Arthropod Communities in Rice Agroecosystems in Northern Vietnam -

Quantifying the Impact of Pesticides and Land Cover Heterogeneity

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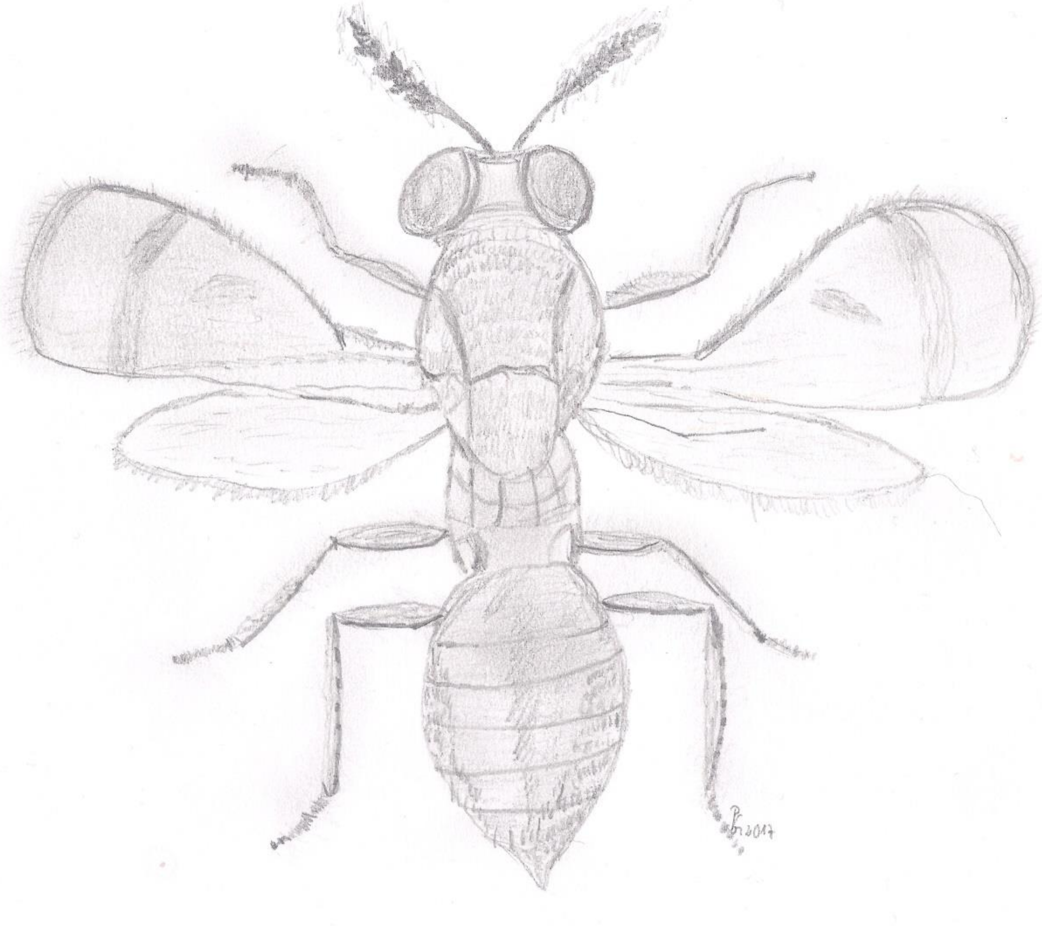
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Summary

Rice is one of the most important crops and nourishes over half of the world’s population. Especially in Southeast Asia, irrigated rice production represents the predominant agroecosystem.

Vietnam is among the five main producers of rice and is the second largest rice exporter worldwide. Strong regulations for pesticide use are lacking in Vietnam and the country is dominated by intensive rice cultivation in the Mekong Delta as well as in the Red River Delta.

During and after the so-called ‘Green Revolution’ of the 1960s, agricultural intensification has seen a considerable increase worldwide and particularly in the developing world. High yielding crop varieties of rice were introduced to Vietnam combined with fertiliser and pesticide application which led to intensive rice production and higher yield. To this day, pesticide application and land-use changes are strongly associated with rice production, environmental degradation, and biodiversity loss in Vietnam.

Biodiversity can be defined across multiple spatial scales (alpha, beta, and gamma) as well as different diversity dimensions (e.g. functional and taxonomic diversity), which is crucial when evaluating ecosystem services. Rice fields can harbour a rich biodiversity of arthropods. Arthropods provide important ecosystem services like controlling species harmful to rice plants, which would otherwise turn into pests and lead to harvest losses when becoming too abundant. To avoid the latter, farmers frequently use pesticides. However, such practices do not only suppress the pests and other herbivores, but also other important functional groups like predators and parasitoids, many of which are natural enemies of rice pests. In addition, important rice pests can become resistant to some insecticides, thus adversely impacting the desired effect of insecticides. To reduce high amounts of pesticides, diverse land cover types (land cover heterogeneity) in the surrounding of rice fields can be promoted as these are beneficial for natural enemies. Diverse land cover types can provide shelter for many arthropods and may also offer additional food sources such as nectar and pollen. However, diverse land cover types may be important for herbivores for the very same reason. Therefore, surveys about the interacting effects between natural enemies (predators and parasitoids) and land cover heterogeneity on herbivores are important to understand ecological processes in rice fields. Effects of pesticides and land cover heterogeneity on multiple spatial scales as well as different diversity dimensions (functional and taxonomic diversity) in rice fields are essential to investigate.

Reliable monitoring techniques of arthropod communities in irrigated rice fields rely on appropriate sampling methods, which serve as basis of all investigations and are therefore fundamental. Knowledge about appropriate sampling methods can save time and reduce workload as well as economic costs. Consequently, the right choice of the sampling method is essential and should be the first step before commencing any investigations.

The overall aim of this thesis is to investigate the interacting effect of communities of different functional groups with pesticides and land cover heterogeneity as well as to examine the effect of land cover heterogeneity and pesticides on functional and taxonomic diversity. The thesis has three major parts:

1) A comparison of three standard sampling methods (sweep net, Malaise trap, and blow vac) in terms of four different focal categories: a) sampled arthropod density, b) time efficiency, c) rescaled abundance, and d) relative abundance of functional groups.
2) A study of functional and taxonomic diversity in two stages: a) diversity partitioning of arthropod communities in rice fields into their alpha, beta, and gamma components at local and landscape scale, and b) analysing the effects of pesticides and land cover heterogeneity on both functional and taxonomic diversity.
3) An assessment of the impacts of interacting effects of natural enemies (predators and parasitoids), land cover heterogeneity, and insecticides on herbivore abundance in rice fields.

To address these objectives, arthropod communities were analysed in two regions in Northern Vietnam (Hai Duong and Vinh Phuc) during the dry season in 2015. Arthropods were sampled in 19 rice fields early in the season (35 and 50 days after the rice was transplanted into the fields), using sweep net, blow vac, and Malaise traps. All sampled arthropods were identified and classified into functional groups: herbivores, predators, parasitoids, decomposers, and fungivores.

Results of part 1: The three sampling methods differed fundamentally and, depending on the research question and targeted taxa, each method has its advantages and disadvantages. For fast, easy, and inexpensive sampling of arthropods in irrigated rice fields, sweep netting seems to be the method of choice. Parasitoids and herbivores were sampled in highest numbers with Malaise trapping. Predators were sampled in highest numbers with blow vac sampling, while decomposers were sampled in highest numbers with sweep netting.

Results of part 2: Partitioned alpha, beta, and gamma of functional and taxonomic diversity were highly correlated and little functional/taxonomic turnover was found at local and landscape scale. Both diversity dimensions of arthropod communities were similarly negatively affected by pesticides. Land cover heterogeneity led to an increase of functional and taxonomic diversity at an early stage of rice plants (day 35).
Results of part 3: Both natural enemies and insecticides reduced herbivore abundance, while land cover heterogeneity indicated no effect.

In general, the results indicate the importance of natural enemies, land cover heterogeneity, and the amount and number of pesticides in rice agroecosystems, though the magnitude of such effects partially depends on the method. Land cover heterogeneity promotes functional and taxonomic diversity of arthropod communities in the early stage of rice plants but increased pesticide application leads to a decline in both diversity dimensions and the benefit of land cover heterogeneity seems to diminish. Therefore, pesticides should be used in lesser quality and quantity in rice agroecosystems. Rice agroecosystems have a high potential of self-regulation in the form of natural enemies, which can be promoted with the approach of ‘ecological engineering’.

Zusammenfassung

Reis ist eines der weltweit wichtigsten Grundnahrungsmittel und wird von über der Hälfe der Weltbevölkerung genutzt. Vor allem in Südostasien dominiert der bewässerte Reisanbau die Landwirtschaft.

Vietnam gehört zu den fünf Hauptproduzenten von Reis und ist weltweit der zweitgrößte Reisexporteur. Wirksame Regelungen für die Verwendung von Pflanzenschutzmitteln fehlen und das Land wird von einem intensiven Reisanbau im Mekong-Delta sowie im Delta des Roten Flusses dominiert.

Während und nach der sogenannten "Grünen Revolution" der 1960er Jahre kam es weltweit und besonders in den Entwicklungsländern zur Intensivierung der Landwirtschaft. Eingeführte Reis-Hochertragssorten, kombiniert mit erhöhtem Dünger- und Pflanzenschutzmitteleinsatz, ließen die Reiserträge steigen. Bis heute wird die Verwendung von Pflanzenschutzmitteln im Reisanbau stark mit Degradierungsprozessen der Umwelt und dem Verlust biologischer Vielfalt assoziiert.

Diversität kann über mehrere räumliche Skalen (alpha, beta und gamma) sowie verschiedene Diversitäts-Dimensionen (z.B. funktionale und taxonomische Diversität), die bei der Bewertung von Ökosystemleistungen entscheidend sind, definiert werden. Reisfelder können eine hohe Diversität an Arthropoden beinhalten. Arthropoden erfüllen wichtige Ökosystem-Dienstleistungen, wie beispielsweise die Unterdrückung von Reisschädlingen, welche bei hoher Abundanz zu Ernteverlusten führen können. Um Ernteverlusten vorzubeugen, verwenden Landwirte hohe Mengen an Pflanzenschutzmitteln. Allerdings werden dadurch nicht nur Reisschädlinge und Herbivoren unterdrückt, sondern auch andere wichtige funktionelle Gruppen, wie Prädatoren und Parasitoide, von denen viele natürliche Feinde der Reisschädlinge sind. Darüber hinaus bleibt oft die gewünschte Wirkung von Insektiziden aus, da wichtige Reisschädlinge Resistenzen gegen einige Insektizide gebildet haben. Zur Reduzierung von Pflanzenschutzmitteln können diverse Landschaftstypen in der Umgebung (Landschaftsheterogenität) von Reisfeldern erweitert werden, da diese begünstigend auf natürliche Feinde wirken können. Verschiedene Landschaftstypen können sowohl Schutz als auch alternative Nahrungsquellen wie Nektar und Pollen bieten. Aus demselben Grund jedoch können diese Landschaftstypen auch Herbivoren beinhalten. Daher ist es wichtig die Wechselwirkung zwischen natürlichen Feinden der Reisschädlinge und der Landschaftsheterogenität auf Herbivoren zu verstehen und in Reisfeldern zu untersuchen. Weiterhin sollten die Auswirkungen von Pflanzenschutzmitteln zusammen mit der

Landschaftsheterogenität auf mehreren räumlichen Skalen sowie unterschiedlichen Diversitäts-Dimensionen in Reisfeldern untersucht werden.

Probenahme-Methoden von Arthropoden-Gemeinschaften dienen als Grundlage aller Untersuchungen in bewässerten Reisfeldern und sind daher von fundamentaler Bedeutung. Kenntnisse über geeignete Methoden können Zeit, Arbeit und Kosten sparen. Folglich ist die richtige Wahl der Probenahme-Methode von wesentlicher Bedeutung und sollte der erste Schritt aller Untersuchungen sein.

Das übergeordnete Ziel dieser Arbeit ist es, die Wechselwirkungen von Arthropoden-Gemeinschaften unterschiedlicher funktioneller Gruppen mit Pflanzenschutzmitteln und der Landschaftsheterogenität zu analysieren, sowie die Auswirkungen der Landschaftsheterogenität und Pflanzenschutzmitteln auf die funktionale und taxonomische Diversität zu untersuchen. Die Arbeit ist in drei Teile gegliedert:

1) Vergleich von drei Standard-Probenahme-Methoden (Steifnetz, Malaise-Fallen und Blow Vac) in Bezug auf vier verschiedene Kategorien: a) beprobte Arthropoden-Dichte, b) Zeit-Effizienz, c) neu-skalierte Abundanz und d) relative Abundanz von funktionellen Gruppen.
2) Analyse der funktionalen und taxonomischen Diversität in zwei Schritten: a) Diversitäts-Partitionierung von Arthropoden-Gemeinschaften in Reisfeldern in ihre alpha-, beta- und gamma-Komponenten auf lokaler und landschaftlicher Skala; und b) Analyse der Auswirkungen von Pflanzenschutzmitteln und der Landschaftsheterogenität auf die funktionelle und taxonomische Diversität.
3) Bewertung der Wechselwirkung zwischen natürlichen Feinden (Prädatoren und Parasitoide), Landschaftsheterogenität und Insektiziden auf Herbivoren in Reisfeldern.

Für diese Ziele wurden Arthropoden-Gemeinschaften in zwei Regionen in Nordvietnam (Hai Duong und Vinh Phuc) während der Trockenperiode im Jahr 2015 untersucht. Die Arthropoden wurden mit Streifnetzen, Blow Vacs und Malaise-Fallen in 19 Reisfeldern während der frühen Reisperiode gesammelt (35 und 50 Tage nach dem die Reispflanzen in die Felder verpflanzt wurden). Alle Arthropoden wurden bestimmt und in funktionelle Gruppen eingeteilt: Herbivore, Prädatoren, Parasitoide, Destruenten und Fungivore.

Ergebnisteil 1: Die drei Probenahme-Methoden unterscheiden sich grundlegend und je nach Forschungsfrage und gezielter Taxa hat jede Methode ihre Vor- und Nachteile. Für eine schnelle, einfache und kostengünstige Probenahme von Arthropoden in bewässerten

Reisfeldern ist das Streifennetz die beste Methode. Parasitoiden und Herbivoren wurden am zahlreichsten durch Malaise-Fallen gesammelt. Prädatoren wurden in größter Anzahl durch die Blow Vac Methode erfasst, während Destruenten durch das Streifennetz am beständigsten gesammelt wurden.
Ergebnisteil 2: Partitionierte alpha, beta und gamma der funktionalen und taxonomischen Diversität waren hoch korreliert und auf lokaler und landschaftlicher Skala wurden geringe funktionale / taxonomische „turnover“ gefunden. Beide Diversitäts-Dimensionen der Arthropoden-Gemeinschaften waren von Pflanzenschutzmitteln im gleichen Ausmaß negative betroffen. Landschaftsheterogenität führte zu einer Erhöhung der funktionalen und taxonomischen Diversität im frühen Entwicklungsstadium der Reispflanzen (Tag 35).
Ergebnisteil 3: Sowohl natürliche Feinde als auch Insektizide führten zur Abnahme von Herbivoren Abundanz, während die Landschaftsheterogenität keine Effekte aufzeigte.

Im Allgemeinen weisen die Ergebnisse die große Bedeutung von natürlichen Feinden, der Landschaftsheterogenität und der Menge und Anzahl der Pflanzenschutzmittel in Reis-Agrarökosystemen nach. Gleichzeitig zeigen die Ergebnisse die teilweise Abhängigkeit von der Probenahme-Methode. Landschaftsheterogenität fördert die funktionale und taxonomische Diversität der Arthropoden-Gemeinschaften im frühen Entwicklungsstadium der Reispflanze. Jedoch führt der erhöhte Einsatz von Pflanzenschutzmitteln zu einem Rückgang beider Diversitäts-Dimensionen und der positive Effekt der Landschaftsheterogenität scheint abzunehmen. Daher sollte der Einsatz von Pflanzenschutzmitteln in Reis-Agrarökosystemen in Menge und Anzahl verringert werden. Reis-Agrarökosysteme haben ein hohes Potenzial an Selbstregulierung in Form von natürlichen Feinden, die mit dem Ansatz des "ecological engineering" gefördert werden können.

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Chapter 1 *Introduction*

The present work is a monographic dissertation. Hypotheses, results and discussion are separated into three sequential parts. The thesis was conducted within the international and interdisciplinary project LEGATO (‘Land-use intensity and Ecological enGineering-Assessment Tools for risks and Opportunities in irrigated rice based production systems; www.legato-project.net). The emphasis of LEGATO is on the sustainable development of irrigated rice landscapes in Southeast Asia. The project aims to quantify ecosystem functions and services in agricultural rice systems to provide guidance on the best possible management solutions in view of both people and biodiversity. Seven study areas were investigated within the project: three in Northern Vietnam; one in the South of Vietnam and three in the Philippines (Settele et al. 2015). The focal issues were: (i) the socio-cultural and economic contexts, (ii) local as well as regional land-use intensity and biodiversity, and (iii) the potential impacts of future climate and land-use change.

In this thesis, the emphasis is on biodiversity and land-use intensity in rice agroecosystems in two regions in the Red River Delta in Northern Vietnam.

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LEGATO
RICE ECOSYSTEM SERVICES

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1.1 History and importance of rice

Rice (*Oryza sativa* L.) is one of the most important crops in the developing world (FAOSTAT 2015) and it nourishes over half of the world’s population (IRRI 2015). Furthermore, it is the single largest food source for the poor (Global Rice Science Partnership 2013).

Oryza sativa was domesticated from the wild grass *Oryza rufipogon* GRIFF. around 10,000 – 14,000 years ago (CGIAR 2014) and was the first cultivated crop plant species in Asia (Global Rice Science Partnership 2013). Two important subspecies were developed from *Oryza sativa* for cultivation: *Oryza sativa japonica*, which is distributed in the temperate and subtropical parts of East Asia, and *Oryza sativa indica*, which is mainly distributed in the tropical regions (CGIAR 2014). Another important species, *Oryza glaberrima* STEUD., was developed and cultivated later in Western Africa (CGIAR 2014).

Rice is cultivated on all populated continents. However, more than 90% of the rice yield is produced in Asia (FAOSTAT 2017). Especially in Southeast Asia, rice areas represent the predominant agroecosystem (Heong and Hardy 2009). Rice production differs greatly among countries depending on economic, geographic, and social conditions. On the one hand, developed countries like Australia and the USA cultivate rice on large fields, applying state-of-the-art technology. On the other hand, developing countries, as in Southeast Asia, cultivate rice on much smaller spatial scales with high input of human labour (Global Rice Science Partnership 2013).

In the 1960s, high yielding crop varieties of rice were introduced to Southeast Asia in combination with higher input of fertilisers and pesticides, leading to intensified rice production and an increase in yield. This shift of cultivation practices is known as the ‘Green Revolution’ (Evenson and Gollin 2003). In Asia, the yield of rice was 1.8 tons/ha in 1961, increasing to 4.6 tones/ha in 2014 (FAOSTAT 2017). The biggest producer worldwide, China, produced 206 million tons of rice in 2014, followed by India, Indonesia, Bangladesh, and Vietnam (FAOSTAT 2017).

1.2 Cultivation

Rice can be cultivated on irrigated rice fields with a controlled water depth (usually 5 to 10 cm) or on rain-fed fields, where the water level is dependent on the duration and amount of rainfall. Occasionally, rice is cultivated in deep water fields with water levels ranging from 0.5 to 3 m, in upland fields which are rain-fed, and in tidal fields which are close to coast lines and influenced by tides (Bambaradeniya and Amarasinghe 2003, Khush 1984). Commonly, rice plants are either directly seeded or transplanted into fields. For transplanting, rice seedlings are grown in a nursery (seedbed) before being transplanted into the field, which normally takes place 15 to 40 days after seeding. This practice of cultivation provides rice plants a head start, e.g. over weeds, which may be competing for the same resources (Bell et al. 2016). The duration of the growth period (which lasts from seedling/transplanting to harvest) depends on the rice varieties and climatic conditions and can be three to six months long. During this time, rice develops in three growing phases: vegetative phase (tillering, leaf emergence), reproductive phase (booting, heading and flowering), and ripening phase (milky, dough, yellow-ripe and maturity stage) (Global Rice Science Partnership 2013).

1.3 Biodiversity in rice agroecosystems

1.3.1 Background

Rice is commonly cultivated as a monoculture. Nevertheless, rice fields can maintain a rich biodiversity (Fernando 1993) of both plants (Fried et al. 2017) and animals (Bambaradeniya and Amarasinghe 2003, Heong et al. 1991). Representative vertebrate and invertebrate inhabitants of rice fields include numerous species of birds (Pierluissi 2010), amphibians (Moreira et al. 2014), rodents (Stuart et al. 2014), fish (Fernando 1993) and arthropods (Heong et al. 1991). In this thesis, the focus lies on arthropods, which are the main invertebrates of rice agroecosystems (Bambaradeniya and Amarasinghe 2003).

Insects and spiders, which are adapted to the seasonal nature of rice agroecosystems (Fernando 1993), are the most abundant arthropods in rice fields (Heong et al. 1991). Arthropods provide important ecosystem services in rice fields like controlling pests of rice plants (biocontrol) (Bambaradeniya et al. 2004, Gurr et al. 2016), decomposition of organic material (Schmidt et al. 2015) and water purification (Heong and Hardy 2009). At the same time, rice pests are harmful to the rice plants which can cause harvest loss

(Norton et al. 2010). Therefore, biocontrol is of particular importance in rice fields because it can suppress potential pest outbreaks (Gurr et al. 2012).

1.3.2 Biodiversity: scales and definitions

Spatial scales are crucial when examining biodiversity and ecosystem functions (Naeem et al. 2012). Diversity can be defined across multiple spatial scales (Rahbek 2005; Willis and Whittaker 2002). For instance, gamma diversity describes the total diversity of species occurring at the largest scale considered (often regional or landscape scale). Alpha diversity defines the diversity at smaller spatial extents (e.g. field within a region, local scale) and beta diversity describes the variation in species composition among sampling units (De Bello et al. 2009, Whittaker 1972, Willis and Whittaker 2002).

Biodiversity can also be measured at varied dimensions (Naeem et al. 2012). Classically, biodiversity is quantified as number of species present (species richness) and distribution of taxa abundance, which is known as taxonomic diversity (Villéger et al. 2010). Likewise, higher taxonomic resolutions like family and genus levels of arthropods can be used when focusing on taxonomic diversity as these are good surrogates of species richness (Báldi 2003, Feio et al. 2006, Heino and Soininen 2007, Timms et al. 2013). Taxonomic diversity classifies species based on species identities and disregards their functional differences (Hooper et al. 2002). A more recent approach is called functional diversity, which considers functional differences among different ecological groups (Cardoso et al. 2014; Naeem et al. 2012) and can be measured in terms of richness, evenness and divergence (Villéger et al. 2008). In contrast to measures of taxonomic diversity, measuring functional diversity can provide a more direct link between organisms and ecosystem processes (Cadotte 2017, McGill et al. 2006). In addition, phylogenetically distantly related organisms can have similar functionality due to convergent evolution; focusing directly on functional diversity instead of taxonomic diversity can thus provide deeper insights into community assembly (Cardoso et al. 2014, Hooper et al. 2002). Based on this, both diversity dimensions (taxonomic and functional diversity) can be affected differently by disturbance like land-use intensification, pesticide application, and habitat fragmentation and do not necessarily correlate (Mayfield et al. 2010, Peco et al. 2012). Land-use intensification can lead to a reduction of functional group richness, whereas taxonomic diversity can be more resilient against external disturbances (Schweiger et al. 2007). Moreover, it is assumed that taxonomic diversity does not reflect the loss of biodiversity adequately and in the same way as functional diversity does (Ernst et al. 2006). So far, functional and taxonomic diversity of invertebrates in rice agroecosystems in Vietnam remain elusive and are poorly understood.

