Biodiversity, agricultural productivity, and landscape context in organic vs conventional rice paddy wetlands in Kerala, India

by

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Abstract

Agriculture is the most extensive global land use and a leading cause of biodiversity loss. Organic farming is often promoted as a means of reducing agricultural impacts on biodiversity by reducing or avoiding chemical fertilizers and pesticides, and can result in a 30 percent increase in biodiversity for some species in some systems. A potential trade-off is that organic agriculture can lower crop yields, thereby requiring a greater land area to meet crop production goals. In this study, I examined whether forest cover surrounding rice wetlands can reduce the trade-off between biodiversity and productivity via comparison of paired organic and conventional farms. I compared abundance, Simpson diversity, and rarefied richness of amphibians, and abundance of arthropods in organic and conventional rice wetlands in four districts in Kerala, southern India, from July to October of 2016. I selected 31 organic rice fields and paired each with a nearby conventional field. Pairs were located to maximize the variation in forest cover in the landscape surrounding the fields. Farmers provided data on mean rice yields of each farm.

Amphibians were significantly more abundant and diverse in organic fields, and species composition differed from those of conventional fields. Arthropods were more abundant in organic fields. While mean yield (tons of rice/hectare) of organic farms was significantly lower than in conventional farms, landscape context ameliorated the trade-off between productivity and biodiversity. In organic fields surrounded by more forest patches, rice yields did not decrease as much compared to the landscapes with less forest, while the increase in biodiversity (as compared to nearby conventional agriculture) was not as large. My results suggest that forested landscapes reduce the trade-off between biodiversity and productivity in rice fields in Kerala. These results could aid in designing agricultural ecosystems that maximize biodiversity benefits. For example, promoting more diversified tree-based agroecosystems, and protecting remaining uncultivated areas in the landscape could improve farmland biodiversity while minimizing the impacts to the agricultural productivity of the landscape. Furthermore, in intensively managed landscapes comprised of cropland and urban land cover, organic farming may have a larger effect on biodiversity than in landscapes with more forest cover.

Lay Summary

There is a general sentiment that organic food is healthy but also good for the environment. In this thesis, I studied organic rice fields in Kerala, India, to determine how biodiversity (specifically of amphibians and arthropods) and productivity of organic fields differ from those of conventional fields nearby. I also looked at how differences in biodiversity and productivity vary depending on the amount of forest in the landscape. My results showed that organic fields have more amphibians and arthropods and produce less rice than neighbouring conventional fields. But, when there is more forest in the landscape, the differences in rice productivity and biodiversity between organic and conventional fields were not as pronounced as in landscapes with less forest. My results indicate that forest cover in the landscape surrounding fields can reduce the trade-off between biodiversity and productivity in agricultural landscapes.

Preface

This dissertation is original, unpublished, independent work by the author, Libin Thaikkattil Louis. In this thesis, I was responsible for identifying the research questions, formulating the methods, conducting the fieldwork and data collection, analysing the data, and writing the thesis. Dr. Jeanine Rhemtulla provided guidance and supervision throughout the project as well as editorial help. My supervisory committee, Dr. Sarah Gergel and Dr. Navin Ramankutty provided insights related to their various expertise and helped with the editing of the thesis.

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Dedication

To my family

Chapter 1. Introduction and Research Objectives

1.1 Agriculture & biodiversity loss

The push for agricultural intensification, which began during the mid 1900s as part of the Green revolution, dramatically increased the use of fertilizers, pesticides and high yielding crop varieties (Tilman 1999). Global food production increased as a result (Evenson & Gollin 2003) and most of the developing world shared the benefits of reductions in food prices and numbers of malnourished people even as human population continued to increase at a high rate (Tilman 1999). Today the total global agricultural area (37%) exceeds the total forest cover (30%; FAOSTATS 2014), making agriculture the most dominant land use in the world (FAO 2016). But this success means that agriculture is also the leading threat to biodiversity. One of the key features of agricultural intensification is to promote large-scale monocultures, which reduce the diversity of wild flora and fauna in landscapes (Matson et al. 1997). Intensification, however, could also hold the key to saving biodiversity through better management and understanding of biodiversity dynamics in agricultural landscapes (Lockwood 1999; Norris 2008).

Agricultural expansion and intensification is responsible for significant loss in forest cover globally (FAO 2016). Biodiversity loss can significantly affect the structure and functioning of whole ecosystems (Jones et al. 1997). Declines in biodiversity were first identified as a global concern in the1980s and international efforts to reduce loss began with the Earth Summit in 1992, followed by the World Summit on Sustainable Development (2002) and the Millennium Ecosystem Assessment (2005). Despite the hard work of scientists, policy makers and conservationists to minimise the loss of biodiversity, the rate of decline has escalated over the past decades and is still continuing to increase (Pearce 2007; Butchart et al. 2010; Pereira et al. 2010). Current measures to minimise biodiversity loss focus mainly on protected areas, but biodiversity is also an important factor in agricultural landscapes, where biodiversity loss is severe.

Biodiversity plays an important role in all ecosystems, increasing biomass, nutrient and water cycling through ecosystems and trophic levels thereby affecting the functioning of ecosystems (Loreau et al. 2001; Cardinale et al. 2012). Ecosystems provide direct and indirect benefits to people (Johnson et al. 2017), for example, direct services such as providing food through fish, meat, fruits and vegetables, and clean water from fresh water ecosystems, while indirect services include pollination and pest control (Millennium Ecosystem Assessment 2005). Reduced biodiversity can alter ecosystems, and lower efficiency or stability (Cardinale et al. 2012); hence, biodiversity is important for human well-being (Hooper et al. 2005).

Human activities such as deforestation, logging, industrialisation, agriculture and other development activities, lead to habitat degradation and clearing (Alroy 2017). Human induced habitat changes can alter population dynamics in an ecosystem. For example, Bailey and colleagues (2010) found that predators are more affected by habitat isolation than herbivorous group of organisms. Further, losing a keystone species or a species at a higher trophic level can have greater impact on ecosystem functioning (Cardinale et al. 2012) because that negatively affects the multiple functions performed by that species. In agricultural landscapes, human disturbances reduce species richness but diversity and heterogeneity of favourable habitat in the landscape can reduce the loss of species (Tews et al. 2004).

Agricultural expansion replaces natural ecosystems and reduces the diversity of in-field flora and fauna of the landscape. Agricultural expansion has already replaced a considerable amount of forest, grasslands and savannas globally (Foley et al. 2005). Today, agricultural expansion is greater in tropical ecosystems, which are rich in biodiversity and ecosystem services (Gibbs et al. 2010; Foley et al. 2011). Clearing more natural habitat in the landscape could result in loss of fertility of the nearby agricultural soil and reduce agricultural productivity (Ramankutty et al. 2002). Agricultural production is still the major ecosystem service that demands the attention of most of the world because of the increasing world population demands to produce more.

With the intention of increasing productivity in existing agricultural land, agricultural intensification makes use of high yielding crop varieties, chemical fertilizers and pesticides. As a result of intensification, over the past five decades, chemical inputs to agricultural systems have increased five times per unit area (Matson et al. 1997; Foley et al. 2011). In the long term, agriculture intensification can increase soil erosion, and reduce soil fertility and biodiversity, thereby negatively affecting ecosystem properties. Runoff from agricultural areas is causing pollution and eutrophication in nearby natural fresh water and marine ecosystems (Matson et al. 1997; Chapin III et al. 2000), which could also cause human health problems.

The impact of agricultural activities on ecosystems needs to be reduced for sustainable food production (Foley et al. 2011). This could be achieved through optimising the use of chemicals in the system and managing agricultural areas for both the conservation of biodiversity and food production. Agriculture includes a wide variety of crop types, management practices and rotation periods; the effects of these intensification practices vary in different agricultural systems. All agricultural systems are not responsible for biodiversity decline; for example, tree-based cropping systems and organic farming have shown positive effects on biodiversity (Foley et al. 2011).

There is a general acceptance among studies that organic farming, which avoids the use of chemicals to the system, reduces the impact of agriculture on ecosystems thereby increasing biodiversity (Bengtsson et al. 2005). Meta-analysis has shown that organic farms host higher abundance of weeds, arthropods, birds, soil invertebrates and some rare plant species (Hole et al. 2005). A few studies have found neutral or even negative differences in biodiversity between organic and conventional farms (Hole et al. 2005). The magnitude of the difference in biodiversity between organic and conventional farming increases with the intensity of the land use. Since differences in biodiversity are expected to be most pronounced in cereals and annual vegetables (Tuck et al. 2014) I chose rice paddy wetlands to study the effect of organic farming.

1.2 Land sharing vs land sparing

Green et al. (2005) proposed the *land sharing vs land sparing* conceptual framework, which presents two approaches to managing the trade-off between agriculture and biodiversity. The *land sharing* approach suggests maintaining patches of natural and semi natural areas within and around farms to reduce the negative effects of agriculture on biodiversity. This approach reduces productivity in a given farm (because it is less intensive) and hence leads to the clearing of more agricultural areas to maintain the same level of food production. On the other hand, *land sparing* suggests reducing the overall agricultural area but increasing the production per unit area by intensifying farming practices using fertilizers and pesticides; biodiversity protection is allocated to ‘spared land’ or abandoned farms that grow back to natural areas (Green et al. 2005).

Agroforestry, organic farming and other wildlife friendly practices are increasingly advocated as strategies for land sharing (Phalan et al. 2011a; Tuck et al. 2014), but these could lead to the clearing of more natural areas, which have higher biodiversity. Productivity in organic farming can be enhanced by improving management practices and growing conditions (Seufert et al. 2012). Management practices such as crop diversification and agroforestry, which increases the diversity of cultivated crops, have been shown to increase biodiversity and productivity in agricultural landscapes (Cardinale et al. 2012).

Because agricultural clearing is the main threat to global biodiversity loss (Phalan et al. 2016), land sparing approaches suggest that the better strategy for minimising negative effects of agriculture on biodiversity is to reduce the total cultivated area by adopting higher intensity farming practices. Phalan et al. (2011a) compared the effect of agricultural intensification on biodiversity and found that birds and trees in Ghana and northern India are more negatively affected by land sharing than land sparing. However, in many countries intensified agriculture using substantial amounts of agrochemicals has resulted in degradation of soil, water and air quality (Phalan et al. 2016). By polluting these natural resources, human health could also be affected which raises concerns about broader food security issues such as reduced dietary diversity and nutritional qualities in the food produced. The long-term productivity of agricultural intensification is also often questioned; for example, in India, large scale intensified crop cultivation systems have led to declines in soil quality and productivity (Matson et al. 1997).

Both approaches have been debated over the past decade, and the decisions on land sharing and sparing depend on the magnitude of the trade-off between biodiversity and productivity of the system (Tuck et al. 2014). The land sharing approach is advisable for a system if the productivity is high and can withstand a reduction in order to conserve biodiversity. The size of the trade-off is also important, as a minor increase in biodiversity with a considerable reduction in productivity is not reasonable from a farmer's point of view. The trade-off between biodiversity and productivity in an ecosystem is much understudied. Agricultural systems vary in potential productivity and existing biodiversity, hence the trade-off between biodiversity and productivity needs to be better understood. The application of both land sharing and sparing approaches need careful consideration of the social, economic and ecological systems.

Studies comparing organic and conventional biodiversity are largely from temperate regions and very few studies examine direct correlations between biodiversity and productivity. The land sparing and sharing debate requires more representation from varied organismal groups and agricultural systems to improve generalisations at a global scale. In this study, I examined biodiversity and productivity in organic vs conventional rice paddies in Kerala, India. I also explored the effect of landscape context on biodiversity and productivity in organic farms. The variability of landscape structure, productivity of rice and importance of tropical forest ecosystems in Kerala makes it an ideal place to conduct the study.

1.3 Kerala context

I conducted my study in Kerala, a state in Southern India. Kerala is an agrarian state where agriculture plays a major part in the economy. Rice is the staple food for Keralites and major portions of the state land area have been under rice cultivation for centuries. During the mid-1900s, about 750,000 hectares of land (19% of the total land area of Kerala) was under rice cultivation, peaking at nearly 881,000 hectares (23% of the total area) in 1975 (Figure 1.1). Dramatic land-use change in Kerala began in the early 1980s, when cash crops such as coconut, arecanut and rubber replaced food crops such as rice and cassava (Kumar 2006).

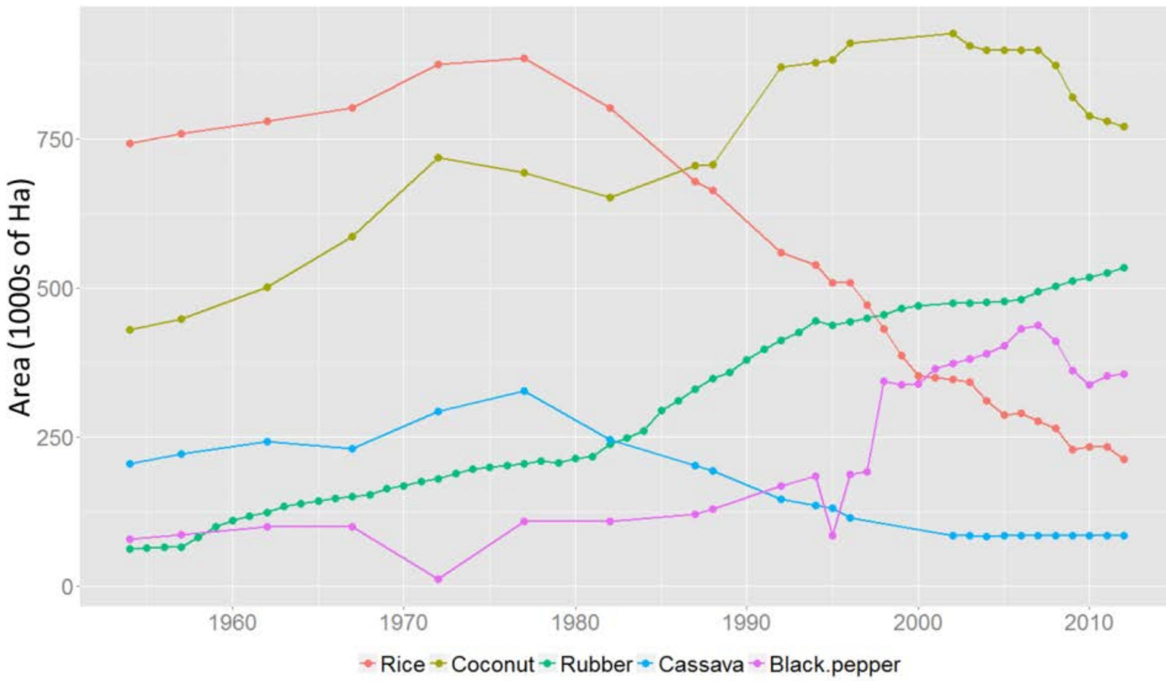

Figure 1.1 Changes in total area cultivated of Kerala's major commercial crops, such as rice, coconut, rubber, cassava and black pepper from 1954 to 2012 (Source: taken from thesis of Fox 2015)

The area under rice was reduced to 197,100 hectares in 2013 (5% of the total area) (Kerala Agricultural Statistics, 2013), one-third of its area in 1975. The rapid decline in rice cultivation was caused by the inflated cost of labour, reduced profits and inflated cost of production (Fox et al. 2017). Despite efforts by the government to reduce the loss of rice wetlands (Kerala Conservation of Paddy Land and Wetland Act 2008), most of the uncultivated rice fields were either abandoned, used for other agricultural uses such as cash crops, or used for non-agricultural purposes such as building houses and other developmental activities.

Rice cultivating areas are considered wetland ecosystems (Hendrickson 2003), and are recognised by the Ramsar convention (Barbier et al. 1997) as manmade wetlands, with high biodiversity of threatened and habitat specific species. In Kerala, rice fields have been part of the landscape for thousands of years and are widespread. These wetlands are very efficient in retaining rainwater in the landscape and promoting water infiltration into the soil. Since rice-cultivating areas are wetlands, cultivation ensures the presence of water in the fields maintaining the water table closer to the surface. Abandoning rice wetlands can increase drought periods, lower the water table and increase soil erosion. It can also change soil properties, such as increased soil macrofauna and high rates of eutrophication (Thomas et al. 2004) and eventually lead to the loss of the wetland qualities of the ecosystem.

Maintenance of rice wetlands for cultivation, however, can also lead to environmental problems. Heavy use of fertilizers in the rice wetland ecosystems in Kerala has caused pollution, eutrophication, and harm to biodiversity (Kittusamy et al. 2014; Sruthi et al. 2017). Intensive rice cultivation can also reduce human wellbeing by increasing pesticide residues in the food and water of local people (Sruthi et al. 2017).

1.4 Research objectives

In this thesis, my main objective is to compare how organic and conventional rice farming affects potential trade-offs between biodiversity and agricultural productivity. My secondary goal is to understand the role of landscape context (the amount of forests in the landscape surrounding fields) and how it augments or reduces such trade-offs. I compared the biodiversity (amphibians and arthropods) as well as agricultural productivity (rice production) in organic vs conventional rice paddy wetlands in Kerala, in southern India. The results will add to the existing knowledge of the effects of organic farming from a tropical and developing country perspective thereby reducing the geographical biases in current studies.

My thesis is composed of four chapters: this introduction (chapter 1), two research chapters (chapters 2 and 3), and a conclusion (chapter 4). Chapter 2 examines the differences in biodiversity and rice productivity in organic vs conventional fields. The specific research objectives and associated questions I address for chapter two are:

1. Does organic management increase biodiversity of amphibians and arthropods, compared to that of neighbouring conventional fields?
2. Do organic paddy fields have lower productivity than conventional rice wetlands?
3. What is the relationship between agricultural productivity and biodiversity of amphibians and arthropods (in terms of diversity, abundance, rarefied species richness and community composition)?

My results showed quite high variability in the impact of organic and conventional fields on biodiversity measures and productivity. To further understand possible drivers of this variability, Chapter 3 assesses if the amount and spatial pattern of forests surrounding the fields impacts biodiversity and productivity patterns and trade-offs. This third chapter addresses the following three questions:

1. Do biodiversity differences between organic and conventional fields vary according to the amount of forest in the surrounding landscape?
2. Can the differences in rice productivity between organic and conventional fields be explained by the amount of forest in the landscape?
3. How does landscape configuration influence the effect of organic farming on biodiversity?

