perennial polycultures than in annual polycultures. In contrast, many parasitoids require nectar and/or pollen as adults, and the combination of trees and crops might provide a constant nutritional source for them because the resource availability over time is increased. Peng et al. (1993) confirmed the increased insect diversity and improved natural enemy abundance in an alley cropping system over that of a traditional crop system.

3.4. Impact of land use changes on insect biodiversity

There have been many investigations of insect biodiversity in humid forest and agroforestry systems around the World. Apart from species inventories, there have been studies of the impacts of ecological changes on appropriate indicators, including insects. The majority of these investigations are focused on one insect order or genus (Hutchings et al. 2011; Grimbacher & Stork 2009), but some of them screen all insect orders in a monitored locality or compare insect distribution across various ecosystems (Bos et al. 2007; Schroth et al. 2004). Research is mostly inspired by actual human activities, such as deforestation. Over recent decades, the harvesting of timber (Davis et al. 2001) and large-scale slash-and-burn activities have become the major source of human disturbance in tropical forests. According to Davis et al. (2001), research on insect species distribution across natural gradients in primary rainforest should be a good way to understand species distribution in disturbed tropical ecosystems.

According to Fowler et al. (1993), large areas of rainforest have been cleared for extensive cattle breeding, causing forest fragmentation. Forest fragmentation exposes species assemblages to changes in habitat heterogeneity and an increased predominance of edge effects (Klein 1989). Edge effects have become increasingly important in natural area management (Fowler et al. 1991). The study by Fowler et al. (1993) took place in a humid tropical reserve forest close to Manaus, Brazil, in which the surrounding parts had been cut, burned, and replaced by grasses and secondary forest vegetation. Insect numbers and size distributions varied significantly between the reserve forest interior and edge, with the forest edge always having significantly higher abundances, and generally larger individual sizes than the interior. Isoptera and Hemiptera were significantly more abundant at the edge than in the interior, while for Diptera and Hymenoptera the inverse was found. Population density at the edge was also more seasonal.

Koh and Wilcore (2008) published an interesting investigation of bird and butterfly biodiversity in Malaysian primary and secondary forest as compared to rubber and oil palm plantations. They describes conversion of primary or secondary forests to oil palm as significant factor of biodiversity losses.

Paredes et al. (2011) published an investigation carried out in the Ecuadorian humid tropics. The authors used malaise traps, pitfall traps, and direct collection methods to find specimens, screening for insects of all orders (including immature stages of hemimetabola insects). Taxonomic identification was realized to the family level. Within a family,

morphological species (morpho-species) was determined according to identification keys. Two of the eleven localities were classified as local biodiversity hot-spots on the basis of qualitative and quantitative data interpretation by the Shannon diversity index.

An interesting investigation of insect biodiversity was done by Shabuddin et al. (2005) in Sulawesi (Indonesia), comparing various tropical ecosystems, such as: natural forest, young secondary forest fragments, agroforestry systems, and annual cultures. The numbers of insect species were significantly higher in forest than in other chosen ecosystems. The mean number of dung beetle specimens at natural forest sites was two times higher than in young secondary forests and almost three times higher than in agroforestry systems. The lowest abundance was in annual cultures. They used an index for land-use intensity to determine human impact on the ecosystem. Results show that their index for land-use intensity was significantly related to the abundance of dung beetles (Shabuddin et al. 2005); dung beetle abundance decreased with increasing land-use intensity. Land-use intensity affected species richness more than abundance.

Bos et al. (2007) evaluated the effect of agroforestry systems on conservation in Sulawesi. For this research, sites of natural forest and agroforestry systems (with cacao as the dominant plant) were chosen. The evaluation of species richness and diversity was based on solitary bees and wasps, dung beetles, and lower canopy dwelling beetles and ants. Chosen groups belongs among insects which are irreplaceable in the ecosystem for example solitary bees and wasps act as crop pollinators or pest predators, dung beetles are decomposing mammalian excrements. The canopy dwelling beetles and ants category includes as herbivores as predators. According to Bos et al. (2007) the main characteristics as diversity, species richness, and abundance of solitary bees and wasps as well as canopy beetles seem to have profited from the effects of opening the upper canopy and changes in shade tree composition (related to forest conversion). There is recommended to include agroforestry systems with a high diversity of shade trees biodiversity conservation management and plans. (Bos et al. 2007).

Estrada and Coates-Estrada (2002) studied the kinds of landscape mosaics that might sustain maximum diversity and minimum species loss. Insects were sampled with pitfall traps to compare species richness and species composition in a tract of continuous forest, forest fragments, and a habitat island consisting of a mosaic of forest and arboreal crops in Los Tuxtlas, southern Mexico. Species richness of forest fragments and mosaic habitat did not differ from that found in the continuous forest; however, species richness in these habitats did differ significantly from that in isolated shaded and unshaded plantations.

Bisseleua et al. (2009) realizes investigation in 17 traditional cocoa forest gardens under different management in southern Cameroon focused on relation between ant ecology and vegetation structure. Results show a significant difference in species richness and abundance across various land use systems represented also by differences in tree density. Bisseleua et al. (2009) observed high ant species richness in florally and structurally diverse extensive old cocoa systems. Ant species richness was significantly related to tree species richness and density. Therefore, it is recommended to conserve a variety of shade trees. The intensification of cocoa production takes with also tree and insect diversity losses.

Lastly, there is the study by Valík (2013), which, like this thesis, was done in the Peruvian amazon in the surroundings of Pucallpa city. This investigation looked at the impact of cacao agroforests on beetle (Coleoptera) and true bug (Heteroptera) biodiversity, comparing species richness and diversity among four habitat types: primary and secondary forest, cacao agroforest, and annual crop. They used pitfall traps and window traps set at two heights of the tree vegetation. According to Valík (2013), all habitat types show relatively high biodiversity indices. Furthermore, even with high human disruption of natural forest, insect diversity remains high, although the species composition is changed substantially. He concludes that cacao agroforests have the capacity to serve as reservoirs for insects.

There are many other investigations of tropical insects that could be outlined herein; however, as with those above, findings indicate that insects play an irreplaceable role in the evaluation of ecological condition and its changes over time. Entomologically-based diversity research is still in the developing stages, but it forms a very important part of modern natural sciences.

4. Objectives

The main objective of this study was to assess insect biological diversity in various land use systems around Pucallpa city in the Peruvian Amazon. We focused on the impact that different degrees of human intervention and agricultural intensity have on biodiversity losses. We concentrated on the following specific objectives:

- (i) Analyze how human activities impact insect biodiversity on sites under different agricultural pressures, with the main focus on the role of agroforestry systems in biodiversity conservation.
- (ii) Analyze the qualitative aspects of insect populations to understand their function in ecosystems. We selected the *Aculeata* group – the most diversified group of sampled insects, in which members differ not only on a species level but also on a sociality level.
- (iii) Evaluate the knowledge in the local population of people from native tribes vs. mestizo (non-indigenous) origin regarding insect biodiversity in their surroundings.

Hypothesis

Based on the main objectives and a literature review, we established several hypotheses:

Insect biodiversity - quantitative analysis

(H₁) There is lower insect species diversity in monoculture plots than in agroforestry systems of multistrata and cocoa production type.

(H₂) There is high similarity of species composition in primary forests and agroforestry systems.

Qualitative analysis of species composition and behaviour

(H₃) Aculeata species are more abundant and rich in natural forests than in other assessed localities.

(H₄) The proportion of social and solitary Aculeata is the same in all evaluated ecosystems.

(H₅) There is no difference in the number of cleptoparasitic Aculeata species among the evaluated sites.

Ethno-entomological research of the area

(H₆) Native ethnicities, such as the Asheninka and Shipibo people, have a deeper knowledge of insects than small-scale farmers of non-ethnic origin.

(H₇) The closer a settlement is to the forest, the greater the amount of knowledge of insects the inhabitants have.

These results could form a valuable baseline for future investigation and represent a complete initial inventory, required for biodiversity conservation not only in target localities, but also in the wider region. This research allowed students of Czech and Peruvian Universities to study and develop sustainable management of natural resources, with the special goal of biodiversity conservation.

5. Methodology

5.1. General description of study area

The Amazon basin lies within the territory of eight countries of South America, Peru being the second largest one. Peru can be divided into three parts: coast, sierra (Andean mountains), and Amazon rainforest (locally called “selva”), which covers more than half of the country. According to the meteorological bulletin (Odar and Rodríguez 2004), it is an area with hot humid climate, where the precipitation falling in spring and autumn is high. Thanks to the climatic conditions, this area is characterized by tropical forest vegetation; however, an increased human population, along with the corresponding increase in food demand, has caused large landscape changes. According to FAO and INRENA (2005), there are about 2.2 million inhabitants in the region; in 2015 the population was already 3 million (INEI 2015). The Peruvian Amazon can be divided into three main regions: Ucayali, Loreto, and Madre de Dios. Of these three regions, the Ucayali has the best infrastructure, promising the easiest logistics. The Ucayali region has a border with Brazil, where there is the most diverse forests of the region; for example, the Sierra de Divisor Mountains. Pucallpa city, the capital of the region, lies on the bank of the Ucayali River. This city is located 890 km north-east of Lima, the Peruvian capital (S 8°23'; W 74°31'; 154 m above sea level) (Figure 2).



Figure 2. Location of the study area of Pucallpa, Ucayali region bordering Brazil.

The Ucayali region is covered mainly by humid tropical forest. The majority of the area is plain landscape with low hills and river valleys in the East and also in a part of the West, where the Andean foothills are located. The annual rainfall average of the Ucayali region, which is increasing to the west, reaches up to 2,300 mm (SENAMHI 2011). Around Pucallpa city, average annual rainfall is up to 1,600 mm, with rainfall increasing to the west. Wet season comes in February and lasts till May and then comes back in September lasting till November. As dry months are recognized June, July and August. Rest of dry season starts in December and ends in January. According to MINAG (2002) the mean annual temperature is 25.7°C, with a maximum of 31°C and a minimum of 19.5°C. Relative humidity rises to 80%, as shown in Figure 3. In the last few years the climate has changed slightly. The difference between dry and wet periods is not so evident. Odar and Rodríguez (2004) assign these changes to the wide deforestation in this region.

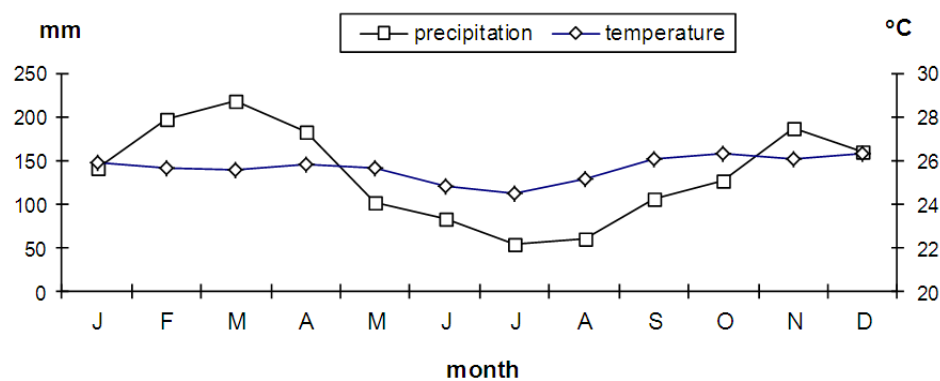


Figure 3. Average monthly precipitation and temperature in Pucallpa, Peru (Lojka 2011, MINAG 2002).

There can be found various types of soils around Pucallpa city. For example alluvial, seasonally flooded, and riverine systems Entisols, called “*restinga*”. There are also higher located, well-drained forest areas of acidic Ultisols, called “*altura*” (Fujisaka 2000; Cochrane et al. 1985; Valík 2013). Upland soils are of lesser quality for agricultural crop cultivation, but have better accessibility and less risk of earlier flooding (i.e. before the harvest) (De Jong 2001).

In the history of this region the original vegetation was tropical lowland forest which is currently being affected by farming practices, and in closes radius around the city was practically deforested.

The population of Pucallpa city, including periphery villages, is approximately 400,000 inhabitants. The infrastructure is based on asphalt streets and concrete houses in the center and mostly wooden or semi-concrete houses on the periphery. Pucallpa is a fast-growing city and is located in one of the Central Amazonian regions where biodiversity is most threatened by fast population and market growth (Riesco 2003). Food supplies are obtained from the capital city using the main road from Lima or by river boats and local agriculture production.

The agriculture around Pucallpa mainly consists of small-scale farmers with terrains along the main road connecting Lima with Pucallpa – Carretera Federico Basadre. Invasion and settlement began in the 1970's in correlation with improvement to the highway (Fujisaka 1999). These farmers live mostly in small wooden houses and their activities are focused on crop production, poultry production, or cattle ranching. The colonists come from non-forest areas (mountains, etc.); therefore, shifting cultivation is adopted very quickly. Slashed-and-burned areas are expanding (Figure 4).

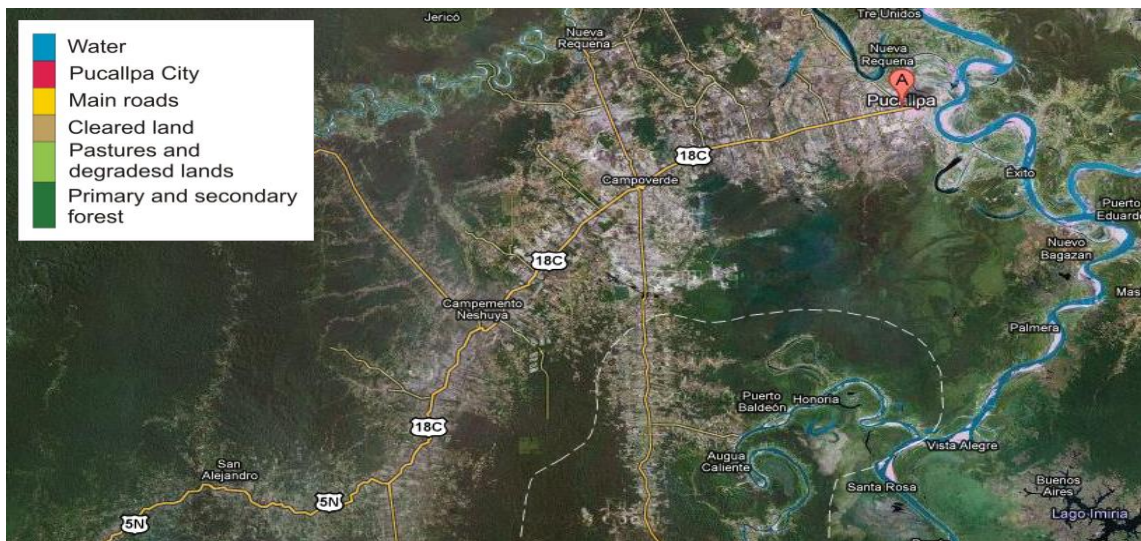


Figure 4. Deforestation around the city of Pucallpa and around the Pucallpa-Lima highway.

Increasing food demand results in a shortening of the fallow period. It is the main reason why soil fertility is rapidly decreasing. Heterogenous land management around Pucallpa includes settlers developing small-scale cattle ranches and others practicing slash-and-burn agriculture, with perennial crop establishment and substantial proportions of land left fallow (Fujisaka & White 1998). We observed large fields of cassava, maize, and oil palm to the west of the Ucayali River. Most of the area is deforested and converted to unproductive grasslands. Hyman and Fujisaka (2008) describe deforestation problems in the central part of the Peruvian Amazon (in the area surrounding the city of Pucallpa) where

massive deforestation and change of land cover caused by development of the region has been observed (Figure 1).

Some of the remaining forest-like vegetation is cleared every year to produce new fields. In plain terrains close to small villages along the river, people grow sugarcane, papaya, banana and plantains, and tobacco. Special products, such as cocoa beans and cocoa leaves, usually come from the hillsides of Padre Abad province, which lies on the main road to Lima, 100 km from Pucallpa city. During recent decades, cocoa plantations have expanded a lot, and many producers are united in associations. Some of them try to produce ecologically without chemicals, but there are not many fair trade buyers. Among other products, we can find upland rice, citrus, and beans cropped using traditional agriculture.

Some producers were motivated by various development projects (Lojka et al. 2016) to adopt agroforestry practices such as multistrata agroforestry based on *Inga edulis* trees in combination with local crops, timber, and fruit trees. In the beginning, agroforestry produces lower yield than monoculture and requires more manual work. In subsequent years, the yield rises and results in more products with higher value. However, several farmers did not persist and returned to monoculture cropping. We observed that those who kept agroforestry practices elevated their standard living and are more self-sufficient. Multistrata agroforestry around Pucallpa city nowadays produces: chilli peppers (*Capsicum frutescens* L.) and their products, black pepper (*Piper nigrum* L.), pineapple, citrus, guaba (*Inga edulis* Mart.), hoja biao (*Calathea* sp.), timber, fuelwood, banana (genus *Musa*), anona (*Annona cherimola* Mill.), and cassava and its products (such as flour or starch). Some local palm products, such as aguaje (*Mauritia flexuosa* L.) and ungurahui (*Oenocarpus bataua* Mart.), comes from agroforestry; however, the majority originates in the wild where fruits are collected by local dwellers.