1.3.3 Functional groups of rice arthropods

Ecologically meaningful classifications of rice arthropods into functional groups are feeding preferences. Thus, it can be differentiated between herbivores (rice pest/ non-rice pest), predators and parasitoids (natural enemies of pests), and decomposers of organic material (Bambaradeniya and Amarasinghe 2003, Heong et al. 1991). Herbivores can be polyphagous or monophagous. Polyphagous herbivores feed on different plant species, whereas monophagous rice herbivores are species-specific and only target rice plants directly (Bambaradeniya and Amarasinghe 2003, Fürstenberg-Hägg et al. 2013). Herbivores can become rice pests when they occur in high abundance. This can result in large reductions of rice yields (Global Rice Science Partnership 2013). Predators can be generalists without prey preferences as well as specialists which target a specific group of prey. Parasitoids are often monophagous and show high specificity in target hosts (Snyder and Ives 2001). They are divided into ecto- and endoparasitoids, whereby ectoparasitoids feed as larvae externally on the host and endoparasitoids feed inside the host's body (Blackburn 1991). Predators and parasitoids are often regarded as 'natural enemies' of herbivores or rice pests (Heong et al. 1992).

Important rice pests are: green leafhoppers (*Nephotettix* spp.; Heteroptera: Cicadellidae) like e.g. *Nephotettix virescens* DISTANT, which can transmit rice tungro; the brown planthopper (*Nilaparvata lugens* STÅL; Heteroptera: Delphacidae), that can transmit rice diseases like grassy stunt and ragged stunt and the white-backed planthopper (*Sogatella furcifera* HORVÁTH; Heteroptera: Delphacidae), which damage rice plants by direct feeding on them, which is called 'hopperburn' (Heong et al. 1992); the small brown planthopper (*Laodelphax striatellus* FALLÉN; Heteroptera: Delphacidae) (Norton et al. 2010); the rice leaf folder (*Cnaphalocrocis medinalis* GUENÉE; Lepidoptera: Pyralidae) (Gurr et al. 2012); stem borer species such as the yellow stem borer (*Schoenobius incertulas* WALKER; Lepidoptera: Crambidae) and the striped stem borer (*Chilo supressalis* WALKER; Lepidoptera: Crambidae) can sometimes cause major yield losses (Norton et al. 2010). Important antagonists (natural enemies) of rice pests are spiders (Sigsgaard 2007), the mirid bug *Cyrtorhinus lividipennis* REUTER (Hemiptera: Miridae), the water bug *Microvelia douglasi atrolineata* BERGROTH (Hemiptera: Veliidae) (Schoenly et al. 2010) and parasitic

Hymenopterans e.g. chalcid wasps (Chalcidoidea), braconids and ichneumonids (Ichneumonoidea) (Gurr et al. 2011).

Decomposers break down organic material (Schmidt et al. 2015). Different to other functional groups, decomposers occur in high abundance in the early stage of rice plants (Bambaradeniya and Edirisinghe 2008, Settle et al. 1996), whereby they can serve as diet and aid as head start for general predators (Settle et al. 1996). Important decomposers are for instance collembolans (Settle et al. 1996).

1.4 Applicability of sampling methods in rice agroecosystems

Many methods exist to assess, quantify, and monitor arthropod communities in agroecosystems (e.g. pitfall traps, light traps, Malaise traps, sweep netting, and vacuum sampling; Báldi et al. 2013, Brunke et al. 2014, Ngo et al. 2013, Palatty et al. 2013, Schoenly and Barrion 2016). Due to the special conditions in rice agroecosystems (e.g. fields are mostly semiaquatic) many methods (e.g. pitfall traps, beat sheet sampling) cannot be used properly to monitor arthropods (Zou et al. 2016). Sweep nets, suction sampling devices (blow vac), and Malaise traps are standard methods (Southwood and Henderson 2000) which are often used to sample arthropods or specific taxa in rice agroecosystems (e.g. Bambaradeniya et al. 2004, Gangurde 2007, Ghahari et al. 2008, Gurr et al. 2016, Schoenly et al. 2010). However, these methods differ fundamentally from each other in their performance and targeted arthropod groups (Buffington and Redak 1998). Sweep netting is a terrestrial sampling method which mainly targets flying arthropods and arthropods sitting on the vegetation (Ausden and Drake 2006). As it is very easy to handle, sweep netting is a fast way to sample high numbers of invertebrates in a short time and the sampling can be performed by a single person (Ausden and Drake 2006, Reed et al. 2010). However, sampling can differ by number of sweeps per sample unit, sweeping intensity and net size, which makes it difficult to compare results among different studies (Southwood and Henderson 2000). Blow vac is a combustion-powered machine similar to a leaf blower (but sucking instead of blowing) and can be used to sample both terrestrial and aquatic arthropods (Schoenly and Barrion 2016). Different to sweep net, blow vac samples arthropods intensively in a defined area (normally within an enclosure), whereas sweep nets sample a wider area more extensively (Ausden and Drake 2006, Dominik et al. 2017, Schoenly and Barrion 2016). As sampled areas can be defined in vacuum sampling, an estimation of arthropod densities is possible (Barro 1991, Harper and Guynn 1998, Reed et al. 2010). Malaise trap is a stationary/passive sampling method which targets flying insects (Yi et al. 2012). It can stay without constant attention in a field, collecting vast numbers of different arthropod species, not expeditiously but over a long time period (one day to several months) (Achterberg 2009, Ausden and Drake 2006).

Depending on the research question, the targeted taxa, and the study area, it is important to use the adequate method to prevent high economic and ecological cost and inefficiency (Cardoso 2009). The inappropriate application of methods can lead to more frequent sampling due to incompleteness of e.g. targeted taxa, which can damage the sampled ecosystem (this can be the case when using active sampling methods; Buffington and Redak 1998, Schoenly and Barrion 2016). Consequently, a higher arthropod abundance is being collected unnecessarily. Furthermore, the right choice of sampling methods to collect important functional groups is necessary to detect pest outbreaks and therefore provide an optimisation of pesticide applications. Especially in developing countries an overuse of pesticides is observed (Ecobichon 2001, Eddleston et al. 2002).

1.5 Land-use intensity and its consequences in rice agroecosystems

1.5.1 Definition and historical background of land-use intensity

Land-use intensification can be defined as an enhanced management of land which entails external inputs (e.g. pesticides) with the intention to increase yield (Foley et al. 2005, Laliberté et al. 2010). This results mostly in a simplification of landscapes and loss of diversity (e.g. large amount of single, homogeneous types) (Foley et al. 2005, Laliberté et al. 2010) which in turn leads to loss of arthropod diversity (Hendrickx et al. 2007).

Historically, irrigated rice agroecosystems developed in deltas and river valleys and remained unchanged for more than 2000 years (Cassman and Pingali 1995). During the Green Revolution, rice production became intensified (Cassman and Pingali 1995), leading to an increase of pesticide applications, irrigation, tillage, and the use of fertilisers (Bambaradeniya and Amarasinghe 2003, Cassman and Pingali 1995).

The Green Revolution resulted not only in an increase of yields but also led to problems such as environmental pollution, threats to human health, and biodiversity loss (Pimentel and Pimentel 1990).

1.5.2 Pesticide usage

Due to pest outbreaks, which can entail major harvest losses, pesticides were applied in high quantities by farmers (Heong et al. 2013). Ironically, pest outbreaks of major pests like the brown planthopper can be pesticide induced because of the pest's high adaptability (Settle et al. 1996, Wang et al. 2008b). Often, pesticides are sprayed directly after transplantation of rice seedlings (Heong et al. 1995). This negatively affects early arriving predators which act as a control for later arriving herbivores (Heong et al. 2013, Settle et al. 1996). Furthermore, pesticides are sprayed by farmers on calendar-based schedules rather than according to the conditions in the fields (Dasgupta et al. 2007, Heong et al. 2013, Settle et al. 1996). Due to the frequent use of pesticides, some herbivores evolved resistance against insecticides (Matsumura et al. 2008). The combination of these issues leads to the assumption that insecticides fail to make an appropriate impact on herbivores (Heong et al. 2013, Settle et al. 1996).

Additionally, it has been shown that frequent application of pesticides leads to decreasing yields and jeopardises the health of people working with pesticides (Ecobichon 2001, Norton et al. 2010). Health problems of farmers arise due to little protection when applying and mixing pesticides (Kishi et al. 1995). Up to 80% of pesticides applied by farmers do not reach the target pest and end up in the environment (Bonmatin et al. 2015, Heong et al. 2013), where they negatively affect microbial processes important for plant growth, crop productivity and soil fertility (Abdullah et al. 1997, Verma et al. 2014). Among other things, pesticide residues can contaminate waterways and soil in rice fields (Abdullah et al. 1997), and sources of drinking water like ground and surface water (e.g. Mekong Delta, Chau et al. 2015). At the same time, important natural enemies of rice pests are suppressed (Bommarco et al. 2011, Way and Heong 1994).

1.5.3 Alternative pest control practices

Many studies have been investigating alternative methods to better control rice pest and to promote natural enemies with the premise to reduce pesticide applications (biocontrol) (e.g. Gurr et al. 2011, Lu et al. 2014, Settle et al. 1996). Natural enemies can benefit from the surrounded land cover, as these land-cover types can act as shelter and also contain alternative food sources (Gurr et al. 2017, Hassan et al. 2016, Westphal et al. 2015). But for the same reason, heterogeneous land cover types can also be a source pool for pest species (Marcos et al. 2001, Way and Heong 1994). The impact of non-crop habitat on natural enemies and pest species is highly complex (Drechsler and Settele 2001, Gurr et al. 2017, Tscharntke et al. 2016) and not yet fully understood. Landscapes cultivated with mixed crops can promote early colonisation of rice plants by generalist predators which are crucial for biocontrol against rice pests (Settle et al. 1996, Wilby et al. 2006).

Land cover types can also be manipulated by men for the benefit of the needs inherent to both society and nature (e.g. flowers or other crops on rice bunds) which is termed ‘ecological engineering’ (Gurr 2009). Ecological engineering aims to distract pests from crops, reduce pest immigration in rice agroecosystems, and to provide resources for natural enemies (Gurr 2009, Mitsch et al. 2012, Westphal et al. 2015).

1.6 Rice farming in Vietnam

1.6.1 Land-use intensification in Vietnam

In Vietnam, the rice production nearly doubled from 23 million tons in 1994 to 45 million tons in 2014, while an area of 6.5 million ha was harvested in 1994 and 7.8 million ha in 2014 (Fig. 1; FAOSTAT 2017). Initiated by economic development, population growth, policy change and new technologies, agriculture became intensified in Vietnam (Schreinemachers et al. 2015). This change of agriculture, known as ‘Doi Moi’ (renovation) (Nguyễn 2013), began with the Green Revolution and accelerated in the mid-1980s in the course of the economic liberalisation (Lamers et al. 2013).

There are two major centres of rice cultivation in Vietnam: The Red River Delta and the Mekong Delta (Global Rice Science Partnership 2013). In the Red River Delta are two growing seasons. Almost 85% of rice fields are irrigated and the rest of the fields are rain-fed. In the Mekong Delta rice is cultivated up to three times a year with 52% of irrigated rice fields and 48% rain-fed fields (Bambaradeniya and Amarasinghe 2003).

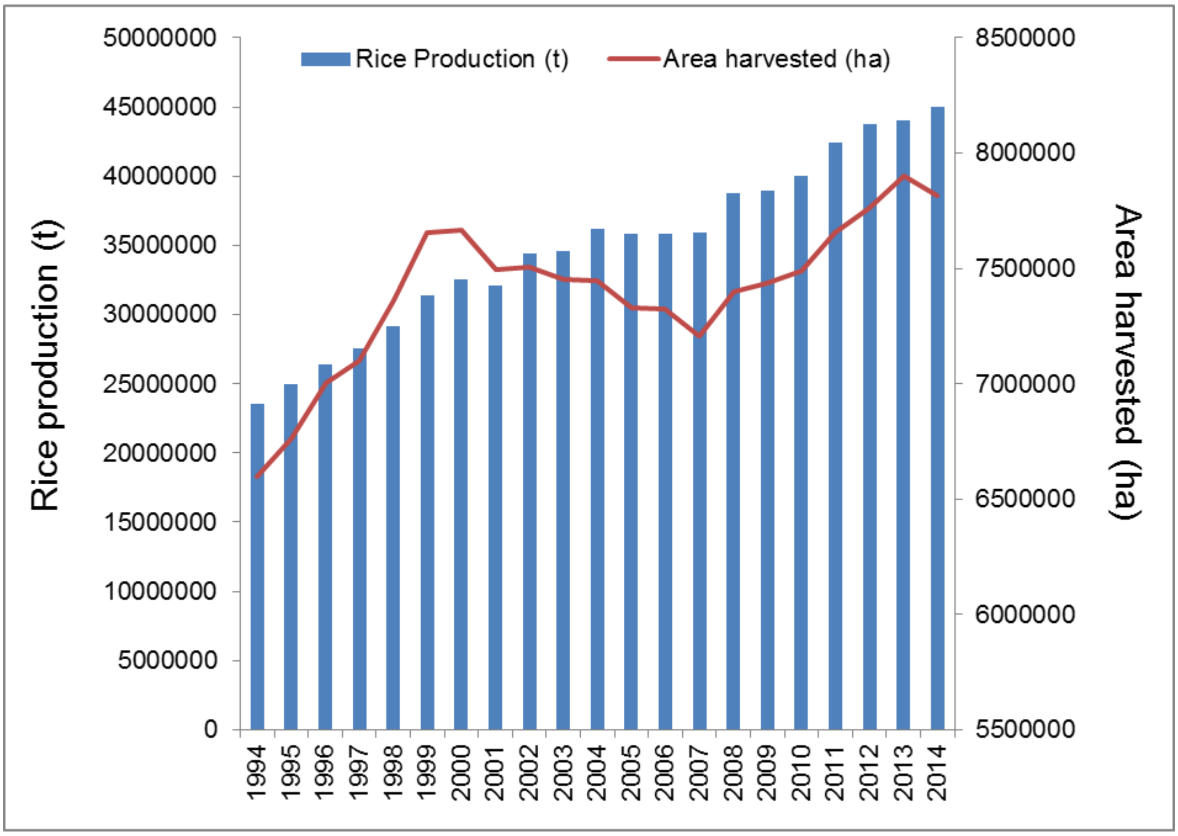


Figure 1 Rice production and harvested area in Vietnam. Increasing rice production and harvested area from 1994 to 2014 in Vietnam. Data obtained by FAOSTAT (www.fao.org/faostat).

1.6.2 Current pest management in Vietnam

From 1991 to 2007, the volume of pesticides increased from 20,000 tons to 77,000 tons (Lamers et al. 2013). On average, 16.2 kg/ha (based on imported quantities per hectare) of pesticides were applied on arable land in 2012 (Schreinemachers et al. 2015). The maintenance of high yield combined with pest outbreaks led farmers to increase pesticide applications (Berg 2001, Cheng 2009). Most pesticides (80-90%) are imported from China (Schreinemachers et al. 2015) and are fully subsidised by the central government because of rice pest outbreaks in the past (Hoi et al. 2013). Phung et al. (2012) compared pesticide regulations in the USA and Vietnam and concluded that there are several legislations concerning pesticides which should be improved in Vietnam. Precise information about the current use of pesticides and their active ingredients are lacking because of high illegal imports of pesticides (30-35%) (Hoi et al. 2013) and data are not available online (Schreinemachers et al. 2015). To this day, pesticide use is an important issue in rice production in Vietnam in regard to overuse as well as lacking knowledge and legislation (Berg 2001, Berg and Tam 2012, Dang et al. 2017, Dijk et al. 2013, La et al. 2013, Lamers et al. 2011).

1.6.3 Enhancement of biocontrol in Vietnam

Studies concerning pesticide use in rice agroecosystems combined with an investigation into improvement activities are mainly done in the Mekong Delta.

Integrated pest management (IPM) is an ecosystem-based approach that keeps pesticide use on ecologically and economically reasonable levels in combination with different management strategies to grow healthy crops (FAO 2017). Berg (2001) surveyed the differences between rice farmers using IPM and farmers who farmed conventionally in the Mekong Delta. Famers using IPM applied fewer pesticides which could be directly related to better ecological knowledge. Another study of Heong et al. (2008) in the Vinh Long province (Mekong Delta) tested an entertainment-education approach (radio soap opera) to convey information about IPM to rice farmers. Farmers who listened to the soap opera changed their behaviour and attitude in terms of pesticide application, resulting in pesticide reduction. This project was refined in 2014 as a TV series with the aim to reduce pesticide application and to introduce ecological engineering to farmers. As a consequence, nectar rich flowers were planted on the bunds between the rice fields (Heong et al. 2014). It has been shown that nectar availability improves the longevity and fecundity of parasitoids significantly and therefore promotes natural enemies (Lu et al. 2015). Another project called ‘women in ecological engineering’ in Tien Giang province (Mekong Delta) with a similar approach has trained farmers to reduce early pesticide application and practice the principles of ecological engineering (Nguyen and Chien 2010).

The provincial government of Tien Giang encouraged farmers to use ecological engineering activities by means of financial support in 2015. Ecological engineering in combination with education and training in pesticide use by local farmers led to a complete cessation of pesticide subsidies in the Tien Giang province (Heong et al. 2015).

Monitoring pesticides and gaining ecological knowledge about herbivores and pesticides is crucial to improve and develop ecological engineering. However, there is little progress in the Red River Delta in terms of pesticide monitoring in combination with the influence of land cover heterogeneity on herbivores. With this premise, it can be assumed that pesticides are still used in high amounts and rice is cultivated intensively with little land cover heterogeneity in the surroundings. Surveys on the interaction of herbivores and land cover heterogeneity and the effect of natural enemies are important in this region to understand ecological interactions in rice fields and to introduce ecological engineering.

1.7 Objectives and Hypotheses

Hypotheses of the present thesis are divided into three main groups and are presented separately in the result and discussion parts as follows:

1) Method comparison

In the first part of the thesis, the performance of three sampling methods (sweep net, blow vac, and Malaise trap) was measured and compared in terms of functional groups. Furthermore, the strengths and limitations of each method were summarised and sampling guidelines were elaborated. The following hypotheses were tested:

(i) Blow vac samples yield more arthropod specimens per area compared to sweep netting.
(ii) Sampling by sweep netting is most efficient in terms of the effort invested for a certain amount of collected specimens per person (sampling time).

2) Functional and taxonomic diversity

In the second part, functional and taxonomic diversity were calculated and partitioned across multiple spatial scales (alpha, beta, and gamma) and compared at local and landscape scale. Moreover, the effects of pesticides and land cover heterogeneity on both diversity dimensions were evaluated. The following hypotheses were formulated:

(iii) Increasing pesticide usage has a negative effect on functional diversity across multiple scales.
(iv) Increasing pesticide usage has a smaller effect on taxonomic diversity than on functional diversity.
(v) Land cover heterogeneity increases taxonomic and functional diversity across multiple spatial scales.

3) Herbivore management/control

The third part focuses on the factors influencing herbivore abundance in rice fields. Here, the interactive effects of land cover heterogeneity, insecticides, and natural enemies (predators and parasitoids) on herbivores (mostly rice pests) were studied. The following hypotheses were investigated:

(vi) Herbivore abundance declines with increasing abundance of natural enemies.

(vii) The impact of natural enemies on herbivores increases with increasing land cover heterogeneity.

(viii) Under the present circumstances in rice agroecosystems in Vietnam, insecticides do not affect herbivore abundance.

Chapter 2 *Material and Methods*

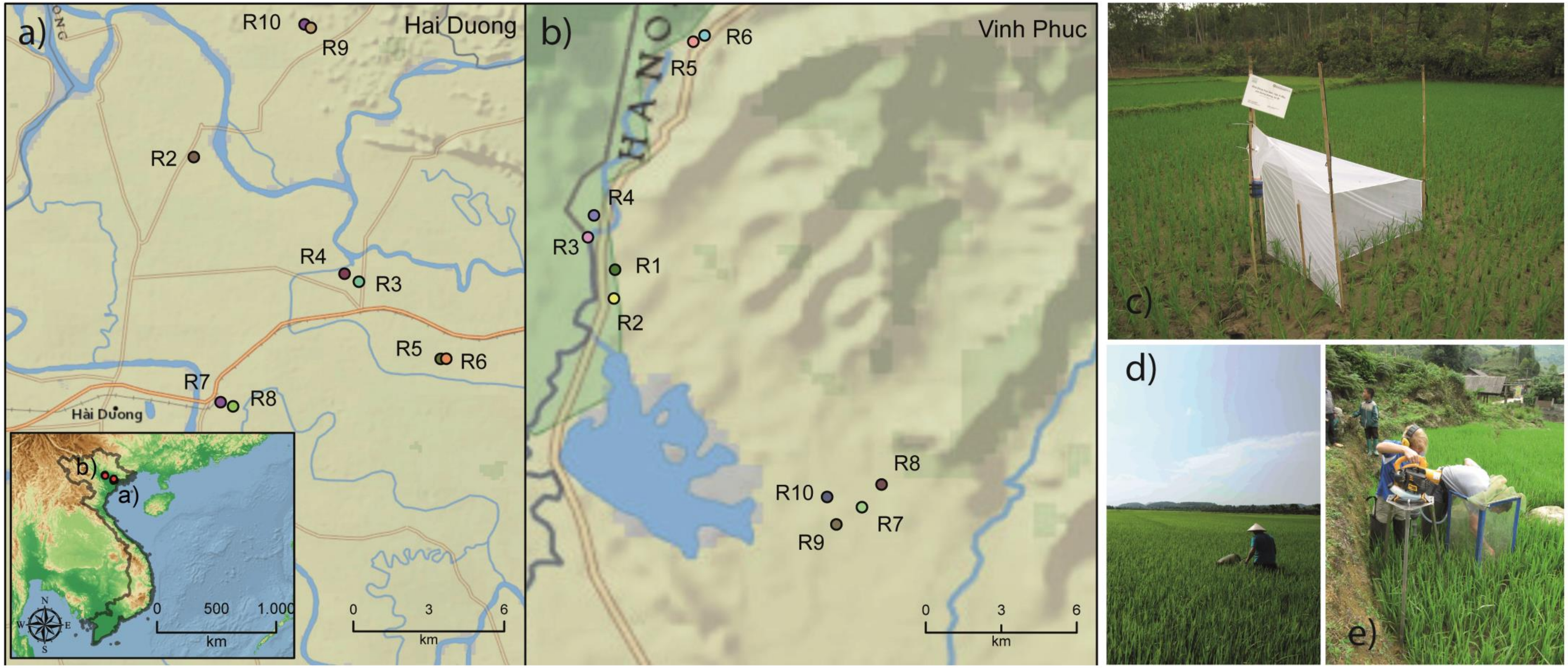
2.1 Study area

The field study was conducted in two rice dominated lowland regions along the Red River Delta in Northern Vietnam, in which rice is the principle crop (Global Rice Science Partnership 2013).