In the last chapter, I conclude the thesis with insights about the overall findings and suggestions for landscape level planning and management of rice paddy wetlands. I have also included suggestions for future research. I hope my thesis will contribute to our general understanding of the effects of organic farming and landscape context on biodiversity and productivity in future organic-farming-related studies.

Chapter 2. Organic Farming Increases Biodiversity but Reduces Productivity: A Strategy for Land Sharing

2.1 Introduction

Biodiversity plays a key role in ecosystems, supporting important ecosystem functions such as pollination, nutrient cycling, pest control and other indirect benefits to people (Tilman & Clark 2014; Lefcheck et al. 2015). But biodiversity is declining globally (Pereira et al. 2010; Gerstner 2017) due to various human pressures like land-use change, climate change, energy production and food production (Alkemade et al. 2009). International efforts to conserve biodiversity largely focus on the creation of protected areas (Gaines et al. 2010), but existing protected areas are not enough to reduce the global loss of biodiversity, hence conservation efforts need to extend beyond protected areas to all landscapes (Mora & Sale 2011).

One of the chief drivers of biodiversity loss globally is agriculture (Hole et al. 2005), which occupies more than 37% of the global land area (FAO 2016). Although agricultural areas have the potential to host biodiversity, the biodiversity loss in these areas is typically very high. There are two reasons for this: 1) through habitat loss, as natural areas are cleared for agriculture; and 2) by means of intensification of existing agricultural land, through a variety of methods like using high-yielding crop varieties, chemical fertilizers and pesticides (Matson et al. 1997). Both activities are intended to increase agricultural productivity (Tscharntke et al. 2005). But increased use of chemical inputs can create hostile environments for organisms by altering the chemical properties of soil and water (Matson et al. 1997) such that only those groups that can adapt to the unfamiliar environment will survive (Gamez-Virues et al. 2015). Under this scenario of intensified agricultural land use, biodiversity needs to be spared elsewhere (land sparing hypothesis). An alternate approach (land sharing hypothesis) is to reduce the impact of agriculture on the ecosystem through wildlife friendly farming, where food production and the conservation of biodiversity are accommodated in the same landscape (Green et al. 2005; Hodgson et al. 2010; Tscharntke et al. 2012).

Organic farming, which reduces or completely avoids the use of chemical inputs to the agricultural system, can lessen the impacts of agriculture on ecosystems (Gomiero et al. 2011) thereby increasing biodiversity (Stolze & Lampkin 2009; Coda et al. 2015). Globally, the area under organic management has been increasing steadily, from 11 million hectares in 1999 to 37.2 million hectares, or about 2.3% of total agricultural area, in 2011 (FAO 2013). Since organic farming has been found to improve biodiversity in agricultural landscapes significantly (Coda et al. 2015) it could be a viable method in a land sharing approach (Schneider et al. 2014). Increasing biodiversity in agricultural areas depends on both the agricultural practices used and the amount of uncultivated areas managed within the farm, including ponds, hedges, ditches and other uncultivated area, that act as breeding habitat and shelter for a diverse group of organisms (Bengtsson et al. 2005). The effect of organic farming appears to be higher in high intensity agricultural systems (higher planting density, fertilizers and other chemicals, longer cultivation period, or higher tillage frequency) (Tuck et al. 2014). Meta-analysis shows that the effect of organic farming on biodiversity also varies depending on the group of organisms and the landscape studied (Batáry et al. 2010; Winqvist et al. 2011).

But increasing biodiversity in organic fields comes with a cost, as the agricultural productivity of organic farms can be significantly lower than that of conventional farms (Badgley et al. 2007; de Ponti et al. 2012; Gabriel et al. 2013). The yield differences between organic and conventional fields can vary depending on the type of agricultural crop, site factors, and management practices (Seufert et al. 2012). The productivity of organic farming seems to be lower in cereals and annual vegetables (Seufert et al. 2012; Tuck et al. 2014) than in crops that have a longer cultivation period, such as perennial vegetables and orchards. Yet surprisingly few studies have simultaneously examined productivity and biodiversity to understand this trade-off better in organic systems. Moreover, existing studies are biased heavily towards temperate and developed countries, despite elevated levels of biodiversity loss in the tropics. The biodiversity and productivity dynamics in organic farming need to be better understood because the effect of organic farming could vary with the existing biodiversity, intensity of management and the crop type. There is a wide range of agricultural systems and taxa yet to be explored (Tuck et al. 2014). Rice is a major cereal crop in which the effect of organic farming on biodiversity and productivity is little studied.

Rice is one of the most important cereal crops globally in terms of dietary intake (Maclean et al. 2013). Rice cultivating areas are considered wetland ecosystems (Hendrickson 2003), and are recognised by the Ramsar convention (Barbier et al. 1997) of globally important wetlands as manmade wetlands with high biodiversity of threatened species. Heavy use of pesticides in these rice ecosystems causes an imbalance in pest and predator populations, leading to pest outbreaks and biodiversity loss (Maclean et al. 2013). According to FAO (2013) estimates, in 2009 rice was cultivated on over 158.5 million hectares globally, or 11.5 percent of the total arable land. Rice cultivation increased to over 162 million hectares globally by 2010. India is currently the largest rice producer in the world in terms of area (Maclean et al. 2013). Most rice cultivation in India is conventional (Priyanga & Venkataraman 2017), but organic farming is increasing with support from government and private organisations (ICCOA reports 2014).

Rice wetlands contain high biodiversity of many taxa including plants, arthropods, amphibians and birds (Bambaradeniya et al. 2004; Miyashita at al 2014; Brogi et al. 2015). Amphibians may be particularly sensitive to conventional agricultural practices, as they depend on these ecosystems for most of their lifecycle, especially for breeding, and are thus directly exposed to agricultural chemicals (Taylor et al. 2005; Bruhl et al. 2013). For example, amphibians in conventional rice-paddy wetland farms in Kerala have been reported with malformed limbs while amphibians in nearby organic farms were unharmed; levels of pesticide residues were significantly greater in malformed frogs than in the healthy ones (Kittusamy et al. 2014). The effects of agrochemicals may also occur for other taxonomic groups such as arthropods, birds, mammals and fishes to varying degrees, depending on the level of agricultural intensification, and the species' use of the agricultural ecosystem and feeding habits (Fryday & Thompson 2012).

To better understand biodiversity-productivity relationships in organic farming, in this chapter, I compared biodiversity of amphibians and arthropods as well as agricultural productivity in organic vs conventional fields in Kerala. In this study, I focused on amphibians, which are an underrepresented group in this type of research (Randall & James 2012). My study addresses the following hypotheses:

1. biodiversity of amphibians and arthropods is greater in organically managed farms, as compared to neighbouring conventional fields
2. organic paddy fields have lower productivity than conventional rice wetlands

3. agricultural productivity is negatively associated with diversity, abundance, rarefied species richness and community composition of amphibians and arthropods

2.2 Methods

2.2.1 Study area and site selection

Kerala is a state in south-western India (8°18' - 12°48' N and 74°52' - 77°22' E) covering an area of 38,863 km^2 (Figure. 2.2.1). Running northwest to southeast, the state has a 580 km coastline from the Arabian Sea in the west to hilly tropical evergreen forest in the east. Geographically the state is divided longitudinally into three regions from west to east: lowland, midland and highland (Kerala Forest and Wildlife Department 2017). The lowlands are coastal plains with river deltas, lagoons and backwaters. Coconut and rice are the main agricultural crops cultivated in this region. The midland region is characterised by undulating terrain with intense agricultural activity and a wide variety of crops, including rice, cassava, black pepper and tree crops. The highland region is characterised by tropical evergreen forest. It lies within the Western Ghats biodiversity hot spot (Myers et al. 2000), a stretch of mountains that covers 56% of the state's land area.

Kerala has a tropical humid climate with average temperatures ranging from 20 to 37 degrees Celsius. It experiences tropical monsoon rains (southwest monsoon and northeast monsoon) from June to December, which bring about 3225 millimeters of rain annually (Kerala Department of Environment and Climate Change, 2014). The state has high biodiversity found primarily in forest ecosystems, which covered 29.1% of the state in 2013, and housed 3800 species of flowering plants, of which 33.5% are endemic to Kerala (Kerala Forest and Wildlife Department 2017). Total faunal diversity is 5103 species, with 145 mammals, 486 birds, 164 reptiles, 4027 arthropods and 85 amphibians.

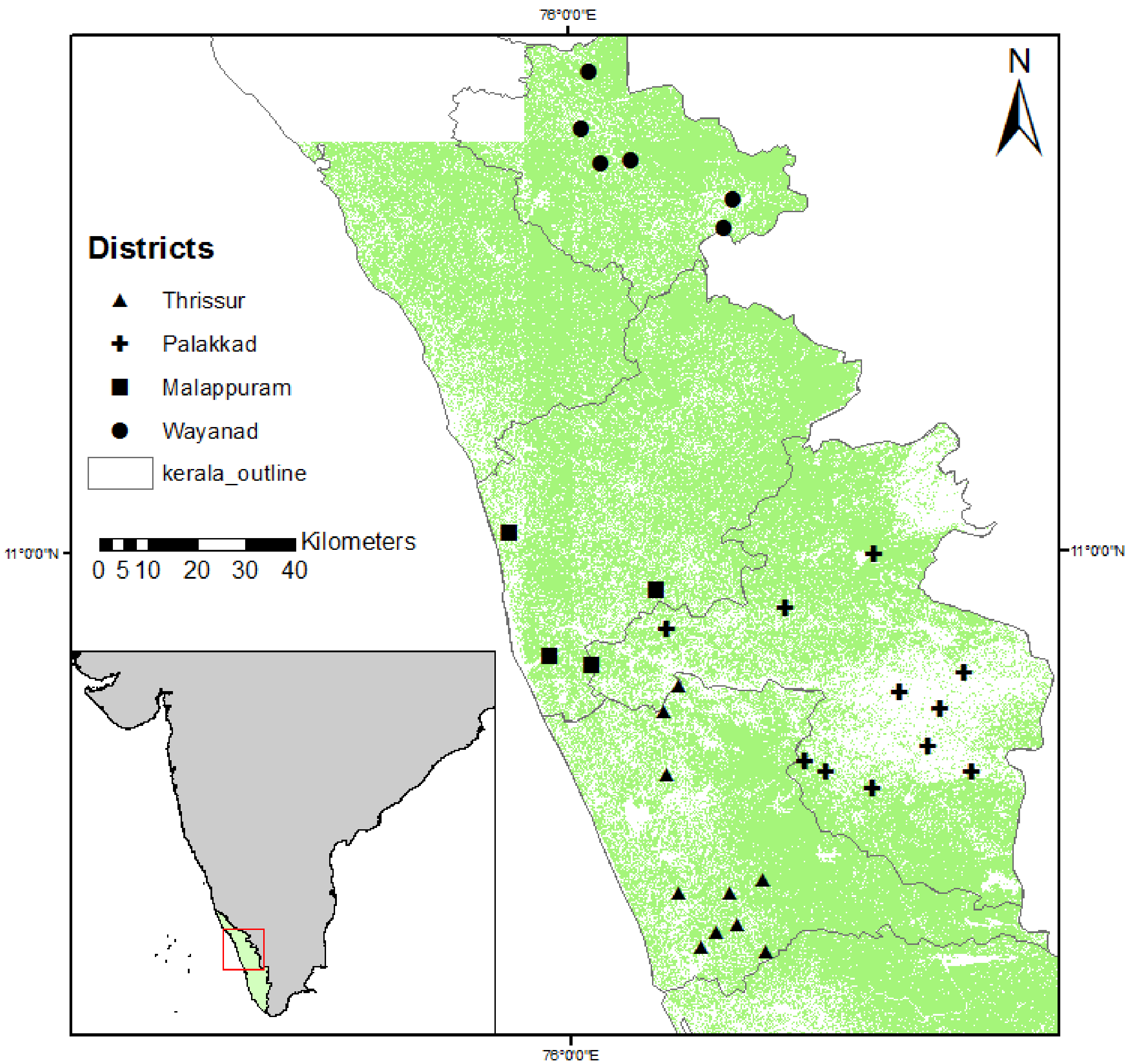

Figure 2.1 Map showing peninsular India and location of Kerala state (green) in the southwest. Enlarged map of Kerala using classified Sentinel 2 imagery showing the forest land cover (green) and the location of the field sites in four districts: Wayanad (circle), Malappuram (square), Thrissur (triangle) and Palakkad (plus).

Apart from forests, Kerala also owes its floral and faunal wealth to home gardens, a traditional tree-based agricultural system that covers approximately 36% of the land area (Kumar 2006). These home gardens host high floral and faunal biodiversity and are often spatially connected with rice wetlands (Coyle 2015). Rice has historically been Kerala's major agricultural crop, covering about 22% of the total geographical area of the state in the1980s, but declining to about

8.8% by 2003 (Kumar 2006). As per the reports of the Kerala Department of Soil Survey and Soil Conservation (2017), rice covered an area of 229,000 ha in 2017, or 5.8% of the total area of the state.

Study locations in rice wetlands were spread across four districts (Malappuram, Palakkad, Thrissur and Wayanad), which are landscape mosaics of cropland, buildings, home gardens, rivers, lakes and forest to varying degrees. Wayanad, located primarily along the Western Ghats, is highly tree-dominated with a low population density, while Thrissur, Palakkad and Malappuram are more highly populated. The landscapes of these four districts span those with highly tree-dominated fields near the Western Ghats (Wayanad and some fields in Palakkad), to landscapes with a mixture of trees and agriculture and urban features in Thrissur and Malappuram, to highly crop-dominated landscapes in parts of the Palakkad gap where the Western Ghats break (Figure 2.2.2). Due to this great variation across landscapes, I used a paired sampling design to only compare organic and conventional fields within the same localized vicinity.

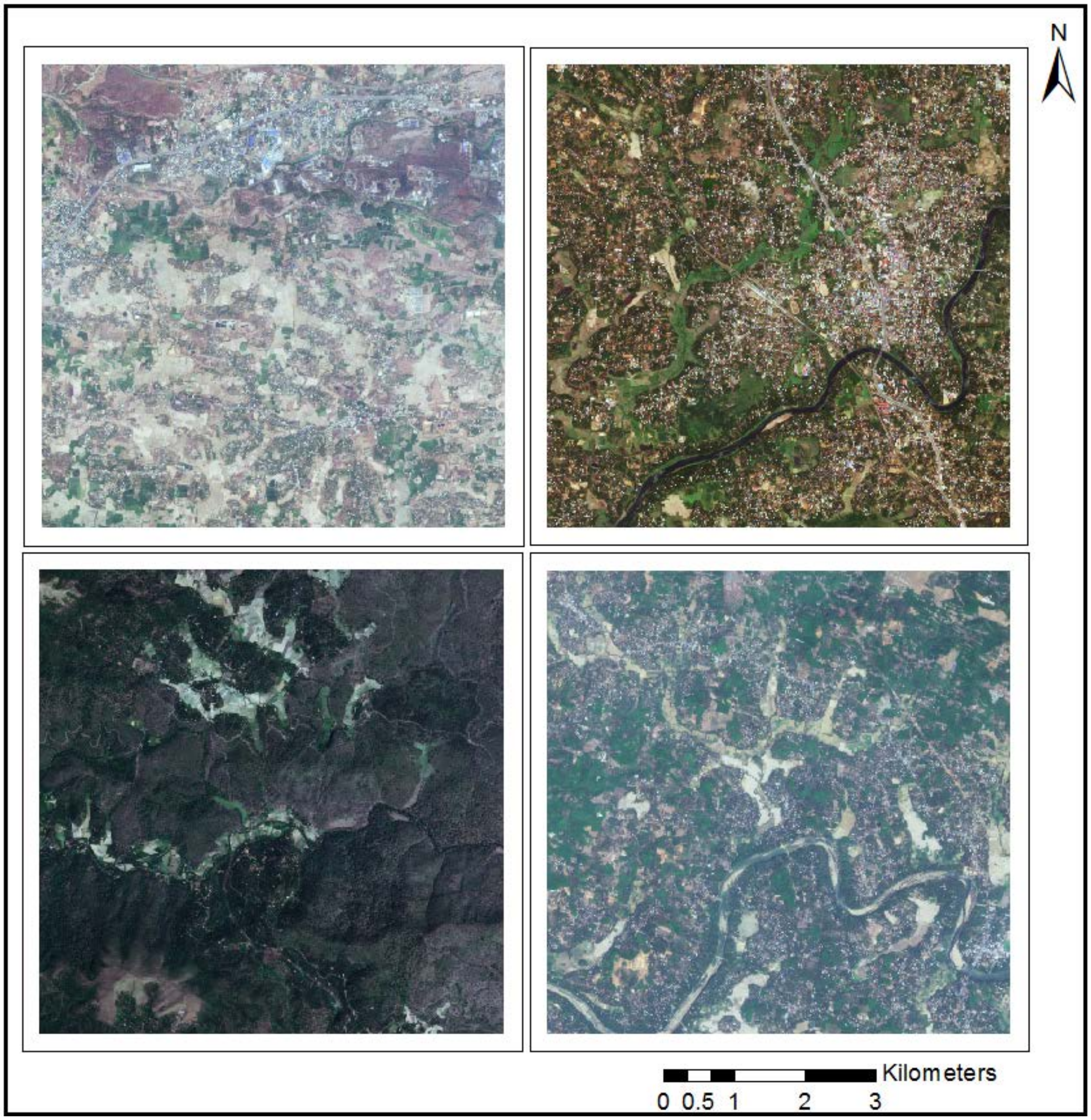

Figure 2.2. True color image (Sentinel 2 satellite imagery with a resolution of 10m) showing landscape variability in the study area: Palakkad (top left) with high paddy dominance and fewer forested areas; Trissur (top right) with high population density; Wayanad (bottom left) with low population and high forest area; and Malappuram (bottom right) with a mixture of land uses.