In addition, nearly every household is surrounded by a home garden with many fruit and timber trees mixed with vegetables and medicinal plants. Local households are also dependent on collecting non-timber forest products (medicinal plants, honey, and fruit) from adjacent forests, as well as fishing and hunting. Farmers may own a few heads of cattle (on average 2-3 heads), or sometimes pigs and horses; however, most only raise poultry. They have very limited opportunities for any off-farm employment (Lojka 2011).

The main non-agricultural economic activities are wood logging and its transformation (mostly illegal for subsistence of the people who live along the river or near the forest). Pucallpa is a commercial center and the logging and oil industries provide much of its revenue but contribute highly to the rapid deforestation of the area. Oliviera et al.

(2007) estimates that up to two thirds of annual deforestation in the Peruvian Amazon is located around Pucallpa, where the people directly economically depend on it.

Cattle ranches have been expanding over the last decade in the Amazon. Cropped and over-grazed land has very degraded soils, mainly infested by weeds, forming green savannah vegetation along the main highway.

In general around Pucallpa, we find very heterogeneous land-use systems: ranging from the small remnants of primary and secondary forests, through various agroforestry systems, plantations, and cropping fields, to degraded land covered with grasses (mainly *Imperata* sp.).

5.2. Study site

Firstly, we selected various land-use systems for monitoring insect biodiversity based on the gradient of agricultural intensity, namely: multistrata and cocoa agroforestry, monoculture with annual crops, and degraded weedy grasslands; these areas were compared to primary forests. For sampling, several villages in the rural area surrounding Pucallpa city were chosen. The Pimental and Antonio Raimondi villages, in 2009, had especially suitable conditions for data collection because there were a variety of land-use systems in close proximity: monoculture fields with annual crops, agroforestry plots, and weed vegetations (abandoned areas without other agricultural intentions) overgrown with weeds *Imperata* sp. The experimental forest of Macuya, managed by the National University of Ucayali, was chosen as the primary forest. Originally, this area was full of primary forest vegetation; however, a large part was selectively logged and it is now classified as partly logged, but preserved primary forest.

Macuya is an experimental primary forest of the National University of Ucayali that is located 9 km from the small town of Alexander Von Humboldt (Carretera Federico Basadre km 86.0). This forest allows university students the opportunity for practical studies focused on tropical forest management. This forest has never been completely cut down. More than fifty years ago, selective wood logging had taken place on a small scale, mainly in the areas near the margins; however, since then, the forest has been untouched. Locations for insect collection were chosen at the center of the forest, which was probably not affected by logging (Figure 5 and Table 1). For the purpose of this study, the site was classified as primary forest.

San Alejandro is a small town, 118 km from Pucallpa (Carretera Federico Basadre) (Figure 5). The town develops in relation to the market which is based on cocoa and livestock production (Gonzales 2008). Local people also use forest resources frequently. Porvenir village was chosen as the best locality for data collection. It is located 2 km from San Alejandro, in the direction of Lima, at higher altitude. The terrain is very diverse with steep hills and humid forest vegetation already modified for cacao plantation. Cocoa production forms the main source of family income. The majority of cocoa plots are classified as agroforestry systems. Sampling was carried out on two agroforestry plots with shaded cacao trees.

Antonio Raymondi is located 19 km from Pucallpa and 7 km from the main road to Lima (S 8°22', W 74°42'). It was first established with about 27 households; currently, it has approximately 200 inhabitants. The locals, who use methods of slash-and-burn farming, have already cut down large forest areas around the village and are cutting more of the remaining forest to establish new plots for cassava, etc. Wide degraded areas are covered by the weed grasses, mainly *Imperata* sp. Several multistrata agroforestry plots were established with the help of Czech Development Cooperation project during 2005-10. Data collection was carried out on: two agroforestry plots (AFS), a cassava monoculture plot (MC), and degraded land (W) infested by weeds (Figure 5).

Pimental is a settlement situated 35 km from Pucallpa and 6 km from the main road (S 8°31', W 74°46') (Figure 5). This village is larger than Antonio Raimondi and, at present, it has approximately 390 inhabitants. In this locality, land-use systems were also based on slash-and-burn farming, however pepper (*Piper nigrum*) and fruit tree plantations had been very common. Nowadays, there are only a few farmers that plant pepper; instead, locals are mostly focused on annual crops, and variety of fruit trees, such as aguaje palm (*Mauritia flexuosa*). Also in this village several multistrata plots were established. Data were collected on plots of multistrata agroforestry (AFS), cassava monoculture (MC), and weedy vegetation (W).

In 2010, our research was extended by the addition of data collection in cacao agroforests in San Alejandro. We also obtained data from original primary forest in the Abujao river valley, where sampling was carried out in cooperation with the National University of Ucayali and CIFA (Centro de Investigación de las Fronteras Amazónicas).

The **Abujao river valley** is an area of 350,000 hectares. The Abujao River is a tributary of the Ucayali River, beginning in Sierra de Divisor on the Peruvian-Brazilian

border, at an altitude of 327 m a.s.l. It has an approximate length of 90 km (connecting coordinates: S 81° 51' W 65° 55' and S 81° 36' W 69° 41') and is characterized by high biological diversity (CIFA 2009). This valley is inhabited by a mestizo population living in small villages, as well as people of native ethnic tribes living in relative isolation. According to CIFA (2006), the valley is naturally covered by lowland rainforest, with the typology changing according to terrain elevation; the upper part, partially represented by pluvial forests, is much more humid than the lower part of the river valley. The upper part of the sector forms the Sierra del Divisor Reserve, founded in April of 2006, and is identified as a priority area of Peruvian biodiversity conservation. It is necessary to note that, for the purposes of this study, only localities outside of protected areas were chosen (Figure 5).



Figure 5. Location of study sites

(Yellow points – main investigation area; white points – comparative investigation area; yellow dashed line in upper-right corner represents the border of Peruvian protected area.)

Table 1. General description of study sites in various locations.

Village	Locality description	Geo position	Inhabitants	Forest vegetation	AFS Multistrata	Other AFS	Monoculture	Weed vegetation
Abujao river valley	Mostly primary forest partly damaged by selective logging and partly converted on river banks by extensive agriculture. There are some villages of native tribes and villages of mestizo people.	S 81° 51' W 65° 55' -- S 81° 36' W 69° 41'	The data were collected in the territory of 5 villages with Ø=60 inhabitants	Mainly primary forest, Secondary forest can be classified at the edge of the primary forests where the logging damage is visible.	--	Silvopastoral systems of <i>Guazuma sp.</i> trees with cattle.	There are a few small plots with sugar cane, maize and cassava, mainly for the subsistence of one or two families.	There are weedy grasslands only in the nearest surroundings of human dwellings with max. radius of 500m from the village
Macuya	Small centre for forest investigation 12 km from Von Humboldt. Undulated terrain, regular water sources, partly damaged-preserved primary forest, developed and managed secondary forest.	S 8°54', W 74°59'	5	Primary forest and 30+ year old forest; trees, palms, shrubs, thick layer of fallen leaves & woody material; Closed canopy; tree density = 9 trees/25 m ² ; 95% ground shade	--	--	--	--
San Alejandro	According to its position, the terrains are steeper and there are rich water sources. Local climate allows effective cacao plantation.	S 8°49', W 75°12'	450	--	--	Cacao plantation with forestry species: <i>Inga sp.</i> , <i>Calycophyllum sp.</i> , <i>Dipteryx sp.</i> , <i>Tabebuia sp.</i>	Cassava cropping; vegetation density low; no shade, combined with 6 months cacao plants	Plentiful weed dominated by <i>Imperata</i> ; compact 1.20 m tall vegetation; 80% ground shade

Table 1 (Continued).

Village	Locality description	Geo position	Inhabitants	Secondary forest	AFS Multistrata	Other AFS	Monoculture	Weed vegetation
Pimental	Middle steep terrains and plains, dry with occasional water sources, small centre for medical consultations, basic school and electricity distribution is in construction.	S 8°31', W 74°46'	300	10+ year old forest, closed canopy 5m, dense vegetation, humid, relatively steep	<i>Inga edulis</i> , pine/ apples, 6 years old; tree density: up to 7 trees/25 m ² ; trees 9 m high; layer of fallen leaves; 80% ground shade	<i>Piper nigrum</i> , <i>Guazuma crinita</i> , six years old; trees 12 m high; tree density: 6 trees/25 m ² ; 50% ground shade	Cassava cropping; vegetation density low; no shade.	Plentiful weed dominated by <i>Imperata</i> ; compact 1.20 m tall vegetation; 80% ground shade
Antonio Raymondi	Slash-and-burn farmers, mainly colonizers. Deforested plains invaded by <i>Imperata</i> weeds, eroded soils and dry local climate.	S 8°22', W 74°42'	200	-- (<i>Secondary forest was slashed and burned.</i>)	<i>Inga edulis</i> , pine/ apples, 6 year old tree density: up to 5 trees/25 m ² ; trees 6 m high; layer of fallen leaves; 75% ground shade	--	Cassava cropping; vegetation density low; no shade.	Plentiful weed dominated by <i>Imperata</i> ; compact 1.20 m tall vegetation; no shade

5.3. Data collection

5.3.1. Sampling: insect trapping and catching

For data collection, we chose four major land-use systems around Pucallpa: agroforestry systems (AFS – multistrata and cocoa), monoculture cropping (MC), degraded land covered by weed vegetation (grassland) (W), and forest vegetation (PF – primary forest). The goal was to collect a complete sampling of insects in all of these ecosystems, evaluate ecosystem biodiversity, and compare obtained data across ecosystems using standardized indices. Insects were collected in 2009 from March until August and in 2010 from February until November. During preparation for sampling, documentation of the terrain and vegetation characteristics, amount of shade, and GPS measurements (Table 1) was done. Sampling was carried out on plots of 25 m x 25 m, always between 6:30 am and 10:30 am.

Because of the large distance between villages, each plot was sampled once per month. After strong rains, sampling in some localities was impossible because they were not accessible with the necessary equipment, due to soaked and muddy local roads. Sampling in Macuya forest was completed only four times per period because of logistical problems and the high cost of transportation. Some weedy grasslands were burned out in a range of several hectares up to three times per year. Sampling in the Abujao river valley was done in November of 2010 in five selected areas of primary forest.

For collection of insects, only standardized entomological materials and methods were used. Totally we get 472 samples.

Malaise trap

The Malaise trap (Figure 6) is one of the most effective and very common flight-intercept traps (Martin 1977). This tent-like trap consists of dark open sides, a black central wall, and a white conical top of the roof, where the collecting head is situated. This is a particularly effective method for the collection of flying insects (mainly Diptera and Hymenoptera species). A liquid-filled trough or pitfall should be placed along the base of the central wall to collect species that drop when they hit a barrier (e.g. many Coleoptera species; ME 1998).

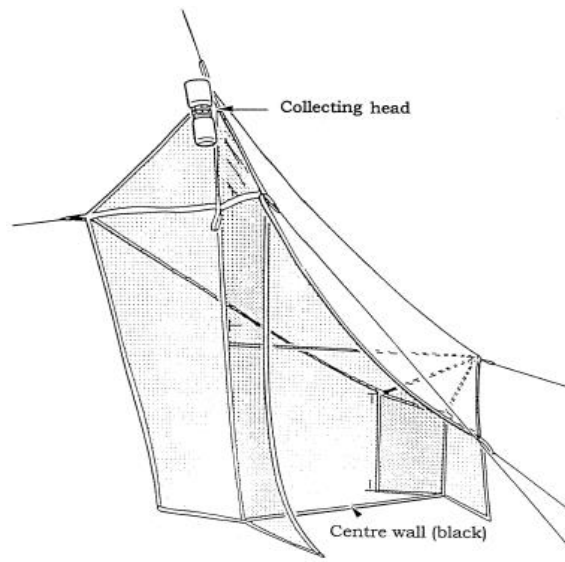


Figure 6: Design and construction of a Malaise trap. (Source: Martin 1977)

The central wall was 2 meters long. The collecting head (bottle with fix solution) was installed 2 meters above the ground. The trap is made of fine polyester net. The collecting head is made of a plastic bottle with fix solution.

First, the collecting head was installed using solid support at two meters above the ground and fixed with some type of dark twine. Then, the diagonal extreme of the trap and side corners were stretched and fixed by the same type of twine to firm vegetation or another type of solid support. Lastly, the collecting head was filled with fix solution (80% water, 19% salt and 1% detergent). There was 1 trap installed in the center of each plot; the trap was installed perpendicular to the flight corridor, the head of the trap pointing into the bright space (Figure 12). There was installed one Malaise trap in the center of the plot (because of the financial reasons we can not instal more traps in one sampling plot). Samples were washed by fresh water and then transferred to Ethanol (96%).

Pitfall trap

The Pitfall trap is standardly used for catching terrestrial insects. It was used in its basic form: as a neutral trap, in which all types of terrestrial insects can fall. For the fix (killing) solution 80% water, 19% salt and 1% detergent was used.

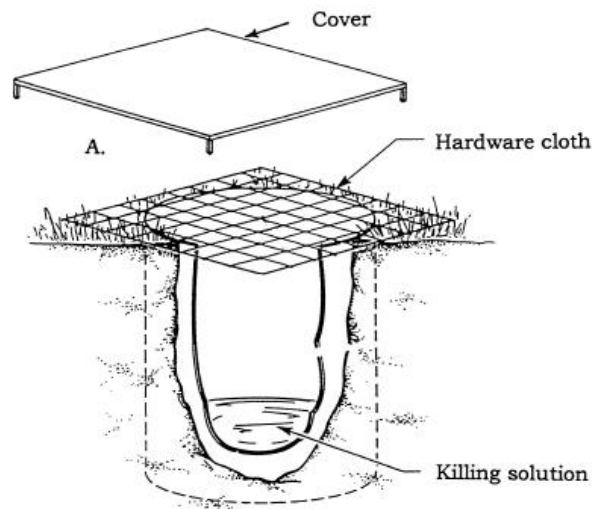


Figure 7: Design and construction of a ground pitfall trap. (Source: Martin 1977)

This trap consists of a plastic pot (with capacity up to 1 liter), a hardware cloth, which prevents infiltration of fallen leaves, and a plastic or natural lid. This type of pitfall trap must be located in the ground according to Figure 7; the neck of the plastic pot must be on the same level as the ground (neither elevated nor lowered). In the tropics, it is very important to protect the trap with a hardware lid and an elevated inclined cover to keep the rain and other debris out. On each plot, 9 pitfall traps were installed (3 rows of 3 traps), with 5 meters between all neighbouring traps (Figure 9 for a depiction of the layout). Samples were washed by fresh water and then transferred to Ethanol (96%).

Sweeping net

According to O'Neil et al. (2002), the sweep net is one of the most common methods used for estimating the relative abundance and community composition of insect populations in grass vegetation. It allows for easy and quick insect collection. This trap is a conical net fixed on a metal orb with a handgrip (Figure 8). There are three aspects affecting sampling: net height, sampling speed, and sweep net arc length (O'Neil et al. 2002).

As the literature recommends (Hawksworth & Bull 2006), a sweep net that was 40-cm in diameter with a white canvas net bag and a green plastic protection sleeve was used for this research. A transect consists of 25 consecutive strides (22-25 m) with consistent walking speed; the net was swung once per step. Transects were of about 80 meters. The sample was fixed by ethanol (96%; which also conserves the material), stored in a special plastic box, and properly marked with the locality label.

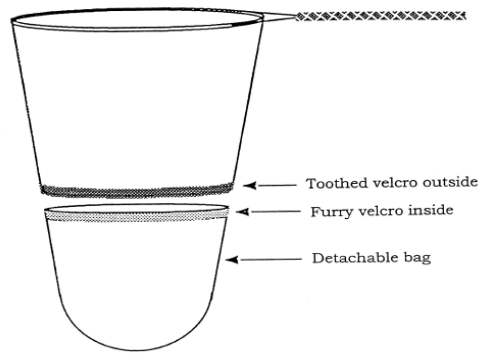


Figure 8. Diagram of sweeping net shows detachable bag (from Milne 1993).

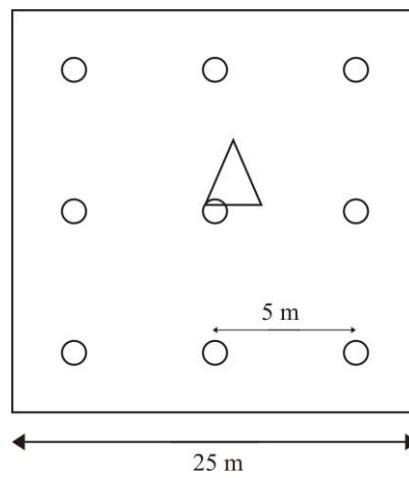


Figure 9. Design of trap installation and transect area. (Circles – pitfall traps; triangle – Malaise trap)

Direct collecting (the specific method for treehoppers, plant louses etc.)