The first region, Hai Duong (LEGATO region VN1: 21°00'N 106°23'E) is situated 60 km east of Hanoi. The region is heavily industrialised and dominated by intensively farmed rice fields. In this region, nine rice fields were selected (in one of originally ten fields the cropping system changed during the investigation period and was dropped out from further analyses; Fig. 2a).

The second region, Vinh Phuc (LEGATO region VN2: 21°20'N 105°43'E) is located 35 km northwest of Hanoi. Similarly to Hai Duong, the landscape is dominated by rice fields but is industrialised to a lesser extent (Burkhard et al. 2015). Ten rice fields were selected in this region (Fig. 2b).

There are two distinct rice growing seasons per year in both regions: the first season is from February to May and the second season is from July to October (Klotzbücher et al. 2015).



Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp

Figure 2 Study area and sampling methods. Left: Location of a) Hai Duong and b) Vinh Phuc including sampled rice fields (R1-R10) in each region. Right: Sampling methods c) Malaise trap, d) sweep net, and e) blow vac. (Photo credit: Cornelia Sattler and Markus Franzén)

2.2 Climate

The Red River Delta is characterised by a warm, humid, and subtropical climate (Klotzbücher et al. 2015) with a distinct seasonality. It is characterised by a wet season from April to October and a dry season from November to April. During the wet season, the monthly average of the precipitation rate and temperature for Hanoi are 217 mm and 27.5°C, whereas, the monthly average of the precipitation rate and temperature for Hanoi are 40 mm and 20.4°C during the dry season (Fig. 3, http://worldweather.wmo.int).

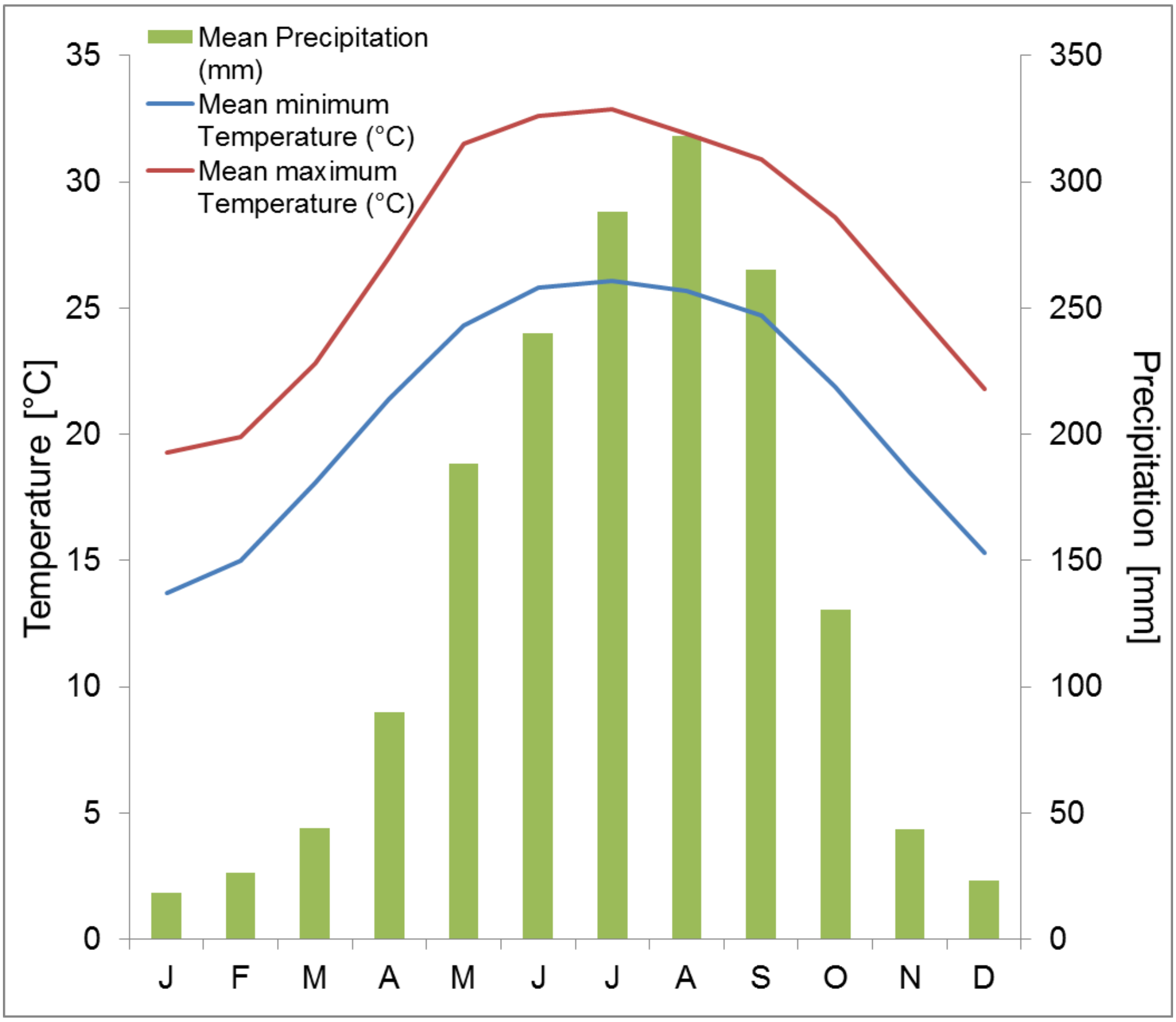


Figure 3 Climate graph of Hanoi. Mean monthly temperatures and precipitation rates of Hanoi which is located between the study regions Hai Duong and Vinh Phuc. Data were taken from the World Meteorological Organization: http://worldweather.wmo.int and based on monthly averages for a 93-year period from 1898-1990.

2.3 Arthropod sampling and assignment

Arthropods were sampled during the dry season from March to April in 2015. The emphasis of the sampling was on the vegetative stage of the rice plant (35 and 50 days after the rice seedlings were transplanted into the fields; days after transplanting = DAT). At this stage, herbivore and major rice pest abundances reach their maximum (Bambaradeniya and Edirisinghe 2008, Heong et al. 1991, Pathak and Khan 1994) and pesticide applications cause the biggest effect on natural enemies (Gurr et al. 2012, Settle et al. 1996). Sampling times are also in accordance with the overall LEGATO sampling design in order to standardise methodologies.

Sampling with sweep net and blow vac was conducted at 35 and 50 DAT in each field, whereas Malaise traps were installed 25 DAT and remained active until 50 DAT. For better comparison between the three methods, all sampling was restricted to the terrestrial part of the rice field. To ensure robust results for the method comparison, different measures of abundance were standardised to 1) arthropod density, 2) time efficiency, 3) rescaled abundance, and 4) relative abundance. These standardisations were defined as categories and are later explained in detail (see 2.4 Standardisation).

2.3.1 Malaise trap

Malaise trapping is a tent-like passive method which is not actively handled by a person. Collected insects fly into a central vertical wall which directs trapped insects upward into a collecting bottle (Fig. 2c). A white Malaise trap (produced by ENTO SPHINX s.r.o.) with two open sides was used. The Malaise traps had a height of 120 cm, a breadth of 100 cm, and a length of 150 cm. In each rice field, one Malaise trap was installed 1.5 m away from the rice bunds (earthen boundary between rice fields). The collecting bottle was filled with a mixture of ethanol (70%) and soapy water. The installation of one Malaise trap (two people were required) and the replacement of the bottles took on average 25 min per trap. In total, traps remained for 30 days in the field and collecting bottles were replaced every ten days. Two sample units per Malaise trap were analysed which were collected at the same time period when sweep net and blow vac were used.

2.3.2 Sweep net

A sweep net was used with 32 cm in diameter and 68 cm depth that was attached to a telescopic rod. The net had a mesh size of 0.5 mm (Fig. 2d).

Arthropods were sampled two times along the rice bunds and three times within the centre of each rice field (in total five sample units). For each sample unit, an area of 30 m² was covered while walking with a speed of approximately 0.5 m/sec and performing 30 sweeps. If the size of a rice field was too small to conduct five sample units, remaining units were taken close to the field (neighbouring field). Sample units did not overlap with one another. After sampling, arthropods were transferred into collecting jars containing cyanide and were stored later in 50 ml vials with 70% ethanol. On average, 'harvesting' one sample unit took 10 min, including active sampling and transferring arthropods into a vial.

2.3.3 Blow vac

Blow vac is a vacuum suction machine which is powered by a combustion engine. The used blow vac machine was constructed in the Helmholtz-Centre for Environmental Research - UFZ (Halle, Germany) based on a design described by Arida and Heong (1992). The machine was installed on three one meter high pillars to stabilise it in the field. Arthropods were sucked in through a hose (Fig. 2e). Within a square plastic enclosure fitted with nylon netting on top to prevent arthropods from escaping, an area of 0.25 m² was sampled in five randomly chosen locations (five sample units) within each rice field. Arthropods were transferred into 50 ml vials containing 70% ethanol. Taking one sample unit required two people and took on average 15 min, considering the transfer of samples into a vial. Sampling time of sweep netting and blow vac was restricted between 8 am and 12 am, when arthropod activities are expected to be highest.

2.3.4 Functional groups and arthropod analysis

Arthropods were assigned to functional groups, which are based on similar functional attitudes and food acquisition. The following functional groups defined after Shepard et al. (1987), Shepard et al. (1995), and Heong et al. (1991) were used: predators, parasitoids, herbivores, decomposers (detritivores and scavengers), and fungivores. Arthropods which could not distinctively be assigned to one of these functional groups due to bad sampling quality affecting the identification process or which could be assigned to more than one group were categorised as 'indifferent'.

To enable the assignment of arthropods into functional groups, most arthropods were identified to family level at the minimum or further. The following arthropods occurring with <100 specimens per order (in total) were only identified to order level: Blattodea (1 specimen), Dermaptera (1), Diplopoda (1), Ephemeroptera (33), Isoptera (1), Gamasina (74), Neuroptera (4), Phasmatodea (3), and Trichoptera (6). Taxonomy follows Wilson and Claridge (1991) and Heinrichs (1994).

When the functional group remained consistent within the order specimens were only identified to order level: Collembola (decomposers), Odonata (predators), Thysanoptera (herbivores), Lepidoptera (herbivores), and Psocoptera (herbivores). Nematocera was the group with the highest number of specimens and dominated by Chironomidae which feed on plankton as larvae (Settle et al. 1996). For simplification, this group was summarised as decomposer. Important Nematocera rice pest as Cecidomyiidae were practically absent.

2.4 Standardisation

Due to the different sampling properties of Malaise trap, sweep net, and blow vac, abundance values of functional groups were standardised according to the following four categories:

1) Time efficiency: arthropod abundance divided by sampling time (time of active sampling and transfer of arthropods into collecting jars; i.e. time spent in the field).

Malaise trap as passive sampling method was not actively used like the other methods. Therefore the average time for installation and the maintenance time (e.g. replacing bottles) per Malaise trap were taken. Sampling time for blow vac and Malaise trap were doubled for all analyses because two people were required for sampling or installation.

2) Rescaled abundance: To enable comparison of abundance data among the three different sampling methods, abundance data were rescaled between zero and 100 in a way that 100 represents the maximum abundance per rice field for each method (1):

$$\mathbf{rescaled\ abundance} = \frac{\mathbf{abundance}}{\mathbf{max(abundance)}} * \mathbf{100} \qquad (1)$$

3) Relative abundance: to compare the composition of functional groups, the relative abundance of functional groups was calculated for each rice field and method.

4) Arthropod density: the total number of arthropods collected by sweep net and blow vac was divided by the sampled area (in m^2). Malaise trap data were excluded from this comparison because the collected arthropods cannot be assigned to a defined area (due to passiveness of the method).

2.5 Land-use intensity

All investigated rice fields were sprayed with pesticides and fertilised using chemically produced NPK during the study (Klotzbücher et al. 2015). Farmers sprayed pesticides on average 4.7 times (ranging from four to six) on their fields during the cropping season (information by interviewed farmers). In Hai Duong farmers use rice varieties which are highly productive, whereas in Vinh Phuc farmers use traditional varieties with higher genetic diversity (Burkhard et al. 2015). Similar to Wilby et al. (2006) and Dominik et al. (2017), all observations and investigations were implemented in real agricultural settings without controlling external factors. Arbitrations about agricultural practices, like fertiliser use, weeding, pesticide application, and the choice of rice varieties were left to the farmers.

2.5.1 Land cover heterogeneity

In both regions, the sampled rice fields were selected pairwise – resulting in five pairs of rice fields in each region (Settele et al. 2015). The average distance between rice field pairs was 338 m. The size of the rice fields was on average 491 m² ranging from 97 – 1883 m² (Table 1). To investigate the relationship between land cover heterogeneity and arthropod functional groups, the land cover around each rice field was recorded within a 300 m radius (Table 1, Appendix I). Land cover types are according to Burkhard et al. (2015). The Shannon diversity (H’) index was applied to measure the land cover heterogeneity based on the land cover units within the 300 m radius (2):

$$\mathbf{H'} = -\sum_{\mathbf{k=1}}^{\mathbf{n}} (\mathbf{Pk}) \, \mathbf{log}(\mathbf{Pk}) \qquad (2)$$

where Pk is the proportion of different types of land cover within the 300 m radius and n is the number of land cover types (Turner 1990). Increasing potential land cover heterogeneity is expressed by a larger value for this index.

2.5.2 Pesticides

In Vietnam, precise information about the current use of pesticides and their active ingredients is lacking because of high illegal imports of pesticides (30-35%) (Hoi et al. 2013) and data are not available online (Schreinemachers et al. 2015). Hence, interviews were conducted to obtain detailed information about time, frequency, and active ingredients used by farmers. During the interviews, contradictory statements, forgetfulness, and lacking knowledge about pesticides used by farmers lead to an additional approach of quantifying pesticide application as interviews alone seemed not reliable.

Pesticide applications were assessed by counting packages along transect lines (50 meters long). Farmers fill up their spraying gear at irrigation canals or other water sources near to their rice fields, where they also dissolve pesticides. Frequently, they dispose empty pesticide packages and containers in channels, drainage systems, and waste land next to their rice fields (own observation). Disposed packages remain on sites for long times and are only transported away by severe flooding during rainy seasons. Transect lines surrounded each of the 19 rice fields (rice fields were always located in the centre of sampled areas). For each package, trade name, volume or weight of the content of packages (compare eq. 3), active ingredients (AIs), and concentration of each AI were listed. Some packages indicated volume (ml) rather than weight (g) of AIs, in which cases it was assumed that 1 ml of content equals to 1 g. The amount of AIs (W) was calculated using following equation (3):

$$\mathbf{W} = \mathbf{np} * \mathbf{vw} * \mathbf{c} \qquad (3)$$

where np is the number of packages, vw is the volume (in ml) or weight (in g) of the collected packages, and c is the concentration of the contained active ingredients. Pesticides and insecticides alone were categorised into three classes referring to the found amount of the active ingredients. For pesticides: low = 0 – 268.63 g, medium = 268.63 – 537.27 g, and high = 537.27 – 805.91 g. For insecticides: low = 0 – 177.96, medium = 177.96 – 355.93 g, and high = 355.93 – 533.89 g. Farmers applied pesticides four to six times and all farmers sprayed pesticides immediately after transplanting the rice plants (information obtained by interviews).

A list of all collected pesticides and active ingredients can be found in Appendix II (List of active ingredients).

2.6 Statistical analyses

For each sampling method (sweep net, blow vac, and Malaise trap) abundance data were analysed separately. For all statistical analyses, either linear regression models (LM) or linear mixed-effect models (LMM) were used (Bates et al. 2015).

All analyses were performed in the statistical environment R for Windows (Version 3.2.4; R Core Team 2016) using the packages ‘lmer4’ (Bates et al. 2015), ‘lsmeans’ (Lenth 2016), ‘MuMIn’ (Bartoń 2016), ‘vegan’ (Oksanen et al. 2017), ‘effects’ (Fox 2003), ‘ggplot2’ (Wickham 2015), ‘entropart’ (Marcon and Hérault 2015), and ‘hier.part’ (Walsh and Nally 2013).

2.6.1 Method comparison

Replicates of each sample unit (five locations per rice field) were aggregated into one sample unit for 35 and 50 DAT. This resulted in one sample unit per sampling day (30 and 50 DAT), per rice field and for each of the three methods sweep net, blow vac, and Malaise trap. Linear mixed-effect models (LMM) and post-hoc pairwise comparisons with Tukey’s test were used to estimate differences between functional groups among the methods based on four categories: 1) sampled arthropod density, 2) time efficiency, 3) rescaled abundance, and 4) relative abundance (see 2.4 Standardisation). Predictor variables were the three methods (sweep net, Malaise trap, and blow vac). The two regions (Hai Duong and Vinh Phuc) were included as random effects to avoid pseudo-replication.

2.6.2 Relationship of land cover heterogeneity and pesticides with functional and taxonomic diversity

For statistical analysis, data of each sample unit per rice field were extracted for sweep net and blow vac (five replicates per method, field and DAT). Malaise trap was excluded from this analysis because of too few sampling units (only two sample units in total per rice field).

All statistical analyses were based on the abundance of either the functional groups or the taxonomic units (families) of arthropod communities. Diversity indices were calculated using Shannon entropy (H’, Shannon-Wiener index). Due to the difficult interpretation of most standard indices (Jost 2007, Marcon and Hérault 2015), the Shannon entropy was converted to its ‘effective number of species’ by taking its exponential (Jost 2006, 2007), which is referred to the ‘effective number of functional or taxonomic groups’. A multiplicative approach was used: Halpha * Hbeta = Hgamma (Jost 2007). For simplification, the term ‘diversity’ will be used instead of ‘effective number of functional groups or taxonomic groups’.

The meta-community was calculated for each rice field and each region (separately for each method and sampling days). Meta-community is ‘the assemblage of communities whose species probabilities are the weighted average of those of communities’ (Marcon et al. 2014). Next, the partitioned diversity (alpha, beta, and gamma) of each rice field and both regions (Vinh Phuc, Hai Duong) was calculated (Marcon and Hérault 2015).

Partitioned diversity (alpha, beta, and gamma) of arthropod communities was calculated at the local scale, where gamma diversity was defined as the diversity of functional or taxonomic groups of all specimens found in one rice field and partitioned into within (alpha diversity) and between (beta diversity) local communities of samples taken. At the same time, the partitioned diversity of arthropod communities was calculated at the landscape scale, whereby gamma was defined as the diversity of functional or taxonomic groups of all specimens found in one region, alpha as the local communities within one rice field of one region and beta as the variations of taxonomic and functional compositions among the rice fields. Scale definitions (local and landscape scale) are according to Willis and Whittaker (2002). To compare the partitioned functional and taxonomic diversity at local scale the Wilcoxon test was used (Wilcoxon 1945).

Data of functional and taxonomic diversity were normally distributed (tested with the Shapiro-Wilk test; Royston 1982). To analyse the relationship of pesticides/insecticides, and land cover heterogeneity with the calculated functional and taxonomic diversity across multiple scales (alpha, beta, and gamma) linear regression models instead of linear mixed effect models were used, as random effects had small standard deviations and did not improve the models (selected by lowest second-order Akaike information criterion; AICc). Model selection followed a multimodel inference approach (Burnham and Anderson 2002). For these analyses, only the partitioned diversity at the local scale was investigated because of too few data points at the landscape scale (only one data point for alpha, beta, and gamma per region). Candidate models included as predictor variables: number of pesticides/insecticides, amount of pesticides/insecticides, and land cover heterogeneity (see 2.5 Land-use intensity for detailed information). All predictor variables were tested for collinearity using Pearson correlation coefficient (r) before the linear regression models were simplified. When predictor variables were collinear, only the one which explained the candidate models best (based on AICc, Burnham and Anderson 2002) was included prior to model selection. The number of pesticides and amount of pesticides improved the linear regression models (selected by lowest AICc) rather than insecticides and were included in all candidate models. The variable importance was computed based on the sum of AICc weights for each model in which the predictor variable appeared.

In total, 24 linear regression models were performed separated by methods (sweep net and blow vac), sampling days (35 and 50 DAT), and for three functional scales and three taxonomic scales (alpha, beta, and gamma). In addition to overall goodness of fit (R^2), for all linear regression models R^2-based hierarchical variance partitioning was performed to assess joint and independent contribution of each variable (Chevan and Sutherland 1991). To compare the effect size (calculated R^2) of pesticides on functional and taxonomic diversity, the Paired Student's t test was used as data were normally distributed (tested with the Shapiro-Wilk test). Pairs were separated into methods and sampling days.

2.6.3 Relationship of natural enemies, land cover heterogeneity, and pesticides with herbivore abundance

To estimate the relationship of natural enemies, land cover heterogeneity, and pesticides with the total abundance of herbivores, linear mixed-effect models (LMMs) were used following a multimodel inference approach (Burnham and Anderson 2002). The initial candidate models for each sampling method included: land cover heterogeneity/rice proportion, amount of pesticides/insecticides, number of pesticides/insecticides, abundance of predators, and parasitoids. Furthermore, to test for the combined effect of the predictor variables, the following two-way interactions were included: land cover heterogeneity/rice proportion with predators and with parasitoids, the two sampling days (35 and 50 DAT) with predators and with parasitoids, number of pesticides/insecticides with predators and with parasitoids, and the interaction of predators and parasitoids. Residuals were normally distributed and not heteroscedastic in accordance with diagnostic plots. All predictor variables were tested for collinearity using Pearson correlation coefficient (r) before the full LMMs were simplified. For predictor variables which were collinear (land cover heterogeneity vs rice proportion r= -0.74; number of insecticides vs pesticides r= 0.92), only the one which explained the candidate models best based on AICc was included. The number of insecticides and amount of insecticides as well as land cover heterogeneity improved the LMMs (selected by lowest AICc) rather than pesticides and rice proportion and were included in all candidate models. The variable importance was computed based on the sum of AICc weights for each model in which the predictor variable appeared.

In all 12 LMMs, the two regions (Hai Duong and Vinh Phuc) were included as random effects to avoid pseudo-replication. Detailed information about each model can be found in Appendix III (Linear mixed-effect models).

To summarise the explained amount of variance in each model, the conditional (variance explained by both fixed and random effects) and marginal (variance explained by fixed effects) coefficient of determination were calculated (pseudo-R^2) using the Nakagawa and Schielzeth (2013) approach.

Table 1 Land-cover. Field size (m^2), land cover types (in %), and land cover heterogeneity (Shannon index, H’) for each rice field (R1-R10) in Hai Duong (VN1) and Vinh Phuc (VN2) within a 300 m radius. Detailed information about each land cover type can be found in Appendix I (Land cover types).