2.2.2 Organic and conventional field selection

Farmers use hedges to divide larger rice wetlands into smaller fields enabling them to regulate water flows through the system. Fields are rectangular rice cultivating areas bordered by hedges and vary in size. The major source of water for cultivation comes from monsoon rains and from the channels running between fields. Minor channels between fields drain excess water from fields into major channels, which eventually drain from the rice wetlands. Because hedges and water channels are shared among multiple fields, mixed water infiltration between organic and conventional farms could occur, however this was not measured in this study. Fields selected for study were waterlogged to varying levels because of monsoon rains. I avoided fields that were completely submerged or too small to fit a sample plot.

To locate potential fields, I found farmers in India practicing organic farming through use of an internet search. Primary sources included Tamil Nadu Agricultural University (TNAU) (http://agritech .tnau.ac.in/org_farm/List%20of%20organic%20farms%20in%20india.pdf) and the Organic Farming Association of India (OFAI) (http://ofai.org/wp-content/uploads/2011/04/ Organic-Farmers-and-Farms-of-Kerala.pdf). These sources contained lists of organic farmers growing different agricultural products. I identified 20 organic rice farmers and contacted them by telephone.

From February 15th to March 2nd, 2016, I conducted a pilot study in the districts of Thrissur, Palakkad, Alappuzha, Ernakulam and Wayanad in Kerala (where most of the organic rice farmers were reported via the above sources) to locate potential fields, and to understand the methods used by farmers in organic rice. During the pilot study, I located and visited 20 farmers and solicited contact information of other organic rice farmers in the region. I collected GPS locations for all farms during the visits.

Based on the data from the pilot study, I developed criteria for selecting organic fields: 1) minimum farm size of 1 acre (to lay out the plots in the field), 2) no use of synthetic or artificial products as inputs (yet farm by-products from plants and animals were fine), 3) under organic management for at least two years, 4) at least 4 km away from all other organic farms in the study, 5) not completely submerged (i.e. water level was below the hedges).

The main study was conducted during the monsoon season from July to October 2016, in 62 fields (31 organic and 31 conventional fields). I paired each organic field with a conventional field located within 2 km. The paired conventional field was selected to be as similar as possible to the organic field, except in its use of chemical fertilizers and pesticides as inputs. Organic - conventional field pairs were between 100m to 2 km distance (except for one pair 6 km apart) so that both fields would share most of the landscape features surrounding them. As much as possible, matched fields had similar water levels, closeness to other land uses like homegardens, and proximity to water channels. Both organic and conventional farmer used local and hybrid rice varieties but higher numbers of organic farmers used local varieties while conventional farmers tended to use hybrid varieties.

2.2.3 Farm level variables

I collected information about farming practices of all farms with the assistance of the farmer. None of the farmers were asked personal details regarding age, occupation, family history, income, religious beliefs or opinions. Farmers were asked about management practices, agricultural yields and other farm variables (datasheet attached as Appendix 1). Specifically, I solicited information about the type and quantity of fertilizers and pesticides used during cultivation and the date of the last application of such chemicals. I also asked the date the crop was planted and if planting and harvesting was manual or mechanized.

Information regarding farming practices such as productivity, the number and type of inputs used and other data were collected for each farm. Conventional fields were carefully chosen to minimize variability between pairs in all variables except for conventional or organic management. Specifically, I controlled for variables such as time of planting (age of the crop), date of last fertilizer application and number of growing seasons in a year when selecting the conventional pair in that area. I made use of local knowledge about the farming community in the area to locate farms best meeting these criteria.

Rice productivity is highly variable within a given farm from year to year, due to precipitation patterns. Thus, I determined mean productivity of rice for each farm by asking the farmers during the interview about the average productivity of rice over the course of several years. I obtained productivity estimates for only 30 organic – conventional pairs because one farm was damaged by heavy rains prior to harvest.

2.2.4 Amphibian and arthropod sampling

Amphibian surveys were conducted in organic - conventional field pairs on the same day from 6:30 pm to 10:00 pm to limit potential diurnal discrepancies. Rainy weather was avoided to improve detection ability. With the help of trained field assistants, I identified amphibian individuals and calls to species level in five 10m x 10m quadrats in each field. Quadrats were dispersed throughout the field maximizing space between them in order to reduce the double counting of amphibians. All quadrats were placed to include a hedge to reduce the differences between quadrats (Figure 2.2.3). The surveyor spent 15 minutes in each quadrat, walking 10m along the side of the quadrat bordering the hedge, carefully scan searching (Cooke & Arnold 2003), and then advancing towards the center of the field. I applied multiple methods (counted number of individual sightings and calls) to yield the best results (Olson et al. 1997). Amphibians show a high degree of movement in the water-rice environment, so the surveyor moved very gently so as not to disturb the organisms or damage the crop while surveying. All amphibian individuals were identified in the field to species; photographs were taken of unknown individuals and later identified either using field guides (Daniels and Indian Academy of Sciences 2005) or by consulting experienced researchers from Kerala Forest Research Institute, in Peechi, Kerala.

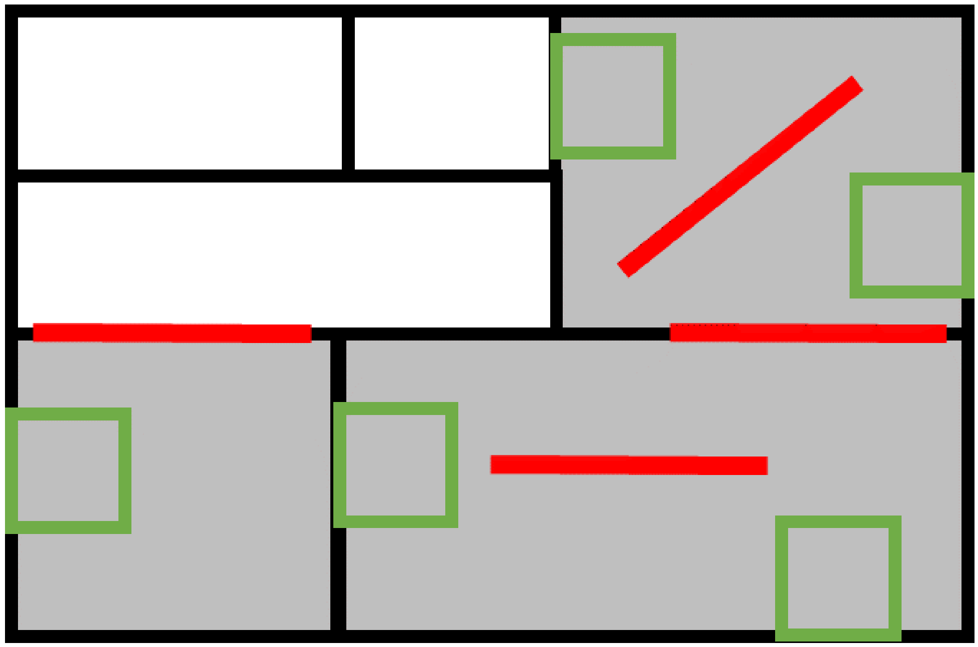

Figure 2.3 Figure showing the fields in the farm (rectangle boxes with black outline which is the hedges) and selection and layout of sample plots and transects for amphibians and arthropods in organic or conventional fields. The largest fields in the farm were selected for biodiversity sampling (shaded in grey), avoiding small fields (shaded in white). For amphibians, five quadrats (10*10m) were placed in the field. Quadrats (green squares) were carefully chosen with a hedge (black line) on one side. For arthropods, transects of 20*2m (red lines) were chosen (2 in the field and 2 on the hedge).

Arthropods were surveyed between 4:00 pm and 6:00 pm on the same day in both organic and conventional fields. All surveys were done in sunny weather and completed before sunset. I used four 20m*2m transects (two along the hedge, and two in the center of the field). For hedge transects, I selected the longest hedge to avoid the hedge intersections. The surveyor spent 10 minutes on each transect advancing forward, using a sweep net (handle length of 1m and net diameter of 30 cm) to complete 50 random sweeps and recording direct observations of all arthropods seen, recording only those distinguishable by the naked eye. No specimens were collected and minimum damage to the crop was ensured during the survey. Morpho-species was determined for all individuals based on color and appearance and used to classify them to order (Oliver 1996; Bridgeland et al. 2010) by trained field assistants. Odonates were present in most of the fields but were highly mobile and not possible to include in the sweep netting. Hence, Odonates were sampled separately by taking direct observations for 15 minutes, standing in the center of the field (see Sutherland 2006 for survey methods). I did not classify Odonates into species level but rather recorded the abundance in each field.

2.2.5 Statistical analysis

2.2.5.1 Biodiversity and organic farming

I calculated three biodiversity measures for amphibians: (1) abundance (counts of individuals and calls); (2) Simpson diversity using R (Core Team 2017) package vegan (Oksanen et al. 2017); and (3) rarefied species richness (field level) (using the R package vegan). For arthropods, I calculated abundance in three ways: total number of individuals in the field (total abundance), total individuals in hedge transects (hedge abundance), and total abundance in center transects (center abundance) separately for each field. For Odonates, I calculated the total abundance in each field. The response variables of amphibian abundance, amphibian rarefied richness, and arthropod total and center abundance, were natural log transformed prior to analysis. As arthropods and Odonates were identified to order level only, I did not assess diversity or species richness for these taxa.

I tested for the effect of management on amphibian abundance, diversity and rarefied richness. Organic and conventional biodiversity was compared with management nested in pairs using nested ANOVA using the nlme package in R (Pinheiro et al. 2017). Further, I tested the effect of management on five individual amphibian species that were present in at least 15 of the 31 locations, comparing organic and conventional fields using nested ANOVA with package MASS in R (Venables & Ripley 2002). Since individual abundance data were counts, I used generalized linear mixed effects model for nested data with Poisson and Quasi-Poisson distribution using the package MASS in R.

The effect of management on arthropod abundance was tested using the same methods. I used abundance measures (total, hedge and center) and total abundance for Odonates as the response variables and management as the explanatory variable using the package nlme. Seven orders were present in more than half of the fields and were tested for the effect of management using nested ANOVA (MASS package). The data were counts and followed Poisson and Quasi-Poisson distribution. Box plots were created with the natural logarithm of the response ratios (organic value divided by conventional value) for every dependent variable (Hedges et al. 1999) for amphibians and arthropods to show the variability of the effect.

2.2.5.2 Community composition

I used Non-Metric Multi-Dimensional Scaling (NMDS), an ordination method for studying community composition, to assess if amphibian species and arthropod order assemblages among fields (n=62) was significantly different and to show the variability between individual organic-conventional pairs. NMDS plots were created using absolute abundance measures using the Bray Curtis distance measure in the package vegan in R. I also created NMDS plots of separate locations (n=31) using absolute abundance of a location (organic + conventional) to study the district-wise relationship between the sites.

I used Blocked Multi-Response Permutation Procedure (MRBP), in the package Blossom in RStudio™ (version 1.0.136, RStudio 2016) to test for average differences in community composition of amphibians and arthropods between organic and conventional pairs. MRBP is a method for testing difference between groups (Ponzetti & McCune, 2001) suitable in a matched pair study design. MRBP was also performed to determine if there was a significant difference between the organic and conventional fields in the same location with respect to the variables controlled within the pairs. MRBP can also be used to test for group differences within blocks (pairs) which yields a delta value and p value. The delta value is obtained by taking the average of the distances between the two fields in the same site from the distance matrix (Bray Curtis distance measure). A lower p-value rejects the null hypothesis that there is no difference between the two groups. I tested using the variables that I tried to control for in the field: age of the crop, days since last fertilizer application, number of seasons, farm area, number of fields in the farm, field area, number of fields and crop variety.

2.2.5.3. Organic farming and productivity

To test for average differences in productivity between organic and conventional farms, I used an ANOVA with linear model in R. The response variable was productivity of rice (t/ha) with management (organic/conventional) as the independent variable. Boxplots were used to depict the average difference in productivity of organic and conventional farms.

2.2.5.4 Biodiversity and productivity

I tested the effect of productivity (of rice in kilograms per acre) on biodiversity using linear mixed effects model with productivity nested in pairs (using the R package nlme). The response variables followed a normal distribution. The effect was tested for all the biodiversity measures calculated for amphibians and arthropods. I used Akaike Information Criterion (AIC) scores with Reduced Maximum Likelihood (REML) estimates for model selection and validation. I also used box plots to examine if there was a difference between local and hybrid varieties used in organic and conventional fields.

2.3 Results

2.3.1 Organic management increased biodiversity

I identified 16 species of amphibians (Appendix 2) with a density of 9,832 individuals per hectare (s.d.=5,201). All amphibian species were on The IUCN Red List of Threatened Species (Version 2017-3) category of least concern except for *Clinotarsus curtipes* (near threatened), *Polypedates occidentalis* (data deficient) and *Indosylvirana aurantiaca* (vulnerable). Amphibian abundance was higher in organic fields (11,043 individuals per hectare) than in conventional fields (8,619 individuals per hectare) ($F_{1, 30}$=10.72, p=0.003).

Amphibian Simpson diversity was also significantly higher in organic fields ($F_{1, 30}$=4.72, p=0.037) but rarefied species richness was not different in organic vs. conventional fields ($F_{1, 30}$=2.45, p=0.128). *Euphlyctis cyanophlyctis, Fejervaria species A, Fejervaria species B, Hoplobatrachus tigerinus* and *Indosylvirana aurantiaca* were the species found in most of the sites and hence I compared the abundance of these species independently. Two species (*Fejervaria* A; $F_{1, 30}$=1.4, p=0.246 and *F.* B; $F_{1, 30}$=0.076, p=0.785), were not significantly more abundant in organic fields. But three others (*Euphlyctis cyanophlyctis* ($F_{1, 30}$=7.719, p=0.009), *Hoplobatrachus tigerinus* ($F_{1, 30}$=18.213, p=0.001) and *Indosylvirana aurantiaca* ($F_{1, 30}$=15.27, p=0.0005) were significantly more abundant in organic fields than in conventional fields.

I identified 16 orders of arthropods with an average density of 24,745 individuals per hectare (s.d.= 15,450). The total abundance of arthropods was slightly but not significantly higher in organic (26,371 individuals per hectare) vs conventional (23,117 individuals per hectare) fields ($F_{1, 30}$=3.91, p=0.057), but not significant in hedges ($F_{1, 30}$=1.64, p=0.21) or in field centers ($F_{1, 30}$=1.95, p=0.173). Araneae, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera and Orthoptera were the orders found in most sites and although I examined the abundance of each of these orders separately, there was no significant difference in the abundance of any of the groups. I also found that there was no significant difference in Odonate abundance ($F_{1, 30}$=0.35, p=0.559). But, the organic conventional ratio of both amphibian and arthropod diversity and abundance measures included in the study indicated that the biodiversity was higher in organic fields (Figure 2.3.1).

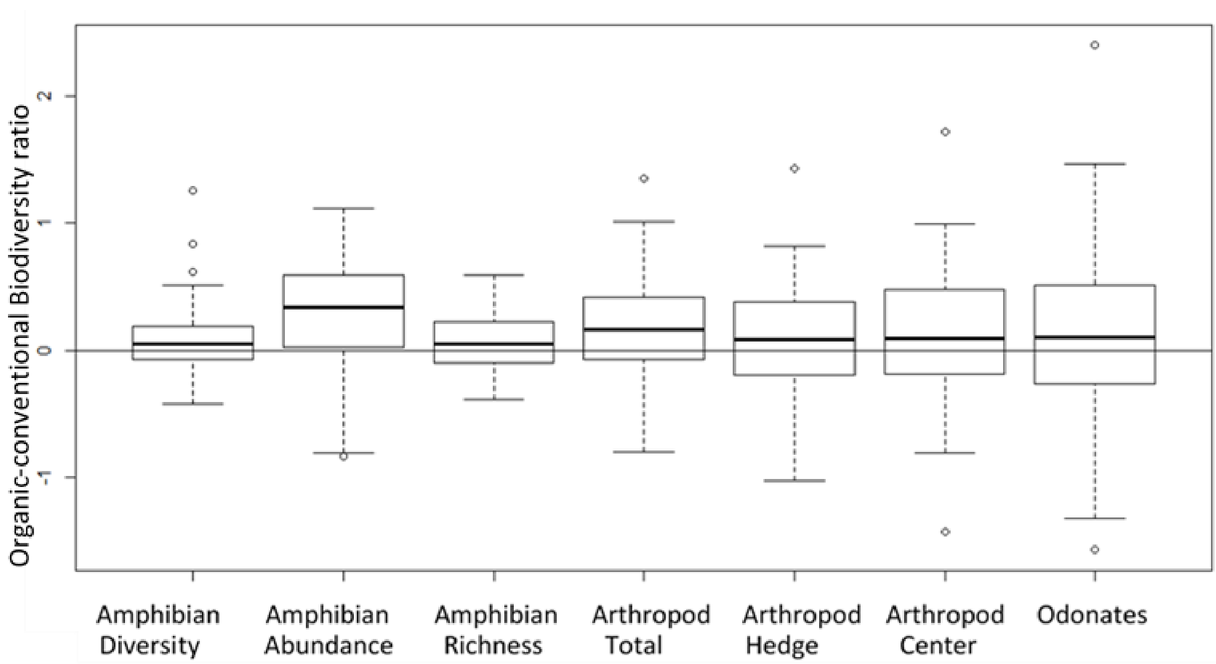

Figure 2.4 Box plots showing effect of organic farming on: Amphibian diversity, abundance and richness; Arthropod abundance total, hedge and center; and Odonate abundance (from left to right). Natural logarithm of biodiversity ratios (organic/conventional) were used to create the box plots.

2.3.2 Amphibian communities in organic different from conventional

NMDS plots of amphibians (3 axis solution, final stress = 0.136 and R^2 = 0.88) in 62 fields show that the fields exhibit a high degree of variability. The fields are evenly scattered across the graph and the distance between individual organic and conventional fields vary from very close to each other to far away. As a whole, community composition of organic fields is not separate from conventional fields for amphibian in the Figure 2.3.2. That is, the organic field cluster is not isolated from the conventional field cluster, instead they are mixed together. Figure 2.3.2 also shows that the organic and conventional fields in a pair varies such that the amphibian species composition of the field is often more similar to a field located far away rather than its pair in the nearby area.

The NMDS plot of arthropods (3 axis solution, final stress = 0.140 and R^2 = 0.92) in 62 fields show that most of the fields are clumped towards the center (Figure 2.3.2). In general, the organic and conventional field clusters are not separated but rather intermixed with each other.