Direct sampling is an additional manual method of insect sampling to complete inaccuracies caused by other methods. Only small numbers of insects can be collected by this method, which does not have significant influence on the results. Insects are collected manually by tweezers (or part of plant with insects) and fixed by 96% ethanol in a plastic box (Figure 10). Every box is properly marked with the locality label.

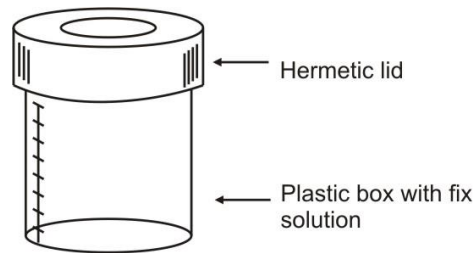


Figure 10. Fix-box for direct collecting

5.3.2. Manipulation of collected material

Collected insects were separated from plant material and conserved with fix solution in hermetic plastic bottles, marked by a numbered locality label, and stored in the dark room for further laboratory identification. We have used 96% ethanol as long-lasting fixation agent to preserve the samples till further identification in the laboratory.

Water-resistant materials were used for sample labels. Each sample was firstly cleaned out of gross impurities as small soil and plant residues, then separated into small plastic Ependorf tubes or larger laboratory fix-boxes, marked by a locality label, and finally fixed by pure 96% ethanol. Samples were divided into basic taxonomic orders and the numbers of species and specimens were calculated. For the purpose of this thesis, the orders of Coleoptera, Orthoptera, Hemiptera and Dictyoptera/suborder Blattodea were chosen. For order Hymenoptera, we chose only the Aculeata group and family Chalcididae, Pseudostigmatidae, Scelionidae. All the samples were classified with the assistance of professional entomologists. Other orders, such as Diptera, etc., were excluded because of numerous samples for which identification was too difficult in our conditions.

5.4. Data analysis

5.4.1. Insect biodiversity – quantitative analysis

All captured insects were classified parataxonomically into morphospecies, based on the sinoptic collections. The number of species and the abundances were recorded in a table. Only standard indices of diversity (Spellerberg 1995; Krebs 2013) were used to determine biodiversity characteristics. In our samples from the primary forest of Abuajo, we found high numbers of ant individuals from five species of ants (numbers that were enormously higher than those of other species). We suppose that this could be a sampling error caused by the location of the pitfall trap (i.e. near to an ant nest or a location that attracted ants: for example, to prey – a trapped frog or mouse can attract a large number of ant individuals). These enormous sample numbers would influence the results and calculations so we decided to exclude the samples [morphospecies code: DolichoderinaeA1 (233 individuals), DolichoderinaeA12 (358 individuals), DolichoderinaeA13 (587 individuals), Camponatus1 (1868 individuals), and MyrmicinaeTrn11 (303 individuals)].

The main component of monitoring ecological state and change is abundance - the number of all specimens of all species in a given locality. Abundance and the accuracy of monitoring, depends on the assessed biotope and a good selection of the collection areas. Values of abundance can be in real (absolute) numbers or in relative values, such as indices, percentages, or degree of frequency. For example, according to Tischler (1949), an abundance measured by degree of frequency is: a) not in occurrence; b) infrequent; c) rare; d) numerous; e) very numerous; or d) numerous on a large scale. **Abundance** is defined as:

$$A = \sum N_i \quad [1]$$

where A is abundance and N expresses the number of specimens in a given (i) locality (Spellerberg 1995).

The abundance index depends on the ‘**species abundance model**’, which is expressed by graphs and shows the structure of the sample. This is because in no community examined would all species be equally common; instead, a few species would be very abundant, some would have medium abundance, and most would be represented by only a few individuals (Magurran 1988).

Shannon diversity is a very widely used index for comparing the diversity between various habitats (Clarke & Warwick 2001). This index assumes that individuals are randomly sampled from an independently large population (Khan 2010). For the purpose of this research, the **Shannon index of diversity** (Krebs 1999) was used:

$$H' = -\sum_{i=1}^s (p_i)(\ln p_i) \quad [2]$$

where H' is an index of species diversity, s represents the number of species, and p_i is the proportion of the total sample belonging to i^{th} species.

Fisher's alpha diversity index (Krebs 2013) is a parametric index of diversity that assumes the abundance of species follows a log series distribution.

$$S = \alpha \log_e \left(1 + \frac{N}{\alpha} \right) \quad [3]$$

where S is the total number of species in the sample, N represents the total number of individuals in the sample, and α is the Index of diversity. The constant α is an expression of species diversity in the community. It is low when the number of species is low and high when the number of species is high (Krebs 2013).

Beta diversity describes the structural complexity of a habitat (environment). It is a measure of the similarity of species composition between localities. The **Index of similarity by Sørensen** (1948) was used in this study. By Spellerberg (1995), it is defined as:

$$c = \frac{2w}{a+b} \quad [4]$$

where c is Sorensen's similarity coefficient, w is the number of species common to both samples (or communities), a represents the number of species in sample A and b is the number of species in sample B.

Jaccard's index of similarity (Spellerberg 1995) is often used to determine the similarity of samples, localities, or communities. It is defined as:

$$J = \frac{w}{a + b - w} \quad [5]$$

where J represents the Jaccard' similarity coefficient, w is the number of species common to both samples (or communities), a represents the number of species in sample A, and b is the number of species in sample B.

For estimation of the total number of species per study site we used **Jackknife estimate of species richness** (Krebs 1999). This coefficient offers an interesting point of view on species richness, which is not influenced by the size of the sample.

$$S = s + \left(\frac{n-1}{n} \right) k \quad [6]$$

Where S is the Jackknife estimate of species richness, s represents the total number of observed species present in n quadrants, n is the total number of sampled quadrants, and k is the number of unique species. This estimation index is based on the observed frequency of rare species in the community.

Statistics

The presented research is focused on a comparison of insect biodiversity in various ecosystems. We use statistics to determine statistically significant differences among them. According to the data set and study methodology, we chose One-way ANOVA with Bonferroni and Holm multiple comparisons, which is necessary when analyzing the same data set from different points of view (Vasavada 2016).

5.4.2. Qualitative evaluation of species composition and behaviour

We focused on the most abundant group in the samples, Hymenoptera: Aculeata. We were interested in the occurrence of these insects in the assessed ecosystems because their profitability is highly influenced by resources and other aspects of the habitat. The poorest habitat of weedy grasslands was excluded from this evaluation because of insufficient data. Captured Aculeata morphospecies were sorted into three main lifestyle strategies: eusocial,

solitary, and clepto-parasitic. First, we tested which strategy predominates in each analyzed ecosystem.

We were also interested in whether the occurrence of social and solitary Aculeata is influenced by the quality of the ecosystem (degree of human impact). For this analysis, we used a One-way ANOVA with Bonferroni and Holm multiple comparisons (Vasavada 2016). We tested if there is a statistically significant difference among ecosystems in regards to the composition of social, solitary, and eusocial Aculeata.

To analyze the proportion of lifestyle strategies in each ecosystem, we used the program, BiodiversityR: Package for Community Ecology and Suitability Analysis, version 2.8-4. The same program was used for the rarefaction analysis of the probability of finding a new species of Aculeata with a certain lifestyle strategy.

5.4.3. Ethno-entomological research of the area

We wanted to analyze how deep the knowledge of local people about the insects is. This part of the research is based on interviews with permanent inhabitants of the countryside in communities where the entire (insect) sampling was done: Pimental, Antonio Raimondi, and San Alejandro. In the Macuya primary forest area, questionnaires were not implemented because the people do not live there permanently; they only commute there for work occasionally. In each community, we randomly chose nine respondents: small-scale farmers, between 21 and 55 years old, all of whom were migrants of mestizo origin.

We compared data collected from mestizo people to the ethno-entomological knowledge of native tribes. For this purpose, we chose nine respondents from the village of San Mateo (Asheninka origin), nine from 28.de Julio (mestizo origin), and nine from Santa Rosa (Shipibo origin), all from the Abujao valley area. Data from the last three mentioned communities were obtained during investigations in the Abujao primary forest, and were then published as the diploma thesis of Perry Davila from the National University of Ucayali (Perry Davila 2012).

In total, we did 54 interviews. Each interview consisted of questions about 35 common insect species occurring in the sampling area. All interviewed people completed the same questionnaire regarding common species of insects, using the prepared bodies of sampled insects and photos (scale 1:1; photos were used only for insects that change shape or color after preparation). Each respondent was asked: (1) to name the insect as specifically as possible; (2) to explain where and how the insect lives (know where it lives, what it eats,

whether it is harmful or not, etc.); and (3) to explain how the insect is used by the community (whether it is linked to agriculture, ethnic traditions, and/or rituals). If the answer is full and correct, the person receives 1 point; therefore, for each insect, there is a maximum of 3 points awarded.

Collected data were summarized in a table and were evaluated using simple descriptive comparative methods and One-Way ANOVA statistics with post-hoc Tukey HSD test (Vasavada 2016).

6. Results

6.1. Insect biodiversity - quantitative analysis

6.1.1. Observed species richness and abundance

In total, we identified 68 insect families, represented by 4,949 individuals, in 756 morphospecies (Table 2, 3 and 4), in all five major habitats (forests, two agroforests, agricultural fields, and degraded lands). Of all investigated habitats, the most species rich and abundant was the primary forest in Macuya, with its 1,496 individuals of 386 morphospecies, which was slightly higher than the number found in the primary forest of the Abujao River. We observed similar species richness in the Abujao forest, with 1,318 individuals in 369 morphospecies and the multistrata agroforestry system, with 1,274 individuals in 298 morphospecies.

Table 2. Species richness and abundance in each ecosystem

Ecosystem	Number of morphospecies	Abundance
Abujao forest	369	1,318
Macuya forest	386	1,496
Multistrata agroforestry	298	1,274
Cocoa agroforestry	146	366
Monoculture	94	319
Weedy grasslands	50	176

Results show (Table 2) a small numerical difference in abundance between cocoa agroforest, monocultures and weed vegetation; however, these localities vary in their species composition (Figure 12 and 13). Overall, we found that order Hymenoptera (group Aculeata and family Chalcididae, Pseudostigmatidae, Scelionidae) was the richest one in species number (381) and the most abundant (2,999 individuals; Table 3): 61% of all captured insect individuals and 50% of all morphospecies (Figure 11). The most abundant Hymenoptera family was Formicidae (22%).

The next largest group was beetles (Coleoptera), represented by 1,183 individuals in 249 species (Table 3). The most abundant families were Chrysomelidae (26%) and Scarabaeidae (17%), together representing 43% of all captured beetles.

Table 3. Species richness and abundance by Order

Order	Number of morphospecies	Abundance
Hymenoptera*	381	2,999
Coleoptera	249	1,183
Hemiptera	53	436
Dictyoptera	38	203
Orthoptera	35	128
Total	756	4,949

(* Hymenoptera: Aculeata and family Chalcididae, Pseudostigmatidae, Scelionidae)

Together, orders Dictyoptera, Hemiptera, and Orthoptera represent only 15% of all captured insects (Table 3). Ectobiidae represented 41% of all captured cockroaches, Cicadelineae represented 61% of all captured leafhoppers, and Acrididae represented 56% of all captured Orthoptera.

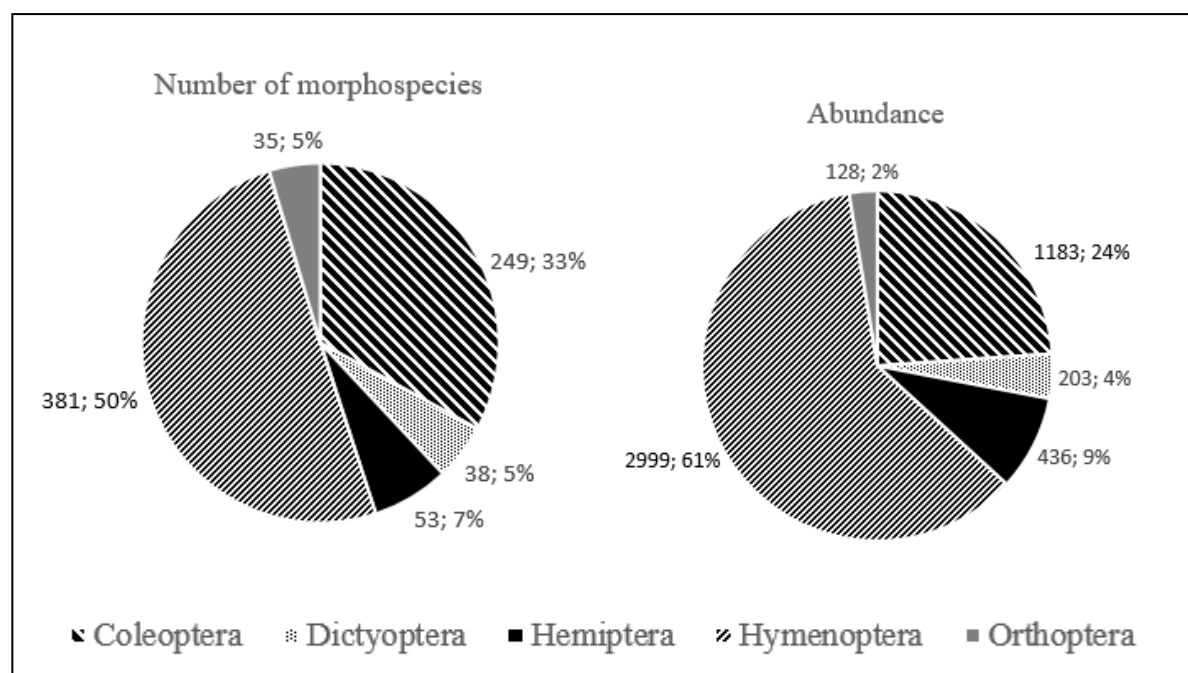


Figure 11. Total sample composition of all assessed ecosystems – morphospecies and abundance.

(Hymenoptera: Aculeata and Chalcididae, Pseudostigmatidae, Scelionidae)

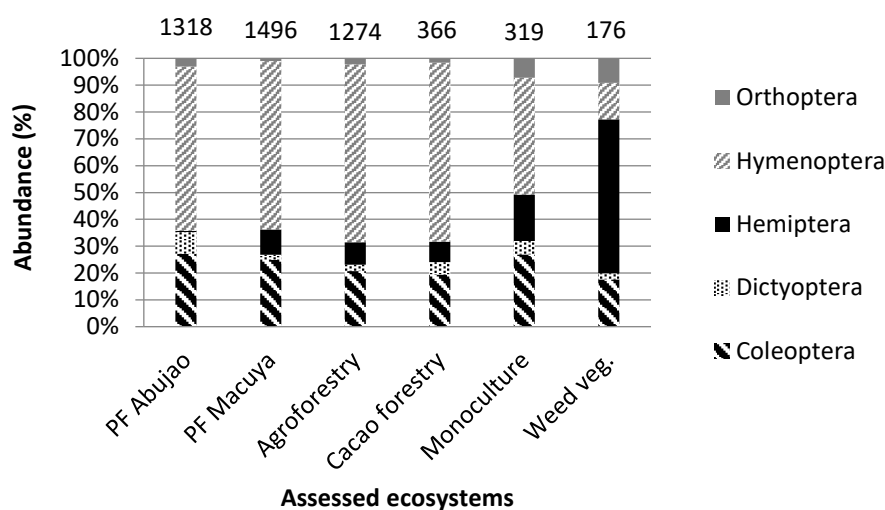


Figure. 12. Insect composition of assessed ecosystems - abundance.

(PF-primary forest) (Hymenoptera: Aculeata and Chalcididae, Pseudostigmatidae, Scelionidae)

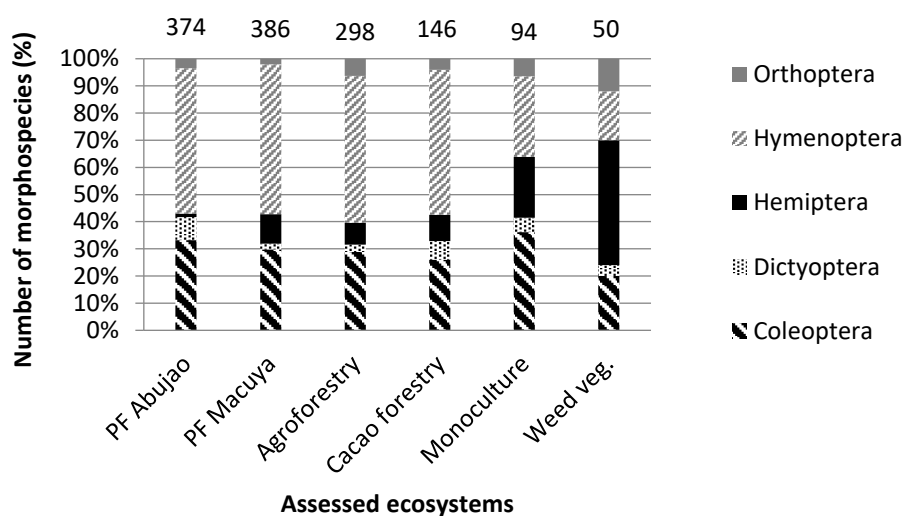


Figure. 13. Insect composition of assessed ecosystems - morphospecies.