Field ID	size	bare soil	forest	fruit	meadow/grassland	rice	vegetable	water	crops	compacted surface	sealed surface	H’
VN1 R2	652.07	0	0	0.15	1.47	96.31	1.32	0.74	0	0	0	0.202
VN1 R3	637.27	0	0	3.78	7.6	70.63	2.05	2.87	0	7.38	5.7	1.102
VN1 R4	283.96	0	4.57	8.88	10.58	47.73	3.07	19.89	0	3.87	1.41	1.561
VN1 R5	1129.12	4.03	0	6.45	8.76	47.64	2.81	16.58	0	3.4	10.33	1.621
VN1 R6	1883.9	5.76	0	5.63	3.16	67.87	0.94	10.65	0	1.57	4.42	1.184
VN1 R7	760.84	4.68	0	0.84	4.39	75.55	4.23	2.22	0	5.51	2.56	1.005
VN1 R8	197.66	0.14	0	8.81	2.39	50.86	0.4	2.46	0	32.59	2.35	1.223
VN1 R9	589.27	1.79	0	23.29	4.56	42.06	3.62	1.9	0	17.15	5.63	1.576
VN1 R10	511.94	1.95	0	18.67	2.97	56.98	1.26	0	0	15.62	2.55	1.254
VN2 R1	97.7	1.13	9.69	24.56	4.53	42.54	3.99	0.46	0	11.61	1.48	1.591
VN2 R2	394	0.17	15.75	13.51	17.94	29.27	3.66	0.24	0.41	14.9	4.15	1.814
VN2 R3	185.77	0.27	3.52	19.55	9.59	47.24	11.16	0.29	0	8.26	0.13	1.508
VN2 R4	166.98	0	9.48	19.94	8.65	39.45	6.18	2.84	5.05	7.94	0.46	1.774
VN2 R5	202.76	0.07	22.24	51.86	8.18	7.69	2.88	0.81	0.27	5.82	0.19	1.416
VN2 R6	404.3	0.33	31.95	35.39	10.12	7.86	2.59	5.97	0.27	5.37	0.15	1.628
VN2 R7	583.13	0	1.85	6.53	1.77	60.31	2.21	5.19	12.82	8.59	0.72	1.376
VN2 R8	158.16	1.19	0	29.47	7.09	43.12	0.21	4.05	0	11.92	2.95	1.464
VN2 R9	130.83	0	0.95	16.94	8.87	55.78	0	4.99	0	10.1	2.38	1.355
VN2 R10	407.66	1.86	1.99	21.96	12.94	33.09	1.97	11.05	1.75	9.22	4.17	1.859

Chapter 3 *Results*

3.1 Taxonomic composition of arthropod communities

The total number of collected arthropods consisted of 217,164 specimens belonging to 20 orders and 91 identified families (Table 2). Arthropods were dominated by the class Insecta with 98.7%. The class of Arachnida was present with 1.3% and one specimen of Diplopoda was found. Decomposers were the most abundant functional group with 167,397 specimens followed by herbivores with 33,152 specimens, predators with 8,952 specimens, parasitoids with 6,764 specimens, and fungivores with 482 specimens. In total, 417 specimens could not be assigned into a specific functional group and were categorised as indifferent.

Table 2 Assigned taxa into functional groups. Total numbers of specimens sampled using blow vac (BV), Malaise trap (MT), and sweep net (SN) in both study regions (Hai Duong and Vinh Phuc). Not all specimens were identified to the lowest taxon shown here and therefore some orders were listed with specimens even if there are families or species within this group identified and listed.

	Hai Duong			Vinh Phuc		
Functional groups/Taxa	BV	MT	SN	BV	MT	SN
Decomposer (detritivore/scavenger)	2847	19152	26887	6462	15583	96466
Coleoptera						
Scarabaeidae		3			1	
Scirtidae		3				
Anthicidae	1	26			5	
Collembola	1411	511	317	781	2081	47
Diplopoda						1
Diptera						
Nematocera	1435	18609	26570	5681	13496	96418
Fungivore	3	38	4	16	386	35
Coleoptera						
Corylophidae	3	25	4	1	306	26
Mycetophagidae		13		15	80	9
Herbivore	398	2662	3255	1122	10793	14922
Coleoptera						
Chrysomelidae	19	241	109	37	213	233
Silvanidae		9				
Curculionidae	3	10	21	14	49	85
Elateridae			1	2		5
Diptera						
Brachycera						
Chloropidae	47	257	336	40	184	595
Anatrichus erinaceus	14		191	28		512
Psilidae					1	

Ephydridae	62	278	286	390	374	2019
Muscidae		148			205	10
Tephritidae	21	24	42	45	9	167
Hemiptera						
Delphacidae	54	6	676	141	2	2047
Nilaparvata lugens	1	7	46	8	5	61
Sogatella furcifera	8	7	304	68	20	1039
Meenoplidae	2	8	9	9	1	16
Cicadellidae	15	33	86	49	149	483
Cicadulina bipunctata		1	2			10
Empoascanara spec.				12	2	205
Hecalus spec.		1			2	1
Nephotettix spec.	2		20	20		208
Recilia dorsalis			3	6	1	9
Coreidae	1	2	7	4		32
Lygaeidae		6			8	3
Miridae	5	3	26	2	10	11
Tingidae					1	1
Pentatomidae	15	2	81	3	1	68
Eysarcoris ventralis		1	1		1	
Nezara spec.			6			
Aleyrodidae	1	2	29	1		2
Aphididae	50	6	109	23	11	127
Hymenoptera						
Apocrita					21	
Apidae					3	
Apis cerana						1
Colletidae						
Hylaeus spec.					2	
Megachilidae					1	
Halictidae	1	5	2		21	2
Symphyta			1	1	3	8
Isoptera					1	
Lepidoptera	20	48	121	22	197	239
Orthoptera						
Acrididae	4	3	55	19	1	396
Pyrgomorphidae						18
Tetrigidae		2	15	2	6	42
Gryllotalpidae					1	
Phasmatodea				1		2
Psocoptera	1	82	21	2	79	84
Thysanoptera	52	1470	648	173	9208	6181
Parasitoid	182	751	2059	192	1293	2287
Diptera						
Brachycera						
Tachinidae	20	13	180	5	10	117

Phoridae	23	133	207	10	175	219
Sciomyzidae						
Sepedon spec.	58	177	1003	27	401	435
Hymenoptera						
Ceraphronoidea						
Ceraphronidae			16	3	7	40
Megaspilidae	1	1	5		18	1
Chalcidoidea						
Aphelinidae	2		43	2	2	162
Chalcididae		4	4			6
Elasminae			1			1
Encyrtidae		4	44	6	7	82
Eulophidae	6	14	57	27	67	377
Eurytomidae		1	2	2	1	18
Mymaridae	34	24	154	33	28	62
Pteromalidae	1	25	15	5	22	34
Trichogrammatidae	1	2	6	3		5
Chrysidoidea						
Bethylidae		3	5		3	
Dryinidae		2	5	1	1	10
Cynipoidea						
Figitidae	5	88	20	1	40	48
Diaprioidea						
Ismaridae					4	
Evanioidea						
Evaniidae			4		1	2
Ichneumonoidea						
Braconidae	10	101	127	22	148	312
Ichneumonidae	5	19	16	9	92	128
Platygastroidea						
Platygastridae			2			4
Scelionidae	12	92	118	27	146	182
Baeus spec.			3			2
Macroteleia spec.		1				1
Proctotrupoidea						
Diapriidae	4	45	22	9	119	38
Proctotrupidae						1
Vespoidae						
Tiphiidae		1				
Vespoidea						
Eumenidae		1				
Pompilidae					1	
Predator	576	1008	2414	1239	623	3092
Araneae	158	44	327	54	39	48
Araneidae	29	88	566	47	67	416
Tetragnathidae						

Tetragnatha spec.	9	4	93	15	3	325
Lycosidae	11	9	8	75	9	13
Oxyopidae	1		7	3	1	77
Salticidae	4		14	10		76
Thomisidae		1	3		1	9
Clubionidae	26	45	29	59	19	44
Coleoptera						
Carabidae	13	5	17	36	11	61
Dytiscidae	1		2	2	4	6
Coccinellidae	1	45	14	2	31	15
Hydrophilidae		1			1	
Staphylinidae	135	95	307	118	64	198
Dermaptera			1			
Diptera						
Brachycera						
Dolichopodidae	53	604	558	119	263	952
Hybotidae	2		1	8		182
Ephydridae						
Ochthera sauteri	9	37	287	13	33	315
Syrphidae		4	5		10	8
Heteroptera						
Corixidae	6			11		
Gerridae						
Limnogonus spec.	1			12		
Veliidae						
Microvelia spec.	73		3	631		1
Geocoridae				1		
Miridae						
Cyrtorhinus lividipennis		1	1	7	1	16
Reduviidae		1				6
Saldidae						11
Hymenoptera						
Apocrita						
Crabronidae			1		4	2
Vespoidae						
Formicidae	7	8	52	7	23	79
Vespidae		1			1	1
Mesostigmata						
Gamasina	33	2	31		8	
Neuroptera	1				3	
Odonata	3		81	8	2	214
Orthoptera						
Gryllidae		13	6	1	25	17
Indifferent	46	124	103	3	80	61
Blattodea					1	
Coleoptera	3	2	6	1	1	2

Diptera	33		5			1
Brachycera	7	115	82		54	3
Stratiomyidae		1				5
Tabanidae		1	6		5	4
Ephemeroptera	3	5	3		13	9
Orthoptera						
Tettigoniidae			1	2		37
Trichoptera					6	

3.2 Method comparison

In all functional groups the highest number of specimens was sampled by sweep netting with 151,585 specimens, followed by Malaise trapping with 52,493 specimens, and blow vac sampling with a total number of 13,086 specimens. The highest number of families (77) was sampled by using Malaise traps. Sweep net samples yielded in 73 different families, whereas blow vac samples resulted in 57 families. The total abundance of decomposers, herbivores, parasitoids, and predators collected with the three methods and separated by sampling days (A = 35 DAT; B = 50 DAT) is shown in Figure 4.

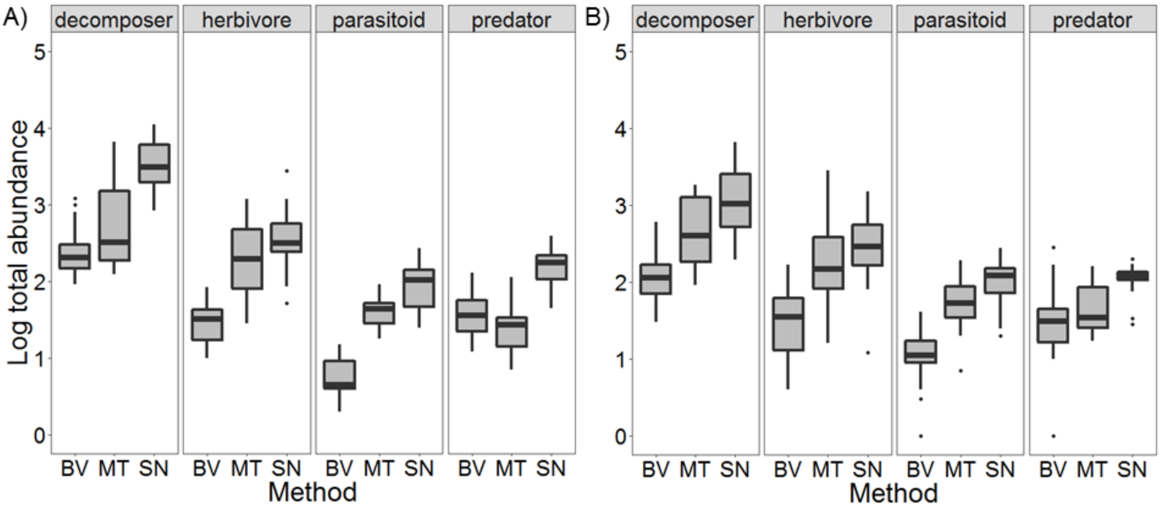


Figure 4 Total abundance of functional groups. Total abundance (log-transformed) of decomposers, herbivores, parasitoids, and predators per rice field. Samples were taken using blow vac (BV), Malaise trap (MT), and sweep net (SN) at 35 (A) and 50 (B) days after transplanting. Boxplots show the median as black line.

3.2.1 Differences in arthropod density and specimens captured per person effort among the three methods

The collected arthropod density (in m²) differed significantly between data of sweep net and blow vac samples (Fig. 5). Independent of the sampling day, samples of blow vac unexceptionally resulted in higher arthropod density per area for all functional groups (Malaise trap data were excluded from this comparison, as sampled specimens cannot be assigned to a defined area). In contrast to this, sweep netting resulted in higher specimens captured per person effort (sampling time) for decomposers, predators, and parasitoids among the three methods. Only herbivores were sampled in the same quantity by sweep netting and Malaise trapping (Fig. 6).

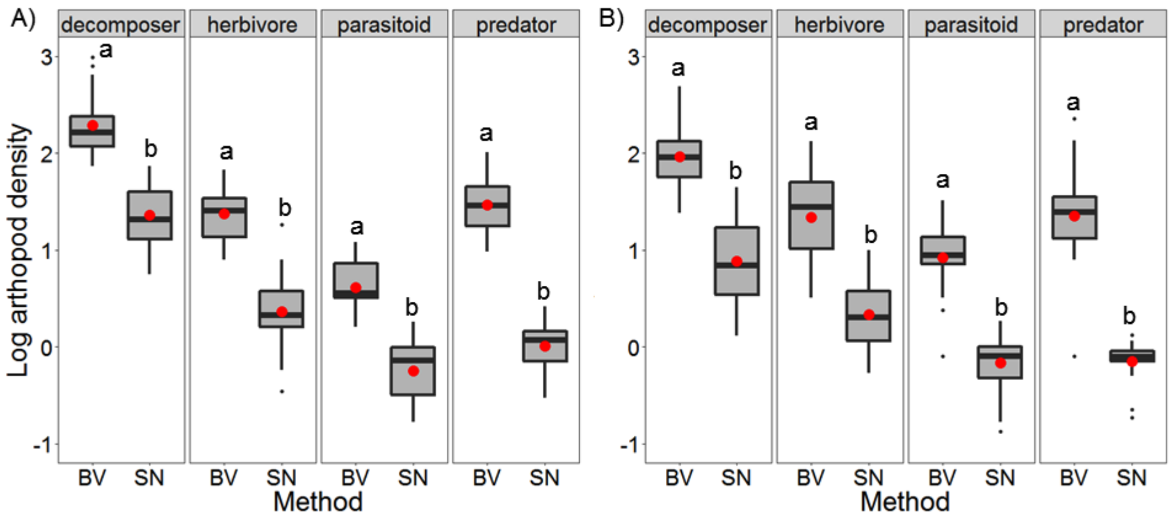


Figure 5 Arthropod density of functional groups. Arthropod density (log-transformed) per rice field was sampled by using blow vac (BV) and sweep net (SN) (specimens per sampled area in m²) at 35 (A) and 50 (B) days after transplanting. Boxplots show the median as black line and the mean as red point. Letters (a-b) indicate significant differences between means (LMM; p<0.05, Tukey post-hoc test). Malaise trap data were excluded from this comparison because the sampled arthropods cannot be assigned to a defined area (due to passiveness of the method).

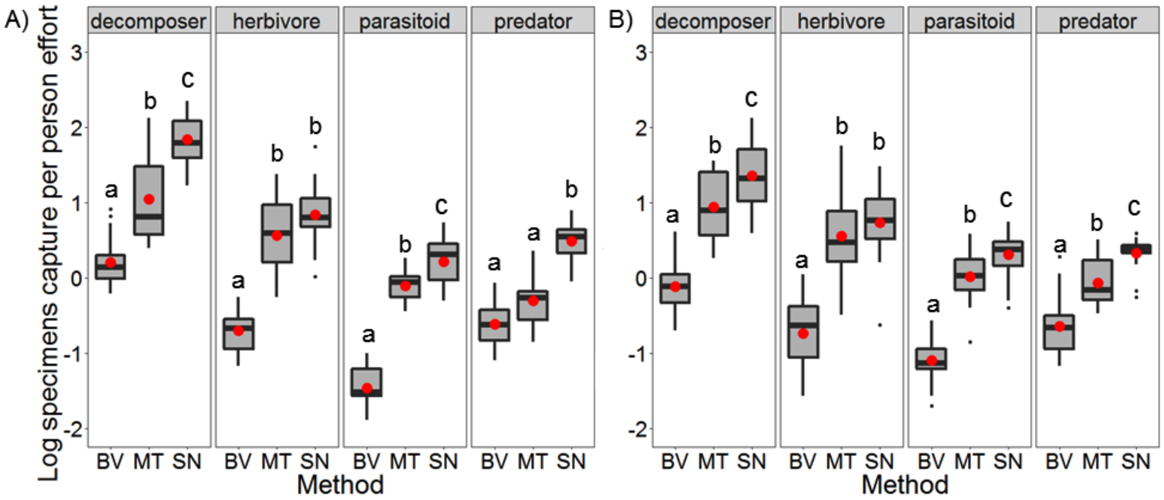


Figure 6 Specimens captured per person effort of functional groups. Specimens captured per person effort (per minute, log-transformed) per rice field were sampled by using blow vac (BV), Malaise trap (MT), and sweep net (SN) at 35 (A) and 50 (B) days after transplanting. Boxplots show the median as black line and the mean as red point. Letters (a-c) indicate significant differences between means (LMM; p<0.05, Tukey post-hoc test).

3.2.2 Differences in composition of rescaled and relative abundance of functional groups among the three methods

At 35 DAT (days after transplanting), the sampling performance of sweep net, Malaise trap, and blow vac resulted in high variations of collected functional groups when standardised to rescaled abundance. Sweep net and blow vac were the most efficient methods in catching the decomposer fauna, whereas sweep net and Malaise trap samples resulted in higher amounts of parasitoids at 35 DAT. Only the functional group of predators were sampled in highest amounts by the blow vac method on both sampling days (Fig. 7).

Considering the relative abundance of functional groups, the decomposer fauna was highest at 35 DAT when sweep net and blow vac had been used. Malaise trap catches contained most herbivores and parasitoids, whereas blow vac samples yielded most predators. There were no differences between the samples of the three methods with regard to the number of decomposers and parasitoids at 50 DAT. With all three methods, herbivorous and predatory arthropods were sampled in similar sequences at 50 DAT as at 35 DAT (Fig. 8).

The ranked results of the method comparisons (Table 3) show that sweep netting ranked first, followed by blow vac sampling, and Malaise trapping.

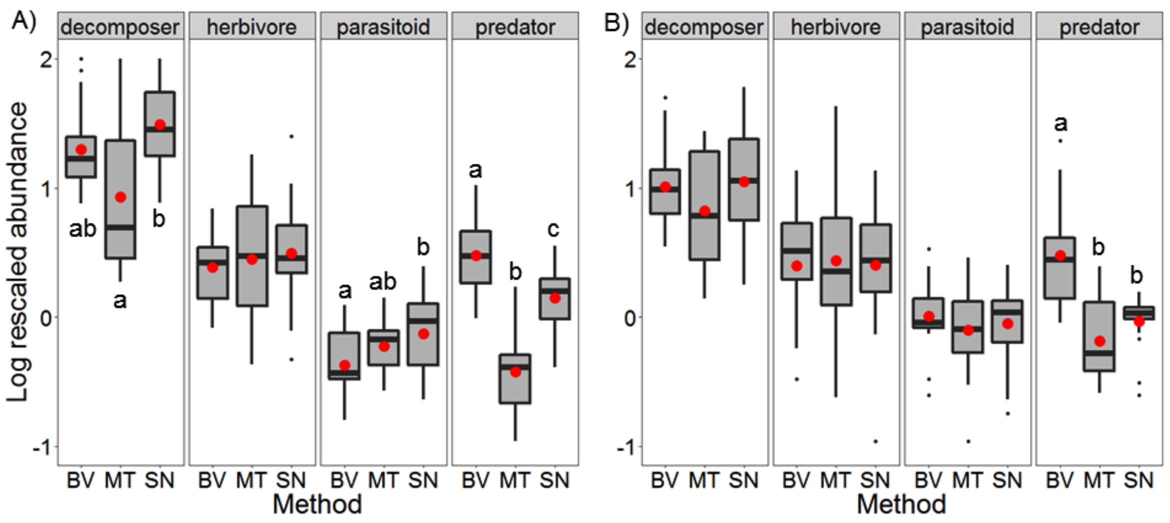


Figure 7 Rescaled abundance of functional groups. Rescaled abundance (log-transformed) of functional groups per rice field was sampled by using blow vac (BV), Malaise trap (MT), and sweep net (SN) at 35 (A) and 50 (B) days after transplanting. Boxplots show the median as black line and the mean as red point. Letters (a-c) indicate significant differences between means (LMM; p<0.05, Tukey post-hoc test).

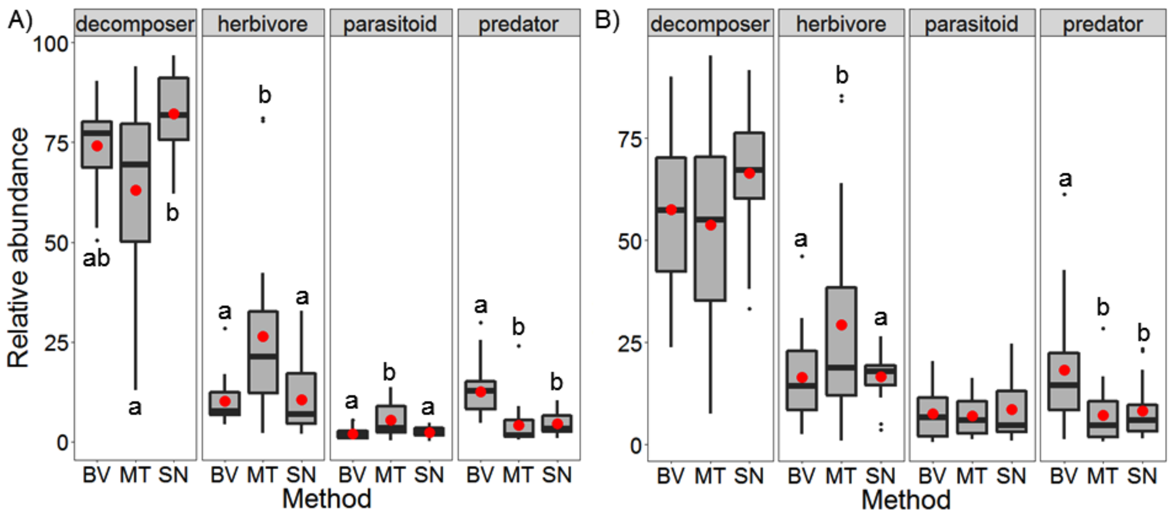


Figure 8 Relative abundance of functional groups. Relative abundance of functional groups per rice field (in percent) was sampled by using blow vac (BV), Malaise trap (MT), and sweep net (SN) at 35 (A) and 50 (B) days after transplanting. Boxplots show the median as black line and the mean as red point. Letters (a-b) indicate significant differences between means (LMM; p<0.05, Tukey post-hoc test).

Table 3 Ranked results of method comparison. Summary of comparison of four categories for blow vac (BV), Malaise trap (MT), and sweep net (SN). Methods were ranked as 1st, 2nd, and 3rd, whereby 1st refers to the method which yielded the highest abundance of specimens in each functional group as well as in the four categories. ‘na’ indicates that Malaise trap was excluded from the respective category (see 2.4 Standardisation). Results were divided into three parts: Result of categories (counting horizontal ranks), result of functional groups (counting vertical ranks), and the final result which is highlighted in red (counting result of categories and functional groups altogether).

Functional group	decomposer			herbivore			parasitoid			predator			Summarised results for categories		
Method	BV	MT	SN	BV	MT	SN	BV	MT	SN	BV	MT	SN	BV	MT	SN
Category of comparison															
1) Arthropod density	1st	na	2nd	1st	na	2nd	1st	na	2nd	1st	na	2nd	1st	na	2nd
2) Specimens captured per person effort	3rd	2nd	1st	3rd	1st	1st	3rd	2nd	1st	3rd	2nd	1st	3rd	2nd	1st
3) Rescaled abundance	1st	3rd	1st	1st	1st	1st	3rd	1st	1st	1st	3rd	2nd	2nd	3rd	1st
4) Relative abundance	1st	3rd	1st	2nd	1st	2nd	2nd	1st	2nd	1st	2nd	2nd	1st	3rd	3rd
Summarised results for functional groups per method	2nd	3rd	1st	3rd	1st	2nd	3rd	1st	2nd	1st	2nd	3rd	**2nd**	**3rd**	**1st**

3.3 Functional and taxonomic diversity across different spatial scales

All analyses were separated for blow vac and sweep net data and divided into the two sampling days (35 and 50 days after transplanting = DAT). Malaise trap data were excluded from this analysis because of too few sampling replicates.