The ordination of amphibians by sites (instead of plots) (Figure 2.3.3) shows that community composition differs significantly among locations (3 axis solution, final stress = 0.106 and R^2 = 0.93); the centroid of the effect shows that there is district-level difference in the distribution of amphibians. The difference between organic and conventional fields in Wayanad is generally smaller (the size of the individual points represents the difference between the organic and conventional pair) and separate from other fields. The distance between pairs in Wayanad is also shorter which indicates that variability between the fields was lower compared to the fields in other districts.

The ordination of arthropods shows that conventional-organic pairs overlap even though there is variability within pairs at the same site (3 axis solution, final stress = 0.122 and R^2 = 0.94) (Figure 2.3.3). At the district level, fields were clumped and the centroids of the fields were very close to each other. However, pairs in Wayanad showed consistently smaller differences and the spread between the pairs was also lower.

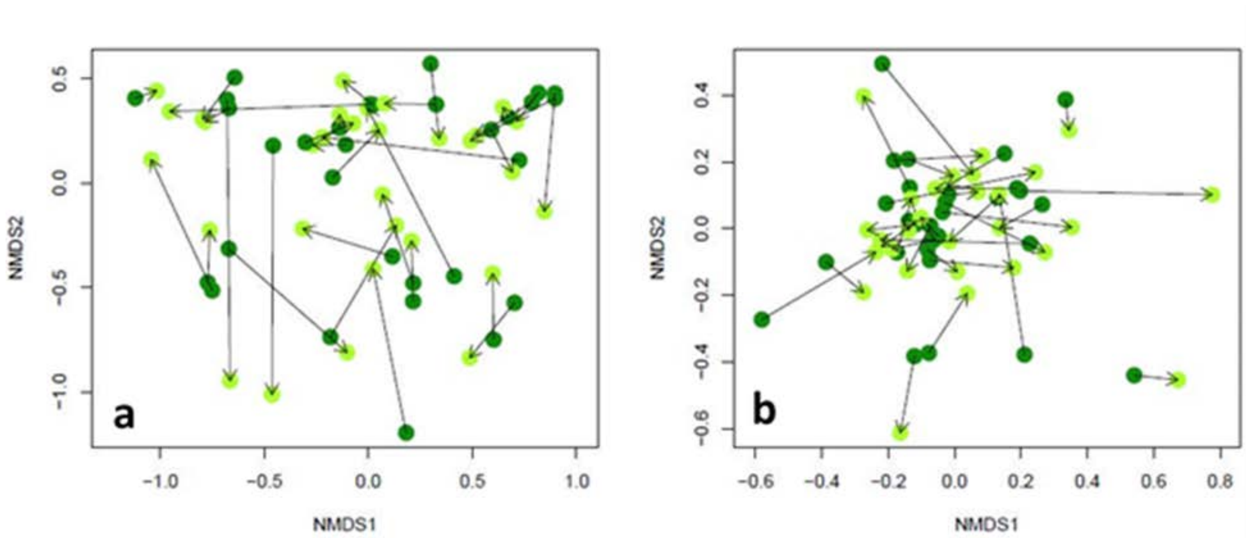

Figure 2.5. NMDS plot of abundance of a) amphibians and b) arthropods. Each point represents an organic (dark green) or conventional (light green) field. Grey arrows join organic-conventional pairs; the length of the arrow represents the difference in species composition.

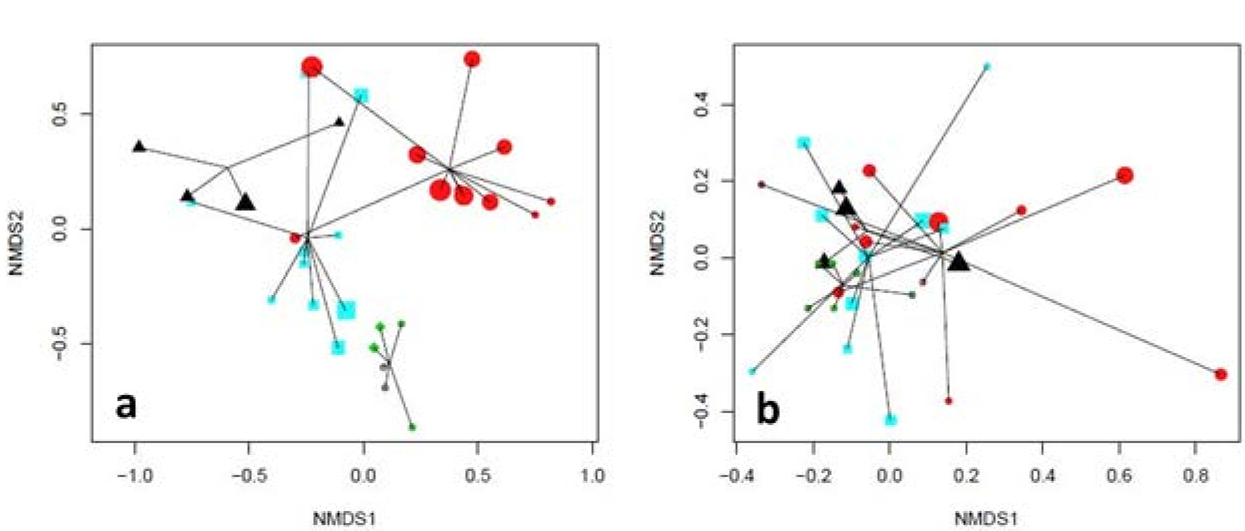

Figure 2.6 NMDS plot of 31 sites a) amphibians and b) arthropods. Each point showing the total abundance of (organic and conventional) amphibians in that location. The size of the points represents the Bray-Curtis distance between the organic and conventional fields in the same location. The colors represent districts: Wayanad (green), Thrissur (blue), Malappuram (black) and Palakkad (red). Lines intersect at the centroid of the effect in each location.

The MRBP results of the community composition of amphibians shows that the average difference between individual organic and conventional field in the same location is significantly different. I also tested for the variables controlled for in the field (age of the crop, days since last fertilizer application, number of season, farm area, number of fields in the farm, field area, number of fields and crop variety), which showed that these variables are not significantly different between organic and conventional fields within a pair (Table 2.3.1). Hence, the results support the assumption that the organic and conventional pairing is meaningful and fields are comparable. Whereas, the average arthropod community composition (order level) difference between organic and conventional fields was not significantly different between organic and conventional.

Table 2. 1. MRBP results, showing the delta value and the p-value for controlled variable difference between organic and conventional fields, community composition of amphibian species and arthropod orders.

Matrix	Delta	p-value
Field and controlled variables	39.3	0.76
Field and Amphibian species	29.3	0.01
Field and Arthropod orders	257.98	0.37

2.3.3 Organic farms are significantly less productive than conventional

The average productivity of organic farms (3.75 tons/hectare with s.d.=1.55 tons/hectare) was approximately 76% than that of conventional farms (4.88 tons/hectare, s.d.=1.13 tons/hectare) ($p=0.002$, Figure 2.3.4). But, there was high degree of variability in both organic and conventional productivity, ranging from 1.73 to 8.9 tons/hectare for organic farms and 2.47 to 7.41 tons/hectare for conventional farms. The organic-conventional productivity ratio (within the same pair) ranged from 0.4 to 1.5, showing the high degree of variability in productivity differences between the two management systems in the same location. The crop variety was not significant ($p=0.99$) (Figure 2.3.5).

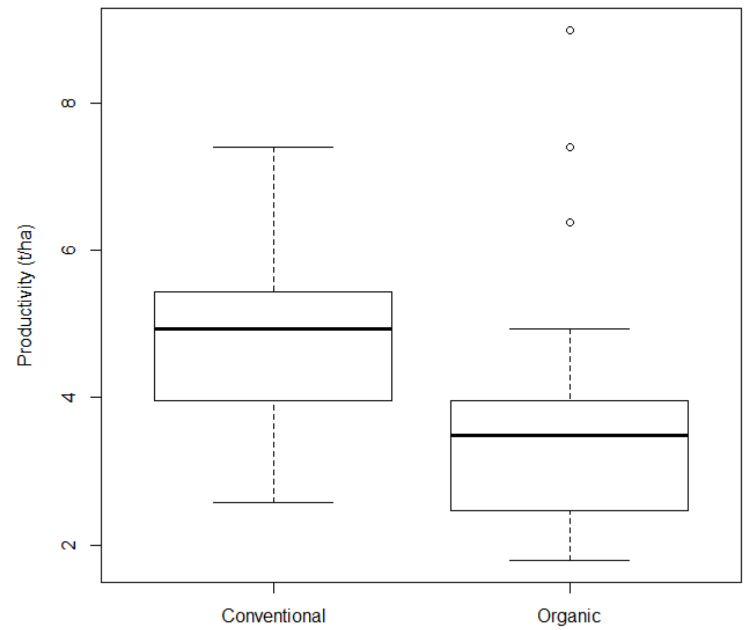

Figure 2.7 Box plots showing the productivity (y-axis) for organic and conventional fields (x-axis).

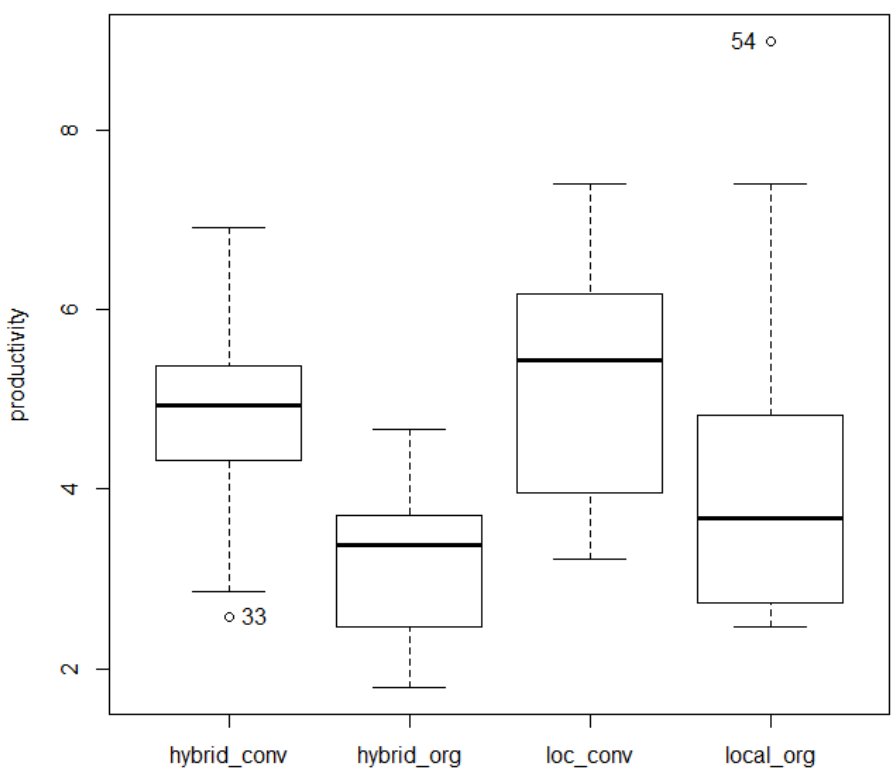

Figure 2.8 Boxplots showing the difference in productivity between conventional hybrid, conventional local, organic hybrid and organic local fields. Local varieties are traditionally cultivated and hybrids varieties are high yielding varieties

2.3.4 Higher biodiversity yet lower productivity

Amphibian abundance is significantly negatively correlated with rice productivity (p=0.002, Table 2.3.2). Generally, a one ton increase in productivity of rice per hectare corresponds with a 12.44% reduction in amphibian abundance per hectare. Simpson diversity was also negatively related to productivity (p=0.009). As productivity increases by one ton, amphibian diversity is reduced by 3.93%. Amphibian rarefied species richness did not change significantly with rice productivity (p=0.39) (Figure 2.3.6). The individual species *Hoplobatrachus tigerinus* (p=0.001) and *Indosylvirana aurantiaca (p=0.0003)* showed a significant negative relationship with productivity.

Table 2.2. The relationship between amphibian and arthropod diversity variables and productivity. The table shows the slope of the productivity (t/ha) and the associated p-values (indicates significant values)**

Taxa	***Productivity (slope)***	***p-value***
Amphibian		
Abundance	*-0.133*	*0.002***
Diversity	*-0.04*	*0.001***
Species Richness	*-0.025*	*0.223*
Arthropod		
Total abundance	*-0.0797*	*0.068*
Hedge Abundance	*-0.0814*	*0.165*
Center Abundance	*-0.0499*	*0.257*

Arthropod abundance was slightly correlated with productivity (p=0.068) (Table 2.3.2). There was no relationship between arthropod abundance in the hedges or center of the organic or conventional fields to productivity. I considered major arthropod orders separately but there was no meaningful relationship between abundance of any of the groups and productivity. Random effects in both arthropods and amphibians was significant with a high degree of residual variance.

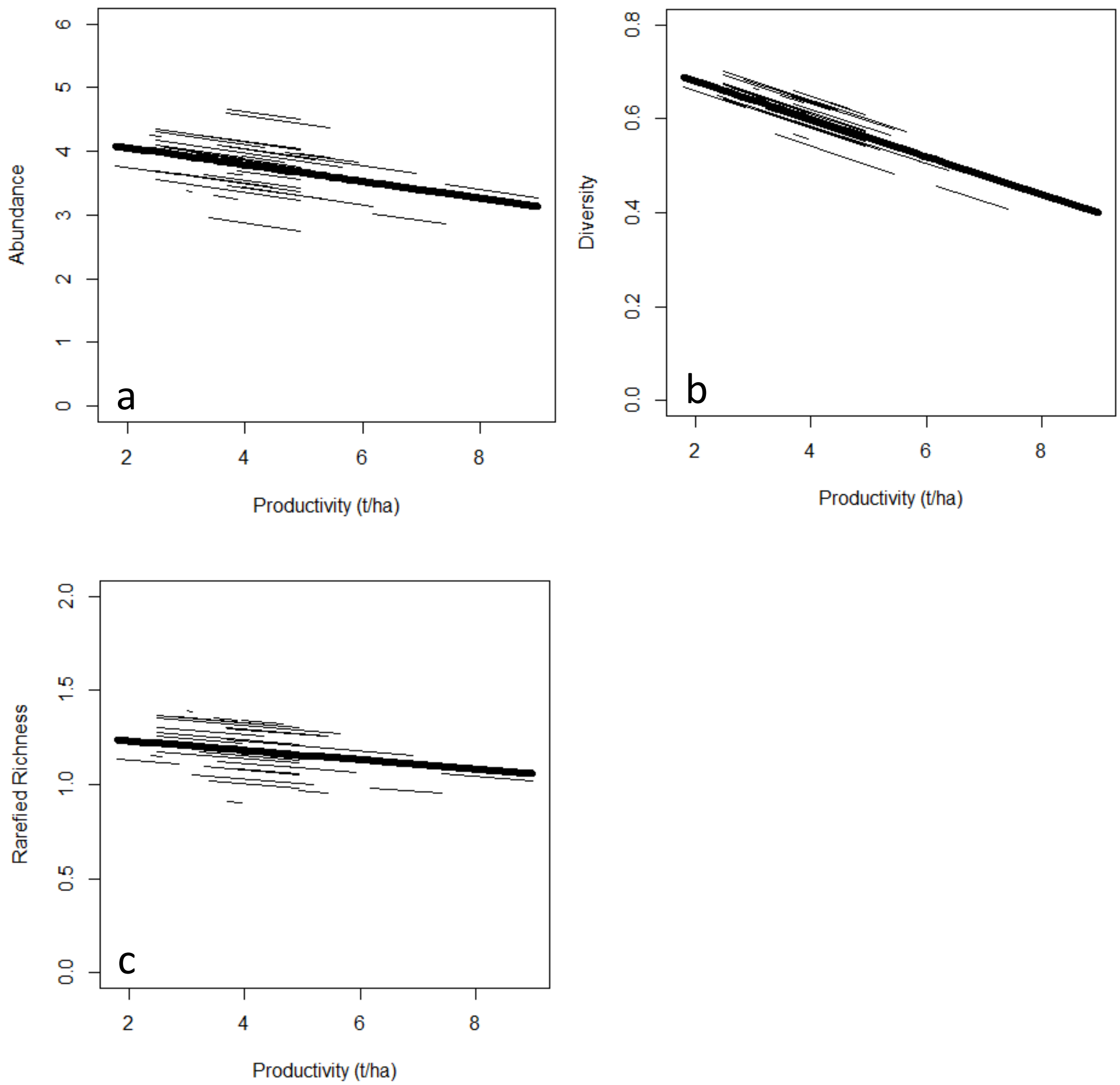

Figure 2.9 Linear mixed effects of the relationship between productivity and (a) amphibian abundance ($p = 0.002$), (b) diversity ($p = 0.001$) and (c) richness ($p = 0.22$). The dark black line is the fitted regression line and the little grey lines represent the individual pairs.

2.4. Discussion

2.4.1 Biodiversity in organic and conventional fields

I found that rice wetlands are important ecosystems for amphibian biodiversity in Kerala. Amphibians occur in high abundance and diversity in these areas. The results support the hypothesis that amphibian diversity and abundance in organic fields was higher than in nearby conventional fields, which could be a consequence of avoiding chemical inputs in organic fields. The high variability in the diversity and abundance of amphibians could be due to several factors such as the: variability in the surrounding landscape context, presence of uncultivated areas in the field, and intensity of management (Altieri 1999; Fahrig et al. 2011). The species richness of amphibians in organic fields was not significantly higher than in conventional fields, which could be because of the proximity of the paired fields, but the abundance of distinct species was higher in organic fields which resulted in significantly greater diversity of amphibians. Organic rice wetlands are important ecosystems for amphibians; by optimizing field management, reducing chemical inputs, and increasing uncultivated areas such as ponds and ditches in the filelds, farmers could improve ecosystem quality to conserve amphibians (Lawler 2001; Schuler et al. 2013).