(PF-primary forest) (Hymenoptera: Aculeata and Chalcididae, Pseudostigmatidae, Scelionidae)

Looking at a detailed insect composition of each habitat (Figures 12 and 13), we see that the proportions of Orthoptera and Hemiptera (which can be classified generally as pest-dominant orders) are increasing with land use-intensity and habitat conversion (monoculture and weed vegetation). On the other hand, the proportion of species and their abundance in Hymenoptera (Aculeata group and family Chalcididae, Pseudostigmatidae, Scelionidae) is decreasing with increasing land use intensity.

Table 4. Detailed table of captured insect families including the number of morphospecies and their abundances.

Order	Family	Primary forest of Abujao		Primary forest of Macuya		Agroforestry		Cacao forestry		Monoculture		Weed vegetation		Subtotal per family	
		Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.
Coleoptera	Aderidae					1	10							1	10
	Alleculidae	2	4	3	12	3	5							4	21
	Anobiidae	1	2											1	2
	Anthribidae			1	1	1	1	1	1					3	3
	Bolboceratidae							1	1					1	1
	Brentidae	1	1											1	1
	Bruchidae	2	5											2	5
	Buprestidae			1	1									1	1
	Cantharidae			1	1	1	2							2	3
	Carabidae	2	3	3	3	2	3	1	2					4	11
	Cerambycidae	4	4	7	18	8	13	1	2					10	37
	Cicindelidae	2	2	3	4	3	3							4	9
	Cleridae	1	1	4	5									4	6
	Coccinellidae			4	5	6	18	2	9	7	33	6	22	10	87
	Curculionidae	13	23	11	27	9	16	3	4	3	5			24	75
	Dasytidae								1	1				1	1
	Dryopidae	1	1											1	1
	Elateridae	4	7	9	26	8	13	2	3	5	5			17	54
	Endomychidae			1	1									1	1
	Erotylidae	4	4	2	5	1	5	1	1					7	15
Eucnemidae			1	3									1	3	
Histeridae	4	43											4	43	
Hybosoridae	4	16											4	16	
Chrysomelidae	24	28	32	133	15	84	17	34	13	27	3	7	58	313	

Table 4. (Continued).

Order	Family	Primary forest of Abujao		Primary forest of Macuya		Agroforestry		Cacao forestry		Monoculture		Weed vegetation		Subtotal per family	
		Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.
Coleoptera	Laemophloeidae	1	1			1	2							1	3
	Lagriidae			1	1									1	1
	Lampyridae	4	5	2	3	2	2							7	10
	Leiodidae	1	28											1	28
	Lycidae	1	1	2	4	1	1							2	6
	Malachiidae	2	3											2	3
	Melandryidae			1	1									1	1
	Melolonthidae			1	13									1	13
	Mordellidae	7	9	4	19	4	17	2	2	1	3			10	50
	Nitidulidae	8	59	3	15	5	9	2	7					11	90
	Ptilodactylidae	3	3	1	1			2	2					3	6
	Scaphidiidae			1	1	1	1							1	2
	Scarabaeidae	12	67	12	65	10	55			5	13	1	2	19	202
	Scirtidae			2	3	2	2	1	1					4	6
	Scolytidae	1	9											1	9
	Scraptiidae					1	1							1	1
	Staphylinidae	14	28					1	1					14	29
Tenebrionidae	1	1											1	1	
Zopheridae			2	2	1	1							2	3	
	Subtotal Coleoptera	124	358	115	373	86	264	38	71	34	86	10	31	249	1183
Dictyoptera	Blaberidae	12	31	2	3	4	10	4	6	4	4	1	2	13	56
	Blattidae	14	53	3	4	1	1	3	5					17	63
	Ectobiidae	6	23	3	21	3	20	3	6	1	12	1	2	8	84
		Subtotal Dictyoptera	32	107	8	28	8	31	10	17	5	16	2	4	38

Table 4. (Continued).

Order	Family	Primary forest of Abujao		Primary forest of Macuya		Agroforestry		Cacao forestry		Monoculture		Weed vegetation		Subtotal per family		
		Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	Sp.	Ind.	
Hemiptera	Cercopidae	3	3	17	56	6	7	4	11	10	23	11	46	21	146	
	Cicadellidae	2	3	21	77	17	96	8	15	8	27	10	50	26	268	
	Delphacidae			4	8	1	2	2	2	3	5	2	5	6	22	
	Subtotal Hemiptera	5	6	42	141	24	105	14	28	21	55	23	101	53	436	
Hymenoptera	Apidae	22	141	17	91	19	88	7	9	2	8			36	337	
	Bethylidae	7	9	5	24	5	13	1	1					14	47	
	Crabronidae	12	27	39	115	22	96	5	6	7	51			56	295	
	Formicidae	57	241	36	184	29	127	19	111	4	15			90	678	
	Halictidae	17	88	11	80	13	140	6	47	2	20			27	375	
	Chalcididae	28	109	21	57	14	104	17	22	3	10	7	11	24	313	
	Chrysididae	1	1	1	1	2	2			1	6			5	10	
	Megachilidae	4	7			1	1							5	8	
	Mutillidae	10	14	18	52	12	21	4	6					29	93	
	Pompilidae	14	22	28	122	14	72	5	14	3	13			40	243	
	Pseudostigmatidae								1	1				1	1	
	Scelionidae	1	1	1	13	1	11	2	5	2	5	2	13	2	48	
	Sphecidae			4	6	2	3							4	9	
	Tiphiidae	1	1	3	28	3	21	2	7					3	57	
	Vespidae	21	146	29	166	24	147	9	15	4	11			45	485	
Subtotal Hymenoptera	195	807	213	939	161	846	78	244	28	139	9	24	381	2999		
Orthoptera	Acrididae	4	4	8	15	12	18	4	4	4	17	5	14	19	72	
	Gryllidae	9	36			2	4							9	40	
	Tetrigidae									1	5			1	5	
	Tettigoniidae					5	6	2	2	1	1	1	2	6	11	
	Subtotal Orthoptera	13	40	8	15	19	28	6	6	6	23	6	16	35	128	
TOTAL			369	1318	386	1496	298	1274	146	366	94	319	50	176	756	4949

6.1.2. Abundance models

Relative species abundance refers to how common or rare a species is relative to other species in a given location or community. There are various ways and models for expressing abundance. In this case, was used a scatter diagram as a function of abundance and number of species per assessed habitat (Figure 14.). The results show steep-sloped curves in forest and agroforestry habitats, expressing the occurrence of a high number of species represented by a small number of individuals and conversely, there are only a few species represented by a high number of individuals. This pattern can be seen in natural non-disturbed ecosystems or ecosystems with a low frequency of disruption. Cacao forestry, monoculture habitat, and degraded weedy grasslands have much steeper curves, caused by the low number of species and abundance.

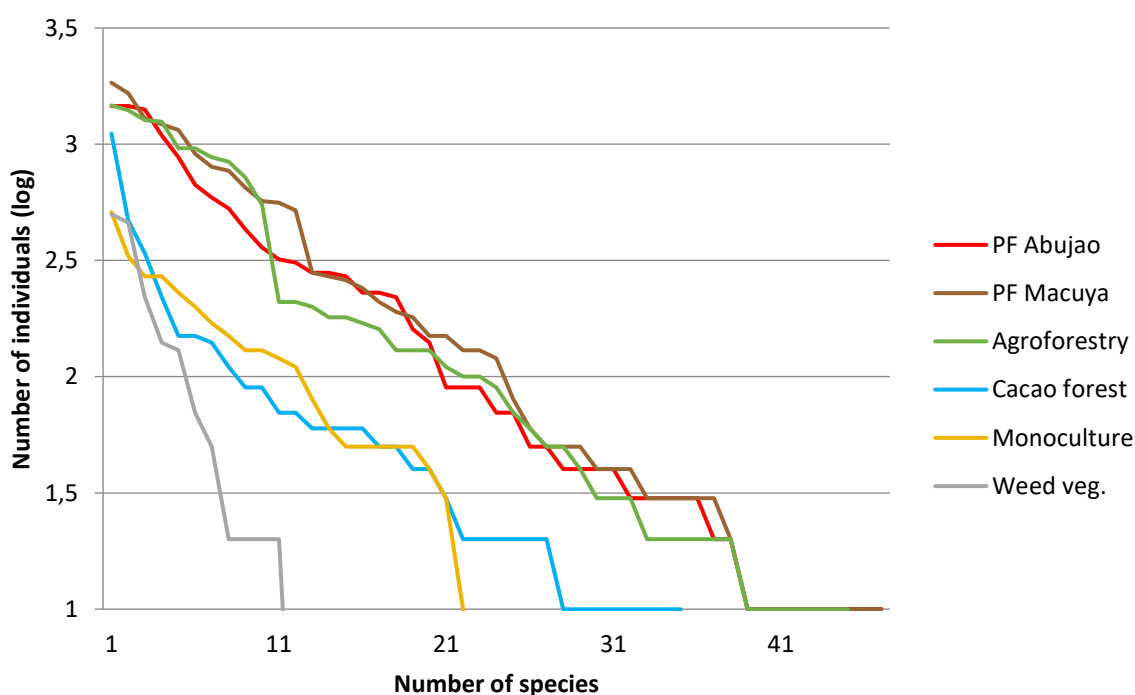


Figure 14. Abundance model – proportion of individuals to number of species in assessed ecosystems. (PF-primary forest)

We tested whether there is a statistically significant difference in abundance and the number of species among sampled localities. Evident from the results (Table 5, resp. table A1 in Appendix A), there are two main highly different groups of data: forest-like ecosystems (primary forest (PF) and multistrata agroforestry (AFS)) and transformed ecosystems (cacao forest (CF), monoculture (MC), and weedy grasslands (W)). The p-value

shows that cocoa agroforestry, monoculture and weedy grasslands does not differ to each other, but they differ significantly to both forest ecosystems and multistrata agroforestry. We have not found statistically significant difference in abundance among forest ecosystems and multistrata agroforestry. We suppose that with more sampling there would be a difference between forest ecosystems and multistrata agroforestry too.

Table 5. Significant differences in abundance among assessed ecosystems

	PF Abujao	PF Macuya	AFS	CF	MC	W	
Bonferoni and Holm p-value	PF Abujao	insignificant	insignificant	** p<0.01	** p<0.01	** p<0.01	
	PF Macuya	2.26	insignificant	** p<0.01	** p<0.01	** p<0.01	
	AFS	12.21	1.48	** p<0.01	** p<0.01	** p<0.01	
	CF	1.71e-06	1.48e-07	2.58e-06	9.32	insignificant	insignificant
	MC	7.30e-07	6.87e-08	1.09e-06	1.40	3.30	insignificant
	W	9.71e-08	1.12e-08	1.39e-07	1.40	3.30	

Stat. Significant difference /
* signal intensity

(ANOVA with Bonferroni and Holm results: all pairs simultaneously compared (p-value) of abundance in lower left corner, Signal intensity in upper right corner. PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland, ps-only pairs relative to A simultaneously compared).

Going into more details in abundance models on a morphospecies level, we can see some interesting facts. In the primary forest of Abujao, wasps were dominant, especially *Angiopolybia paraensis* (48 individuals), followed by the Nitidulidae family (m. sp. 5) with 36 captured individuals, and ants of the Formicinae subfamily with 31 individuals. Another important order was Coleoptera, with the dominant family, Scarabaeidae, representing 35% of captured beetles in the Abujao river valley (Table 6).

Table 6. Detailed abundance models – three dominant species of each ecosystem.

Ecosystem	Morphospecies	Order	Individuals
PF Abujao	<i>Angiopolybia paraensis</i>	Hymenoptera	48
	Nitidulidae m.sp.5	Coleoptera	36
	Formicinae m.sp.9	Hymenoptera	31
PF Macuya	<i>Trigona pallida</i>	Hymenoptera	41
	Chrysomelidae m.sp.1	Coleoptera	40
	<i>Liris</i> m.sp.1	Hymenoptera	34
AFS	Polistinae m.sp.15	Hymenoptera	47
	<i>Augochlora</i> m.sp.3	Hymenoptera	44
	Cicadellinae m.sp.1	Hemiptera	41
CF	Dolichoderinae m.sp.B1-12	Hymenoptera	59
	<i>Augochlora</i> m.sp.3	Hymenoptera	28
	Paraponerinae m.sp.1	Hymenoptera	14
MC	<i>Liris</i> m.sp.1	Hymenoptera	30
	<i>Augochlora</i> m.sp.1	Hymenoptera	18
	<i>Pseudophyllodromiinae</i> m.sp.1	Blattodea	12
W	Agallinae m.sp.5	Hemiptera	12
	Agallinae m.sp.2	Hemiptera	11
	Scelionidae m.sp.1	Hymenoptera	10

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland; m.sp.-morphospecies)

In primary forest on the opposite bank of the river – the Macuya forest – the most abundant group were also ants (12% of samples in Macuya), but on a species level, the stingless bee, *Trigona pallida*, was the most abundant, with 41 individuals. The next most abundant species was a morphospecies of Chrysomelidae beetles with 40 individuals (family Chrysomelidae represents 8% of samples in Macuya forest).

In multistrata agroforestry systems, the most abundant species was a morphospecies of the Polistinae family (47 ind.), followed by one bee species of genus *Augochlora* (44 ind.) and one Cicadellid species (41 ind.). In general, the dominant families were Vespidae, with a total of 147 individuals, and Halictidae (140 ind.), both of the Hymenoptera order. The Cacao agroforest was dominated by one morphospecies of the Dolichoderinae subfamily (Formicidae) with 59 individuals (16% of cacao agroforest samples) and the *Augochlora* bee (28 ind.) The remaining species captured in this locality were represented by an average of 2 individuals per morphospecies.

For annual crop vegetation, the most abundant species was a morphospecies of digger wasp *Liris* (Crabronidae) with 30 individuals, followed by the *Augochlora* genus with

18 individuals. Other species are each represented by an average of 3 individuals. Samples from degraded lands infested by weeds are dominated by two morphospecies of the Agalinae family and one morphospecies of the Scelionidae subfamily. Notably, the most abundant family was represented only by 12 individuals (Table 6). Monoculture and weedy grassland environments are both characterized by low species richness and abundance.

6.1.3. Estimated species richness

Species richness and diversity are the most important characteristics used for evaluating the environmental situation. For the purpose of this thesis, the Jackknife species richness estimator was used and shows interesting results (Table 7 and 8).

Of all assessed sites located on the left bank of the Ucayali River (Macuya, San Alejandro, Pimental, and Antonio Raymondi), the richest one was the primary forest of Macuya with 386 captured species. The value of the Jackknife species richness estimation index decreases with increasing intensity of land-use and/or conversion: Abujao primary forest (S=524) is followed by Macuya forest (S=485), then multistrata agroforestry (S=350), cocoa agroforest (S=161), followed by monoculture (S=103) and degraded lands infested by *Imperata* weeds (S=50).

Comparing productive land-use systems (AFS, CF and MC), the estimated species richness in cacao agroforest is more than two-times lower than in multistrata agroforestry systems. Also, in annual crop monoculture, it is up to three-times lower than in multistrata agroforestry and approximately two times lower than in cacao agroforest. These low values can be explained by the structure of the vegetation cover. Multistrata agroforestry, as the name implies, has a higher diversity of trees and annual plants in the undercover. It forms a better environment for various insect species. On the other hand, cacao agroforests are mainly cacao plantations shaded by fast-grown timber trees with almost no undercover for annual plants. Therefore, cacao forests can ecologically resemble a monoculture environment, which could explain their proximity in the Jackknife species richness index values (a difference of only 58). See the ANOVA with Bonferroni and Holm analysis comparing all pairs simultaneously (Table 6, resp. table A2 in appendix A).

Table 7. Significant differences in species richness among assessed ecosystems.

	PF Abujao	PF Macuya	AFS	CF	MC	W
PF Abujao		insignificant	insignificant	**p<0.01	**p<0.01	**p<0.01
PF Macuya	0.066		insignificant	**p<0.01	**p<0.01	**p<0.01
AFS	0.18	9.78		**p<0.01	**p<0.01	**p<0.01
CF	3.00e-05	1.12e-07	2.27e-07		insignificant	insignificant
MC	5.65e-06	2.97e-08	5.80e-08	5.76		insignificant
W	2.44e-07	2.44e-09	4.41e-09	1.98	1.20	

(ANOVA with Bonferroni and Holm results: all pairs simultaneously compared (p-value) of Shannon diversity index. Bonferroni and Holm p-value in lower left corner, Signal intensity in upper right corner. PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland, ps-only pairs relative to A simultaneously compared).

Our results show a highly significant statistical difference between multistrata agroforestry and cacao forestry, which also statistically differ from both primary forest ecosystems. According to this data, cocoa agroforest is not the best biodiversity reservoir in comparison to multistrata forestry.