The term ‘diversity’ is used here for the ‘effective number of functional or taxonomic groups’ (for details see 2.6.2).

3.3.1 Differences of partitioned functional and taxonomic diversity across different spatial scales

Functional and taxonomic diversity (alpha, beta, and gamma) were highly correlated. At the local scale, functional and taxonomic beta diversity were close to one (Fig. 9 and Fig. 10), indicating high functional and taxonomic similarity between the sample units within the rice fields (Marcon et al. 2014). Functional alpha and gamma diversity were similar with one exception for blow vac data at 50 DAT, where functional gamma diversity was higher than alpha diversity (Fig. 9 B). However, taxonomic alpha and gamma diversity differed on both sampling days when using blow vac (Fig. 10A, B).

Over the two sampling days, the functional alpha, beta, and gamma diversity increased for both methods (sweep net and blow vac) with one exception for beta diversity, which did not change between 35 and 50 DAT when analysing sweep net data. This was similar for the taxonomic alpha, beta, and gamma diversity, which also increased from 35 to 50 DAT.

At the landscape scale, functional and taxonomic diversity showed similar patterns compared to the local scale (Table 4). Beta diversity of both diversity dimensions was close to one, indicating little turnover between the rice fields within each region. Similar to the local scale analysis, functional and taxonomic alpha, beta, and gamma diversity increased from 35 to 50 DAT for both methods.

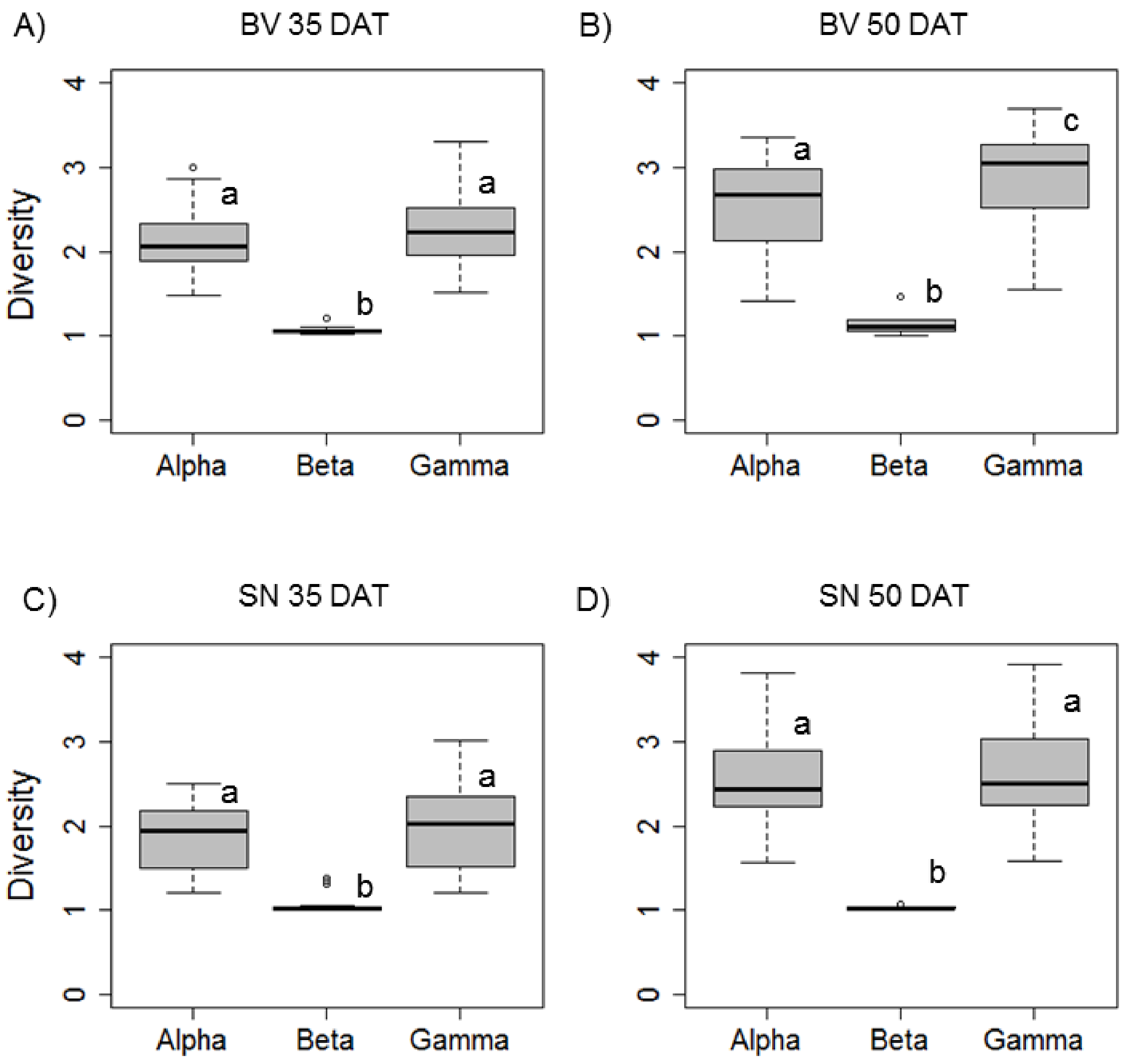


Figure 9 Functional alpha, beta, and gamma diversity at the local scale. Samples were taken with blow vac (BV) at 35 (A) and 50 (B) days after transplanting (DAT) and sweep net (SN) at 35 (C) and 50 (D) DAT. Boxplots show the median as black line and letters (a-c) indicate significant differences between indices (Wilcoxon-test; $p<0.05$).

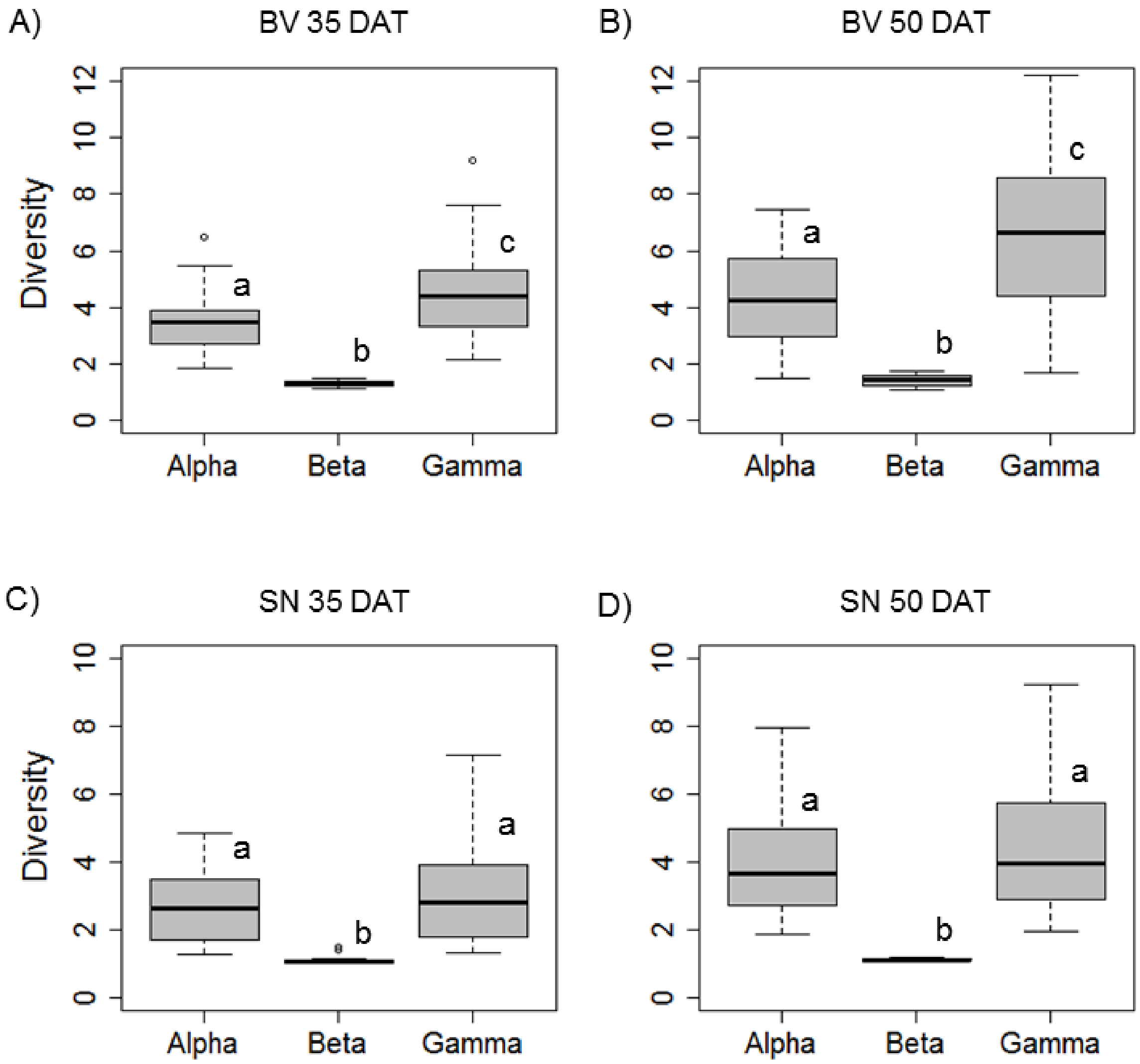


Figure 10 Taxonomic alpha, beta, and gamma diversity at the local scale. Samples were taken with blow vac (BV) at 35 (A) and 50 (B) days after transplanting (DAT) and sweep net (SN) at 35 (C) and 50 (D) DAT. Boxplots show the median as black line and letters (a-c) indicate significant differences between indices (Wilcoxon-test; $p<0.05$).

Table 4 Functional and taxonomic alpha, beta, and gamma diversity at the landscape scale. Functional and taxonomic alpha (α), beta (β), and gamma (γ) diversity for Hai Duong (VN1) and Vinh Phuc (VN2), separated for blow vac (BV) and sweep net (SN) as well as for sampling days (35 and 50 days after transplanting).

Method	Reg.	α (functional)	β (functional)	γ (functional)	α (taxonomic)	β (taxonomic)	γ (taxonomic)
BV 35	VN1	2.16	1.02	2.20	4.14	1.35	5.57
	VN2	2.04	1.05	2.15	3.46	1.32	4.58
BV 50	VN1	2.82	1.08	3.06	5.65	1.41	7.98
	VN2	2.48	1.18	2.94	4.93	1.54	7.61
SN 35	VN1	1.83	1.02	1.87	2.47	1.07	2.65
	VN2	1.72	1.05	1.81	2.24	1.09	2.45
SN 50	VN1	3.18	1.05	3.32	5.53	1.18	6.52
	VN2	2.08	1.03	2.13	2.86	1.10	3.15

3.3.2 Relationship of land cover heterogeneity and pesticides with functional diversity (alpha, beta, and gamma) at the local scale

Functional alpha and gamma diversity of arthropod communities decreased with an increasing number (Fig. 11A) and amount of pesticides (Fig. 11B; for details see: 2.5.2 Pesticides) sampled by using blow vac at 35 DAT. At 50 DAT, only functional alpha diversity decreased with an increasing amount of pesticides (Fig. 12). Similar to blow vac data, the number of pesticides had a negative relationship with alpha and gamma diversity at 35 DAT when using sweep net data (Fig. 13A, C). Functional alpha and gamma diversity sampled by sweep net at 35 DAT increased with increasing land cover heterogeneity (Fig. 13B, D). No relationships were found when using data of sweep net at 50 DAT. Functional beta diversity sampled by sweep netting and blow vac sampling showed no correlation with either land cover heterogeneity or number and amount of pesticides. Linear models of the functional diversity (alpha, beta, and gamma) can be found in Table 5.

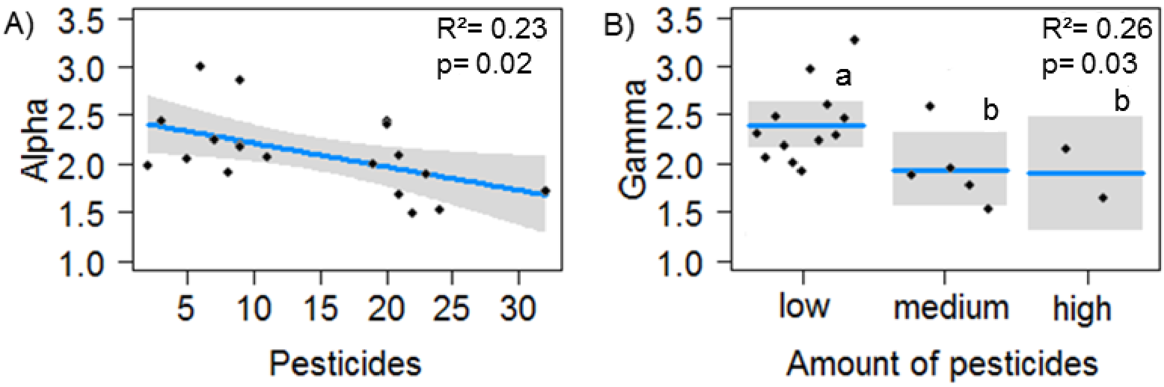


Figure 11 Relationship of pesticides with functional diversity of blow vac data at 35 days after transplanting. Diversity was partitioned into its alpha (A) and gamma (B) components, based on the exponential Shannon entropy and expressed as effective numbers of functional groups. Pesticides were measured in numbers of active ingredients as well as categorised into three classes: low, medium, and high referring to the amount of pesticides. Measures of goodness of fit are adjusted R-squares. Boxplots show the median as blue line and original values as black dots. Letters (a-b) indicate significant differences between means.

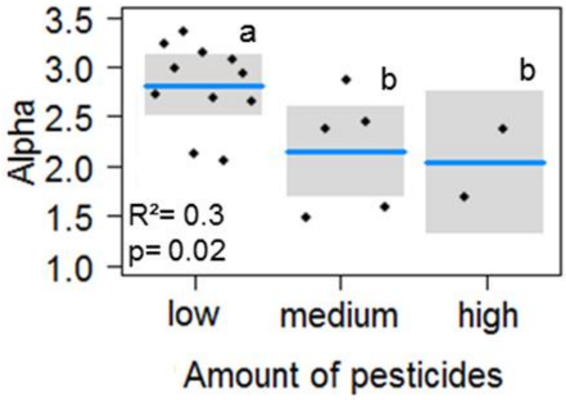


Figure 12 Relationship of pesticides with functional diversity of blow vac data at 50 days after transplanting. Alpha functional diversity was calculated based on the exponential Shannon entropy and expressed as effective numbers of functional groups. Measures of goodness of fit are adjusted R-squares. Pesticides were categorised into three classes: low, medium, and high referring to the amount of pesticides. Boxplots show the median as blue line and original values as black dots. Letters (a-b) indicate significant differences between means.

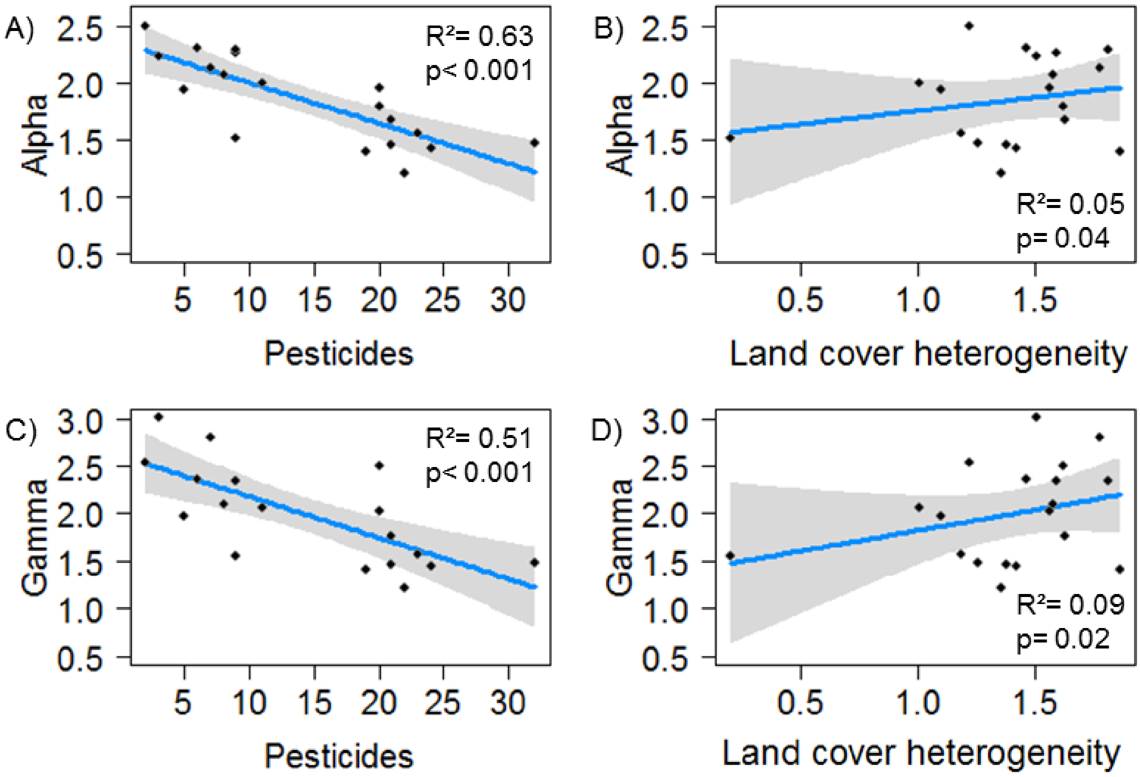


Figure 13 Relationship of pesticides and land cover heterogeneity with functional diversity of sweep net data at 35 days after transplanting. Functional diversity was partitioned into its alpha (A) & (B) and gamma (C) & (D) components, based on the exponential Shannon entropy and expressed as effective numbers of functional groups. Original values are shown as black dots. Pesticides were measured in numbers of active ingredients. Land cover heterogeneity is based on Shannon index (H'). Measures of goodness of fit are adjusted R-squares. For the linear regression model of alpha (A) & (B) the total R-square is $R^2= 0.68$, joint contribution is j= -0.018. For the linear regression model of gamma (C) & (D) the total R-square is $R^2= 0.61$, joint contribution is j= -0.02.

Table 5 Linear models of functional diversity (alpha, beta, and gamma). Models were separated by blow vac (BV) and sweep net (SN) as well as sampling days (35 and 50 days after transplanting). NS indicates no significant predictor variable in the model.

Models	Responds variable	Predictor variable	p-value	Variable importance
BV 35	alpha diversity	Pesticides	0.02	0.62
BV 35	beta diversity	NS		
BV 35	gamma diversity	Amount of pesticides	0.03	0.46
BV 50	alpha diversity	Amount of pesticides	0.02	0.65
BV 50	beta diversity	NS		
BV 50	gamma diversity	NS		
SN 35	alpha diversity	Pesticides	<0.001	1
		Land cover heterogeneity	0.04	0.75
SN 35	beta diversity	NS		
SN 35	gamma diversity	Pesticides	<0.001	0.92
		Land cover heterogeneity	0.02	0.85
SN 50	alpha diversity	NS		
SN 50	beta diversity	NS		
SN 50	gamma diversity	NS		

3.3.3 Relationship of land cover heterogeneity and pesticides with taxonomic diversity (alpha, beta, and gamma) at the local scale

Similar to the functional diversity, the taxonomic diversity (alpha and gamma) of arthropod communities had a negative relationship with the number of pesticides when using blow vac data at 35 DAT (Fig. 14A, B). At 50 DAT, taxonomic alpha diversity had a negative relationship with the amount of pesticides and gamma diversity decreased with increasing number of pesticides (Fig. 15A, B).

For sweep net data, similar patterns were found at 35 DAT. With an increasing number of pesticides, taxonomic alpha and gamma diversity decreased (Fig. 16A, C) and taxonomic alpha and gamma diversity increased with increasing land cover heterogeneity (Fig. 16B, D). At 50 DAT, no relationships were detected when using sweep net data. Taxonomic beta diversity did not relate with land cover heterogeneity or pesticides (amount or number) in any regression model (sweep net and blow vac). All linear models of the partitioned taxonomic diversity (alpha, beta, and gamma) can be found in Table 6.

The effect size (R^2) of pesticides on functional and taxonomic diversity showed no differences based on the Paired Student's t test ($p>0.05$). Therefore, the relationship of pesticides with both diversity dimensions (functional and taxonomic diversity) was negative to a similar extent.

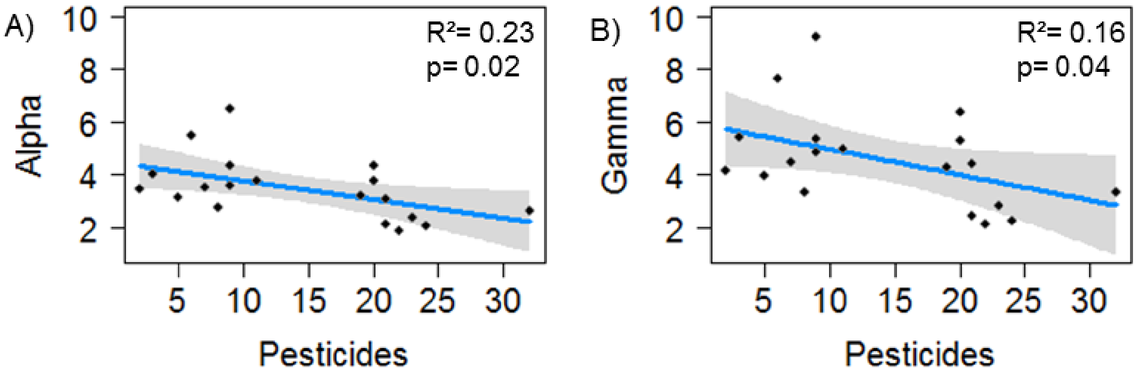


Figure 14 Relationship of pesticides with taxonomic diversity of blow vac data at 35 days after transplanting. Taxonomic diversity was partitioned into its alpha (A) and gamma (B) components, based on the exponential Shannon entropy and expressed as effective numbers of taxonomic groups. Original values are shown as black dots. Pesticides were measured in numbers of active ingredients. Measures of goodness of fit are adjusted R-squares.