This study was conducted during the monsoon season, when amphibian use of the wetlands for breeding is high. Even though I used calls and direct sightings for amphibians, the presence of weeds (especially in organic fields) and high mobility of amphibians in wetlands could have hindered my amphibian counts. In this study, many taxa (11 out of 16 species of amphibians and 9 out of 16 arthropod orders) were sighted in fewer than 15 locations, indicating that there is high spatial variability in amphibian species and arthropod order distribution in wetlands. Uneven amphibian distribution could indicate that the species that persist in these wetlands are those that have adapted to high human disturbances, and those species that were sighted infrequently could be at risk for future loss from these agricultural wetlands.

According to the latest published checklist, Kerala hosts 151 amphibian species (Das 2015). In addition, recent studies have reported 13 new species from the Western Ghats (Garg & Biju 2016; Garg & Biju 2017; Garg et al. 2017). In a period of three years from 2014 to 2017, 34 new species of amphibians were reported using new tools and technologies (Biju et al. 2014; Garg & Biju 2016; Garg & Biju 2017; Garg et al. 2017). Indeed, numerous species complexes that were previously considered to be a single species were reclassified as multiple distinct species. A complex species is a group of closely related species that shows morphological resemblance but identification to species level needs detailed measurements and molecular analysis. I encountered a considerable number of amphibians in the *Fejervarya* and *Microhyla* genera which were not identified to species level in this study because they require more details for identification. Hence, under this pace of rapid discovery of new species, these species complexes could be classified as multiple species in the future.

Most of the amphibian species found in the wetlands were common and of least concern according to The IUCN Red List of Threatened Species (Version 2017-3) categories, apart from one species listed as vulnerable (assessments are based on 8 to 12-year-old data). Three of the sixteen species are endemic to the Western Ghats while the rest of the species have wide distributions. Amphibian species richness in rice wetlands from my fields appears to be much lower (16 species) than that of nearby natural forest, which has more than 150 species in the reported checklist (Das 2015). However, the goal of this study was not to document the entire amphibian biodiversity in rice wetlands but rather to understand the difference between organic and conventional rice paddy wetlands. The total area of rice wetlands I surveyed is very small compared to the total rice wetlands in the state. These wetlands have the potential to support amphibian and arthropod biodiversity because of their proximity to natural areas, distribution throughout the state and importance of these wetlands for breeding habitat for amphibians (Dodd et al. 1998). Even though species richness in rice wetlands is lower than in forest areas, considering the high number of amphibians and arthropods using these ecosystems and the high degree of endemism in the forests, these wetlands can support and extend the conservation of biodiversity beyond protected areas for some taxa.

This study reported more arthropods from the organic fields in comparison to the conventional but the difference was not statistically significant. Arthropods were only identified to the order level which may explain these results, because the number and type of morpho-species (morphological characters used to classify individuals into orders) that we observed within each order was quite high. The difference in arthropod abundance between organic and conventional pairs was very low indicating that the arthropod abundance could depend on field factors such as crop age, fertilizer or pesticide application date and the landscape surrounding the field. There was high variability in amphibian and arthropod abundance between various locations. There was no significant difference between arthropods in the hedge and center of the fields, which suggests that arthropods were distributed evenly on the hedges and in the center of the fields. Meta-analysis of the effect of organic management on a wide range of crop types and animal taxa showed that on average species richness increased by 30% and abundance increased by 50% in organic fields over conventional fields (Bengtsson et al. 2005; Tuck et al. 2014).

2.4.2 Amphibian and arthropod communities in wetlands

The results suggest that amphibian community assemblages were highly variable, depending on the district location. In general, the difference between organic and conventional species composition of amphibians was lower in Wayanad, which is located primarily in the forested Western Ghats region, than in fields in Palakkad, where the landscape is highly dominated by paddy. This could be because the large-scale paddy cultivation is more intensified hence more amphibians depend on organic fields whereas in a forest dominated landscape the amphibians depend more on the forests. Amphibian communities in Wayanad were different from other districts indicating that these wetlands could be important for conserving amphibians in the nearby forest ecosystem. Arthropod orders were not very distinct between fields, perhaps because orders include a wide variety of predators, prey and herbivores in the same order. More detailed study of individual arthropod species could reveal the differences in the arthropod community composition in the agricultural wetlands.

In this study I observed regional differences in insect abundance and amphibian diversity. The average arthropod abundance was higher in organic and conventional fields in Wayanad. Amphibian abundance was similar in all the districts but the average Simpson diversity and rarefied richness was higher in Palakkad and lower in Wayanad. The fields in Wayanad were smaller but were divided into greater number of fields by hedges hence the percent of hedges in the field was very high which could be one of the reasons for the observed differences in arthropods and amphibians. Increased uncultivated areas within the field can increase biodiversity (Bengtsson et al. 2005; Coda et al. 2015). In my study, arthropod abundance was higher in fields with more uncultivated plants and amphibians were higher in fields with higher amount of water in the fields.

2.4.3 Lower productivity in organic farms

The results from the study support the hypothesis that the overall organic farm productivity is significantly lower than that of conventional farms, by 1.13 tons per hectare on average. The reduced organic yield could be because organic farmers only used plant and animal by-products to meet nutrient requirements and control pests on their farms. My results are in accord with other studies showing that organic management reduces agricultural productivity (Badgley et al. 2007; de Ponti et al. 2012; Gabriel et al. 2013). Meta-analysis suggests that, on average, organic yields are 80% that of conventional yields but the variation is high, depending on the crop type and geographical region (de Ponti et al. 2012).

In developing countries, Badgley et al. (2007), debated that organic productivity could be higher than conventional productivity, perhaps because organic management is incorporated with a wide variety of management practices like agroforestry, water management, and crop rotation. Incorporating leguminous crops in the field could also increase productivity of organic farms (Badgley et al. 2007). Where I sampled, farmers used leguminous crops and vegetables such as peas and *Sesbania bispinosa* (a leguminous plant) but many of the conventional farmers also used similar legumes, which could be why the effect was not visible in this study. The cultivation of leguminous plants was secondary for the farmers, used primarily for household use and was only done occasionally, hence the data were not included in the analysis.

Across diverse agricultural products, cereals and annual vegetables have been shown to have particularly high drops in productivity in organic systems (Tuck et al. 2014). The effect may differ by crop type, however, with Pondi and colleagues (2012) reporting that organic rice performance was higher than other crops like organic wheat. The magnitude of the productivity gap found in my study is highly variable, which along with the variation in biodiversity will be examined with respect to differences in the surrounding landscape context in the next chapter. Since the fields in this study are within the same state and the survey was conducted in the rainy season (June to December), I believe that the variability due to precipitation is of lower magnitude than the variability in landscape context, in driving the productivity gap.

Two-thirds of organic farmers used traditional crop varieties, which have lower productivity in general, yet even organic farmers using hybrid varieties (11 farmers) had reduced yields. Most conventional farmers used hybrid varieties (26 farmers) and very few used local varieties (5 farmers). Crop variety seemed to be a crucial factor driving productivity but as there were few organic farmers using hybrid and few conventional farmers using local crop varieties, the comparisons between them and the conclusions that can be drawn are limited.

The productivity of agricultural systems is very important because of the increasing global demands for higher food production. Since the human population is increasing dramatically, agricultural production needs to increase accordingly, but the effect of agricultural intensification on ecosystems needs to be minimised (Foley et al. 2011). If organic productivity is significantly lower than that of conventional systems, the choice will be between increasing the area cultivated under organic farming or using conventional agriculture on a smaller land base (Foresight, 2011). The results showed productivity differences to be highly variable in distinct locations for rice. The productivity could be increased by providing the optimum management practices and growing conditions (Seufert et al. 2012) and by promoting more uncropped areas like hedges and ponds (Fuller et al. 2005; Norton et al. 2009). Theses uncropped areas may act as refuge sites for a wide range of animal taxa, which could benefit productivity through biological control of the pests in the rice fields. Under the present circumstances in Kerala, there is a large amount of rice wetlands being abandoned due to excessive cost of production and lack of labourers; these areas could be used for meeting the production goals coupled with intercropping and mixed cropping during the non-rice season, which could increase overall productivity.

Reduced productivity of organic farms was found to be different in different agricultural systems, soil characteristics, and other growing conditions (Stanhill 1990; Seufert et al. 2012). Better understanding of the organic effect requires a wider range of studies in different agricultural systems, taxa studied and from tropical and developing countries. Organic farming has been increasing throughout the globe for the past few decades. Kerala is in a developing country with a tropical climate and the landscape is very different, which makes this study unique and adds to our knowledge of the effects of organic agriculture on productivity. In my study the ratio of organic productivity to that of the conventional productivity varied from 0.5 to 1.2. Even though the variability is small the reason for that could be the organic and conventional farms were similar in terms of use of other vegetables in their farm and close to each other.

2.4.4 Biodiversity-productivity trade-off

Agriculture covers a considerable portion of the land globally and is important for humans. Conserving wildlife in these regions is also important because it plays a significant role in ecosystem services such as pest control and pollination. Although intensifying agriculture by using agrochemicals has led to increased productivity, these inputs have reduced abundance and diversity of many groups of wild organisms (Relyea 2005). Hence there is a trade-off between biodiversity conservation and productivity, the latter of which cannot be sacrificed from a farmer's perspective. The effect on biodiversity is always fluctuating (Willig 2011) depending upon the group of organisms studied (Gabriel et al. 2013), the type of agricultural system studied, and the location of the study.

The results from this study support the hypothesis that lower productivity is coupled with greater amphibian biodiversity in organic farming. The decrease in productivity is an overall consequence of organic management (Seufert et al. 2012) and my results also support this. In this study, the results have shown that there is a direct relationship between amphibian abundance and productivity of rice in rice wetlands in Kerala. There was no meaningful relationship between arthropods and productivity, however, which could be because I only identified these to order level.

Rice wetlands are anthropogenically constructed wetlands and hence require agricultural cultivation to maintain the wetland qualities. These wetlands provide various ecosystem services such as flood control, maintenance of the water table, and purification of incoming water from nitrogen and phosphorous (Natuhara 2013). Abandoning rice wetlands causes increased urbanization (because of the land being converted by the farmers to build houses) and eutrophication (Czech and Parsons 2002). Higher rates of secondary succession in these abandoned rice fields could cause habitat loss for many aquatic groups such as frogs, fishes and aquatic arthropods (Natuhara 2013). Rice wetlands under organic management have improved water purification capability (Shibahara 2010). In Kerala there are large areas of paddy fields that are abandoned and used for other agricultural practices. From the perspective of Kerala, there is a need to cultivate these abandoned rice fields to prevents the loss of wetland properties through succession in these areas. Considering the higher biodiversity in organic fields, these areas could act as refuge or shelter compared to conventional farming and help maintain biodiversity particularly in large-scale cropland landscapes. Overall, organic farming results in increased biodiversity and reduced productivity hence, more areas need to be considered for agricultural production to meet the productivity of conventional farming. Land should be shared for biodiversity conservation and for food production since the protected areas would not be enough for biodiversity conservation in the future. Converting the entire cultivation to organic may result in considerable reduction in food production hence the number of organic farms should be less so that the biodiversity in rice wetlands can be conserved with minimum sacrifice to productivity.

2.5 Conclusion

Rice is one of the most widespread crops in the developing world. According to IRRI (2013), 3.5 billion people depend on rice as a staple food and part of their livelihoods. In Kerala, rice wetlands are an important part of the mosaic landscape. My study suggests that rice wetlands support high biodiversity of amphibians and arthropods; the overall biodiversity of amphibians could be increased by organic management in these ecosystems. The increased biodiversity under organic management is coupled with reduced productivity of rice from these fields, which also depends on the crop variety used by the farmers. My study also indicates that there is a direct relationship between reduced productivity and increased amphibian diversity and abundance.

Organic rice wetlands could be one of the conservation measures for biodiversity considering the global spread of rice wetlands from highly human disturbed areas to areas near natural forests in many of the developing parts of the world like Kerala. Rice wetlands in Kerala and in many parts of the world are disappearing due to inflated cost of production and housing developments. The results suggest that promoting organic farms in the area could increase the biodiversity of that area. I suggest that using agricultural land for conservation of biodiversity is essential because increasing human population could exert more pressure on biodiversity and the existing protected areas would not be enough for preventing future biodiversity loss. Thus, organic farming, or wildlife friendly farming, could be a key tool for sharing land for food production and biodiversity conservation.

Chapter 3. Forests Surrounding Rice Paddies Support Biodiversity and Agricultural Productivity

3.1. Introduction

Agricultural ecosystems are not isolated systems, but are embedded in larger landscapes that mediate many functions and processes (Burkhard et al. 2009). Landscape context includes the amount and spatial arrangement of habitat patches in the landscape, and can affect the regional population size and distribution of many species and taxa (Holland et al. 2004; Jackson & Fahrig 2014). Greater habitat within close vicinity enables better dispersal and survival for arthropods, birds and mammals in agricultural landscapes (Benton et al. 2003). Particularly in human-dominated landscapes, higher heterogeneity of habitats can support biodiversity by distributing the favourable habitat throughout the landscape (Tscharntke et al. 2002). For example, landscapes with more forest patches and field margins have been shown to have improved biological control (Östman et al. 2001). Thus, landscape heterogeneity can increase biodiversity in agroecosystems, which can in turn better support ecosystem services such as carbon storage, pollination, pest control and increased biomass, thereby increasing agricultural productivity (Burkhard et al. 2009; Gamfeldt, et al. 2013; Franceschinelli et al. 2017).

The effect of landscape context is particularly acute in agricultural landscapes. Agricultural extensification affects landscape context by potentially clearing larger areas, while agricultural intensification results in broad-scale monocultures, reducing heterogeneity in farms. Biodiversity can be greater in more heterogeneous agricultural landscapes than in simpler landscapes (Roschewitz et al. 2005). Organic management, which reduces or avoids the use of chemicals, reduces agricultural impacts on ecosystems and has shown positive effects on biodiversity. Meta-analysis shows the impacts of organic farming on biodiversity vary by organism group, crop type, and land-use intensity (Tuck et al. 2014). The greatest benefits are seen for predators within the vicinity of cereal crops (Tuck et al. 2014).

The composition and configuration of favourable habitat necessary to conserve biodiversity differ by organismal group. For example, retaining 20% of habitat in agricultural landscapes can increase pollinator populations (Banaszak 1992), while increasing uncultivated areas from 5 to

30% can lead to increases in various groups of arthropods (Kretschmer & Hoffmann 1997). Furthermore, a landscape with numerous smaller habitat patches may be favoured by groups that prefer scattered small patches throughout the landscape, but be insufficient for other organisms that require larger habitat patches (Tscharntke et al. 2005; Tscharntke et al. 2012). Species with relatively smaller body size and less mobility responded to local landscape extent while others such as birds and mammals responded to much larger landscape extent (Bowman et al. 2002; Tscharntke et al. 2005; Jackson & Fahrig 2012). This variation in response is highly correlated with species traits such as dispersal, home range size, and landscape features (Bowman et al. 2002; Holland et al. 2005; Ricci et al. 2013). Therefore, identifying the scale of maximum effect—the extent of the landscape around a focal site at which the relationship between biodiversity and landscape context is highest—is necessary for effective management of biodiversity at the landscape level (Holland et al. 2004; Jackson & Fahrig 2012; Jackson & Fahrig 2015).

In Chapter 2, I showed that organic management could lead to better biodiversity outcomes but usually at the expense of crop productivity. How landscape context mediates this relationship is not well known. There is variability in the rice productivity in organic management compared to conventional management, and it depends on the location and crop type. When organic and conventional farms are identical with respect to all the variables except for management, there was a higher drop in productivity than in systems in which organic and conventional are different in other variables such as crop type and diversity (Seufert et al. 2012). Hence, while there is often a trade-off between biodiversity and agricultural productivity on farms, organic management on the other hand has higher biodiversity and reduced productivity compared to conventional farming. Amphibian richness and abundance in agricultural farms showed a positive relationship with increasing forest cover in the landscape (Collins & Fahrig 2017). Agroforestry systems like homegardens in Kerala may also cause variability in diversity and abundance in nearby agricultural fields since the higher tree species richness in homegardens could increase productivity through ecosystem services such as pest control (Gamfeldt et al. 2013). This variability in biodiversity and productivity needs further investigation to understand the factors responsible for these variations.

Few studies have examined the influence of landscape context of organic farming on biodiversity and productivity in agricultural systems, especially simultaneously. In the previous chapter, I found that organic fields generally had higher amphibian and arthropod diversity, but that these differences were highly variable. To assess how much of this variability can be explained by landscape context, in this chapter, I further evaluate the effect of landscape context (in terms of percent forest cover and spatial arrangement of the forest patches) on biodiversity and agricultural productivity in conventional vs organic farm fields in Kerala, India. My study addresses the following hypotheses:

1. higher biodiversity in organic farming compared to the conventional fields will be lower in forest dominated landscapes
2. the difference in productivity between organic and conventional farms will be lower in forest dominated landscapes
3. greater landscape heterogeneity of forest patches will reduce biodiversity differences between organic and conventional fields.

3.2. Methods

3.2.1 Study context

Kerala, a state in southern India, has an area of 38,863 km^2 and a population density of 860 people per square kilometer, more than twice the national average (2011 census data from Census of India). The landscape is a mosaic of mixed land uses including forests, paddy rice and other crops, buildings, roads and water. Forest cover in the state is a combination of forests and tree-dominated agroforestry systems called homegardens, which play a vital role in supporting biodiversity (Coyle, 2015). Homegardens in Kerala are ecologically and agriculturally diverse, and include crops such as coconut, arecanut, banana, jackfruit, mango, curry leaves and others (Fox et al. 2017). In contrast, croplands are usually monoculture systems, dominated by rice cultivation but also including vegetables and other crops. Rice is the staple food in Kerala and the most important food crop in the state (Viswanathan 2014). Rice wetlands dominate low-lying areas in the landscape and are considered a type of wetland (Hendrickson 2003) with intensive agriculture making heavy use of pesticides and fertilizers. Due to the increasing population, the landscapes are very dynamic; for instance, many of the croplands are being abandoned and replaced by other land uses like buildings and tree crops (Fox et al. 2017).