Comparing the primary forests located on different sides of the Ucayali River (Table 8) shows that primary forest located closer to protected areas should have higher values of Jackknife species estimation index. In total, the Abujao rainforest contains more unique species (uniques) than the Macuya forest; however, it contains a lower estimated number of species ($s=369$). These two forests share only 106 species and their species compositions are not similar. The Abujao forest, even with a lower species richness value, is still unique and worthy of protection.

Accumulation curves express the number of new morphospecies captured in every successive sample (Figure 15). Curves for weedy grasslands (W) and annual crop monoculture (MC) show an increase until the 10th sampled locality and then it remains more or less constant, meaning there were no further new species found. The cacao forest (CF) curve shows higher values than monoculture, but it keeps the same pattern. The multistrata agroforestry system is represented by a steeper curve than CF so we expect more species to

Stat. Significant difference / * signal intensity

be captured there. Both primary forests appear highly similar on the graph. The Macuya forest curve has higher values than the primary forest of Abujao, but both are similar in their increase.

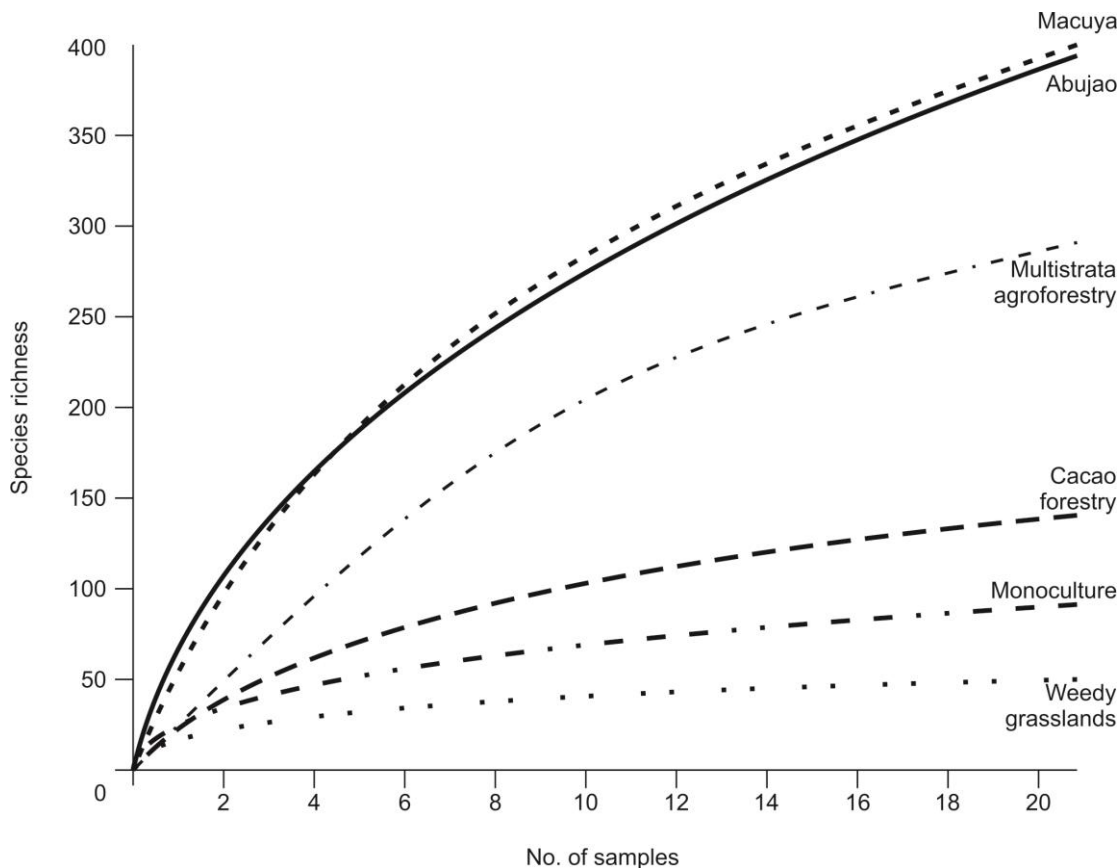


Figure 15. Accumulation curves of sampled morphospecies.

Sampling in the Abujao River valley was time-limited and there were only samples from 20 localities (that is why the graph is limited to 20 sampled localities); we suppose that, with more sampling days, we would have obtained even more diverse data than in the Macuya forest. This theory is confirmed by the continued increase of the Abujao river curve (it has not yet leveled off on the graph, Figure 15). There is a similar pattern to the progress of the cacao agroforest curve.

Table 8. Summary results of main biodiversity characteristics in sampled ecosystems.

Characteristic	Unit	PF Abujao	PF Macuya	AFS	CF	MC	W
		stand. dev.	stand. dev.	stand. dev.	stand. dev.	stand. dev.	stand. dev.
Abundance		1318	1 496	1 274	366	319	176
Total sp. number		369	386	298	146	94	50
Average sp. number		13.0 ±106.4	3.9 ±5.8	4.3 ±6.7	2.5 ±5.6	3.4 ±4.0	3.6 ±2.6
	sp./m2	0.60	0.62	0.48	0.23	0.15	0.08
Average species density	sp/plot	67	76	54	19	10	6
Average ind. density	ind/m2	7.47	2.39	2.04	0.59	0.51	0.28
Singletons	species with only one individual in samples	186	164	136	91	24	2
Doubletons	species with only two individuals in samples	76	60	53	26	33	15
Uniques	species that occur in only one sample	207	132	70	20	12	8
Duplicates	species that occur in only two samples	56	98	91	22	19	6
Jackknife richness estimator		524.3	485.0	350.5	161.0	103.0	56.0
Shannon diversity index (H')		2.78 ±0.35	4.80 ±0.06	4.77 ±0.12	3.68 ±0.29	3.67 ±0.14	3.33 ±0.14
Fishers alpha diversity index (S')		83.5 ±9.4	123.9 ±6.2	138.8 ±14.1	81.9 ±28.3	76.3 ±28.9	62.1 ±8.4

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland; stand.dev.-standard deviation, ind.-individual/s, spec.rich.-species richness). Interesting results in bold.

6.1.4. Biological diversity

For biodiversity evaluation we used the Shannon index of diversity. Originally, we supposed that we would find a constantly decreasing biodiversity index value from primary forests of Abujao to disturbed ecosystems (monocultures and weedy grasslands). However, our results differed slightly from this assumption, as shown in table 8 and in figure 16. The primary forest of Macuyya had the highest diversity ($H'=4.8$) among all assessed ecosystems. As we supposed, the diversity index decreases along an ecological gradient. Multistrata agroforestry reached a relatively high index of diversity ($H'=4.7$). The value of the diversity index in cocoa agroforestry ($H'=3.68$) was close to that of monocultures ($H'=3.67$). For weedy grassland, we obtained a diversity index (H') of 3.33. Surprisingly, the Abujao primary forest had the lowest value of the diversity index ($H'=2.78$). We also tested the diversity of these ecosystems using Fisher's alpha diversity index and found that the primary forests of Abujao ($S'=83.5$) and Macuyya ($S'=123.9$) had even lower values than the multistrata agroforestry system ($S'=138.8$) using this measurement (Table 8).

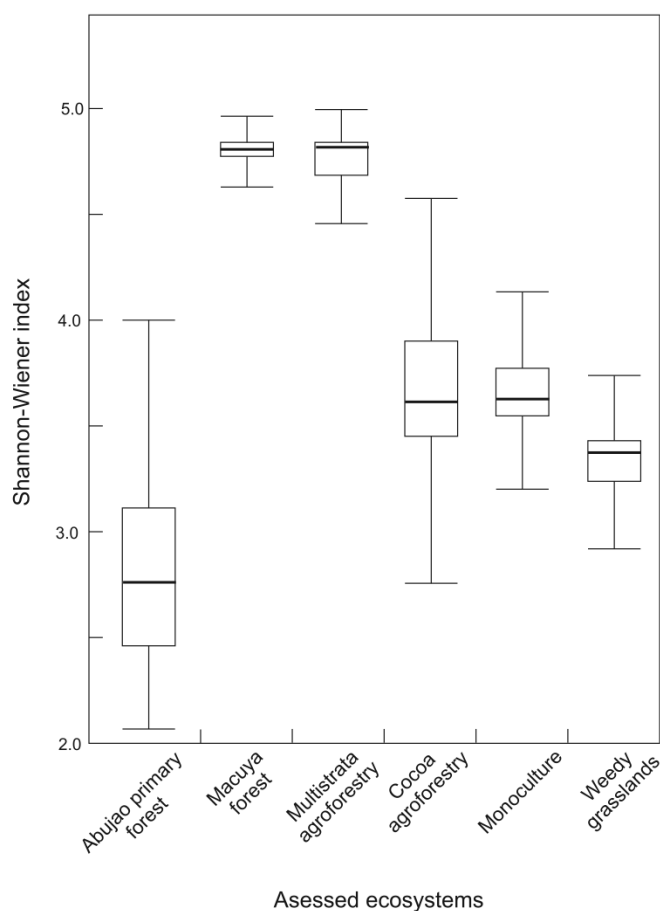


Figure 16. Shannon diversity indices of assessed ecosystems on a box plot graph.

We tested the results of the Shannon diversity index statistically (Table 9). Statistical analysis using Bonferroni and Holm (all pairs simultaneously compared) confirmed our results presented in figure 16 for all ecosystems. Interestingly, we found no statistical difference between the Macuya primary forest and multistrata agroforestry. On the other hand, there is significant statistical difference in diversity between the two agroforestry habitats: multistrata (higher diversity) and cocoa (lower diversity). Surprisingly, there was no statistical difference between cocoa agroforestry, monocultures, and weedy grasslands.

Table 9. Significant differences in diversity among assessed ecosystems

	PF Abujao	PF Macuya	AFS	CF	MC	W	
Bonferroni and Holm p-value	PF Abujao	** p<0.01	** p<0.01	** p<0.01	** p<0.01	** p<0.05	Stat. Significant difference/ * signal intensity
	PF Macuya	1.25 e-08	insignificant	** p<0.01	**p<0.01	**p<0.01	
	AFS	1.5e-08	1.72	**p<0.01	**p<0.01	**p<0.01	
	CF	0.0004	4.24e-05	4.88e-05	insignificant	insignificant	
	MC	0.0005	4.25e-05	4.99e-05	0.96	insignificant	
	W	0.03	1.38e-06	1.75e-06	0.25	0.20	

(One-way ANOVA with Bonferroni and Holm results: all pairs simultaneously compared (p-value) of Shannon diversity index. Bonferroni and Holm p-value in lower left corner, Signal intensity in upper right corner. PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland, ps-only pairs relative to A simultaneously compared).

6.1.5. Similarity among ecosystems

Along with diversity and species composition, we also evaluated the similarity of these ecosystems. For this, we used two coefficients of similarity: Jacquard's and Sorensen's indices. These formulas are based on species incidence and allow us to determine the extent to which two assemblages or localities differ or resemble each other.

Results show (Table 10) that the primary forest of Abujao was most similar to other forest and forest-like ecosystems: to Macuya forest (28%) and to the multistrata agroforestry system (30%). Comparisons between the primary forest of Macuya and both agroforestry systems – multistrata (51%) and cacao agroforestry (37%) – were among the highest values of similarity for all ecosystems.

The two agroforestry systems were also very similar in species composition (39% Sørensen, 24% Jaccard), especially in ant species. Monoculture and weedy grasslands share 23 species (Table A5 in appendix A) and according to the Sørensen index are 32% similar (19% for the Jaccard index). There are only two morphospecies shared by all of the assessed ecosystems.

Table 10. Jaccard's and Sørensen's indices of similarity (%)

	PF Abujao	PF Macuya	AFS	CF	MC	W	
Sørensen's index	PF Abujao		16%	18%	13%	7%	3%
	PF Macuya	28%		35%	23%	13%	8%
	AFS	30%	51%		24%	15%	6%
	CF	22%	37%	39%		15%	11%
	MC	13%	24%	26%	27%		19%
	W	7%	14%	11%	20%	32%	
							Jaccard's index

(Sørensen's index -lower left corner, Jaccard's index -upper right corner. PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland).

To better illustrate the similarity relationships between these ecosystems, we made a cluster diagram (tree) (Figure 17). There are two main visible clusters: the first includes only cassava monoculture and weedy grasslands, while the second group encompasses all the remaining primary forest and “forest-like” (less degraded) ecosystems.

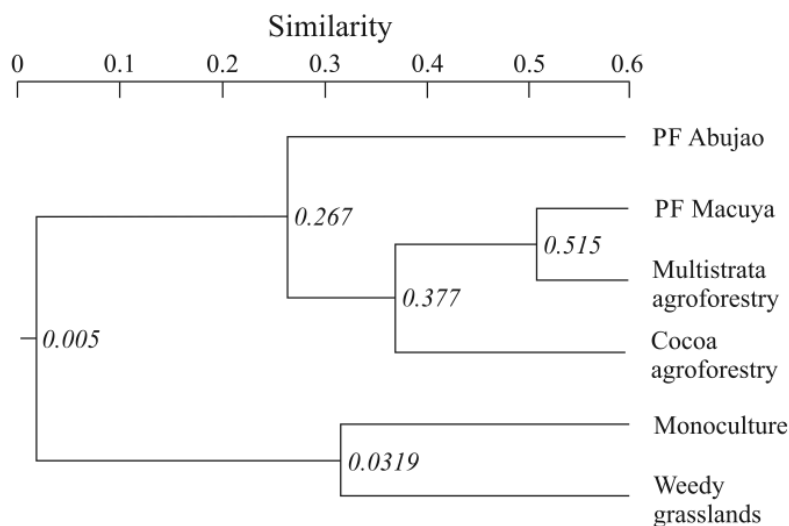


Figure 17. Similarity tree diagram resulting from average linkage clustering using the unweighted pair-group method (UPGMA) on sampled localities.

6.2 Qualitative analysis of the lifestyle strategy of Hymenoptera: Aculeata in assessed ecosystems

Among the Aculeata, we observed a wide variety of feeding and nesting strategies that reflect differences in lifestyle strategies and sociality. Therefore, we analysed the chosen ecosystems in regard to different Aculeata characteristics and tested whether they vary according to the ecological gradient.

First, we were interested in determining which strategy dominates in each ecosystem. In weed vegetation, only small numbers of Aculeata species were found; thus we decided to exclude data from this environment. Our results (summarized in Table 11) show that, in Abujao, it was predominantly social species ($s=103$) that were found. In Macuya forest, solitary species ($s=95$) were the largest group; however, they were closely followed by social species ($s=73$). The numbers of social species and solitary species that were found in multistrata agroforestry, cacao agroforestry, and monoculture were roughly equal within each ecosystem (AFS – 67 social sp./ 60 solitary sp.; CF – 34 social sp./ 20 solitary sp; MC – 9 social sp./ 13 solitary sp). The two forest ecosystems favour either social or solitary species (different in each forest) but that all the agroforestry/agricultural ecosystems have approximately an equal number of social and solitary. Cleptoparasitic lifestyle is only represented by a small number of species in all ecosystems; the small differences between ecosystems are statistically insignificant (Figure 18, resp. table A4 in Appendix A).

We observed that the number of social species found decreases along an ecological gradient towards monocultures, but this decrease is not consistent: there is a sharp decrease between multistrata and cocoa agroforestry (from 67 to 34 social species), and again between cocoa agroforestry and monocultures (in which only 9 social Aculeata species were found). A decrease along the ecological gradient was not found for solitary species. A similar number of solitary species were observed in Abujao primary forest ($s=54$) and multistrata agroforestry ($s=60$); however, the highest number of solitary species were found in Macuya forest ($s=95$). In cocoa vegetation ($s=20$) and monocultures ($s=13$), only a few solitary species were found.

Table 11. Number of *Aculeata* species with different lifestyle strategies per ecosystem.

	PF Abujao	PF Macuya	AFS	CF	MC
solitary	54	95	60	20	13
cleptoparasitic	14	24	19	4	1
social	103	73	67	34	9
Total	171	192	146	58	23

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture).

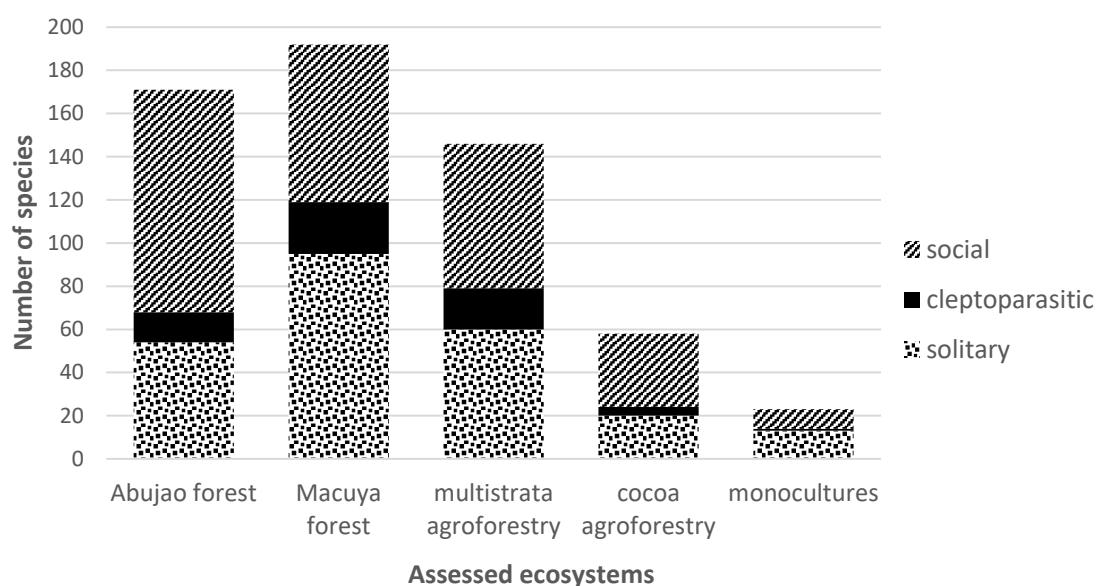


Figure 18. Lifestyle strategy of *Aculeata* species in assessed ecosystems.