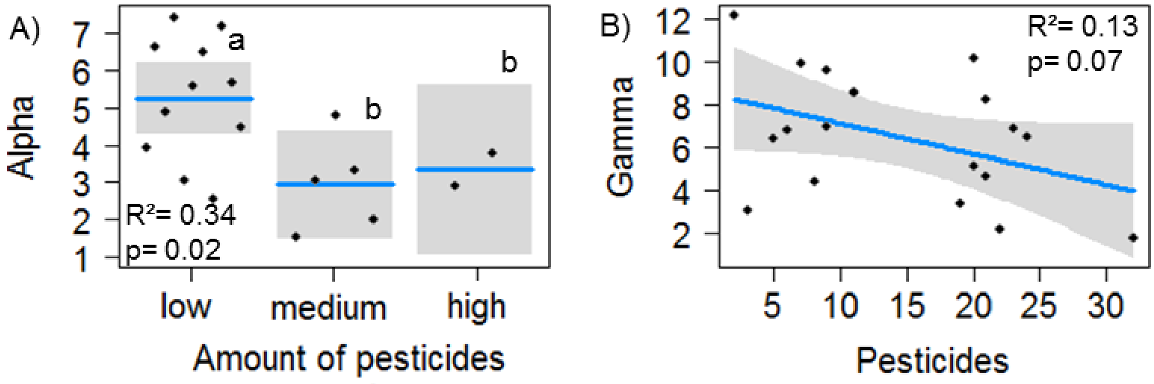


Figure 15 Relationship of pesticides with taxonomic diversity of blow vac data at 50 days after transplanting. Taxonomic diversity was partitioned into its alpha (A) and gamma (B) components, based on the exponential Shannon entropy and expressed as effective numbers of taxonomic groups. Pesticides were measured in numbers of active ingredients as well as categorised into three classes: low, medium, and high referring to the amount of pesticides. Measures of goodness of fit are adjusted R-squares. Boxplots show the median as blue line and original values as black dots. Letters (a-b) indicate significant differences between means.

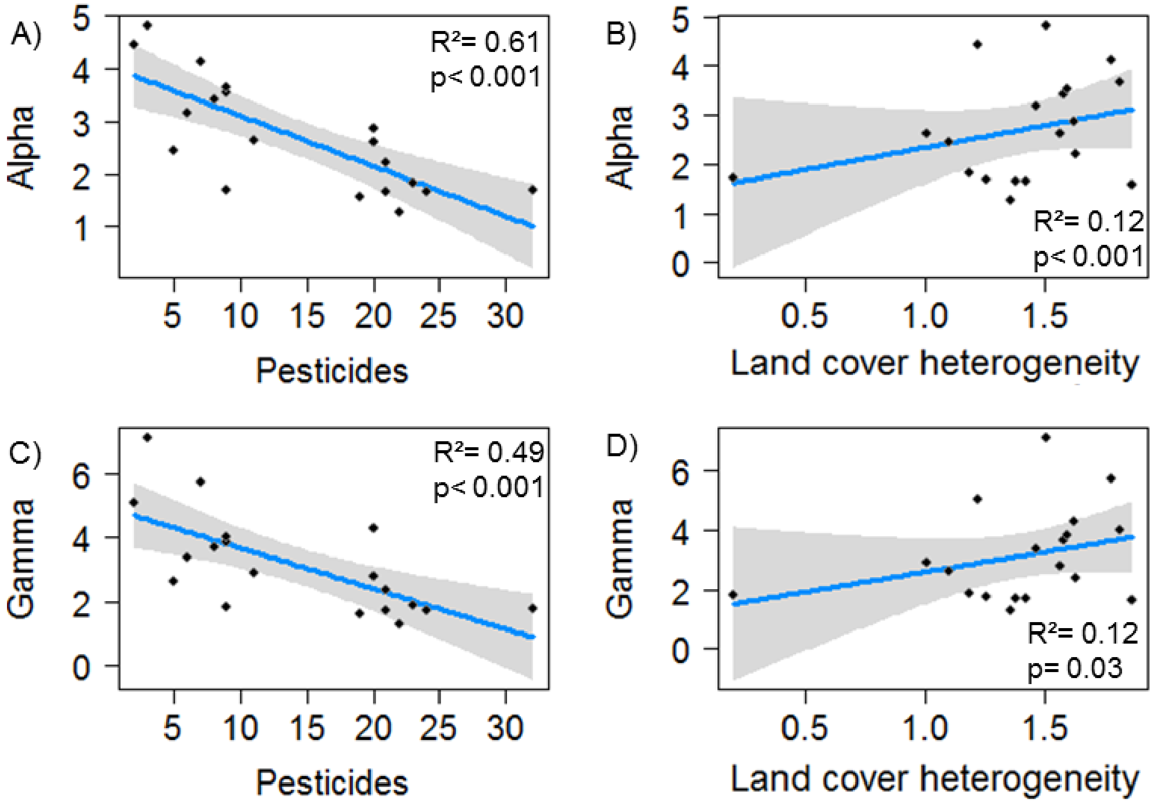


Figure 16 Relationship of pesticides and land cover heterogeneity with taxonomic diversity of sweep net data at 35 days after transplanting. Taxonomic diversity was partitioned into its alpha (A) & (B) and gamma (C) & (D) components, based on the exponential Shannon entropy and expressed as effective numbers of taxonomic groups. Original values are shown as black dots.

Pesticides were measured in numbers of active ingredients. Land cover heterogeneity is based on Shannon index (H'). Measures of goodness of fit are adjusted R-squares. For the linear regression model of alpha (A) & (B) the total R-square is $R^2 = 0.73$, joint contribution is j= -0.02. For the linear regression model of gamma (C) & (D) the total R-square is $R^2 = 0.61$, joint contribution is j= -0.02.

Table 6 Linear models of taxonomic diversity (alpha, beta, and gamma). Models were separated by blow vac (BV) and sweep net (SN) as well as sampling days (35 and 50 days after transplanting). NS indicates no significant predictor variable in the model.

Models	Responds variable	Predictor variable	p-value	Variable importance
BV 35	alpha diversity	Number of pesticides	0.02	0.68
BV 35	beta diversity	NS		
BV 35	gamma diversity	Number of pesticides	0.04	0.55
BV 50	alpha diversity	Amount of pesticides	0.02	0.68
BV 50	beta diversity	NS		
BV 50	gamma diversity	Number of pesticides	0.07	0.3
SN 35	alpha diversity	Number of pesticides	<0.001	1
		Land cover heterogeneity	<0.001	0.93
SN 35	beta diversity	NS		
SN 35	gamma diversity	Number of pesticides	<0.001	0.96
		Land cover heterogeneity	0.03	0.8
SN 50	alpha diversity	NS		
SN 50	beta diversity	NS		
SN 50	gamma diversity	NS		

3.4 Relationship of natural enemies (predators and parasitoids), land cover heterogeneity, and insecticides with herbivore abundance

All three regression models of blow vac, sweep net, and Malaise trap showed a positive relationship of parasitoids with increasing herbivore abundance. Particularly relationships of insecticides were only obtained with blow vac data. Land cover heterogeneity showed no relationship with herbivore abundance in any regression model (Table 7).

Sweep net data indicated that herbivore abundance declined from 35 to 50 DAT. This decline of herbivore abundance became stronger when parasitoids became more abundant (Fig. 17).

Blow vac data showed a positive relationship of predator and parasitoid abundances with herbivore abundance. Only the combined effect of high numbers of insecticides with either increasing abundance of predators or parasitoids resulted in a negative relationship with herbivore abundance when using blow vac data (Fig. 18).

Malaise trap data showed a minor increase of herbivore abundance over time (from 35 to 50 DAT) which, however, decreased with increasing abundance of predators. High abundance of both predators and parasitoids led to a decrease of herbivore abundance when using Malaise trap data (Fig. 19)

Regression models using sweep net data were best explained by random effects (two regions, conditional variance = 0.60) rather than fixed effects (predators, parasitoids, land cover heterogeneity and insecticides, marginal variance = 0.26). This was similar for regression models of blow vac data, where random effects explained most of the regression models (conditional variance = 0.54, marginal variance = 0.24). Regression models of Malaise trap data were explained with lowest support by their fixed and random effects (conditional variance = 0.18, marginal variance = 0.1). Detailed results of each statistical regression model (see 2.6.3) can be found in Appendix III (Linear mixed-effect models).

Table 7 Linear mixed-effect models (LMM) of herbivore abundance. Predictor variables with estimates and variable importance for each model. Models were separated by sweep net (SN), blow vac (BV), and Malaise trap (MT) as well as sampling days (35 and 50 days after transplanting = Day). * indicates interactions of the predictor variables.

Estimates	Day	Parasitoids	Predators	Insecticides	Land cover heterogeneity	Day* Parasitoids	Day* Predators	Predators* Parasitoids	Insecticides* Predators	Insecticides* Parasitoids
SN Model	-282.8	502.8	-180.1			-392.3				
BV Model		13.032	19.523	-11.084					-9.056	-10.618
MT Model	39.2	221.55	-16.79				-220.31	-76.29		
Variable Importance	Day	Parasitoids	Predators	Insecticides	Land cover heterogeneity	Day* Parasitoids	Day* Predators	Predators* Parasitoids	Insecticides* Predators	Insecticides* Parasitoids
SN Model	0.97	1	0.87			0.85				
BV Model		0.89	0.97	0.76					0.36	0.36
MT Model	0.70	0.87	0.87				0.29	0.25		

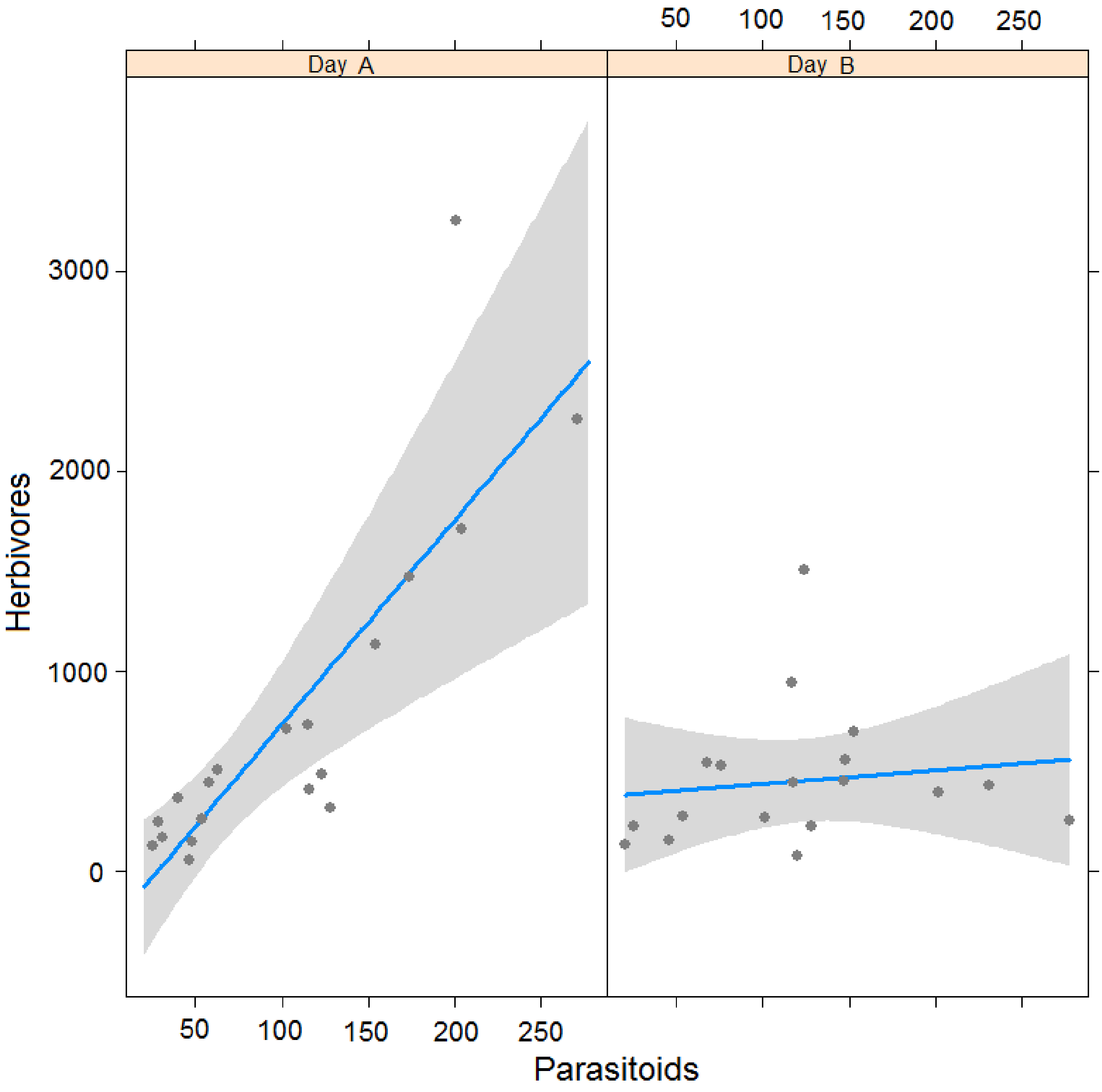


Figure 17 Relationship of sampling days and parasitoid abundance with herbivore abundance. Declining herbivore abundance over the two sampling days, 35 (Day A) and 50 (Day B) days after transplanting, with increasing parasitoid abundance using sweep net data.

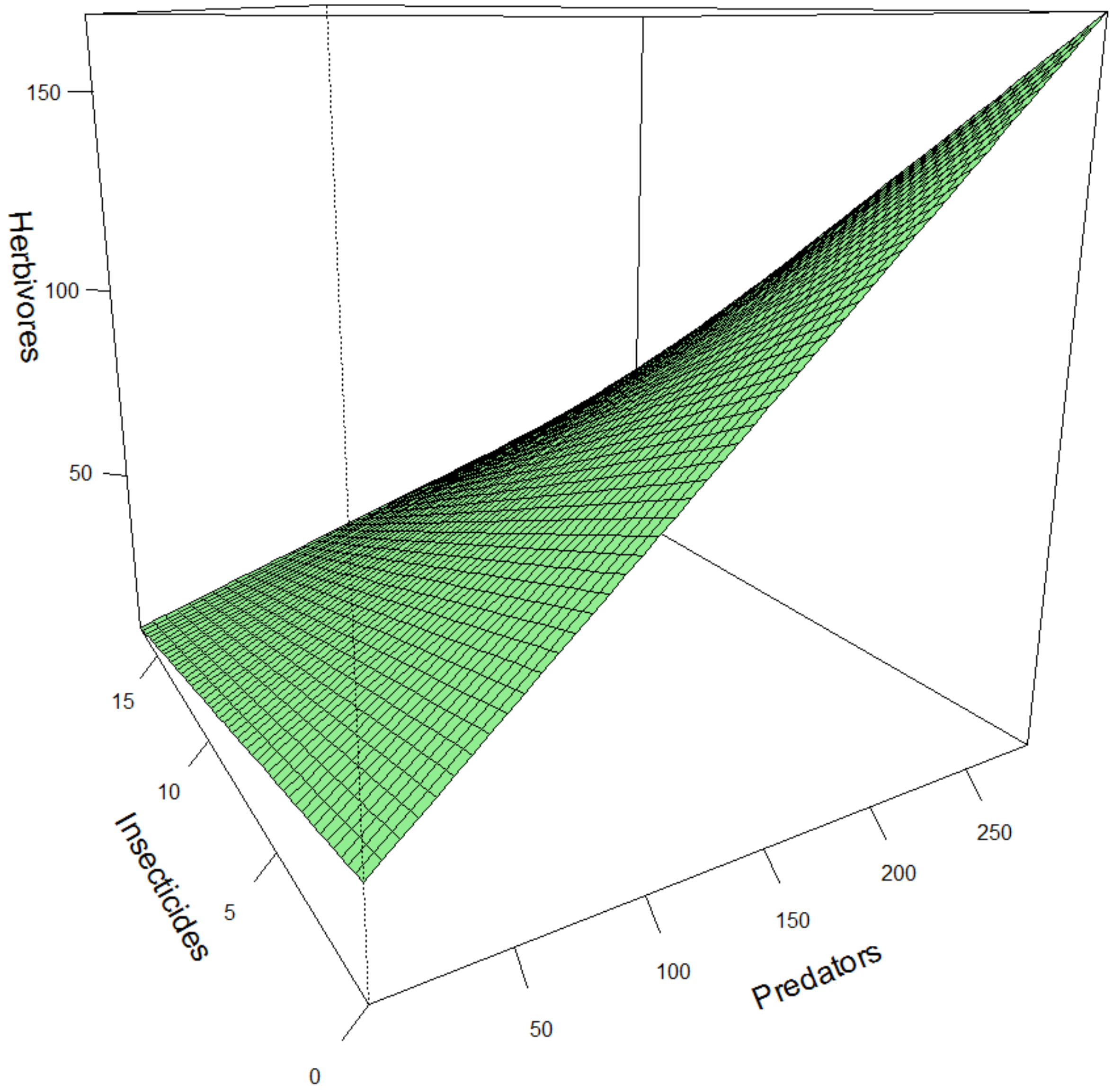


Figure 18 Relationship of predator abundance and insecticides with herbivore abundance. Decreasing herbivore abundance by the interaction effect of predators with number of insecticides when using blow vac data.

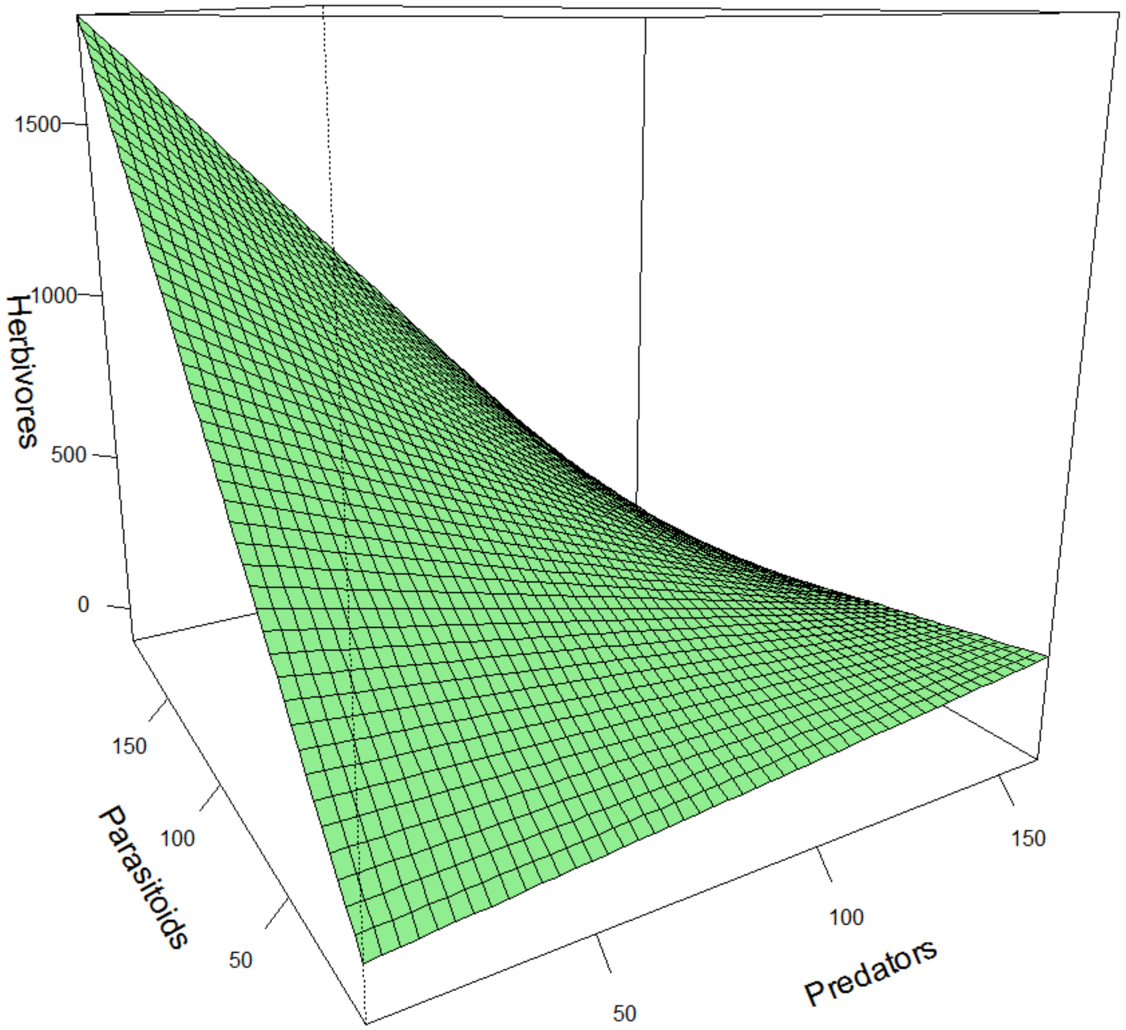


Figure 19 Relationship of natural enemy abundance (predators and parasitoids) with herbivore abundance. Decreasing herbivore abundance by the interaction effect of predators with parasitoids when using Malaise trap data.

Chapter 4 *Discussion*

The discussion section is separated into three parts: the first part deals with the results of the method comparison of sweep net, blow vac, and Malaise trap. Furthermore, strengths and limitations of each method are discussed as well as guidelines for best use elaborated. The second part focuses on the functional and taxonomic diversity of arthropod communities and the effects of pesticides and land cover heterogeneity on two diversity dimensions across multiple scales are discussed. The third part deals with the combined effect of natural enemies and insecticides as well as land cover heterogeneity on herbivore abundance. These three parts are summarised in a synthesis and an outlook.

4.1 Method comparison

Sweep nets, Malaise traps, and blow vac are three frequently used methods for the collection of arthropods in various ecosystems (Southwood and Henderson 2000) and can be further regarded as the standard methods at hand. The results show that the recorded composition of functional groups, as well as arthropod abundance, differ greatly depending on which of these three methods is used. The suitability of a certain sampling method highly depends on the research question, targeted taxa and study area. Especially when designing experimental studies, knowledge about appropriate sampling methods can save time, reduce workload and costs. Based on these considerations, four categories were chosen to compare blow vac, sweep net, and Malaise trap from different perspectives: 1) recorded arthropod density, 2) time efficiency, 3) rescaled abundance and 4) relative abundance of predators, parasitoids, herbivores, and decomposers (for a detailed description of 3) and 4) see 2.4 Standardisation). The following hypotheses were tested:

- (i) Blow vac samples yield more arthropod specimens per area compared to sweep netting.
- (ii) Sampling by sweep netting is most efficient in terms of the effort invested for a certain amount of collected specimens per person (sampling time).

Blow vac samples included all functional groups in highest density per area, while sweep net catches resulted in fewer numbers of functional groups (Fig. 5; note: Malaise trap data were excluded from this comparison, as the sampled specimens cannot be assigned to a defined area, due to passiveness of the method), which confirmed the first hypothesis (i). One possible reason for this could be that with blow vac sampling, a certain area is sampled intensively and precisely, whereas with sweep netting a larger area is sampled more extensively and imprecisely (Ausden and Drake 2006) and therefore when standardising methods to arthropod density, blow vac sampling is in advantage over sweep netting. This is in accordance with a study by Buffington and Redak (1998) who compared vacuum and sweep net sampling in coastal sage scrubs in California (USA). Vacuum sampling had apparent advantages in reaching the interior parts of the sage scrub plants (Buffington and Redak 1998) and, transferred to the present study, the blow vac method was especially suitable for reaching the lower parts of rice plants. Though, in contrast to this, Reed et al. (2010), who conducted a similar study in sweet potato foliage in Mississippi (USA), collected higher numbers of insects when using sweep nets and recommend this method over vacuum sampling. The efficiency of vacuum sampling is highly dependent on the structure of the sampled plants (e.g. shrubs and grasses), explaining the large variation in capture efficiency between the studies (Hossain et al. 1999). Hence, the same sampling method might perform differently in terms of taxonomic composition of sampled arthropods, depending on the ecosystem studied.