Despite this high level of anthropogenic modification, Kerala is characterized by high biodiversity of flora and fauna (5725 endemic species), much of it within the Western Ghats biodiversity hot spot (Kerala Forest and Wildlife Department 2013). The main land cover types in the state are forest (29.1% in 2013; Kerala Forest and Wildlife Department 2013) and cropland (Figure 3.2.1). The state has a tropical climate with monsoon rains (3000 mm annually) from June to December, and annual average temperatures ranging from 20 to 37 degrees Celsius. The state is bordered by the Arabian sea in the west and hilly Western Ghats on the east making the landscape a gradient of altitudes from close to zero in the west to about 2500m in the east.

The study was conducted in four districts in Kerala: Malappuram, Palakkad, Thrissur and Wayanad (Figure 2.2.1). The field locations included in this study are very diverse in composition and configuration of different land covers. Fields in Wayanad (n=6) were at a higher elevation with low population and dominated by homegardens. Fields in Palakkad were either in the Western Ghats region (n=2), a mountainous region with high homegarden dominance in the landscapes surrounding the sampled fields, or in the Palakkad Gap (n=5), a low-lying pass that breaks the Western Ghats mountains, has lower forest cover and is dominated by rice wetlands (Figure 3.2.1). Malappuram and Thrissur are variably dominated by homegardens and rice fields. Out of 31 locations included in the study, about a third were highly forested, primarily in Wayanad (6 fields), Thrissur (2 fields) and Palakkad (2 fields).

3.2.2. Biodiversity & productivity sampling

I sampled amphibians in five 10*10m quadrats and arthropods in four 20m transects in both organic and conventional fields. Paired fields were sampled on the same day. Amphibians were sampled using direct observations and calls; arthropods were sampled by sweep netting (50 sweeps) coupled with direct observations (20m in each transects). I surveyed Odonates separately due to their higher mobility by direct observations while standing in the center of the field. I also collected the average rice productivity in each farm with the help of the farmers (see Chapter 2 for detailed explanation of biodiversity and productivity sampling methods).

I calculated amphibian abundance (total number of individuals), Simpson diversity (using R package vegan) and rarefied species richness (field level) (using the R package vegan) for each field. For arthropods, I calculated total abundance, hedge abundance and center abundance separately for each field. For Odonates, I calculated the total abundance in each field. I calculated productivity of rice as tonnes per hectare from the total rice produced reported by farmers. Biodiversity and productivity data were transformed into natural logarithm of response ratios (organic divided by conventional) as the response variable to capture the variability in the effect of organic farming at each site.

3.2.3. Sentinel 2 image analysis

In order to make a land cover map of the study location satellite imagery was needed. Furthermore, due to the nature of tree canopy and surrounding forests high spatial resolution imagery was needed. The spatial resolution of Sentinel 2 (10m) was useful in distinguishing agricultural croplands from forest cover such as homegardens and forest. Six Sentinel-2 multi-spectral remote sensing images were chosen to cover all the study locations. Selected images were all taken during February 2017 (Appendix 3) to minimise seasonal differences in the images and to represent landscape features as close in time to when field sampling was conducted. I made a composite image in ArcMap for each of the six images separately, by combining 4 bands (red, green, blue and near infra red, each having 10m spatial resolution) and excluding bands with coarse spatial resolution (20m and 60m resolution).

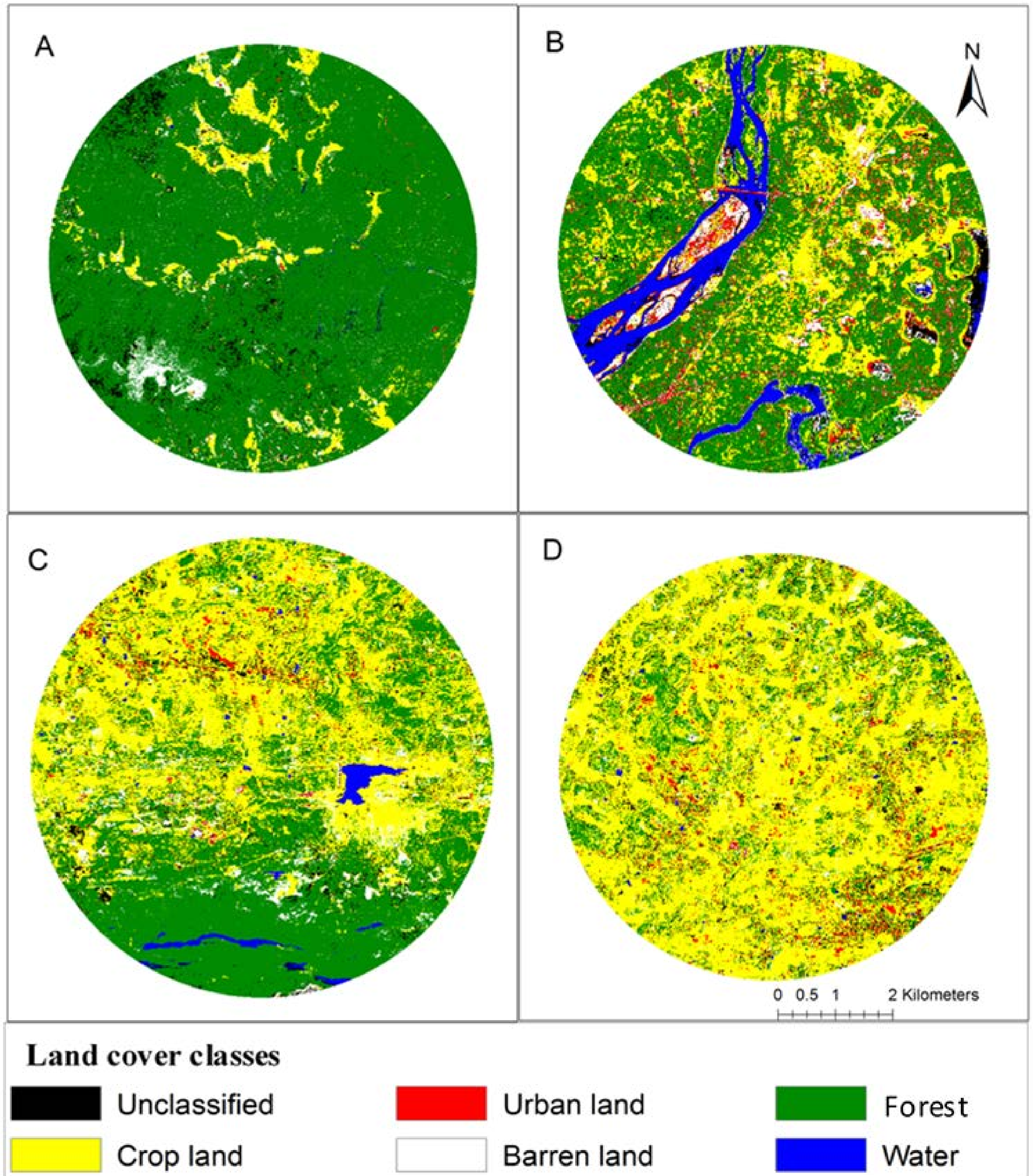

Figure 3.1. Example of a classified image showing the surrounding landscape in a 4 km radius around a field site in A) forest dominated landscape, Wayanad, B) mixed forest and cropland site in Thrissur, C) site with a gradient of forest cover in the Western Ghats, Palakkad and D) crop dominated landscape in Palakkad.

I conducted a pixel-based maximum likelihood supervised classification for each image independently using ENVI (version 5.4, Exelis 2016). The size of individual pixels were 10*10m; hence to include small land cover types such as buildings, roads and ponds, I used individual pixels as training points. Images were classified into five classes using training data composed of > 200 manually-selected individual pixels identified using Google Earth throughout Kerala. Images were classified into: (1) forest areas, which are composed of homegardens, plantations and forests; (2) cropland, areas that have major cultivation such as rice; (3) barren land, areas which have no vegetation with exposed soil; (4) urban land, which includes buildings, roads and other human constructions; (5) water, which includes rivers, lakes, reservoirs, ponds and other water bodies.

An accuracy assessment was conducted using independent validation data for a minimum of 200 pixels for each class. Google Earth was used to manually select locations for validation, independent of the training pixels. The number of pixels used for each land cover class was weighted according to the abundance of each class in the image. For example, more than 3000 training pixels were used for a major land cover class such as forest or paddy, whereas about 300 to 700 pixels were used for training buildings and barren land. I created confusion matrices using ENVI and reported the overall accuracy and Kappa coefficient for each image (Appendix 4).

3.2.4. Quantifying landscape context: composition and configuration of forest cover

In order to characterize landscape context surrounding fields, I used the classified imagery to quantify the amount and arrangement of the forest cover class. I only examined composition and configuration for this one class because forest cover was assumed to be the most important for influencing biodiversity; moreover, there was a high degree of correlation among proportions of different land covers in the landscape. To quantify landscape context, I used Fragstats 4.2 (Mcgarigal & Ene 2013) to extract several landscape metrics for this class within a circular radius surrounding each field. Forest composition was represented as percentage area of forest land cover (PLAND). Forest cover configuration was quantified in three ways: 1. area weighted mean forest patch area (Area_AM); 2. interspersion-juxtaposition index (IJI), which measures how intermingled the forest land cover is with other land covers, (i.e., the higher the interspersion, the greater the intermixing of patches with other land covers); and 3. clumpiness index (CLUMPY), which measures how clumped the forest land cover patches are in the landscape (where values closer to 1 mean the forest patches are more clumped towards each other and values closer to -1 indicates that the forest patches are far away from each other).

Because I was also interested in examining the impact of landscape context over differing spatial extents, I demarcated five concentric radii (of 250, 500, 1000, 1500 and 2000m radius) around each sampled field using ArcMap (Figure 3.2.2). I calculated each of the measures of composition and configuration for these five radial extents.

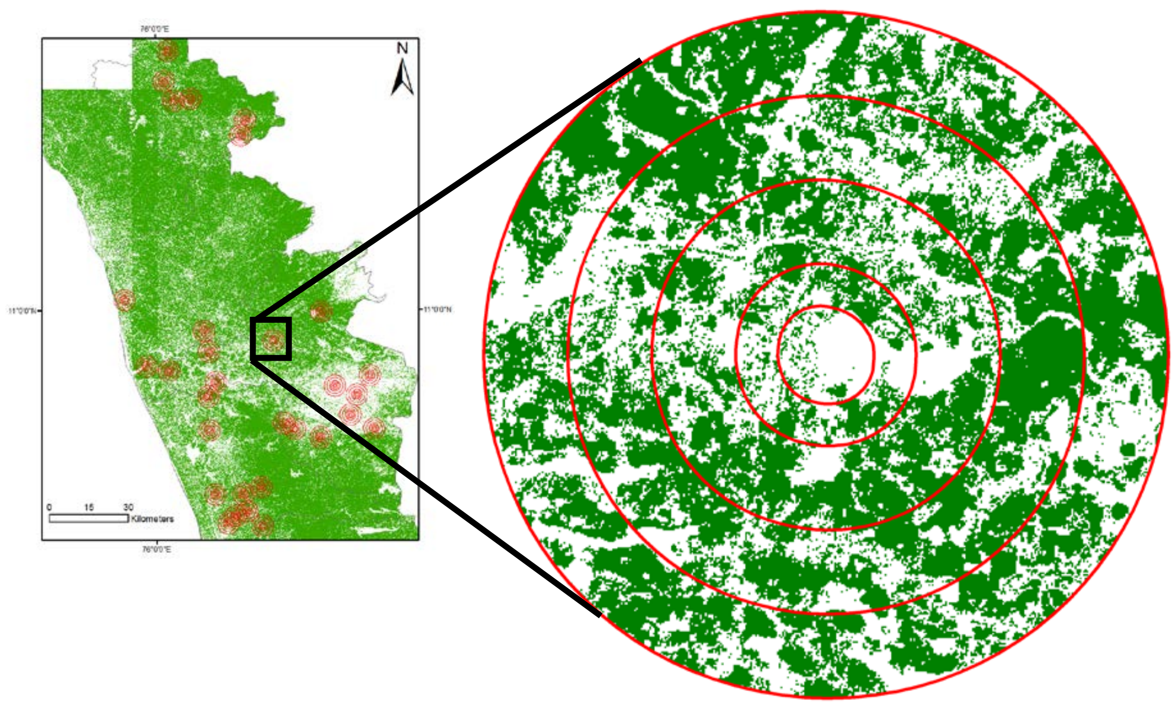

Figure 3.2 Forest land cover (green) throughout the state of Kerala (left) and enlarged portion of the site showing the radii used in analysis: 250, 500, 1000, 1500 and 2000 (from the inside)

3.2.5. Statistical analysis

3.2.5.1. Effective radius

The effect of landscape context can vary with the size of the radius surrounding the sampling point, hence it is important to determine the radius size with the maximum effect, also called the *effective* radius (Jackson & Fahrig 2015; Miguet et al. 2016). I identified the effective radius size using linear regression to predict the abundance of arthropods and amphibians (separately) as a function of percent forest cover at each radius. I used the slope of the curve, the p-value and R^2 values to select the effective radius in each scenario (Appendix 5). I used the package ggplot2 (Wickham 2009) graphics to create the graph of the effective radii.

3.2.5.2. Landscape level effect of organic farming

To test my first hypothesis, that biodiversity increases with percent forest cover and interspersion juxtaposition index, I used simple linear regression with biodiversity and productivity as response variables as explained by: percent forest cover (landscape composition) and interspersion juxtaposition index (landscape configuration) at their effective radii sizes. I conducted the analysis for organic and conventional separately.

To test my second hypothesis, that the added benefit of organic farming is lower as percent forest increases, I used a Linear Model approach. The response variable was the natural log of the ratio of organic-conventional for all amphibian and arthropod diversity measures. The explanatory variables were landscape composition (PLAND) and configuration (IJI, CLUMPY and AREA_AM).

I also tested whether percent forests in the landscape improved productivity of the organic farms. I used a Linear Model with organic-conventional productivity ratios as the response variable and PLAND, IJI and CLUMPY as explanatory variables. Models were fit using backward/forward model selection based on the AIC values in R studio.

3.3. Results

3.3.1. Effective radius

For amphibians, I identified 500m as the effective radius (p-value = 0.03) based on the p-value and the slope of the curve. Amphibian abundance was negatively correlated with percent forest cover for all radii (Figure 3.3.1). The slope consistently increased from 2000m until 500m and then decreased at 250m. There was a significant correlation between amphibian abundance and percent forest cover at the 250m radius (p-value = 0.032) but the slope was lower, and the p-value was higher than at the 500m radius. Hence, I chose the 500m radius to examine the effect of landscape on the effect of organic farming in further analysis.

The abundance of arthropods and Odonates was negatively correlated with percent forests in all radii, but none were statistically significant. There was no effective radius showing convergence in slope, hence the landscape effect on organic farming for arthropods and Odonates was not included in the study.

Productivity showed a strong, statistically significant, positive slope for every radius size analysed. I selected 1000m as the effective radius size for productivity based on the higher slope and the lowest p-value (0.0006). Thus, all subsequent analysis of the effect of landscape context on productivity used an effective radius of 1000m.

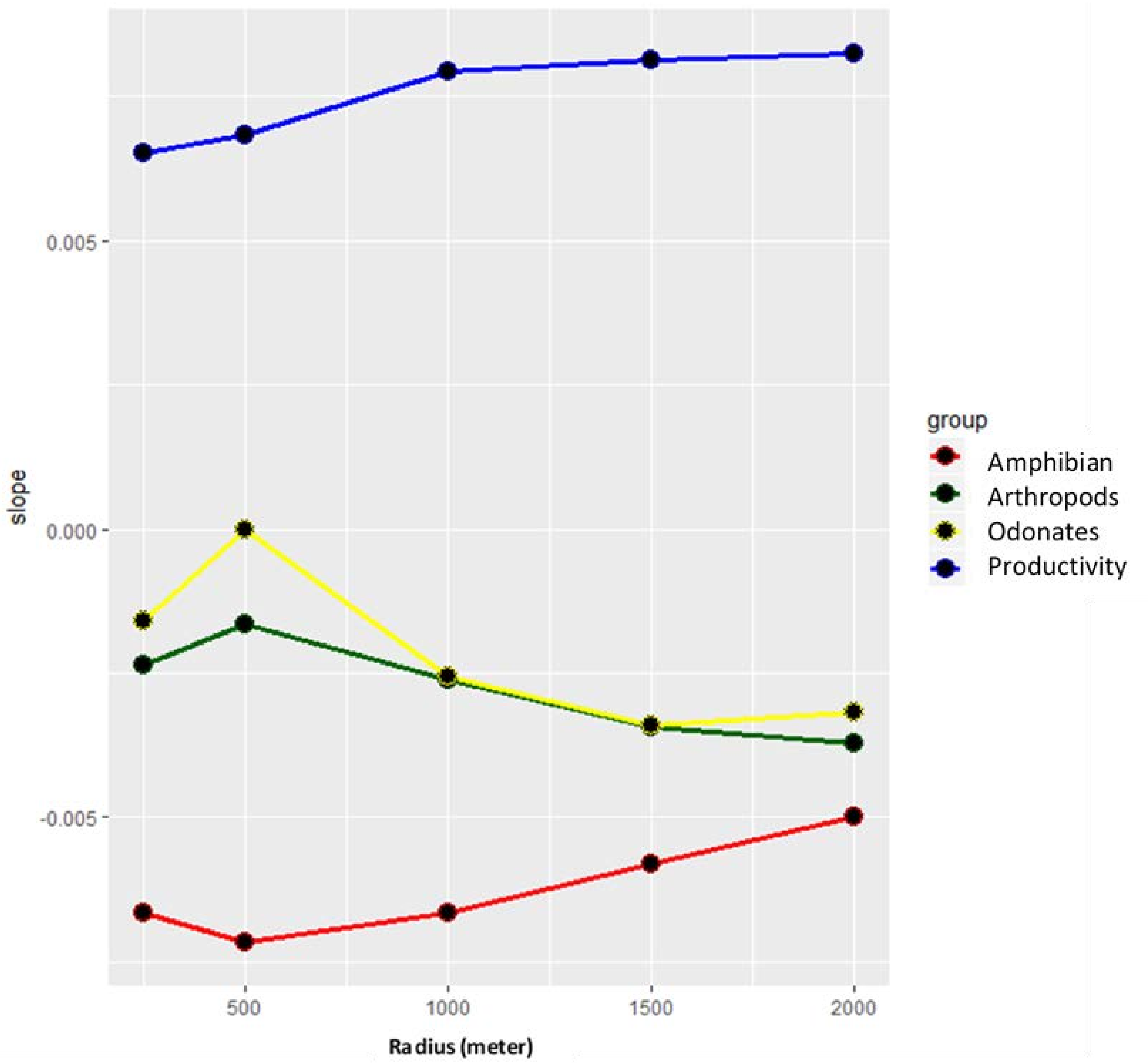

Figure 3.3 Slope of the relationship between amphibians, arthropods, Odonates and productivity vs percent forest cover in different radii

3.3.2. Effect of landscape on overall biodiversity and productivity

Overall variation in amphibian abundance (organic and conventional) was not correlated with landscape composition (p = 0.89) or configuration (p = 0.12) in the 500m surrounding landscape (Figure 3.3.2). Amphibian abundance in organic fields did not change significantly (p = 0.34) with percent forest cover but there was a significant increase in amphibian abundance in conventional fields (p = 0.05) as percent forest cover increased. There was no correlation between interspersion juxtaposition index and amphibian abundance in organic ($p = 0.84$) or conventional fields ($p = 0.34$).