(Based on data in table A7 in appendix A.)

The data in Figure 18 also show a relationship between the number of cleptoparasitic species and the number of solitary species. Cleptoparasitic species mainly parasitize solitary species and we see that higher numbers of solitary species are associated with higher numbers of cleptoparasitic species. However, this relationship is not exact, as nature is very variable and various cleptoparasitic *Aculeata* species do not have other *Aculeata* for hosts.

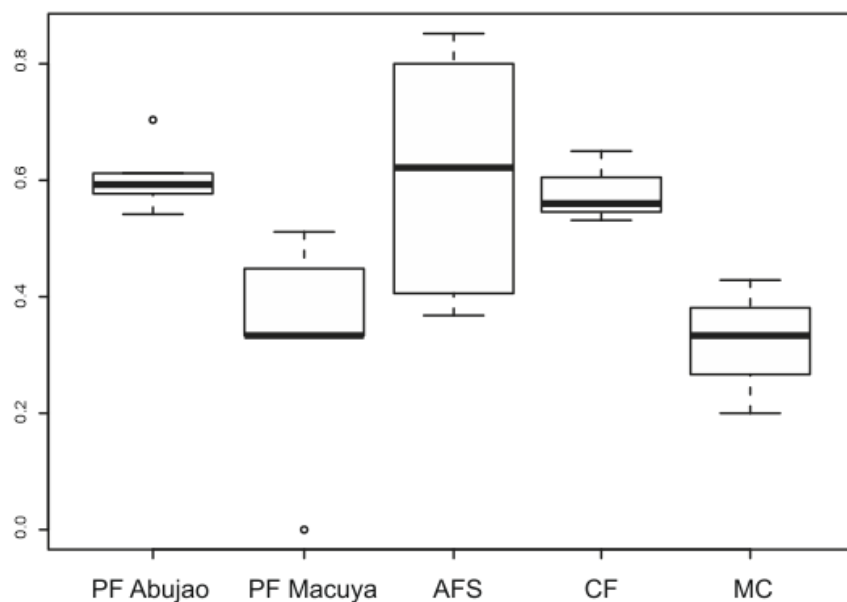


Figure 19. Proportion of eusocial species to other lifestyle strategies in *Aculeata*. (PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture).

We also analyzed the proportion of eusocial species to insect species with other lifestyle strategies as we supposed that the proportion of solitary *Aculeata* to others is the same in all assessed ecosystems. This proportion is not significantly different between Abujao forest, multistrata agroforestry and cacao agroforestry: however, there is a significant difference between the Macuya forest and monoculture (Figure 19). In Macuya and monocultures, lower numbers of eusocial species were found. The high numbers of eusocial species found in the primary forest of Abujao may be caused by the large amount of ants sampled; therefore, we expressed the ant species as distinct values in the graph (Figure 19). The proportional occurrence of other species (non-ant species) in Abujao is probably also influenced by the predatory habits of ants and their reducing effect on many insect species.

Figure 20 shows the results of the rarefaction models that were done using the biodiversity R program. The curves for the primary forest of Macuya and multistrata agroforestry are very steep with a high number of new species. Figure 20 shows all results including ants, which were highly abundant in the primary forest of Abujao. This may be why the pattern of this curve is very different from the others.

We supposed that the trend of increase would be steepest for the primary forest of Abujao, which is the ecosystem that is the least affected by human activities. However, the curve for Abujao primary forest is quite shallow and may be influenced by a large number of individuals from only a few species (fam. Formicidae).

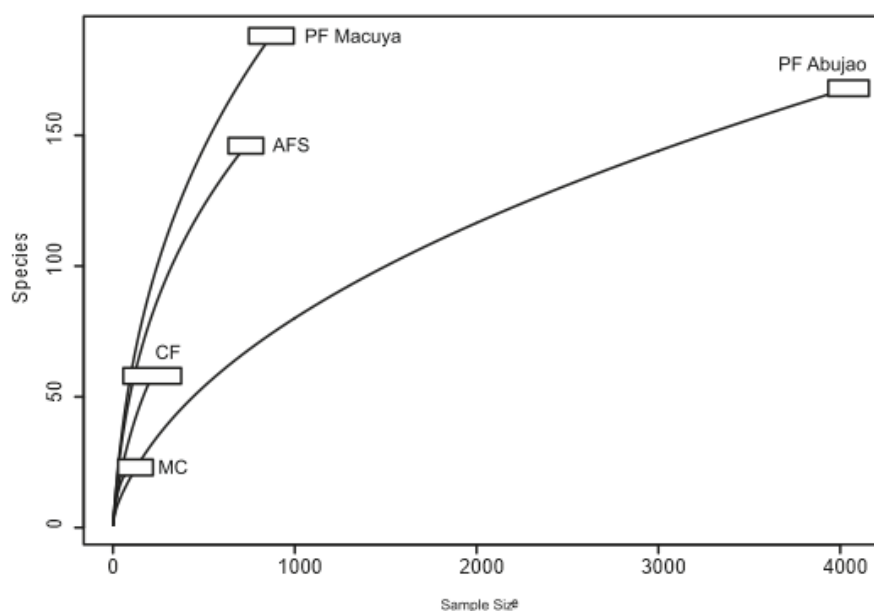


Figure 20. Rarefaction curves show Aculeata species of all lifestyle strategies (social, solitary, cleptoparasitic) in assessed ecosystems.

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture; x – Sample size, y – number of species).

In Abujao forest, we found high numbers of ants; therefore, we decided to test how the model looks without them (Figure 21). Results show that even without ants, the Macuya forest is species rich. The curve for multistrata agroforestry is very similar to both curves for natural forests, supporting the theory that multistrata agroforests can be biodiversity reservoirs for less sensitive species. The curves for cocoa agroforestry and monoculture show low species richness in these ecosystems.

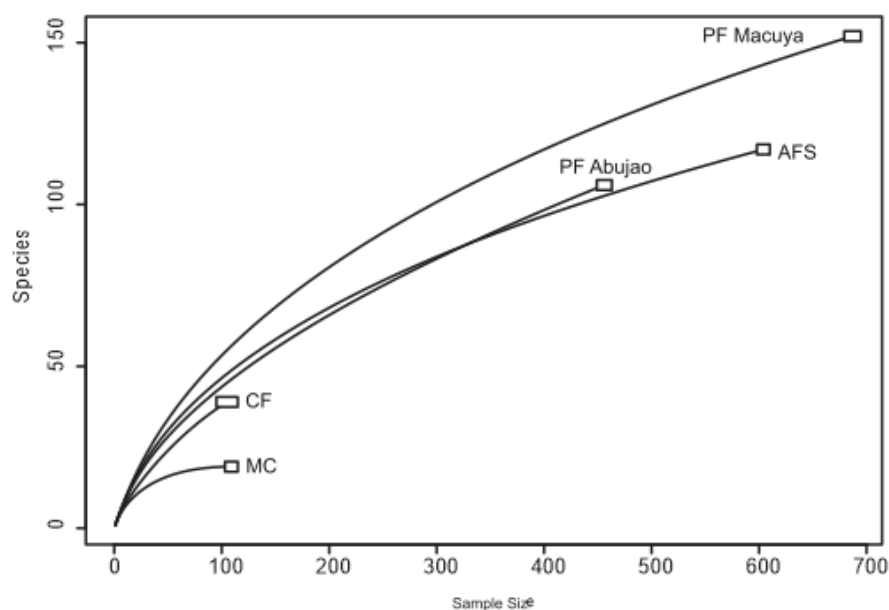


Figure 21. Rarefaction graph of all Aculeata species without ants.

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, x – Sample size, y – number of species).

Testing the same pattern only on ants (Figure 22) highlighted the enormously large number of ant species found in the primary forest of Abujao. The Abujao forest curve has strikingly different progress than all the others, which confirms our theory that the general data (in Figure 20) were influenced by ants in Abujao. This deviation is probably caused by the large number of ants caught in pitfall traps in Abujao, which were possibly installed close to a nest or next to a corridor or ant-path.

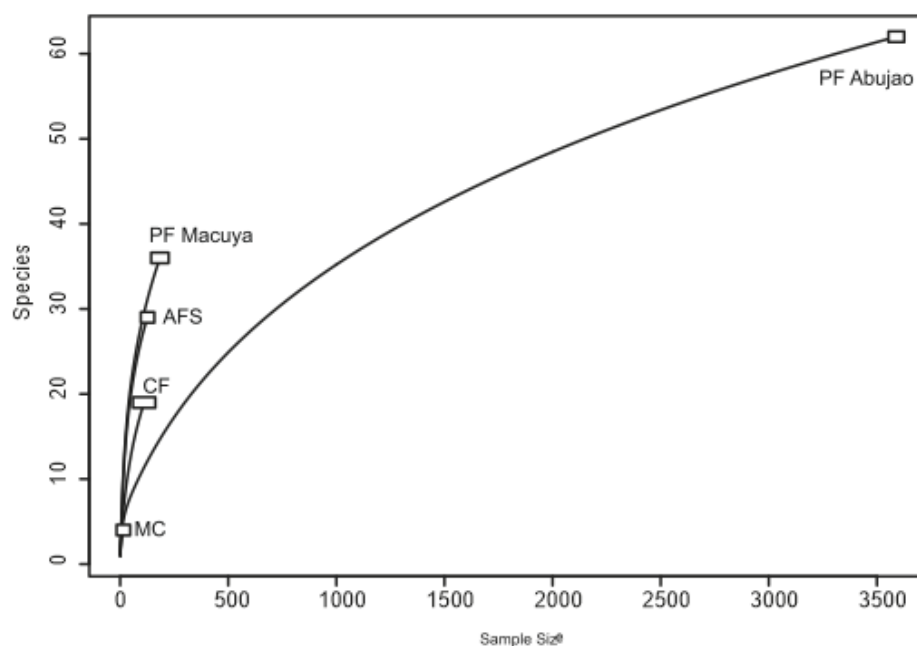


Figure 22. Only ant's rarefaction graph.

(PF-primary forest, AFS-multi-strata agroforestry, CF-cacao forest, MC-monoculture, x – Sample size, y – number of species).

It is very interesting that the Abujao curve is not similar to the Macuya primary forest curve. We assume that there is a factor of human influence in Macuya forest. This forest was selectively logged in its history and this environmental change could have caused slower development of ant dominance in this area.

We also analyzed cleptoparasitic and solitary Aculeata species individually using rarefaction modeling. Both groupings result in very similar curves, which have the same pattern as in the previous group (all Aculeata species included): the curves for cocoa agroforestry and monoculture are very shallow, which refers to low species richness in these ecosystems (Figure 23 and 24). Cleptoparasitic Aculeata species mainly parasitize solitary species, which is confirmed by the very similar trends of the curves for these groups. We must take these results with some degree of consideration because cleptoparasitic species do not only have Aculeata hosts: some of them parasitize spiders, lepidopterans, etc.

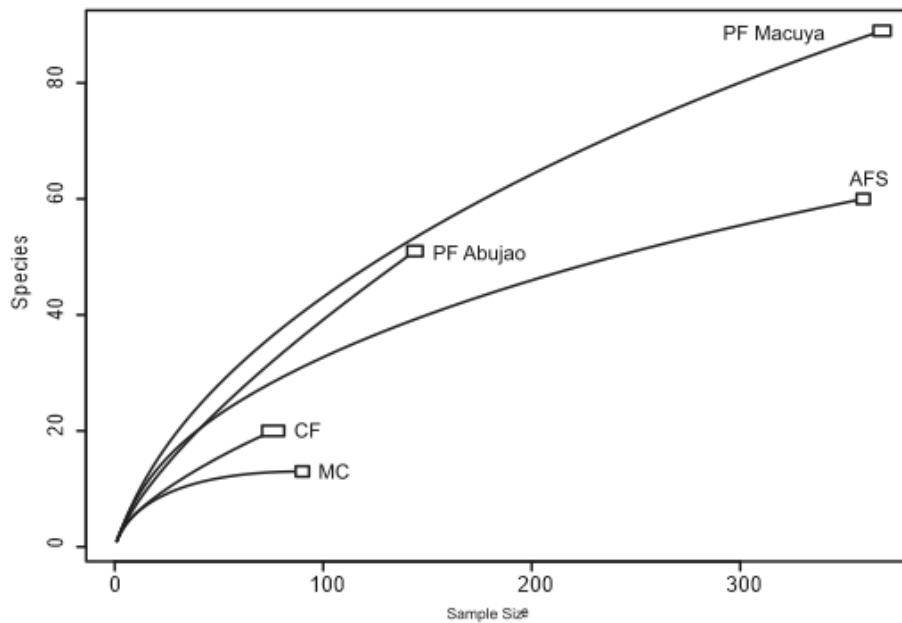


Figure 23. Only solitary Aculeata rarefaction graph.

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, x – Sample size, y – number of species).

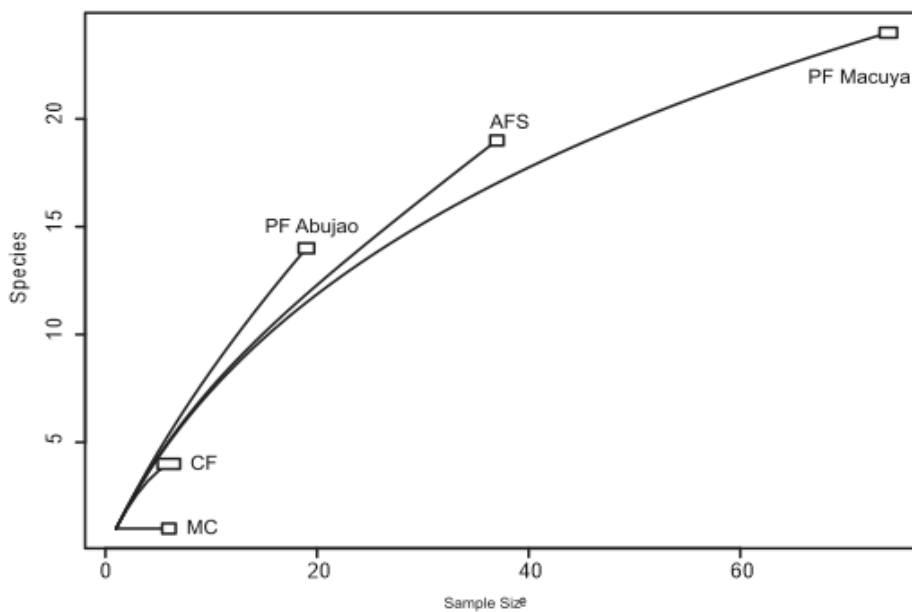


Figure 24: Only cleptoparasitic Aculeata rarefaction graph.

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, x – Sample size, y – number of species).

Nature cannot be clearly described in definitions or graphs and therefore it is not possible to determine, in this diversified environment, which life strategy is the most favorable in any given ecosystem.

6.3. Ethno-entomological knowledge of the local population

Firstly, we were interested in determining the depth of knowledge of respondents. The highest knowledge score was found in the native ethnic community of the Asheninka tribe in San Mateo in Abujao river basin (Table 12, resp. Table A8 in Appendix). Asheninka people live in the upper region of the Abujao River and they depend on resources found in the forest. They also plant maize and cassava, but on a minimal scale. Surprising data were obtained in the case of the Shipibo inhabitants of the Santa Rosa community because they had the lowest score for ethno-entomological knowledge.

Table 12. Summary results of knowledge score in assessed communities

	Village/community	Ethnic origin	Distance to nearest PF (km)	Knowledge level			Score per community
				I.	II.	III.	
left river bank	Pimental	Mestizo	35	285	152	54	491
	Antonio Raimondi	Mestizo	54	257	112	40	409
	San Alejandro	Mestizo	44	292	168	55	515
right river bank	28. de Julio	Mestizo	1	261*	120*	42*	423
	San Mateo	Asheninka	1	313*	215*	87*	615
	Santa Rosa	Shipibo	1	250*	107*	25*	382
Total				1658	874	303	2835

(PF – primary forest, I. Name the insect as specifically as you can; II. Describe where and how the insect lives; III. Specify any special utilization of this insect as food, medicinal, ornamental, mystic, etc.; * data published by Perry Davila (2012).