In a study by Schoenly and Barrion (2016), different sampling methods, including sweep netting and vacuum sampling, were tested in irrigated rice agroecosystem in the Philippines to assess invertebrate biodiversity. In their study, sweep netting yielded smallest catches in terms of sampled taxa and abundance. Thus, the authors concluded that sweep netting could be excluded from method selection when assessing biodiversity in irrigated rice fields.

With regard to the area sampled, their result is in accordance with the present study. However, economic costs also often play an important role when collecting arthropods (Gullan and Cranston 2014). Methods like e.g. blow vac are labour intensive as adequate handling requires more than one person. In this study, economic costs have been quantified as specimens captured per person effort (time of active sampling) and the highest number of specimens per person effort was collected by sweep netting (hypothesis ii; Fig. 6); hence, this method can be regarded as the most economical and labour-efficient method and should not be excluded when assessing arthropod diversity in rice agroecosystems when resources are limited.

When considering the invested time for identification of arthropods, the very high quantities in samples of sweep nets and Malaise traps significantly reduced time-efficiency. The sampling by blow vac yielded the lowest quantity of arthropods, which theoretically could result in lower effort for the follow-up processing of samples (sorting, identification). However, this advantage was cancelled by the very bad quality of specimens (many were destroyed by the physical impact of the sucking device), which prolonged and complicated the identification process enormously and often resulted in impossible or uncertain identification.

When comparing the sampling methods in regard to rescaled and relative abundance (see 2.4 Standardisation), all three methods differed clearly in collecting one of the four functional groups (Fig. 7 & 8). Blow vac was the only method suitable for sampling higher numbers of ground-dwelling arthropods, like spiders and hemipterans sitting on or close to the water surface. Thus, blow vac sampling yielded the highest number of taxa assigned to the functional group of predators (rescaled and relative abundance). The same is true for ground-dwelling decomposers, like Collembolans, while most flying decomposers have been collected using sweep nets. Malaise trap sampling, however, resulted in more herbivores and parasitoids (relative abundance). The advantage of the passivity of Malaise traps is the reduced disturbance (active sampling methods often cause disturbance). This allows for collecting many flying arthropods, like herbivorous true flies (e.g. Chloropidae, Ephydridae) or parasitic wasps, which would be chased away while approaching a particular spot for blow vac sampling or sweep netting.

All three sampling methods have their strengths and limitations which will be discussed in the following section.

4.1.1 Strengths and limitations

4.1.1.1 Sweep net

Uncomplicated handling was a major advantage of sweep net over the two other methods. Moreover, sweep net was the most time-efficient method and sampled all functional groups in highest abundance based on specimens captured per person effort. Sweep net also sampled all functional groups in highest number when comparing total number of collected specimens (non-standardised). The nets are comparatively cheap and easy to obtain. It was the only method in the study which could be carried out by a single person. However, in rainy and windy weather conditions their use can become problematic. When rice plants are moist and flattened by wind and close to the ground, the net becomes inefficient (Ausden 1996). Sample series should be carried out by the same person to avoid sampling biases as large variation in speed of sweeps and walking, depth, and angle of the sweep net can occur (Ausden and Drake 2006). Likewise, sampling should be carried out in an early stage of rice plant growth to avoid damage on rice plants and thus decreasing yield (Rubia et al. 1988, Schoenly and Barrion 2016). Hence, sampling during the whole season with sweep nets is not advisable unless agreed with the rice farmers (who e.g. might be compensation for possible yield loss).

4.1.1.2 Blow vac

Blow vac sampling collects arthropods via a narrow hose which can be precisely positioned by the collecting person. This makes blow vac sampling highly efficient for the collection of arthropods in dense vegetation and between rice plants. Blow vac sampling also represents a good method for collecting sucking insects and those which are generally hard to detect, like nymphs of Hemiptera (Buffington and Redak 1998). However, of the three tested methods, blow vac was the most time-inefficient one. Field work required great expenditures - economical (because of the costs and wear of equipment) as well as regarding the labour-intensity (unhandy in use, reduced mobility in field). In the present study, using blow vac always required two people, one to handle the operating engine and one to sample arthropods within the enclosure. The ‘quality’ of collected specimens was generally low, as arthropods got damaged or destroyed by the air flow of the used blow vac type (this type is a standard one for rice research; Arida and Heong 1992, De Kraker et al. 1999, Dominik et al. 2017, Wilby et al. 2006). This complicated and severely delayed the identification process, or even made it impossible. To avoid the latter, the blow vac machine can be adjusted to e.g. Zou et al. (2016) blow vac design which does not destroy arthropods.

4.1.1.3 Malaise trap

Once a Malaise trap is installed in the field it can collect arthropods over a long period of time with little additional sampling effort. This passiveness, however, also increases the chance that Malaise traps get stolen or destroyed (Devigne and Biseau 2014). Malaise traps do, however, have the advantage of low disturbance of fast flying arthropods due to their passiveness. Regrettably, a comparison with the other two (active) methods in terms of density estimation is not possible as the sampled specimens cannot be assigned to a defined area. To simplify the installation of the trap in the field, two people are recommended. Malaise traps cannot be used under windy and other unfavourable conditions (such as heavy rain), because the traps might get destroyed (Southwood and Henderson 2000). Investment costs for Malaise traps depend on the quality of the trap.

4.1.2 Conclusions - Method comparison

The right choice of the respective sampling method for collecting a certain functional group - predators, parasitoids, decomposers, or herbivores - is not only necessary to reduce economic and ecological costs but it also helps in detecting pest outbreaks early enough and therefore in providing optimisation options for pesticide application (Heong et al. 1992). The incorrect use of pesticides can be observed frequently, especially in developing countries, which makes the monitoring and early detection of pests a very important measure for promoting the sustainability in such agricultural ecosystems (Ecobichon 2001, Eddleston et al. 2002).

All three methods have advantages and disadvantages when sampling arthropods in irrigated rice agroecosystems. When summarising and ranking the methods by categories - 1) sampled arthropod density, 2) time efficiency, 3) rescaled-, and 4) relative abundance of functional groups (see Table 3) - sweep netting is the most effective method, followed by blow vac and Malaise trap.

All three methods can be highly effective, when analysing each of the four categories separately, depending on functional group in focus. Based on rescaled and relative abundance of functional groups, parasitoids and herbivores were most successfully sampled by Malaise traps, predators, and ground-dwelling decomposers by blow vac and flying decomposers by sweep nets. Sweep net can be recommended over the other two methods in terms of time, labour, and cost-efficiency. However, Schoenly and Barrion (2016) argue that sweep netting can be excluded when investigating invertebrate biodiversity in rice agroecosystems due to the low faunal abundance they discovered by this method. Nevertheless, due to the high time-efficiency of sweep netting, it is not recommend to exclude this method when sampling arthropods in rice fields, especially when labour and economic resources are limited.

4.2 Functional and taxonomic diversity

Community composition and taxonomic diversity of arthropods in rice fields are well documented and investigated in different parts of Southeast Asia (e.g. *the Philippines*: Heong et al. 1991, Schoenly et al. 1996; *Java*: Settle et al. 1996; and *Sri Lanka*: Bambaradeniya et al. 2004). Taxonomic diversity is, among others, an important index for inventorying biodiversity in rice fields, although it provides scarce information about the ecological role of species in ecosystems (Eros et al. 2009, Teresa and Casatti 2012). Yet, little is done to investigate and promote functional diversity in irrigated rice ecosystems in Vietnam. In contrast to the traditional concept of ‘biodiversity’, which only considers the classification of organisms by their taxonomic identity, functional diversity focuses on the practical role an organism has in its ecosystem which can be further linked to ecosystem services (Peco et al. 2012, Villéger et al. 2010). The total taxonomic and functional diversity of a region (gamma diversity) can be partitioned into within community diversity at smaller spatial scales (alpha diversity) and among community diversity (beta diversity; De Bello et al. 2009, Whittaker 1972). Here, the partitioned taxonomic and functional diversity at the local scale were related to the effects of pesticides and land cover heterogeneity in rice fields. Following hypotheses were formulated:

(iii) Increasing pesticide usage has a negative effect on functional diversity across multiple scales.

(iv) Increasing pesticide usage has a smaller effect on taxonomic diversity than on functional diversity.

(v) Land cover heterogeneity increases taxonomic and functional diversity across multiple spatial scales.

Generally, beta diversity was very low within and among the rice fields for both functional and taxonomic diversity (Fig. 9 and 10, Table 4). Diversity (at the given level of precision) is defined at the regional scale and taxonomic and functional diversity are the same within and among the rice fields. Low beta diversity indicates little functional and taxonomic turnover (Villéger et al. 2013) of arthropod communities in different parts of an area where samples were taken. In Southeast Asia, rice fields are comparatively small (Global Rice Science Partnership 2013), which may facilitate a permanent colonisation of arthropods within the entire rice field rather than an aggregation on field edges like observed in other agroecosystems, e.g. as in large winter wheat fields in the United Kingdom (Holland et al. 1999).

At the local scale, samples of blow vac showed higher variation between taxonomic alpha and gamma diversity than samples of sweep net (Fig. 10). The probability to cover all arthropods within one sample unit is higher when using sweep net than using blow vac, which might explain the higher variation between alpha and gamma diversity for blow vac samples. Blow vac samples are restricted to a small part of a rice field generated by its square plastic enclosure (Fig. 2e), whereas sweep netting allows for covering a wider area and thus recording various arthropod communities within rice fields. Another explanation for this difference is that there seems to be some spatial variation within the rice field – detectable only when local communities are sampled at a very small scale (that of the blow vac and perhaps even more so at finer scales) but not with the usual area coverage of sweep net.

The abundances of predators, parasitoids, and herbivores often increase with crop age (Bambaradeniya and Edirisinghe 2008, Heong et al. 1991) which can explain the increase in functional and taxonomic diversity from 35 days after transplanting (DAT) to 50 DAT for both blow vac and sweep net samples. Decomposer abundance, however, normally peaks very early in the season between five to 20 DAT and declines afterwards (Bambaradeniya and Edirisinghe 2008, Settle et al. 1996). This was also observed in the present study, where samples of 50 DAT contained fewer decomposers than samples of 35 DAT.

At the landscape scale, beta diversity within each region was equally low for both sampling methods and sampling days (Table 4). This indicates not only homogeneity of functional and taxonomic composition within one rice field but also between the regions. Both regions are dominated by intensive homogeneously cultivated rice fields (Burkhard et al. 2015) which can be one reason for the high similarity of the functional and taxonomic composition (Ekroos et al. 2010). At the same time, lower taxonomic resolution (species level) might show higher variation in taxonomic and functional composition within each region, resulting in higher beta diversity at local and consequently at landscape scale. Nevertheless, most studies are limited in available funds, and higher taxonomic resolution increases labour, time and economic cost (Marshall et al. 2006). In the present study, the main objective was to examine the impact of environmental disturbance like pesticides on functional and taxonomic diversity. For this purpose, higher taxonomic resolutions (like family level) were used for analysis as taxonomic identification to family level seems to yield similar patterns like results gained on species level when examining environmental impacts (Feio et al. 2006, Heino and Soininen 2007, Timms et al. 2013).

4.2.1 Effects of pesticides and land cover heterogeneity at the local scale

In Vietnam, pesticide usage in rice fields is still not sufficiently regulated by the government (Hoi et al. 2013). Pesticide retailers try to push their sales by providing farmers misleading recommendations and thus inappropriate pesticide dosages are applied (Schreinemachers et al. 2015). Additionally, it is still solidly anchored in people's minds that the application of pesticides is an essential element for successful farming (Schreinemachers et al. 2015). The negative impact of these practices on the rice field fauna is reflected in the results of the present study. Functional and taxonomic diversity consistently showed a negative response to the amount and respectively the number of applied pesticides regardless of the sampling method (Fig. 11-16). Therefore, the third hypothesis (iii), that an ‘Increasing pesticide usage negatively affects functional diversity across multiple scales’ can be confirmed. Only effects of pesticides on beta diversity could not be found since the variation in beta diversity within the rice fields was more or less negligible. In general, strong relationships between indices of functional and taxonomic diversity were found, which can explain the similar effect of pesticide on both diversity dimensions. Thus, the fourth hypothesis (iv) that ‘Increasing pesticide usage has a smaller effect on taxonomic diversity than on functional diversity’ has to be rejected. Farmers often spray pesticides at inappropriate times and rather affect natural enemies than herbivores and rice pests (Heong et al. 1995, Settle et al. 1996). For instance, pesticides are often sprayed directly after transplanting of rice seedlings. This does mostly affect early arriving predators (Heong et al. 1995, Settle et al. 1996) which can normally suppress herbivore abundance already at an early stage of rice growth when rice plants are particularly vulnerable. With such an early loss of predators, also indicated by a reduction of the functional and taxonomic diversity of faunal groups, important ecosystem services like biocontrol (Wilby and Thomas 2002) cannot be performed anymore, which highly increases the risk of pest outbreaks (Savary et al. 2012).

The fifth hypothesis (v) ‘Land cover heterogeneity increases taxonomic and functional diversity across multiple spatial scales’ can be confirmed. In general, effects of land cover heterogeneity were only found with sweep net data and at 35 DAT. A study by Wilby et al. (2006), which dealt with similar questions like in the present study, under ‘real’ agricultural conditions without external control of factors like pesticide input, found that arthropod diversity in rice fields generally decreases with a decrease in structural diversity in the surroundings, which is in line with the results from the sampling campaign carried out at 35 DAT. In their study, species density and diversity concomitantly increased in these surrounding structures (fruit orchards and flower/vegetable crops) with a reduction in land cover heterogeneity. They argued that this pattern might be due to higher pesticide applications in such land-use types (Hoi et al. 2016, Van Mele et al. 2002) compared to rice fields, which make rice fields a ‘resource’ of arthropod diversity. Hence, when surrounding structures suffer from a high contamination with pesticides, the reduction of their prevalence would also have a positive effect on the rice field fauna. As many of the rice fields in the present study were surrounded by fruit and vegetable fields as well, this could have been a reason that no effect of land cover heterogeneity was obtained at 50 DAT. This means that not only pesticide application within rice fields influences the rice arthropod communities, but also the application of pesticides in the surrounding non-rice habitats may play an important role as the positive effect of land cover heterogeneity fails to appear. Thus, management practices in the surrounding land-use types might be important drivers for the diversity in rice agroecosystems.

Furthermore, as the effect of land cover heterogeneity was only found for sweep net data, different arthropod compositions of blow vac and sweep net could have led to different effects. Sweep net data contained a higher abundance of different functional and taxonomic groups (see 3.2 Method comparison) compared to blow vac samples which could explain why only data of sweep net showed an effect of land cover heterogeneity. In addition, as functional and taxonomic diversity abundance change with crop age (Wilby et al. 2006), different functional groups may respond differently to land cover heterogeneity. Early arriving arthropod groups mainly immigrate into the rice fields from the surroundings (Settle et al. 1996, Wilby et al. 2006). These groups benefit from the surrounded land cover heterogeneity as the results have shown. However, this effect might be diminished at a later stage of rice plants (50 DAT) when arthropod composition changes.

4.2.2 Comparison of functional and taxonomic diversity

In literature, taxonomic and functional diversity indices are widely discussed and compared (e.g. Diaz and Cabido 2001, Flynn et al. 2009, Hooper et al. 2002, Marcon et al. 2014, Peco et al. 2012, Petchey and Gaston 2006). Taxonomic richness is a proxy often used for describing biodiversity changes (Ernst et al. 2006, Hooper et al. 2002), even though this approach is based on taxonomic identity alone and treats taxa as being ecologically equal and disregards different ecological functions (Cardoso et al. 2014, Villéger et al. 2013). Consequently, taxonomic diversity gives an incomplete view on biodiversity (Villéger et al. 2010). Functional diversity is linked to ecosystem processes and gives more information about the functionality of organisms in a system (Hooper et al. 2002). Taxonomic diversity and functional diversity can be closely connected but do not necessarily need to correlate (Cardoso et al. 2014, Mayfield et al. 2010).

Nevertheless, in the present study, functional and taxonomic diversity were highly correlated at the local scale, which is reflected by similar responses to pesticides and land cover heterogeneity.

The effect of land-use intensity on functional and taxonomic diversity seems to be dependent on the studied organisms. Flynn et al. (2009) studied the effect of land-use intensity on mammals, birds, and plants. Similar to the present study, both species richness and functional diversity, declined with land-use intensity. However, Ernst et al. (2006) found a negative effect of forest degradation on functional diversity of amphibians but no effect on taxonomic diversity. Similar to this, Peco et al. (2012) studied the effect of grazing abandonment on functional and taxonomic diversity of grasslands and found a loss of functional diversity rather than species richness. In a study of Schweiger et al. (2007), increasing land-use intensity led to decreasing functional richness of hoverfly communities rather than affecting species richness. Villéger et al. (2010) showed contrasting response of aquatic ecosystems to habitat degradation: functional diversity of fish was negatively affected whereas fish species richness increased.

In this study, pesticides may act as abiotic environmental filters (Kraft et al. 2015) which increase the similarity of functionality of arthropod groups and decrease the number of arthropod taxa within the rice fields which in turn lead to a decrease of both diversity dimensions.

4.2.3 Conclusions - Functional and taxonomic diversity

Functional diversity provides more information about the functionality of organisms than taxonomic diversity and is an important aspect of biodiversity. Its relevance for biological studies is steadily increasing (Marcon et al. 2014), but so far little research has been done on the effects of pesticides and land cover heterogeneity on functional and taxonomic diversity in rice agroecosystems in Vietnam. In contrast to other studies (e.g. Ernst et al. 2006, Peco et al. 2012), in this thesis both functional and taxonomic diversity, were affected by pesticides to a similar extent. Pesticides had a negative effect on functional and taxonomic diversity. However, land cover heterogeneity led to an increase of both diversity dimensions at 35 DAT.

The decline of functional diversity can lead to a loss of ecosystem services (Villéger et al. 2010). In rice agroecosystems biocontrol is one of the most important services as rice pests can be controlled by natural enemies (Way and Heong 1994). However, a change in taxonomic composition, too, can disturb ecosystem processes as even single species can hold key functionalities necessary for a stable ecosystem (Chapin et al. 2000, Hooper et al. 2002). Therefore, the maintenance of taxonomic and functional diversity is important for rice agroecosystems. Especially, the overuse of pesticides leads to major disturbances in these environments (Normile 2013, Settle et al. 1996). This study shows the potentially positive effect of land cover heterogeneity in the surrounding of rice fields - if it is not treated with pesticides - especially in the early stage of rice plants. Pesticides had an invariably strong negative impact on taxonomic and functional diversity. Heterogeneous land cover types can be realised as ‘man-made’, manipulated non-rice habitats in the surrounding of rice fields (ecological engineering) which will be discussed in the next chapter.

4.3 Herbivore management/control

With the increasing rice production due to fast population growth (34 million people in 1960 to 91 million people in 2015 in Vietnam; The World Bank 2017), unexpected ecological consequences occurred in rice agroecosystems (Cheng 2015). Agricultural management methods like the application of pesticides, irrigation, tillage, and fertiliser use increased during the last decades (Bambaradeniya and Amarasinghe 2003, Cassman and Pingali 1995, Hoi et al. 2013), leading to enormous problems like environmental pollution and threats to human health (Pimentel and Pimentel 1990).

Pest outbreaks became a major problem due to an overuse of pesticides and a consequential pesticide resistance of major pests (Cheng 2015, Heong et al. 1995, Matsumura et al. 2008, Settle et al. 1996). The importance of antagonists controlling herbivore abundance in the form of natural enemies in rice agroecosystems is not questioned. Without control of herbivores by natural enemies, herbivore abundance would increase steadily, making rice cultivation more and more problematic (Horgan 2017). Land cover heterogeneity and pesticides are key factors for the abundance and diversity of natural enemies and herbivores. Therefore, the complexity of these factors is important to understand and to study (Tscharntke et al. 2016).

In this part of the thesis, the interacting effects of natural enemies with land cover heterogeneity on herbivore abundance was investigated as well as the interacting effect of insecticides with natural enemies on herbivore abundance. The following hypotheses were tested:

(vi) Herbivore abundance declines with increasing abundance of natural enemies.
(vii) The impact of natural enemies on herbivores increases with increasing land cover heterogeneity.
(viii) Under the present circumstances in rice agroecosystems in Vietnam, insecticides do not affect herbivore abundance.

4.3.1 Herbivores and natural enemies

The sixth hypothesis (vi) ‘Herbivore abundance declines with increasing abundance of natural enemies’ is confirmed by the results of the present study. The interaction of predators and parasitoids (natural enemies) controlled herbivores when using data obtained with Malaise trap (Fig. 19). Studies of Bambaradeniya and Edirisinghe (2008) and Heong et al. (1991) showed positive relationships between natural enemies and the density of pest insects, indicating that natural enemies increased with higher abundance of their prey (mainly herbivores). In this study, parasitoid abundance increased with herbivore abundance in all regression models (Appendix III). The decrease of herbivores from 35 to 50 DAT became stronger with an increasing abundance of parasitoids (Fig. 17). This stronger decline in herbivore abundance from 35 to 50 DAT might have been delayed because of the development of parasitoids within the host's egg or body. For example, parasitoids of the family Trichogrammatidae emerge 11-12 days after oviposition (Gurr et al. 2011). Therefore, the effect of parasitism is not immediately observable.

Only the model of blow vac data showed no effect of natural enemies on herbivores alone. Predators and parasitoids only negatively affected herbivore abundance when insecticides were found (Fig 18). This implies that natural enemies only had a negative effect on herbivore abundance in combination with insecticide applications. This result was contrary to data obtained with Malaise trap and sweep net. Malaise trap data showed a decreasing effect by the interaction of natural enemies (predators and parasitoids) on herbivore abundance and sweep net data showed a decline in herbivore abundance with increasing predator abundance. In both models (sweep net and Malaise trap), no effects of insecticides were ascertained. One reason for this could be the significantly different arthropod communities sampled with blow vac compared to Malaise trap and sweep net (see 3.2 Method comparison), which may respond differently to insecticide pressure. Another reason could be that blow vac, unlike to Malaise trap and sweep net, sampled lowest herbivore abundance and therefore unique effects of natural enemies were not detected.

4.3.2 Pesticides and land cover heterogeneity

No combined effect of land cover heterogeneity and natural enemies on herbivore abundance was found and therefore the seventh hypothesis (vii) 'The impact of natural enemies on herbivores increases with increasing land cover heterogeneity' has to be rejected. Land cover heterogeneity showed no effect in any regression model on herbivore abundance (sweep net, Malaise trap and blow vac). Non-rice agricultural systems (e.g. vegetables plantations, orchards, grasslands, fallow) can serve as refuge for natural enemies, especially during the fallow period in rice agroecosystems (Marcos et al. 2001). Thus, heterogeneous land cover types should be implemented around rice agroecosystems. For biocontrol, it is important that predators arrive early in the season after the rice is transplanted. These predators can immigrate and benefit from the surrounding landscape (Settle et al. 1996, Way and Heong 1994). Under insecticide-free conditions, early populations of hopper pests can be controlled by predators and maintained at low levels (Heong et al. 1992). Thus, the management intensity (input of pesticides) of rice fields has an enormous influence on predator-prey interactions (Settle et al. 1996, Way and Heong 1994, Veres et al. 2013). The relatively new approach of ‘ecological engineering’ aims to support natural enemies by providing adequate nesting and food resources which can be achieved by a reduction of pesticide use (Gurr et al. 2011). Food resources can be flowering plants (which provide nectar and pollen) in the surrounding of rice fields, which are not treated with pesticides. The choice of vegetation is crucial for successful biocontrol because flowering plants can be inhibiting or toxic for natural enemies due to inappropriate ingredients (e.g. xylose) (Lu et al. 2014).