Overall variation in rice productivity was not correlated with landscape composition ($p = 0.77$) or configuration ($p = 0.41$) in the 1000m surrounding landscape. Productivity of rice in conventional farms was not correlated with either percent forest cover ($p = 0.31$) or the interspersion juxtaposition index ($p = 0.99$). But there was perhaps an increase in the productivity of rice in organic farms as percent forest cover ($p = 0.08$) increased but not with interspersion juxtaposition index ($p = 0.12$). Overall, organic and conventional productivity did not respond to the changes in the surrounding landscape.

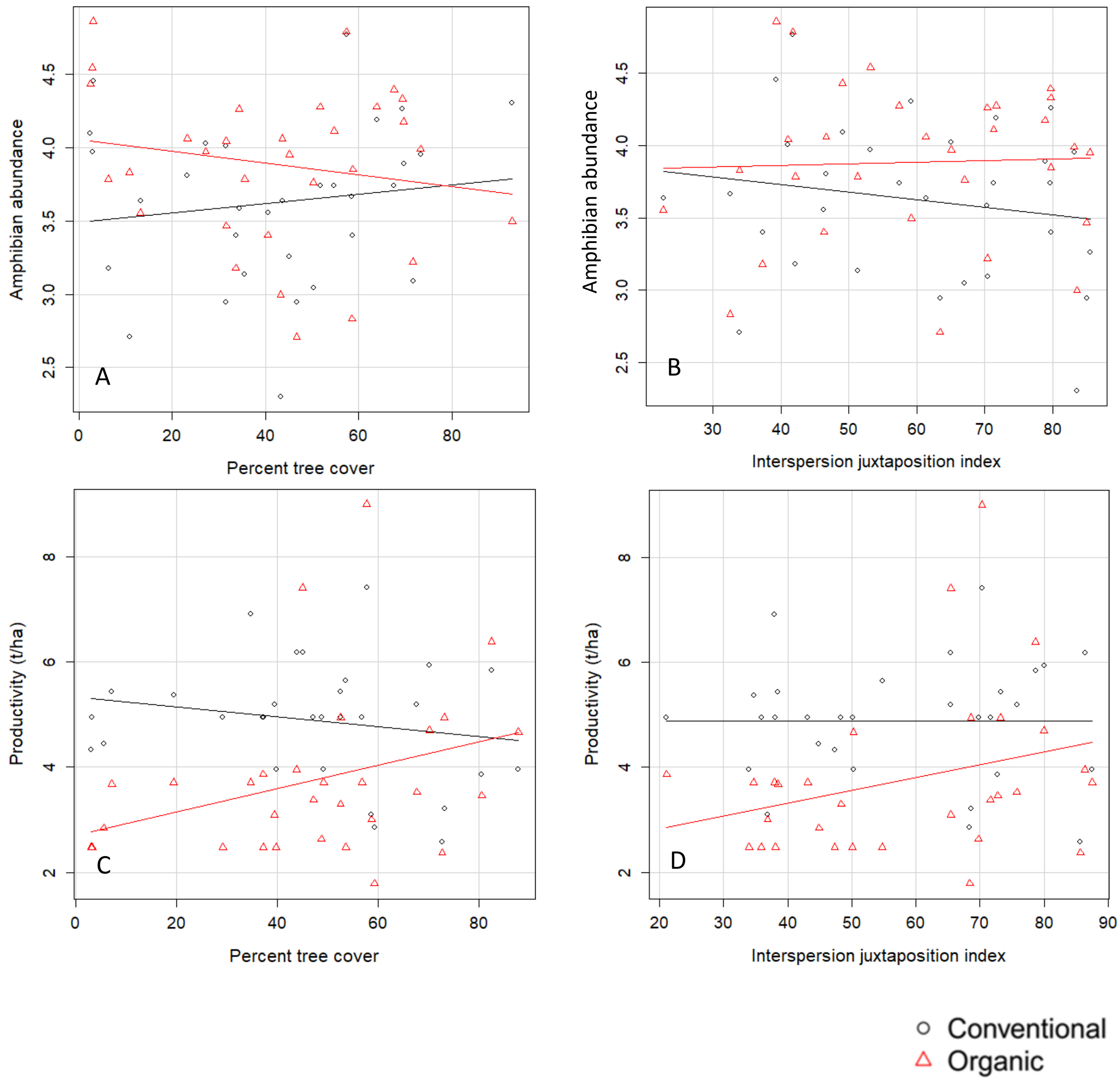

Figure 3.4 Biodiversity (A, B) at 500m radius and productivity (C, D), 1000m radius patterns vs. landscape configuration and composition. Axes are as follows: Left column - percent forest cover; Right column - interspersion juxtaposition index. Organic farms shown in (red) and conventional (black). The p values are A (organic, p = 0.34; conventional p = 0.05), B (organic, p = 0.84; conventional p = 0.34), C (organic, p = 0.08; conventional p = 0.31), D (organic, p = 0.12; conventional p = 0.99)

3.3.3. More forest patches reduce the difference in biodiversity and productivity between organic and conventional fields

The organic-conventional ratio for amphibian abundance (i.e, the ratio of amphibian abundance in the organic field to the amphibian abundance in its paired conventional field) was inversely correlated with percent forest in the surrounding landscape (p=0.03, Figure 3.3.3). The organic-conventional ratio was not related to interspersion ($p=0.15$). Percent forest cover and interspersion (IJI) were the two variables selected in the model but since the two were correlated ($r= 0.55$) I tested each variable separately. The organic-conventional ratio for amphibian diversity was not related to percent forest ($p=0.82$) yet increased with increasing interspersion ($p = 0.049$). The organic-conventional ratio for amphibian rarefied species richness did not show a meaningful relationship to any of the landscape variables.

Productivity differences between organic and conventional fields were related to landscape context. The organic-conventional ratio for rice yields increased with greater percent forest in both 500m ($p = 0.006$) and 1000m ($p=0.0006$) radii (Figure 3.3.3). The organic-conventional productivity ratio also increased as IJI increased with borderline significance ($p=0.052$). CLUMPY and area weighted mean forest patch area were not significant for organic-conventional ratios for either biodiversity or productivity in any of the models.

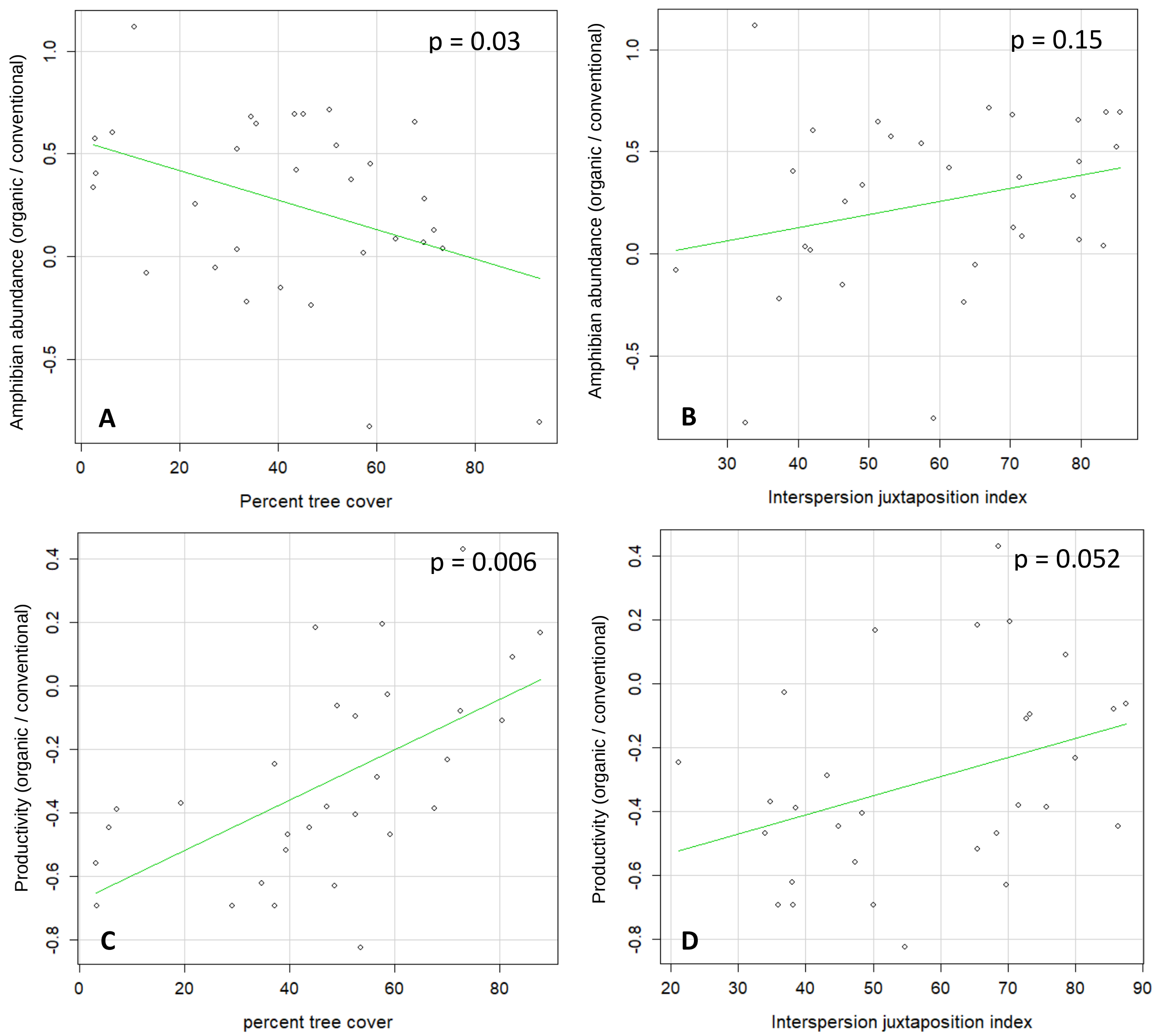

Figure 3.5 Biodiversity ratio (organic / conventional) (A, B) at 500m radius and productivity ratio (organic / conventional) (C, D), 1000m radius patterns vs. landscape configuration and composition. Axes are as follows: Left column - percent forest cover; Right column - interspersion juxtaposition index.

3.4. Discussion

3.4.1. Landscape context should not be ignored

Agricultural ecosystems are not isolated from their surrounding ecosystems, but interact with each other through exchanges in biodiversity, water and nutrients. Rice paddy wetlands also receive hydrologic inputs from the surrounding landscape, and biodiversity in nearby ecosystems benefit from linkages with these wetlands. To better understand the relationship between ecosystems and their surrounding landscape, the extent of the landscape at which the biodiversity or productivity is maximum needs to be identified (Ricci et al. 2013). Hence, ecosystem studies should not ignore the surrounding landscape context of focal sites and should also examine multiple radii to identify the effective scale of such impacts (Jackson and Fahrig 2015). When explaining the effect, the radius at which the effect is at a maximum should be identified so that it will result in better interpretation and understanding of the effect and for future management decisions at landscape level.

While it is strongly recommended that the effective radii included in a study are meaningful with respect to ecological factors such as dispersal distance, home range, body size and other indirect factors that could predict the extent of landscape, these factors are not frequently tested (Jackson & Fahrig 2015; Miguet et al. 2016). Jackson & Fahrig (2015) showed that the average of the effective radii for amphibians and arthropods was about 500m, and the range of scales analysed in different studies are very broad. In this study, I included five different radii of landscape context surrounding the focal site, ranging from 250m to 2000m to identify the effective radius. My results also indicate that amphibian abundance were most significant at 500m which suggest that including a narrow range of radii without biological reasons could result in not finding a biodiversity-landscape relationship. The effective radius is determined by the surrounding landscape characteristic and could be species specific, hence multiple scales should be studied (Holland et al. 2004; Jackson & Fahrig 2015).

My results suggest that amphibians in organic rice wetlands in Kerala are most affected by surrounding forests within 500m of the field, similar to an extensive meta-analysis which also showed that mean amphibian abundance is responsive to landscape structure within 500m (Jackson & Fahrig 2015). This could be because forest within 500m would be the accessible habitat for species dispersal for amphibians in rice wetlands in Kerala. Hence, there is ample evidence that amphibian wetlands conservation in Kerala should emphasize landscape level protection and management at this spatial extent in particular. In contrast, variation in arthropods and Odonates did not show any correlations with landscape contextual features. The diversity of morpho-species identified from my study was very large suggesting that there could be variation in the arthropod abundance and richness at the species level requiring more detailed study.

The productivity ratio between organic and conventional farms showed highly significant responses with forests in the surrounding landscape over all the radii examined. This broad level of significance implies a synergistic “win-win” whereby landscape-level management for a wide range of taxa could potentially improve agricultural productivity within fields. Higher productivity through biological pest control in organic fields could be the reason for reduced productivity difference between organic and conventional fields in forested landscapes compared to less forested landscapes. Landscape context is specific to the organismal group studied, so, these results could vary even for the same forest cover scenario with respect to different taxa and agricultural systems. The variation in organic and conventional productivity in response to the landscape context is little studied but is worthy of more research as the low productivity of organic farming is a major concern limiting its adoption in many areas.

3.4.2. Overall biodiversity and productivity unaffected by landscape

In general, amphibian abundance in organic and conventional fields was not affected by landscape context, either in regards to percent or interspersion of forest cover in the landscape. High variability in the surrounding landscape context could be the reason for no overall variation in amphibian abundance between organic and conventional. If there is high variability in surrounding landscape context, the overall effect due to management could be trivial (Bengtsson et al. 2005). There was high variability in amphibian abundance, which could be related to other field-level variables such as the amount of water, crop age, and microhabitats.

My results indicate that the overall amphibian abundance in organic fields was not enhanced by landscape context, yet in conventional fields amphibian abundance increased with higher forest cover. That is, conventional fields with less forest in the surrounding landscape had lower amphibian abundance compared to the conventional fields with more forest in the landscape. This suggests more forest cover in the landscape surrounding rice wetlands could mitigate negative effects of agricultural intensification on biodiversity.

Rice yields in conventional farms showed no changes with landscape context yet organic yields increased with percent forest in the landscape. This could be because conventional productivity is mainly backed by heavy agrochemicals whereas significantly lower productivity of organic fields benefits more from nearby ecosystem services such as pest control and nutrient exchange. Altogether, my study indicates that rice wetland biodiversity and productivity are not significantly affected by the surrounding landscape context. But there is variability in amphibian abundance and yield of rice between different locations.

I observed a correlation between landscape variables included in the study. Percent of forests in the landscape was correlated with the interspersion. All variables included in the study are correlated to varying extents. Landscape composition and configuration are not independent especially when the lower and upper limit of composition is very wide. In my study, I believe that landscape context could be correlated to other features in the field such as the soil characteristics, weed abundance and diversity, microclimate and other growing conditions. For example, I observed that in Wayanad, the fields had higher forest cover in the surrounding landscape also had higher weed abundance.

3.4.3. Biodiversity-productivity trade-offs can be reduced by consideration of landscape context

My results show that the organic-conventional ratio for amphibian abundance was inversely correlated with forest cover. This indicates that the percentage of forest cover in the landscape reduces the difference in amphibian biodiversity between organic and conventional rice wetlands in Kerala. Forest in agricultural landscapes is known to facilitate mobility between different habitat types during seasonal migration of amphibians (Fahrig et al. 2011; Nowakowski et al. 2013). My results also indicate that conventional amphibian abundance is positively correlated to percent of forest in the landscape, which suggests that forest in the surrounding landscape improves quality of habitat for amphibians in conventional fields. But this increase in amphibian abundance is not significant in organic fields. The result is consistent with other studies that show forest in the surrounding landscape increase amphibians in agricultural ecosystems (Guerry & Hunter 2002; Porej et al. 2004; Collins & Fahrig 2017).

The amphibian diversity ratio was positively correlated with the interspersion-juxtaposition index. That is, when the forest patches are more intermixed, the organic and conventional farms have more difference in amphibian diversity than when the patches are less intermixed. The variability in landscape configuration need to be better understood because higher intermixing of natural areas increases landscape heterogeneity. Higher landscape heterogeneity enhances faunal diversity (Fahrig at al 2011). In this study, the variability due to percentage of forest in the landscape is very high which could be the reason that interspersion is not significant. Hence, it is suggested that studies on the effect of landscape configuration should control for the variability in landscape composition. I used percent of forest in the landscape to identify the effective radius, which may mean that the effect due to interspersion could be better explained using a different radius to determine landscape context.

My work showed no relationship between biodiversity or productivity ratios and the area weighted mean size of the patches or clumpiness of forest cover. Organic fields with higher forest cover showed higher productivity while the biodiversity increase was not as high in fields with lower forest cover. This could be because the forest in the surrounding landscape increases pest control in the farms. The surrounding forests could also improve the soil properties through exchange of nutrients and other growing factors.