On the left riverbank, we found the highest value (515) in San Alejandro, where the people mainly work in agroforestry producing cacao. This value was also relatively high in Pimental (491). Antonio Raimondi had the lowest value (409). Another interesting result is that there is no statistical difference in entomological knowledge among mestizo communities of the left and right bank of the river (28. de Julio with 423 points). An alarming fact is that, on average, the mestizo people know how to use less than 17% of recognized insects.

The Asheninka people had the highest scores among all communities for each level of knowledge, including the third level, meaning they have wide knowledge about the practical uses and traditional importance of the presented insects. This tribe is conserving its knowledge, passing it on through generations and using it frequently in practice. According

to our records, they can use over 27% of recognized insects. In mestizo communities, sometimes people know these traditional usages, but only theoretically as they do not use them, thinking they are just myths (personal observation).

Table 13. Statistical difference in ethno-entomological knowledge among communities

	Pimental	Antonio Raimondi	San Alejandro	28. de Julio	San Mateo (Asheninka)	Santa Rosa (Shipibo)	
Pimental		insignificant	insignificant	insignificant	*↑	*↓	Stat. Significant difference / * signal intensity
Antonio Raimondi	0.218		insignificant	insignificant	**↑	insignificant	
San Alejandro	0.899	0.051		insignificant	insignificant	**↓	
28. de Julio	4.17e-01	8.99e-01	1.25e-01		**↑	insignificant	
San Mateo (Asheninka)	1.30e-02	1.00e-03	7.60e-02	1.00e-03		**↓	
Santa Rosa (Shipibo)	4.10e-02	8.99e-01	6.00e-03	8.44e-01	1.00e-03		

*(One-way ANOVA with post-hoc Tukey HSD test results: (p-value) of knowledge score, *intensity of the statistical signal, ↑increasing trend, ↓ decreasing trend, San Mateo and Santa rosa – native tribes, other villages are of mestizo origin).*

Ethno-entomological knowledge in San Mateo (Asheninka tribe) results as statistically different because of its highest values (↑) and Santa Rosa (Shipibo tribe) with lowest values (↓).

We supposed that the factors influencing the amount of entomological knowledge would be: ethnic origin and the distance between the place of residence and primary forest. To test the factor of ethnic origin, we divided the data into two groups: native knowledge (San Mateo and Santa Rosa) and mestizo knowledge (Pimental, Antonio Raimondi, San Alejandro and 28. de Julio). To test the factor of distance to primary forest, the first group was classified as having close proximity to the forest (1 km in distance; San Mateo, 28. de Julio, Santa Rosa) and the second group was classified as being distant from the forest (distance ranging between 35-54 km; Pimental, Antonio Raimondi and San Alejnadro). Our results (Table 14) show that neither ethnic origin, nor distance to the forest influences directly the ethno-entomological knowledge. The results may be significant with more sampling in the assessed localities, as our sample sizes were small.

Table 14. Factors influencing ethno-entomological knowledge

Treatments	Pair Tukey HSD Q statistics	Tukey HSD p-value	Tukey HSD inference
Short vs. Long distance to the forest	0.079	0.899	insignificant
Native vs. Mestizo origin	1.789	0.211	insignificant

(One-way ANOVA with Tukey HSD, testing origin and distance as influencing factors).

7. Discussion

7.1. Insect biodiversity - quantitative analysis

Many large entomological and ecological studies of tropical ecosystems (Footit and Adler 2017; Blüthgen et al. 2000; Blüthgen & Fiedler 2002; Tanaka et al. 2010; Dejean et al. 2010) are mainly focused on biodiversity of the forest canopy (Erwin 1982). For canopy sampling, various sophisticated techniques such as canopy fogging, canopy cranes, balloons, canopy-bridges and walkways, as well as a range of tree-climbing techniques or simply night lights to attract insects have been developed (Basset et al. 2012; Lowman et al. 2012, Yusah et al. 2012); however, using these was not possible in our research for technical reasons. The situation of the lower layers is often neglected in the literature. Our sampling was focused on lower strata layers and, according to the results, seems to be a reasonable sampling strategy because the data follow the ecological gradient. With added sampling of canopies in forest habitat, the differences among the ecosystems could have been even higher. We have used most of the feasible and manageable methods. We realize that forest undergrowth and the undergrowth of artificially created agrocenosis (habitats) are almost incomparable environments because the lower strata in agrocenoses are more influenced by human activities and domestic animals; however, results show that the methods used seem to be sufficient for the purpose of this work and the evaluation.

The fact that forests are highly varied and full of life has been confirmed from the first numerical results, as almost five thousand individuals were identified in the morphospecies. This number would be several times higher if the order Diptera were included in this research: although insects of this order were captured in very high numbers, we were not able to process all of them comprehensively, so this group was excluded from the evaluation.

7.1.1. Abundance

The highest number of insect species and individuals, as expected, was found in both the Macuya and Abujao forest ecosystems. The numbers for Macuya forest were slightly higher than those of Abujao forest, which is less disturbed by human activity and forms part of the protected area. We suppose that this is due to a difference in the amount of sampling: if the same number of samplings had been possible for Abujao forest as in Macuya, we may

have found different results (i.e. the number of species and number of captured individuals would be similar or higher in the Abujao forest ecosystem than in Macuya), which is supported by the accumulation curves (Figure 15).

The order with the greatest abundance and species richness was Hymenoptera (Aculeata and family Chalcididae, Pseudostigmatidae, Scelionidae), found mainly in forest and agroforestry habitats. Dominance of Hymenoptera (including ant species) in the sample is quite common in tropical environments, as Bos (2006), in a study of insect diversity and trophic interactions, mentions a high abundance of ants in the sample and its high proportion in comparison to other sampled families and insect orders. According to our findings, the most abundant group of insects were ants, mainly Formicinae, Dolichoderinae and Paraponerinae. Compared to the study of Bos (2006), we observed a similar species composition of ants. Ants are a very specific group and, according to Blüthgen et al. (2000), we would find even more in the canopy layers because some species nest and feed in the higher parts of trees. In weedy grasslands, we did not find any ant species. This is most likely due to the sampling methodology for ants – we caught ants that fell into our traps without attractants; if we had used specific methods for ant collection (Longino et al. 2002; Kalif Mountinho 2000), we would probably have found some. Ant specific sampling methods were not possible because of technical reasons.

Non-ant Hymenopteran species were also very abundant in forest biotopes but found in much lower numbers in weedy grasslands. A possible explanation may be found in the general species composition and abundance of other arthropods and the way of life of certain Hymenoptera. The weedy grasslands possess the lowest species richness and abundance among all assessed habitats. This may be the result of a lack of carnivore Hymenoptera because there are not enough prey to sustain them. This is confirmed by Klein et al. (2002) who state that the predator-prey ratios in the entomo-fauna changed with intensifying land-use, where herbivores increased and entomophagous species decreased.

The degraded lands are infested by aggressive Imperata weeds, forming such a homogenous vegetation that herbivorous hymenopterans cannot find enough flowering plants to gather pollen and other food sources. This pattern could be applied also to the order Coleoptera. Other factors could be nesting places and frequent fires (Griffith 2000). Cassava monoculture is also relatively poor in plant diversity, but has a bit higher occurrence of other insect orders. However, we must expect fluctuation of the insect population in periods of harvest and new planting.

Order Hemiptera has a relatively similar amount of species across assessed ecosystems, except in the Abajao rainforest (we suppose that this difference is caused by a smaller amount of sampling). Many leafhoppers are closely related to grasslands, where they feed on dominant or subdominant grass such as *Imperata cylindrica* (Hamilton and Whitcomb 2010), which is the reason they were found mainly in grasslands. Leafhoppers were also found in forest and agroforestry habitats, but they were of different morphospecies (probably species more related to forest vegetation) than in the grasslands. In the ecosystem, they play the role of herbivore and prey for other species. Orthopteran species abundance followed the same pattern as leafhoppers because of the sufficient food sources in certain habitats.

Abundance model curves show very similar progress for Abujao forest, Macuya forest, and multistrata agroforestry. Surprisingly, the curve for multistrata agroforestry was not much worse than in the case of primary forest biotopes. In multistrata agroforestry was higher vegetation diversity and species richness than in cocoa agroforestry, monocultures and degraded lands; so we suppose that the higher abundance is consequence of ecological characteristics of multistrata agroforestry.

7.1.2. Species richness and diversity

Although the Shannon biodiversity index of Abujao primary forest was a much lower value than that of Macuya, we expect that there would be higher diversity there. Each site of Abujao forest is characterized by different species (only few species repeats among sampling sites) so we suppose higher diversity with more sampling. This expectation is supported by our results from the Jackknife richness estimator (highest sp. richness 524.3), which refers to even higher values supporting our assumption of incomparably higher biodiversity there. Data collection in Abujao forest was time, financially and technically very limited thus more sampling wasn't possible for these reasons.

Biodiversity in other systems – Macuya primary forest, multistrata agroforestry, cocoa agroforestry, monoculture, and weedy grasslands – shows a decreasing trend for the values of species richness and diversity. According to these data, we cannot disprove our first hypothesis unequivocally; however, this does support our hypothesis that there is lower biodiversity in monoculture than in agroforestry systems (H_1). The same pattern is described by Schulze (2004), who states that decreasing biodiversity trend from near primary to secondary forests, followed by agroforestry systems and then annual crops. As expected, overall species richness tended to decrease within this gradient of increasing habitat

modification. We are convinced that insect biodiversity and species richness is not predetermined only by the ecological gradient and the degree of anthropogenic environmental changes (on a local scale), including edge effects.

We also found interesting fluctuations in the results of Fisher's alpha diversity index. The reason for the fluctuation in Abujao and Macuya primary forests is probably the heterogeneity of species abundance there, especially the abundance of dominant ant species. Fisher's index assumes that species abundance follows log distribution and can be underestimated in communities where clustered distribution of species is found. If the abundance would be more homogenous it would probably present an index value more similar to the assumed trend and Fisher's alpha diversity index of those two forest ecosystems would be higher than in the multistrata agroforestry system. Sampling in the Abujao river valley was also time-limited. Therefore, the biodiversity hotspot should be in Macuya primary forest and Abujao river valley (conditionally).

The literature (Rosenzweig 1992) describes the process of biodiversity change in relation to ecosystem productivity on a regional scale: as productivity rises within a region, first diversity rises and then it falls. Biodiversity also fluctuates and differs within the year depending on climate conditions, harvest, and floods, etc. Primary forest vegetation is mostly unseasonal (Phillips et al. 1994); on the other hand, agroforestry and monocultures are more driven by dry and rainy seasons – perennial cultures are influenced also indirectly through microclimate changes and changes in species assemblages (Bos et al. 2007).

We did not find a statistically significant difference between the species richness and diversity of multistrata agroforestry and Macuya forest. Conversely, our results do show an important statistical difference between multistrata agroforestry and agroforestry based on cocoa production in both species richness and biodiversity. Cocoa agroforestry vegetation structure is probably more simplified than multistrata agroforests, as it is frequently weeded and the vegetation is mainly formed by monospecific cocoa trees and a relatively low number of shade trees. Structurally, it is very different to the forest ecosystem but also more complex than annual cropping.

We found that species richness and diversity in cocoa agroforestry is closer to annual cropping than to forest. This is contrary to the finding of Bos et al. (2007), who published that in comparison to other forms of land-use, such as annual crops and oil palm plantations, richness of cacao agroforestry systems is high (Bos et al. 2006) and can be comparable with that of rainforests. Other authors have also found cacao agroforests to be very rich in species and good biodiversity reservoirs. For example, Rice and Greenberg (2002) found that cacao

plantations can resemble forests in terms of tree cover: accordingly, cacao agroforestry systems have gained interest as a tool for tropical biodiversity conservation. However, according to our results, the cacao agroforests seem to be not as rich in insect species as multistrata agroforestry systems. On the other hand, as Urquhart (1955) published, cacao agroforestry systems have received increasing attention for their potential for harboring tropical diversity because they cover at least 8 million hectares of land worldwide.

Differences in species richness among the assessed ecosystems are more visible on accumulation curves of the sampled morphospecies. The abundance models showed similar trends for Macuya forest, Abujao forest, and multistrata agroforestry ecosystems; however, accumulation curves of richness reveal that multistrata agroforestry does not reach the same high numbers of both primary forests. An imaginary gap separates cacao forestry and monoculture from multistrata agroforestry, which supports our assumption that cocoa plantation has characteristics of a monoculture environment.

We consider multistrata agroforestry as a good model for bioreservoirs in landscapes where monoculture and degraded lands predominate, and also as acute reservoirs in pressing situations such as fires in natural habitat, etc. Griffith (2000) published that agroforestry forms a refuge for birds and other animals during large fires. Some less sensitive species and adaptive species can find refuge and new territory in agroforestry locations.

7.1.3. Similarity in species composition

Our second hypothesis (H₂), that there is a high similarity of species composition between primary forest and agroforestry systems (AFS, CF) cannot be disproved. Our finding (Figure 17) that multistrata agroforestry species composition highly similar (51%, Sørensen index) to that of primary forest is also supported by other studies, such as Bhagwat et al. (2008), who classify heterogeneous agroforestry systems in which tall trees are maintained and planted for shade (agroforestry systems) as a refuge for tropical biodiversity.

Our results also correlate to other studies that have found that, although cacao agroforests can easily be as rich in insect species as nearby natural forest sites (Bos et al. 2007, Delabie et al. 2007), species assemblages have been found to differ between natural forests and cacao agroforests and between differently shaded cacao agroforestry (Bos et al. 2007). We also found that the species composition of cacao agroforests is very similar (39%, Sørensen index) to that of multistrata agroforestry systems, including the composition of ant species.

According to the literature, ants are a species rich and ecologically important group of insects that are directly affected by changes in agroforestry management (for example, by altered resource and nest site availability; Ambrecht et al. 2004), but also indirectly through a complex interplay between the microclimate and subsequent changes in the species composition.

Delabie et al. (2007) found that a Brazilian cacao agroforest with a species poor stand of shade trees harbored a high proportion of forest ants when compared with other tropical agroecosystems and urban habitats. Similarly, Bos et al. (2007) found that about half of the ant species in Indonesian cacao agroforests also occurred in nearby forest sites, but its proportion decreased with decreasing shade cover (Bos et al. 2007). We can only speculate that the similarity we found between cocoa agroforest and Macuya forest is influenced by their proximity (distance of 28 km).

Our most important result is the relatively low similarity of Abujao forest to other forest-like sites (from 30% to 7%, along a decreasing gradient; Sørensen index), which points to the fact that modified or artificial forest-like vegetation sites are inhabited by species that are able to spread out, so they are not in population depression. More tolerant species are able to profit in alternative biotopes.

7.2. Qualitative analysis of species composition and behavior

The most abundant and species rich group sampled was Hymenoptera: Aculeata. We were interested in whether a particular life strategy prevails in certain ecosystems. We hypothesized that the highest number of Aculeata is in natural forests and, according to our results, the highest number was indeed found in the primary forest of Macuya, followed by the forest of Abujao. This finding supports our hypotheses (H3). Sampling in Abujao was time limited; if a longer time period for sampling had been possible, we would expect to have found even more Aculeata species there than in Macuya forest.

Previous investigations (Arneson and Wcislo 2003; Dejean et al. 2007; Wilson 1990) have found that eusocial Aculeata are dominant in natural primary forest. Further supporting this are other authors who have found that most of the tree species of tropical forests are insect-pollinated, most often bee-pollinated (Michener 2000; Frankie et al. 1990; Bawa 1990). Conservation of many habitats thus depends upon preservation of bee populations: if the bees disappear, reproduction may be severely limited in major elements of the flora

(Michener 2000). Our statistical analysis of the proportion of social Aculeata to other Aculeata species resulted in interesting data. We found that social Aculeata are predominant in the primary forest of Abujao, as we. Conversely, in monoculture, there were significantly less social species.

We expected that social Aculeata could survive on monoculture land because of the strength of their organized character and generalist (wide) food repertoire. In primary forest, these insects can find food sources in abundance but monocultures probably do not provide enough food sources. We obtained a significantly higher proportion of social Aculeata in multistrata agroforestry than in monoculture, which could be explained by a diversity of flowering plants and nesting opportunities which agroforestry provides during the whole year. The proportion of social Aculeata in Macuya was surprisingly lower than in Abujao and even in multistrata and cocoa agroforestry. These results are difficult to interpret and we have no specific explanation for it. These results cannot support our hypothesis (H₄) that the same proportion of social and solitary Aculeata are in all assessed habitats.

Rarefaction curves helped us to discover the large influence that ant species had on all sample evaluation. When we analyzed social Aculeata without ants, the curves for primary forests followed the expected progress and multistrata agroforestry had a similar curve to both forests. The abundant samples of ants in Abujao forest can be explained by deviations in the sampling: the pitfall trap was probably placed too close to an ant nest and/or ants were attracted by prey that had fallen into the trap (Wang Ch et al. 2001). Ants are very social and predatory animals, so they influence the diversity and abundance of other insect species; although, some recent studies of Papua New Guinea have shown the exact opposite of this theory (Novotný & Toko, 2014).