Due to the high application of pesticides in the present and in the past, some herbivores developed resistance against some insecticides (Matsumura et al. 2008, Wang et al. 2008a). Based on this, it was hypothesised (viii) that ‘Under the present circumstances in rice agroecosystems in Vietnam, insecticides do not affect herbivore abundance’. This hypothesis has to be rejected. The regression model of blow vac data showed a decline of herbivore abundance by insecticides, yet no other regression model (sweep net and Malaise trap data) showed an effect of insecticide application. Herbivores like planthoppers have a short lifecycle (10-18 days), are long-range migrants and have a high fecundity (Cheng 2009, Heinrichs 1994, Wang et al. 2008b). These characteristics support the ability to adapt to environmental impacts like insecticides (Wang et al. 2008b). In the present study, planthoppers were one of the main sampled herbivores (see Table 2), which might be the reason why only regression models of blow vac showed insecticide effects on herbivore abundance as the effect might diminish for the two other methods.

4.3.3 Conclusions - Herbivores

To enhance biocontrol by natural enemies it is important to reduce the use of pesticides (Settle et al. 1996). Horgan (2017) lists three beliefs of farmers which highly influence the management of rice agroecosystems: (1) insects are harmful to the crop, (2) damage of herbivores always leads to yield losses, and (3) insecticides prevent harvest loss and are therefore indispensable. In this study, the results showed strong effects of natural enemies (predators and parasitoids) on herbivore abundance. Insecticides seemed to have little effect and land cover heterogeneity had no effect on herbivore abundance. A reduction of insecticide applications in rice fields seems to be most important for natural enemies (Tscharntke et al. 2016) and should be combined with non-rice land cover types in the surrounding of rice fields which are not treated with pesticides to optimise biocontrol (ecological engineering). Non-rice land cover types can promote natural enemies by providing food resources such as nectar and pollen and can act as shelter (Hassan et al. 2016). Previous studies successfully introduced ecological engineering to farmers in the Mekong Delta (e.g. Heong et al. 2014; Le 2014) but field studies are mostly local and there is no law enforcement to implement ecological engineering by farmers. For further success of ecological engineering, this approach should be promoted by the Vietnamese government (as implemented in the Tien Giang province; Heong et al. 2015) and farmers should be better educated about pesticide application.

Chapter 5 *Synthesis*

5.1 General discussion

The aim of this thesis was to investigate the composition of taxonomic and functional groups of arthropods in irrigated rice fields in relation to land cover heterogeneity and pesticide application. Furthermore, the performance of three standard sampling methods (sweep net, blow vac, and Malaise trap) was compared and presented using four categories (see 2.4 Standardisation: 1) sampled arthropod density, 2) time efficiency, 3) rescaled abundance, and 4) relative abundance). Likewise, functional and taxonomic diversity indices based on Shannon entropy were partitioned into their alpha, beta, and gamma components and the effect of land cover heterogeneity as well as pesticides was investigated. Similarly, the interacting effects of natural enemies with land cover heterogeneity and insecticides on herbivore abundance were evaluated.
The key results are as follows:

i) The choice of sampling method depends on the research question and sampling area. In the overall ranking of this thesis, sweep netting performed best in comparison with Malaise trapping and blow vac sampling.
ii) The functional and taxonomic diversity in irrigated rice fields were similarly negatively affected by pesticides. Land cover heterogeneity only affected samples of sweep netting and led to an increase of the diversity dimensions at 35 DAT.
iii) The interaction of predators and parasitoids negatively affected the abundance of herbivores. Effects of insecticides seemed to depend on the sampling-method and were rarely detected. Effects of land cover heterogeneity were not found.

When linking hypotheses and results of all three parts, this thesis highlights the close connection between the important choice of sampling methods (chapter **3.2**) with the key results of chapter **3.3** and **3.4** (ii, iii). As shown in chapters **3.3** and **3.4**, different methods can reveal different results for effects of external factors, like land cover heterogeneity and pesticides, on functional and taxonomic diversity and herbivore abundance. This demonstrates the importance of carefully choosing the appropriate sampling method when designing field studies. Furthermore, the effects of pesticides had a major effect on the whole community (functional and taxonomic diversity) rather than on herbivores alone, which leads to the assumption that insecticides do not efficiently control herbivore abundance but lead to a decline of functional and taxonomic diversity which in turn has a negative effect on ecosystem services in rice agroecosystems. Rice agroecosystems which are not treated with pesticides have been found to contain a higher variety of arthropods with proportionally small numbers of rice damaging herbivores (Horgan 2017, Way and Heong 1994). Therefore, a high degree of pesticide applications in rice agroecosystems highly increases the probability of pest outbreaks (Settle et al. 1996). In this thesis, early application by farmers led to a decline of functional and taxonomic diversity (chapter **3.3**), but no or minor effects were observed when focusing on herbivore abundance (chapter **3.4**). Land cover heterogeneity showed positive effects on functional and taxonomic diversity during the early stage of rice plants (35 DAT) and no effects were found for herbivore abundance. Thus, natural enemies may benefit more from continuous food resources from the surrounding landscape than herbivores (Marcos et al. 2001, Veres et al. 2013).

To provide natural enemies with continuous food availability and distract rice pests from rice plants, ‘ecological engineering’ was introduced and investigated in several studies (Gurr 2009, Lu et al. 2015). Management practices in agriculture landscapes are very important for effective biocontrol of pests (Tscharntke et al. 2016). Since pest outbreaks are pesticide-induced, this conclusion can be assigned to rice agroecosystems. Therefore, the introduction of ecological engineering to local stakeholders like farmers should be impelled (Settele et al. 2008), because it combines the effect of managed land cover types (flower strips) in the surrounding and the reduction of pesticide application.

5.2 Challenges and outlook

The present field study was carried out in two rice dominated landscapes in Northern Vietnam. Contrary to experimental study designs, it is difficult to account for each possible influential factor in field studies. This study was conducted under real field conditions without controlling external inputs (like pesticides), which reflects the actual circumstances in rice agroecosystems. Field studies in rice agroecosystems in various countries of Southeast Asia are an integral part in rice research as agricultural management practices differ between countries (Bambaradeniya and Amarasinghe 2003). However, ideal research conditions, like for example in experimental field studies at the International Rice Research Institute (IRRI) in the Philippines, do not exist in Vietnam and are difficult to replicate. Due to these constraints, information about agricultural practices has been reliant on field observations in this thesis. Pesticide packages were collected in the surrounding of the investigated rice fields. Thus, exact names of active ingredients, volume/weight, and concentration were recorded, which is an advantage of this method. However, the amount of pesticide applied by farmers was not measured in the field as it was beyond the scope of this thesis. Even though this easy approach can cause inaccuracy, effects of pesticides were detected and results were in accordance with other studies (Bambaradeniya and Edirisinghe 2008, Desneux et al. 2007, Heong et al. 1995, Liu et al. 2012). Therefore, it is assumed that this simple approach was sufficient to test for pesticide effects. In the future, soil and water samples of rice fields should be incorporated and analysed to account for more precise conclusions of pesticide effects on arthropod communities.

Furthermore, as part of ecological engineering, it is recommended that farmers should establish flower strips on field bunds to support natural enemies and reduce the use of pesticides. In South Vietnam, the approach of ecological engineering was successfully implemented. Farmers sprayed less pesticides and planted flower strips on rice bunds. To support ecological engineering, farmers should be subsidised by the government, which has already been implemented in parts of South Vietnam (Heong et al. 2015).

5.3 Conclusion

Irrigated rice fields contain a high richness of arthropods which provide important ecosystem services. In the present thesis, the performance of sampling methods (sweep net, Malaise trap, and blow vac) were measured and interacting effects of functional groups with external factors were studied in irrigated rice fields in Northern Vietnam. The performance of sampling methods differed fundamentally and, as measured by different categories, there was no single ‘best method’. When ranking and summarising the categories and the collected functional groups by the sampling methods, sweep netting ranked first, followed by blow vac sampling, and Malaise trapping. Furthermore, the influence of land cover heterogeneity and pesticides on functional diversity as well as taxonomic diversity across multiple scales (alpha, beta, and gamma) was investigated. Pesticides had strong negative effects on both diversity dimensions and highlight the importance and high influence of agricultural practices. Land cover heterogeneity showed positive effects on functional and taxonomic diversity in the early stage of rice plants. Likewise, the results showed the importance of natural enemies in rice agroecosystems which controlled herbivore abundance, whereas insecticides showed little effects on herbivore abundance. To promote natural enemies, pesticide application should be reduced. Additionally, land cover heterogeneity may be enhanced by promoting ecological engineering.

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Glossary of terms as used in the present thesis

Ecological engineering: Non-rice habitats which are manipulated by men for the benefit of both needs of society and nature (e.g. flowers or other crops on rice bunds) (Gurr 2009)

Ecosystem functioning: reflects the collective life activities of plants, animals, and microbes and the effects these activities - feeding, growing, moving, and excreting waste, etc. - have on the physical and chemical conditions of their environment (Naeem et al. 1999)

Ecosystem services: benefits humans obtain from ecosystems e.g. provisioning services such as food, water, timber, and fibre; regulating services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, and spiritual fulfilment; and supporting services such as soil formation, photosynthesis, and nutrient cycling (Millennium Ecosystem Assessment 2005)

Functional diversity: the value and the range of those species and organismal traits that influence ecosystem functioning (Tilman 2001)

Functional group: a collection of organisms with similar suites of co-occurring functional attributes. Groups are traditionally associated with similar responses to external factors and/or effects on ecosystem processes (De Bello et al. 2010)

Integrated Pest Management (IPM): is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides (FAO 2017)

Land cover heterogeneity: is the recorded land cover within a 300 meter radius around each rice field. A diversity index was applied to measure the land cover heterogeneity based on the land cover units within the 300 m radius using the Shannon index (H’).

Land use intensification: the conversion of complex natural ecosystems to simplified managed ecosystems and the intensification of resource use, including application of more agrochemicals and a generally higher input and output, which is typical for agroecosystems as relatively open systems (Tscharntke et al. 2005)

Meta-community: the assemblage of communities whose species probabilities are the weighted average of those of communities (Marcon et al. 2014)

Natural enemies: are organisms that kill, decrease the reproductive potential of, or otherwise reduce the numbers of another organism. Natural enemies that limit pests are key components of integrated pest management programs. Important natural enemies of insect and mite pests include predators, parasite, parasitoids, and pathogens (Flint 1998)

Rice pest: organisms that attack the rice crop from the time the nursery bed is prepared until harvest (Pathak and Khan 1994)

Taxonomic diversity: the number and the relative abundance of taxa in a community (Moore 2001)

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Appendix

Appendix I

Land cover types

Ecosystem types included in the respective land cover type. Land cover types were recorded within a 300 m radius around each rice field. Land cover types are according to Burkhard et al. (2015).

No.	Land cover types	Ecosystem types included
1	bare soil	bare rock, sand etc.
2	forest	principally trees, also shrubs, bushes and storey
3	fruit	fruit trees, banana plantations, coconut trees, etc.
4	meadow/grassland	grass cover mainly for grazing
5	rice	permanently irrigated rice fields
6	vegetable	potato, eggplant, pepper, pumpkin etc. plantations
7	water	lakes, rivers, and ponds
8	crops	agricultural areas not covered by types 1-6
9	compacted surface	unpaved roads, compacted soil surface
10	sealed surface	houses and other buildings, streets, etc.

Appendix II

List of active ingredients

List of found active ingredients (AI) classified into substance group and pesticide types and weight of found pesticides in g and number of sites where AI was found.

AI	Substance group	Pesticide types	Weight of AI (g)	Number of sites
Abamectin	Avermectine	Insecticide	32.7755	11
Acetamiprid	Neonicotinoid	Insecticide	4.35	3
Acetochlor	Chloroacetamide	Herbicide	77.518	7
Alpha-Cypermethrin	Pyrethroid	Insecticide	40.9235	10
Atrazine	Triazine	Herbicide	240	3
Azoxystrobin	Strobilurin	Fungicide	1	1
Bensulfuron-methyl	Sulfonylurea	Herbicide	26.057	11
Beta-Cypermethrin	Pyrethroid	Insecticide	12.9	2
Bismerthiazol	not listed	Bactericide	8.75	1
Bromadiolone	Cumarinderivate	Rodenticide	0.225	4
Buprofezin	not listed	Insecticide	14.585	5
Butachlor	Chloroacetamide	Herbicide	245.28	5
Carbaryl	Carbamate	Insecticide	7	1
Carbendazim	Benzimidazole	Fungicide	4.02	2
Carbosulfan	Carbamate	Insecticide	1.2	1
Chitosan	Animal derived	Nematicide	0.418	2
Chlorantraniliprole	Anthranilic diamide	Insecticide	2.25	4
Chlorpyrifos-ethyl	Organophosphate	Insecticide	872.815	10
Cymoxanil	Cyanoacetamide oxime	Fungicide	2.4	1
Cypermethrin	Pyrethroid	Insecticide	121.14	10
Diazinon	Organophosphate	Insecticide	0.1	1
Emamectin benzoate	Avermectine	Insecticide	5.892	7
Ethoxysulfuron	Sulfonylurea	Herbicide	9.9	5
Etofenprox	Pyrethroid	Insecticide	1.2	1
Fenclorim	Pyrimidine	Herbicide	60	4
Fenobucarb	Carbamate	Insecticide	96	1
Fipronil	Phenylpyrazole	Insecticide	19.705	10
Hexaconazole	Triazole	Fungicide	96.98	12
Imidacloprid	Neonicotinoid	Insecticide	25.16	5
Indoxacarb	Oxadiazine	Insecticide	1.5	3
Iprobenfos	Organophosphate	Fungicide	8.4	1
Isoprocarb	Carbamate	Insecticide	0.375	2

Isoprothiolane	Phosphorothiolate	Fungicide	236.5	5
Kasugamycin	Micro-organism derived	Fungicide	9.36	9
Lambda-cyhalothrin	Pyrethroid	Insecticide	12.22	8
Mancozeb	Carbamate	Fungicide	19.2	1
Matrine	Alkaloid	not listed	0.008	1
Metaldehyde	Cyclo-octane	Molluscide	6.845	5
Myclobutanil	Triazole	Fungicide	4	1
Nereistoxin	not listed	Insecticide	190	4
Niclosamide	Chloronitrophenol	Fungicide	508.93	13
Niclosamide-olamine	Chloronitrophenol	Fungicide	42.6	2
Ningnanmycin	not listed	Fungicide	1.2	2
Paraquat dichloride	Quarternary ammonium compound	Herbicide	145.2	3
Permethrin	Pyrethroid	Insecticide	5	1
Phoxim	Organophosphate	Insecticide	1	1
Polyoxin B	Nucleoside antibiotics	Fungicide	0.36	1
Pretilachlor	Chloroacetamide	Herbicide	30.015	2
Profenofos	Organophosphate	Insecticide	2.7	1
Propisochlor	Chloroacetanilide	Herbicide	20.25	6
Pymetrozine	Pyridine	Insecticide	16.5	2
Pyrazosulfuron-ethyl	Pyrazole	Herbicide	10.575	8
Quinalphos	Organophosphate	Insecticide	50.625	2
Quinclorac	Quinolinecarboxylic acid	Herbicide	152.36	11
Streptomycin sulphate	Aminoglucoside antibiotic	Antibiotic	1.26	1
Sulfur	Inorganic compound	Fungicide	8.05	2
Thiamethoxam	Neonicotinoid	Insecticide	1.5	4
Thiophanate-methyl	Benzimidazole	Fungicide	83.5	2
Thiosultap-sodium	not listed	Insecticide	171	2
Trichloroform	not listed	not listed	180	3
Tricyclazole	Triazolobenzothiazole	Fungicide	135.73	6
Trisiloxane-Ethoxylate	not listed	not listed	9	1
Validamycin	Aminoglucoside antibiotic	Fungicide	13.75	4
Validamycin A	Aminoglucoside antibiotic	Fungicide	8.25	6
Warfarin	Coumarin anticoagulant	Rodenticide	0.8	4

Appendix III

Linear mixed-effect models

Linear mixed-effect models (LMMs) of sweep net, blow vac and Malaise trap refer to chapter 3.4. * indicate interaction of the predictor variables. All candidate models (SN, BV, and MT) included following predictor variables and random effects:

Predictor variables:

Predator and parasitoid: abundance data

Day: sampling days 35 (A) or 50 (B)

Insecticides: number of insecticides (active ingredients)

Div: Land cover heterogeneity -> based on Shannon index (H’)

Random effects:

Region: Vinh Phuc, Hai Duong

Candidate model:

Lmer(herbivore ~ scale(parasitoid)*scale(Div) + scale(predator)*scale(Div) + scale(predator)*scale(parasitoid) + Day*scale(parasitoid) + Day*scale(predator) + scale(Insecticides)*scale(parasitoid) + scale(Insecticides)*scale(predator) + (1|Region))

Sweep net

Lmer(herbivore ~ Day + scale(parasitoid) + scale(predator) + Day*scale(predator) + (1|Region))

Predictor variables	Estimate	Std. Error	t value
(Intercept)	664.7	257.1	2.585
DayB	-282.8	160.1	-1.767
parasitoid	502.8	132	3.810
predator	-180.1	114.7	-1.571
DayB*parasitoid	-392.3	170.2	-2.305

Blow vac

Lmer(herbivore ~ scale(Insecticides) + scale(parasitoid) + scale(predator) + scale(Insecticides)*scale(parasitoid) + scale(Insecticides)*scale(predator) + (1|Region))

Predictor variables	Estimate	Std. Error	t value
(Intercept)	41.176	13.837	2.976
Insecticides	-11.084	4.482	-2.473
parasitoid	13.032	4.397	2.964
predator	19.523	6.557	2.978
Insecticides*parasitoid	-10.618	5.298	-2.004
Insecticides*predator	-9.056	5.907	-1.533

Malaise trap

Lmer(herbivore ~ Day + scale(parasitoid) + scale(predator) + Day*scale(parasitoid) + Day*scale(predator) + (1|Region))

Predictor variables	Estimate	Std. Error	t value
(Intercept)	383.76	167.94	2.285
DayB	39.2	188.25	0.208
parasitoid	221.55	257.68	0.86
predator	-16.79	172.87	-0.097
DayB*parasitoid	-76.29	278.58	-0.274
DayB*predator	-220.31	207.56	-1.061

Curriculum Vitae

CORNELIA SATTLER

Date of birth: 23.04.1990
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Education

Dec 2014 – present	PhD student at Martin-Luther-University Halle-Wittenberg (MLU), Institute of Biology; Helmholtz-Centre for Environmental Research (UFZ), Department of Community Ecology, Germany/Vietnam PhD Thesis: ‘*Arthropod Communities in Rice Agroecosystems in Northern Vietnam -* *Quantifying the Impact of Pesticides and Land Cover Heterogeneity’* Supervisor: Prof. Dr. Josef Settele (UFZ, MLU)
Oct 2011 – Dec 2013	Martin-Luther-University Halle-Wittenberg Master of Science in Natural Resource Management Master Thesis at Helmholtz-Centre for Environmental Research/ Department of System Ecotoxicology: *‘Minderung kurzzeitiger Pflanzenschutzmittelwirkungen auf aquatische Lebensgemeinschaften durch bewaldete Oberläufe in Fließgewässern‘* [1.3] Supervisors: Prof. Dr. Matthias Liess (UFZ), Prof. Dr. Bruno Glaser (MLU) Final mark: 1.8
Oct 2008 – Sept 2011	Bachelor of Science in Natural Resource Management Bachelor Thesis: *‘Welche Rolle spielen Feuer als Form des Ressourcen-Managements?‘* [2.1] Supervisors: Dr. Monika Partzsch, Prof. Dr. Reinhold Jahn Final Mark: 2.4
Aug 2002 – Jul 2008	Domgymnasium Merseburg, High school diploma A-Level

Work experience

Jul 2014 – present	Scientific Assistant at Helmholtz-Centre for Environmental Research, Department of Community Ecology (Vietnam/Germany)

Aug 2017 – Oct 2017	Intern at Deutsche Gesellschaft Internationaler Zusammenarbeit GmbH (GIZ) (Mongolia)
Jan 2015	Intern at Station Linné Öland (Sweden)
Apr 2013 – Nov 2013	Scientific Assistant at Helmholtz-Centre for Environmental Research, Department of System Ecotoxicology
Apr 2011 – Feb 2013	Scientific Assistant at Martin-Luther-University Halle-Wittenberg, Institute of Soil Biogeochemistry
Jul 2012 – Aug 2012	Intern and Scholarship recipient at Institute for Development of Water Resources Jaroslav Cerni (Belgrade, RS)
Aug 2010 – Oct 2010	Intern at Sustainable Solutions (Washington D.C., USA)

Teaching and supervision

Jun 2017	teaching of pupils
Jun 2016	teaching of pupils
Dec 2014 – Apr 2015	supervision of undergraduate students

Publication and conference contributions

Julian Schrader, Markus Franzén, Cornelia Sattler, Paul Ferderer, Catrin Westphal (2017). Woody habitats promote pollinators and complexity of plant– pollinator interactions in homegardens located in rice terraces of the Philippine Cordilleras. *Paddy and Water Environment. 1-11.*

Cornelia Sattler, Julian Schrader, Viktor Mátyás Farkas, Josef Settele, Markus Franzén (2016) *Pesticide diversity in rice growing areas of Northern Vietnam.* Poster, Sustainable Land Management: Final Conference 2016, Berlin.

Cornelia Sattler, Oliver Schweiger, Markus Franzén, Josef Settele (2016) *A comparison and guideline of three sampling methods to evaluate functional traits, species richness and abundance of arthropods in irrigated rice fields of Northern Vietnam*. Talk, Asian ESP Conference “Ecosystem Services for Nature Based Solutions”, Ansan-si, Republic of Korea.

Cornelia Sattler, Le Huu Hai, Tran Thi Minh Tu, Thai Hoang Phuc, Tran Le Vinh, Nguyen Vi Nhan, Ho Van Chien, Le Quoc Cuong, Do Van Van, Monina Escalada, KL. Heong (2016) *Female Farmer’s Participation in Ecological Engineering in Cai Lay District, Tien Giang Province, Vietnam.* Talk, Terra Madre Salone de Gusto, Italy-Vietnam Forum on Sustainable Development and Biocultural Landscape, Torino, Italy.

Further acquirements

Language skills:	German: Native English: Fluent French: Basic
Computer skills:	Geo-Information-System (GIS) R (programming language) MS Office

Non-university activities

Jul 2016 – Aug 2016	Field excursion, Kirgizstan
Jan 2014 – Mai 2014	Travel: Singapore, Malaysia, Taiwan, Thailand, Myanmar, Indonesia

Halle, 26.04.2018

Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich die Arbeit mit dem Titel „Arthropod Communities in Rice Agroecosystems in Northern Vietnam - Quantifying the Impact of Pesticides and Land Cover Heterogeneity“ selbstständig und ohne fremde Hilfe verfasst, keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt und die den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen als solche kenntlichgemacht habe.
Ich erkläre, die wissenschaftliche Arbeit an keiner anderen wissenschaftlichen Einrichtung zur Erlangung eines akademischen Grades eingereicht zu haben und keine vergeblichen Promotionsversuche unternommen zu haben.

26.04.18

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