We used rarefaction curves to describe the situation of solitary Aculeata as well. These species are usually very narrowly specialized on food sources, accessibility and natural conditions; therefore, they are a very sensitive group among analyzed Aculeata (Lasalle and Gauld 1993; Loyola et al. 2006). We measured the highest values in natural forest habitats, which can be explained by these ecosystems having the widest offer of food and nesting sources, as well as the required microhabitats. In contrast, cocoa agroforestry and monocultures, where the acceptable habitats are strongly disturbed by human activities, had the lowest values of solitary Aculeata. Multistrata agroforestry lies between these two extremes, apparently because of a lack of appropriate conditions (for example, old wood to nest in). In this ecosystem, those species that are less sensitive, with less strict ecological requirements, should survive.

We also hypothesized that cleptoparasitic Aculeata will be represented by a very similar number of species in all assessed habitats (H₅). We found the highest number of cleptoparasitic species in Macuya forest, which also had the highest number of solitary species. According to the data, it seems that there is a relationship between the number of solitary species and the number of cleptoparasitic ones. In cocoa agroforestry and monocultures, fewer solitary species were found and, similarly, only a few cleptoparasitic species. In multistrata agroforestry, we observed a comparatively higher number of species from the cleptoparasitic group, which seems to indicate that this is a relatively good habitat for them. Cleptoparasitism is a very specialized life strategy (Lasalle and Gauld 1991), so we expected there to be less species in this locality; however, our finding of the opposite, likely means that multistrata agroforestry provides a sufficient diversity of host species. According to these results, we cannot support our fifth hypothesis because the data shows that the reality is somewhat different; however, we also cannot disprove it unequivocally.

7.3. Ethno-entomological research in the study area

We were surprised by the high amount of ethno-entomological knowledge that was found among the native Asheninka people of the upper Abujao River and conversely, the very low score that we found in another native ethnic group, Shipibo. These results cannot support our hypothesis (H₆) that native ethnic tribes have deeper knowledge of insects than the small scale farmers of non-ethnic origin. Lower ethno-entomological knowledge in Shipibo tribe could be explained by the geographical position of the village and also the way of life. Shipibo people have a close relationship to the forest, but an even closer one to the river; thus, their diet is rich in fish. This village is located at the confluence of the Abujao and Ucayali rivers and it is very easy to reach Pucallpa city (only a few hours voyage). Their relationship with the forest is not as essential for their survival as it is for other tribes. Younger generations are moving towards modern lifestyles and probably do not find traditional ecological knowledge as important as people of other, more rural, communities do. Espinosa (2012) wrote that the Shipibo people are afraid of forgetting their traditions among young members of the tribe and our results indicate that there might be some possibility of this happening.

Mestizo people had regular entomological knowledge, but not as deep as we had expected. Originally we supposed that farmers will recognize various species (or morphological groups of insects) as pests in this case, but this type of knowledge was found only rarely. For example knowledge and use of termites and their nests (*Nasutitermes* sp.), commonly known among native tribes, wasn't found in farmers communities, or just a myth.

We expected that knowledge of insects is directly proportional to the distance between the forest and the village (H₇). However, our study found that this factor is statistically insignificant; it is likely that a difference could be found with more sampling in native and mestizo settlements that are located at various distances from the forest. According to the results, our seventh hypothesis cannot be supported.

More precise data would be possible with more respondents, but neither Asheninka nor Shipibo communities had a sufficient number of respondents of the required age. San Mateo is a very small village and some of the hunters were not present at the time of our data collection. Santa Rosa, the village of Shipibo people, was more inhabited but the people were not willing to answer our questions.

Regrettably, we must admit that our data support the conclusion that the knowledge passed down by native ethnic tribes through the generations is gradually declining. Our findings agree with those of Perry Davila (2012), who did an investigation in the same communities. There is a worldwide trend in native communities that follows this same pattern – traditional knowledge is preserved by the oldest members of the community and the younger members are not interested in learning it to preserve it for future generations. This is the main reason why traditional knowledge is disappearing with each generation. Although our results have shown that affiliation with native ethnicity has no impact on ecological knowledge, it is necessary to collect and record this knowledge because it contributes to the cultural wealth of subsequent generations and of humanity as a whole.

8. Conclusion

The impact of human activity on landscape transformation and land-use, as well as its overall impact on diversity is an important subject of research in the tropics around the world. We focused on the Peruvian region of Ucayali, specifically, in the surroundings of the rapidly growing city of Pucallpa, where the environment has been and continues to be widely transformed. We found a large reduction in diversity, coinciding with increasing human activity. Our results strongly suggest that multistrata agroforestry has the ability to form a bioreservoir for a variety of insect species that also occur in tropical forests because the composition of less sensitive and adaptable species is similar in both kinds of ecosystems (forests and agroforests). Agroforestry based on cocoa production showed average values for diversity and a lower similarity to the species composition of the forest than in the case of multistrata agroforestry. Given that cocoa production is expanding, we consider cocoa agroforestry to have good potential as a bioreservoir for a variety of forest insect species. Based on our results we would like to recommend farmers to keep more tree species on agroforestry fields which would increase insect diversity. There would be beneficial to establish more multistrata agroforestry plots in the Ucayali region and give farmers education and instructions how to manage an agroforestry system. This study forms a background for future investigations and further research on insect biodiversity, especially in the canopy layer, should be also done.

We also evaluated the life strategies that are being used by representatives of Hymenoptera: Aculeata in the assessed ecosystems. According to our results, eusocial species predominate in forest systems and their numbers decrease along a decreasing ecological gradient. Solitary species follow a similar pattern. Only a few cleptoparasitic species were found in degraded lands and monocultures. In general, monoculture and weedy grasslands were species poor. We are convinced that this is the result of a lack of food sources during some periods of the year due to frequent human disturbances in the form of harvesting and fires.

This study also investigated the entomological knowledge of local inhabitants of mestizo origin and two native groups: Asheninka and Shipibo. We tested their knowledge of insects and the possible uses they can have. We supposed that the most knowledge would be found among native tribe people, but this was not fully supported. Widespread knowledge was found among people of the Asheninka tribe, who still keep traditional knowledge of the

uses of many insects. In contrast, people of the Shipibo tribe had less knowledge than farmers of mestizo origin. We consider this knowledge to be part of the cultural wealth of a given tribe and for humanity in general and, therefore, it must be kept for future generations. Among the native tribes Asheninka and Shipibo is deficiency of books and papers summarizing their knowledge about nature, traditions and rituals in their own language. We recommend to publish the information from ethno-entomological research about Asheninka and Shipibo people in their own native language, which can serve to educate young generations.

9. References

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Appendix A- Tables

Table A1. One-Way ANOVA with Tukey test and Bonferroni and Holm results: all pairs simultaneously compared – Abundance.

	PF Abujao	PF Macuya	AFS	CF	MC	W
mean	330.5	373	323.75	91,5	77.25	41.25
sum of squares (*1000)	446.6	565.8	426.4	34.9	24.8	7.031
sample variance S2	3247	3117.3	2384.9	491	314.9	74.91
sample st. dev.	56.98	55.83	48.83	22.1	17.74	8.65
st. dev. of mean	28.49	27.91	24.41	11.07	8.87	4.32
	sum of squares	degrees of freedom	mean square	F statistic	p-value	
treatment	456333	5	91266.7	56.86	2.14E-10	
error	28890	18	1605			
total	485223	23				

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland, St. dev. – standard deviation. If the value is lower than 0.05, it is a statistically significant difference).

Table A2. One-Way ANOVA with Tukey test and Bonferroni and Holm results: all pairs simultaneously compared – Species.

	PF Abujao	PF Macuya	AFS	CF	MC	W
mean	136.25	171.75	166.75	61.25	51.5	31.25
sum of squares (*1000)	75.173	118.877	112.507	15.921	10.826	3.981
sample variance S2	305.58	294.91	428.25	304.91	72.33	24.91
sample st. dev.	17.48	17.17	20.69	17.46	8.5	4.99
st. dev. of mean	8.74	8.58	10.34	8.73	4.25	2.49
	sum of squares	degrees of freedom	mean square	F statistic	p-value	
treatment	77757.8	5	15551.5	65.209	6.73E-11	
error	4292.7	18	238.48			
total	82050.6	23				

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland, St. dev. – standard deviation. If the value is lower than 0.05, it is a statistically significant difference).

Table A3. One-Way ANOVA with Tukey test and Bonferroni and Holm results: all pairs simultaneously compared – Shannon index of diversity.

	PF Abujao	PF Macuya	AFS	CF	MC	W
mean	2.78	4.8	4.77	3.67	3.6	3.33
sum of squares (*1000)	31.5	92.2	91.1	54.5	53.9	44.5
sample variance S2	0.16	0.004	0.02	0.12	0.02	0.3
sample st. dev.	0.41	0.06	0.13	0.34	0.16	0.16
st. dev. of mean	0.2	0.03	0.06	0.17	0.08	0.08
	sum of squares	degrees of freedom	mean square	F statistic	p-value	
treatment	12.8389	5	2.5678	42.7976	2.25E-09	
error	1.0800	18	0.06			
total	13.9189	23				

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland, St. dev. – standard deviation. If the value is lower than 0.05, it is a statistically significant difference).

Table A4. One-Way ANOVA with Tukey test and Bonferroni and Holm results: all pairs simultaneously compared, p-value, *Aculeata* species.

	PF Abujao	PF Macuya	AFS	CF	MC		
Solitary	PF Abujao	-	0.35	1.45	5.8	2.83	Cleptoparasitic
	PF Macuya	0.9	-	4.6	0.21	0.08	
	AFS	1.83	1.33	-	1.99	0.3	
	CF	8.7	0.28	3.14	-	6.15	
	MC	6.6	0.08	1.2	5.97	-	
Social	PF Abujao	-					
	PF Macuya	0.13	-				
	AFS	1.72	1.65	-			
	CF	8.78	0.19	1.83	-		
	MC	1.46	0.51	0.14	2.36	-	

(PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture. If the value is lower than 0.05, it is a statistically significant difference).

Table A5. Number of shared species between ecosystems

	PF Abujao	PF Macuya	AFS	CF	MC	W
PF Abujao		106	101	58	30	14
PF Macuya			176	98	57	31
AFS				86	51	19
CF					32	20
MC		2				23
W						

(Grey field - totally shared species among all ecosystems. PF-primary forest, AFS-multistrata agroforestry, CF-cacao forest, MC-monoculture, W-weedy grassland.)

Table A6. One-Way ANOVA with Tukey test and Bonferroni and Holm results: all pairs simultaneously compared – Ethno-entomological knowledge score.

	Pimental	Antonio Raimondi	San Alejandro	28. de Julio	San Mateo	Santa Rosa
mean	54.55	45.44	57.22	47	68.33	42.44
sum of squares (*1000)	27.26	18.64	30.29	21.35	42.55	16.27
sample variance S ²	59.77	7.27	102.94	183.75	66.75	7.02
sample st. dev.	7.73	2.69	10.14	13.55	8.17	2.65
st. dev. of mean	2.57	0.89	3.38	4.51	2.72	0.88
	sum of squares	degrees of freedom	mean square	F statistic	p-value	
treatment	4125.27	5	825.05	11.57	2.29E-07	
error	3420.22	48	71.25			
total	7545.5	53				

Table A7. Sampled Aculeata families sorted by lifestyle strategy.

Sociality	Family	Abujao river primary forest		Macuya forest		Agroforestry-multistr.		Agroforestry-cacao		Monoculture	
		species	individuals	species	individuals	species	individuals	species	individuals	species	individuals
solitary	Apidae	2	2	3	3	4	31	2	2	1	6
	Bethylidae	7	9	9	24	5	13	1	1	0	0
	Crabronidae	12	27	34	101	19	84	5	6	7	51
	Halictidae	14	76	9	74	9	125	5	46	2	20
	Megachilidae	3	6	0	0	0	0	0	0	0	0
	Pompilidae	14	22	28	124	14	72	5	14	3	13
	Sphecidae	0	0	4	6	2	3	0	0	0	0
	Tiphiidae	1	1	3	28	3	21	2	7	0	0
	Vespidae	1	1	5	8	4	10	0	0	0	0
	Subtotal	54	144	95	368	60	359	20	76	13	90
cleptoparasitic	Apidae	1	1	1	7	1	1	0	0	0	0
	Crabronidae	0	0	4	14	3	12	0	0	0	0
	Chrysididae	1	1	1	1	2	2	0	0	1	6
	Halictidae	1	2	0	0	0	0	0	0	0	0
	Mutilidae	10	14	18	52	12	21	4	6	0	0
	Megachilidae	1	1	0	0	1	1	0	0	0	0
		Subtotal	14	19	24	74	19	37	4	6	1
social	Apidae	18	138	13	81	14	56	5	7	1	2
	Formicidae	62	3590	35	184	29	127	19	111	4	15
	Vespidae	20	145	23	158	20	137	9	15	4	11
	Halictidae	3	10	2	6	4	15	1	1	0	0
		Subtotal	103	3883	73	429	67	335	34	134	9
	Total	171	4046	192	871	146	731	58	216	23	124

Table A8. Ethno-entomological knowledge of presented insects per ethnic group.

order	family	presented insect	Asheninka			Mestizo			Shipibo			Subtotal
			I.	II.	III.	I.	II.	III.	I.	II.	III.	
Coleoptera	Scarabaeidae	brown rhinoceros beetle	9	9	6	36	33	14	9	9		54
	Silphidae	carrion beetle	9	9		36	22		9	9		54
	Scarabaeidae	dung beetle	9	9		36	27		9	9		54
	Carabidae	ground beetle	9	1	1	31	1					40
	Coccinelidae	lady beetle	9	1		36	12	1	9			54
	Chrysomelidae	leaf beetle subfam. Galerucinae	9	1		33	19	1	7			49
	Lampyridae	lightning bug	9	9	4	32	32	15	9			50
	Cerambycidae	longhorn beetle	9	9		36	7		9			54
	Tenebrionidae	Mealworm beetle	9	4	1	34	24	8	4			47
	Dryophthoridae	palm weevil <i>Rhynchophorus</i> sp.	9	9	9	36	36	36	9	9	9	54
Dictoptera	Ectobiidae	Cockroach	9	9	3	36	1		9	8		54
	Blattidae	large cockroach	9	9		36	1		9			54
	Mantidae	praying mantis	9	9	6	36	32	18	9	9	4	54
	Termitidae	termite <i>Nasutitermes</i> sp.	9	9	9	36	24	13	9	9		54
Hemiptera	Cicadidae	Cicada	9	9		36	1		9			54
	cercopidae	Froghopper	9	8		32	11		9			50
	Fulgoridae	Lanternfly	9	9	9	32	31	9	9	9		50
	Auchenorhyncha	leafhopper	7	1		19	7					26
	Delphacidae	planthopper	9	1		8						17
	Membracidae	treehopper	9	1		17						26
Heteroptera	Reduviidae	conenose bug	9	1		36			9			54
	Pentatomidae	shield bug	9	1		36	2		9			54

(I. naming the insect, II. ecological indication, III. use or traditional significance.)

Table A8. Continued. Ethno-entomological knowledge of presented insects per ethnic group.

order	family	presented insect	Asheninka			Mestizo			Shipibo			Subtotal
			I.	II.	III.	I.	II.	III.	I.	II.	III.	
Hymenoptera	Formicidae	ant subfam. Dolichoderinae	9	9		36			9			54
	Formicidae	army ant <i>Eciton</i> sp.	9	4	4	26	22	7	9	9		44
	Formicidae	Atta ant	9	9	4	36	36	8	9	9		54
	Sphecidae	digger wasp subfam. Sphecinae	9	1		12			7			28
	Vespidae	paper wasp subfam. Polistinae	9	9		36	23		9			54
	Formicidae	paraponera giant ant	9	9	7	36	36	31	9	9	4	54
	Pompilidae	spider wasp	9	1		11						20
	Apidae	stingless bee <i>Partamona</i> sp.	9	9	5	36	23	19	9	9	8	54
	Apidae	sweat bee	9	9	1	24	8		7			40
Orthoptera	Gryllidae	Cricket	9	8	8	36	10		9			54
	Acrididae	Grasshopper	9	9	5	36	32	11	9			54
	tettigonidae	long-horned grasshopper	9	9	5	36	32		9			54
	Gryllotalpidae	mole cricket	9	1		28	7					37
Total			313	215	87	1095	552	191	250	107	25	1658

(I. naming the insect, II. ecological indication, III. use or traditional significance.)

Appendix B- Photodocumentation



Primary forest in Abujao



Macuya primary forest



Multistrata agroforestry



Cocoa agroforestry



Weedy grasslands



Cassava monoculture



Slash and burn (logged and burned forest)



Burned weedy grassland



Pitfall trap installation (Agroforestry)



Local rural road after rain (Antonio Raimondi)



Hymenoptera: Meliponini (Abujao River valley)



Coleoptera: Passalidae



Interview with Asheninka woman (San Mateo)



Paraponera clavata (Formicidae)