The variation between organic and conventional biodiversity and productivity was not significant when average organic outcomes was compared to average conventional outcomes. But when the organic fields are compared with their paired conventional fields, the effect was significant for both amphibian abundance and productivity. This indicates that the difference between organic and conventional fields need to be compared in pairs (i.e. organic conventional ratios) to better understand the difference in biodiversity and productivity. That is, the trade-off between biodiversity and productivity can be reduced by managing the surrounding landscape context for more forest cover and more intermixing of forests which can act as refuge sites for a wide range of taxa. The results are in agreement with others who also found that increasing uncultivated areas in the landscape will increase biodiversity (Bengtsson et al. 2005). The influence of the surrounding landscape could go unnoticed if landscape configuration and composition are not considered when examining biodiversity or productivity gaps between organic and conventional fields.

The results may differ for different systems, organismal groups, and regions. Hence, there is a need to better understand the variability in the trade-off between biodiversity and productivity from a landscape perspective. Biodiversity of organic fields in forest dominated landscapes will be more similar to that of the conventional field in the same landscape and vice versa. Crop diversification is also found to reduce trade-offs between biodiversity and productivity in agricultural fields (Iverson et al. 2014). The fields in my study are paddy fields and the surrounding forest cover in the landscape is homegardens in Kerala, which are forest dominated agroecosystems rich in biodiversity (Coyle 2015).

3.5. Conclusion

My results support the need to include multiple scales with biological justifications to identify the biodiversity-landscape relationship. The scale at which the relationship is best explained will depend on the taxa and landscape context. My study suggests that we need a better understanding of the effect of organic farming, in particular to understand the factors driving variability in biodiversity abundance and productivity of agricultural crops. Through this study, I suggest that it is not only about how the fields are managed and what crops and biodiversity are studied, but also where the fields are located—the surrounding landscape of the fields also matters. Comparisons between organic and conventional systems need to be done in pairs rather than comparing overall differences. Land-use policies should consider including management of the surrounding landscape before making decisions.

Chapter 4. Conclusion and Future Research

Though the practice of rice cultivation began about 10,000 years ago, it is still one of the most important economic activities in the world, with more than 1000 varieties world-wide (Maclean et al. 2013). About 3.5 billion people depend on rice as a major food source, the majority of which are from the low and middle-income countries. India and China are the major rice producing countries in the world (Maclean et al. 2013). Rice paddy wetlands are a central part of the Kerala landscape, and are important in providing benefits to people both economically and ecologically. Rice cultivating areas are manmade wetlands undergoing intense agricultural activities; abandoning or converting these areas may result in the loss of wetland ecosystem services. In this thesis, I used quantitative methods to compare biodiversity and productivity of organic and conventional rice wetlands in Kerala. I also examined the variability in the biodiversity and productivity between organic and conventional fields in various locations and I studied how much of this variability is explained by landscape variables such as the amount and arrangement of forests in the landscape.

4.1. The scale of land sharing vs land sparing matters

In chapter 2, I addressed two main questions. First, does organic farming increase biodiversity of amphibians and arthropods in rice wetlands in Kerala? My results agreed with the general consensus about the effect of organic farming: that the biodiversity in organic fields is greater than conventional fields. Secondly, does organic farming reduce rice productivity? I found that organic productivity is significantly lower than conventional. Hence, future management decisions in conserving biodiversity in rice paddy wetlands need to consider the trade-off between biodiversity and productivity. That is, management decisions should address the question of whether we should prioritize feeding ourselves or reduce the trade-off to retain some biodiversity in these areas.

Under the current situation the ever-increasing human population will continue to cause more and more threats to biodiversity in the future. Under the land sparing scenario, the chance of a mass reduction of species in agricultural landscapes will be higher. Because agricultural systems are not isolated systems, high intensity agriculture can impact nearby ecosystems, eventually leading to problems in human wellbeing. Also, land sparing could make the agricultural ecosystems inhospitable for biodiversity increasing the stress on spared areas for biodiversity. On the other hand, land sharing may also not be completely acceptable because under less intensive management, crop productivity will be reduced and to meet productivity goals more areas will have to be cleared. Even though biodiversity-friendly management enhances biodiversity compared to conventional farming, there will be a problem for higher trophic level organisms. The reduced biodiversity may not be entirely compensated by organic management since biodiversity of the organic agriculture is lower and different than in natural areas (Phalan et al. 2011b).

Hence, rather than thinking only about land sharing vs land sparing, the discussion should further think about the scale at which these approaches should be adopted in each ecosystem. Biodiversity cannot be completely sacrificed even in an agricultural ecosystem because essential ecosystem functions need to be maintained. Hence, instead of maximising the yield, the optimum yield and biodiversity should be the goal of intensification. This could be achieved through promoting organic farming at varying scales in the landscape to avoid a complete vanishing of farmland biodiversity. Land sharing should be implemented proportionally to land sparing in a landscape scale, such that, there should be more favourable habitat and organic farms in the landscape to serve as refuge sites for biodiversity; the reduced productivity could be compensated through intensive agriculture in the same landscape.

4.2. Biodiversity in organic farms should be managed at a landscape level

Agricultural systems are embedded in larger landscapes and the organic farming effect thus needs to be generalised from a landscape perspective. In Chapter 3, I further studied the variability in biodiversity and productivity between organic and conventional fields with respect to the changes in forest cover and arrangement in the landscape. The results suggest that with higher amounts of forest in the landscape, average amphibian abundance of organic fields didn’t change noticeably but that of the conventional fields slightly increased. On the other hand, the change in the average productivity was not significant in conventional and organic farms. The variation in the overall biodiversity and productivity was not significant in the initial result, which could be because of the high variability in the surrounding landscape context.

Further results indicate that the response ratio (organic divided by conventional) for biodiversity decreased as the percent of forests in the landscape increased but the productivity ratio increased. This indicates that organic farming productivity and conventional biodiversity could be sensitive to configuration and compositional changes in the forest cover of the landscape. The productivity and biodiversity of agricultural ecosystems depends on the landscape context of the surrounding. Landscapes with more forest will have reduced trade-offs between biodiversity and productivity in agricultural fields. More uncultivated areas in the landscape can improve biodiversity dispersal and reduce the impact of agriculture on ecosystems. Land-use policies in Kerala need to focus on landscape level management of rice wetlands. The number of abandoned paddies should be reduced and better management should be practiced in paddy-dominated landscapes.

4.3. Future research

There remain significant gaps in our knowledge of trade-offs between biodiversity and productivity. Studies portray biodiversity and productivity as inversely related in agricultural ecosystems due to intensification while the opposite is true in natural ecosystems. Despite looking at biodiversity and productivity explicitly, very few studies explain the dynamics of both simultaneously. Understanding more about the characteristics of the variability in biodiversity and productivity in organic management could result in better management of agricultural ecosystems. There is a need for more studies at the landscape scale rather than field or farm scale. There is also a need for more studies that include the surrounding landscape context as a continuous variable rather than categorising them as simple or complex, homogeneous or heterogeneous.

Rice wetlands are very complex ecosystems particularly in Kerala, where the productivity is sensitive to the availability of rain water and other weather parameters. The yield of rice is also very low taking into consideration the intensive labour and other agricultural activities. Due to these reasons farmers often use their rice fields for other agricultural crops or leave them uncultivated. Hence, there are many field level factors (e.g., abandoned land, ponds, floral biodiversity of the area) which are not included in this study but may have a strong effect in driving biodiversity and productivity at the local scale. Future research in Kerala should include more studies on the connectivity of rice wetlands and the effect of abandonment and conversion of rice wetlands to other land uses.

References

Alkemade R, Oorschot MV, Miles L, Nellemann C, Bakkenes M, Brink BT, 2009. GLOBIO3: a framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems. 12, 374-390.

Alroy J, 2017. Effects of habitat disturbance on tropical forest biodiversity. Proceedings of the National Academy of Sciences of the United States of America. 114, 6056-6061.

Altieri MA, 1999. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems and Environment. 74, 19-31.

Badgley C, Moghtader J, Quintero E, Zakem E, Chappell MJ, Aviles-Vazquez K, Samulon A, Perfecto I. 2007. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems. 22(2), 86-108.

Bailey D, Schmidt-Entling MH, Eberhart P, Herrmann JD, Hofer G, Kormann U, Herzog F, 2010. Effects of habitat amount and isolation on biodiversity in fragmented traditional orchards. Journal of Applied Ecology. 47, 1003-1013.

Bambaradeniya CNB, Edirisinghe JP, De Silva DN, Gunatilleke CVS, Ranawana KB, Wijekoon S, 2004. Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. Biodiversity & Conservation. 13, 1715-1753.

Banaszak J, 1992. Strategy for conservation of wild bees in an agricultural landscape. Biotic Diversity in Agroecosystems. 40, 179-192.

Barbier EB, Acreman M, Knowler D, 1997. Economic valuation of wetlands: a guide for policy makers and planners. Gland: Ramsar Convention Bureau.

Batáry P, Báldi A, Kleijn D, Tscharntke T, 2010. Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proceedings of the Royal Society of London B: Biological Sciences. 278, 1894-1902.

Bengtsson J, Ahnström J, Weibul A, 2005. The Effects of Organic Agriculture on Biodiversity and Abundance: A Meta-Analysis. Journal of Applied Ecology. 42, 261-269.

Benton TG, Vickery JA, Wilson JD, 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology & Evolution. 18(4), 182-188.

Biju S, Garg S, Gururaja K, Shouche Y, Walujkar SA, 2014. DNA barcoding reveals unprecedented diversity in Dancing Frogs of India (Micrixalidae, Micrixalus): a taxonomic revision with description of 14 new species. Ceylon J. Sci. (Biol. Sci.). 43(1), 37-123.

Bowman J, Jaeger JA, Fahrig L, 2002. Dispersal distance of mammals is proportional to home range size. Ecology. 83(7), 2049-55.

Bridgeland WT, Beier P, Kolb T, Whitham TG, 2010. A conditional trophic cascade: birds benefit faster growing trees with strong links between predators and plants. Ecology. 91, 73-84.

Brogi A, Pernollet CA, Gauthier-Clerc M, Guillemain M, 2015. Waterfowl foraging in winter-flooded ricefields: Any agronomic benefits for farmers? Ambio. 44, 793-802.

Bruhl CA, Schmidt T, Pieper S, Alscher A, 2013. Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline? Scientific Reports. 3, 1135.

Burkhard B, Kroll F, Müller F, Windhorst W, 2009. Landscapes' Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. Landscape Online. 15, 1-22.

Butchart SHM, Walpole M, Collen B, Strien AV, Jörn PW, Scharlemann, Rosamunde EA, Almond, Jonathan EM, Baillie, Bomhard B, Brown C, Bruno J, Carpenter KE, Carr GM, Chanson J, Chenery AM, Csirke J, Davidson N, Dentener F, Foster M, Galli A, Galloway JN, Genovesi P, Gregory RD, Hockings M, Kapos V, Lamarque J, Leverington F, Loh J, McGeoch MA, McRae L, Minasyan A, Morcillo MH, Oldfield TEE, Pauly D, Quader S, Revenga C, Sauer JR, Skolnik B, Spear D, Stanwell-Smith D, Stuart SN, Symes A, Tierney M, Tyrrell TD, Vié J, Watson R, 2010. Global Biodiversity: Indicators of Recent Declines. Science. 328, 1164-1168.

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S, 2012. Biodiversity loss and its impact on humanity. Nature. 486, 59.

Chapin III FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC, Díaz S, 2000. Consequences of changing biodiversity. Nature. 405, 234-242.

Coda J, Gomez D, Steinmann A, Priotto J, 2015. Small mammals in farmlands of Argentina: Responses to organic and conventional farming. Agriculture Ecosystems & Environment. 211, 17-23.

Collins SJ, Fahrig L, 2017. Responses of anurans to composition and configuration of agricultural landscapes. Agriculture Ecosystems & Environment. 239, 399-409.

Cooke AS, Arnold HR, 2003. Night counting, netting-and population dynamics of Crested Newts (Triturus cristatus). Herpetological Bulletin. 5, 5.

Coyle T, 2015. Conserving god's own country: biodiversity in agroforestry landscapes of Kerala, India (Masters Thesis, McGill University, Montreal, Quebec).

Czech HA, Parsons KC, 2002. Agricultural wetlands and waterbirds: a review. Waterbirds. 25, 56-65.

Daniels RJR, Indian Academy of Sciences, 2005. Amphibians of Peninsular India. Universities Press (India). Hyderabad.

Das S, 2015. A checklist of amphibians of Kerala, India. Journal of Threatened Taxa. 7, 8023-8035.

De Ponti T, Rijk B, van Ittersum MK, 2012. The crop yield gap between organic and conventional agriculture. Agricultural Systems. 108, 1-9.

Dodd CK, Cade BS, Jr, 1998. Movement Patterns and the Conservation of Amphibians Breeding in Small, Temporary Wetlands. Conservation Biology. 12, 331-339.

ESRI, 2016. ArcGIS Desktop (version 10.5). Redlands. CA: ESRI.

Evenson RE, Gollin D, 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. Science. 300, 758-762.

Exelis, 2016. ENVI (version 5.4). Microsoft Windows. Boulder, Colorado: Exelis Visual Information Solutions.

Fahrig L, Baudry J, Brotons L, Burel FG, Crist TO, Fuller RJ, Sirami C, Siriwardena GM, Martin J, 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecology Letters. 14, 101-112.

FAO STAT, 2014. Food and Agricultural Organization. http://www.fao.org/faostat/en/#home, Accessed on August 2017.

FAO, 2013: World Food and Agriculture. 2013. FAO Statistical Yearbook. Food and Agriculture Organization of United Nations. Rome.

FAO, 2016: Global Forest Resources Assessment, 2015. How are the world's forests changing? Second edition, Rome, Italy.

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK, 2005. Global Consequences of Land Use. Science. 309, 570-574.

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, Balzer C, Bennett EM, Carpenter SR, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Siebert S, Tilman D, Zaks DPM, 2011. Solutions for a cultivated planet. Nature 478, 337.

Foresight, The future of food and farming. Final project report. The Government Office for Science, London. Published in 2011. pp. 211. Available at http://www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/11-546-future-of-food-and-farming-report.pdf", 2011, Animal Genetic Resources/Ressources génétiques animales/Recursos genéticos animales, 48, 127. Accessed on June 2017

Fox T, 2015. Land-use Dynamics of Kerala's Agroforestry Systems (Masters Thesis, McGill University, Montreal, Quebec).

Fox TA, Rhemtulla JM, Ramankutty N, Lesk C, Coyle T, Kunhamu TK, 2017. Agricultural land-use change in Kerala, India: Perspectives from above and below the canopy. Agriculture, Ecosystems and Environment. 245, 1-10.

Franceschinelli EV, Elias MAS, Bergamini LL, Silva-Neto CM, Sujii ER, 2017. Influence of landscape context on the abundance of native bee pollinators in tomato crops in Central Brazil. Journal of Insect Conservation. 21, 715-726.

Fryday S, Thompson H, 2012. Toxicity of pesticides to aquatic and terrestrial life stages of amphibians and occurrence, habitat use and exposure of amphibian species in agricultural environments. EFSA Supporting Publications 9(9).

Fuller RJ, Norton LR, Feber RE, Johnson PJ, Chamberlain DE, Joys AC, Mathews F, Stuart RC, Townsend MC, Manley WJ, Wolfe MS, Macdonald DW, Firbank LG, 2005. Benefits of organic farming to biodiversity vary among taxa. Biology Letters. 1, 431-434.

Gabriel D, Sait SM, Kunin WE, Benton TG, Steffan-Dewenter I, 2013. Food production vs. biodiversity: comparing organic and conventional agriculture. Journal of Applied Ecology. 50, 355-364.

Gaines SD, Lester SE, Grorud-Colvert K, Costello C, Pollnac R, 2010. Evolving science of marine reserves: New developments and emerging research frontiers. Proceedings of the National Academy of Sciences of the United States of America. 107, 18251-18255.

Gamez-Virues S, Perovic D, Gossner M, Borsching C, Bluthgen, N, de Jong H, Simons NK, Klein A, Krauss J, Maier G, Scherber C, Steckel J, Rothenwohrer C, Steffan-Dewenter I, Weiner C, Weisser W, Werner M, Tscharntke T, Westphal C, 2015. Landscape simplification filters species traits and drives biotic homogenization. Nature Communications. 6, 8568.

Gamfeldt L, Snäll T, Bagchi R, Jonsson M, Gustafsson L, Kjellander P, Ruiz-Jaen MC, Fröberg M, Stendahl J, Philipson CD, Mikusiński G, Andersson E, Westerlund B, Andrén H, Moberg F, Moen J, Bengtsson J, 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. Nature Communications. 4, 1340.

Garg S, Biju SD, 2016. Molecular and Morphological Study of Leaping Frogs (Anura, Ranixalidae) with Description of Two New Species. PLoS One. 11, e0166326.

Garg S, Biju SD, 2017. Description of four new species of Burrowing Frogs in the Fejervarya rufescens complex (Dicroglossidae) with notes on morphological affinities of Fejervarya species in the Western Ghats. Zootaxa. 4277, 451-490.

Garg S, Suyesh R, Sukesan S, Biju SD, 2017. Seven new species of Night Frogs (Anura, Nyctibatrachidae) from the Western Ghats Biodiversity Hotspot of India, with remarkably high diversity of diminutive forms. PeerJ. 5, 3007.

Gerstner K, 2017. The global distribution of plant species richness in a human-dominated world. Frontiers of Biogeography. 9 (1).

Gibbs HK, Ruesch AS, Achard F, Clayton MK, Holmgren P, Ramankutty N, Foley JA, 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. Proceedings of the National Academy of Sciences of the United States of America. 107, 16732-16737.

Gomiero T, Pimentel D, Paoletti MG, 2011. Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture. Critical Reviews in Plant Sciences. 30, 95-124.

Green RE, Cornell SJ, Jörn PW Scharlemann JP, Balmford A, 2005. Farming and the Fate of Wild Nature. Science. 307, 550-555.

Guerry AD, Hunter ML, 2002. Amphibian distributions in a landscape of forests and agriculture: an examination of landscape composition and configuration. Conservation Biology. 16(3), 745-54.

Hedges LV, Gurevitch J, Curtis PS, 1999. The Meta-Analysis of Response Ratios in Experimental Ecology. Ecology. 80, 1150-1156.

Hendrickson O, 2003. Influences of global change on carbon sequestration by agricultural and forest soils. Environmental Reviews. 11, 161-192.

Hodgson JA, Kunin WE, Thomas CD, Benton TG, Gabriel D, 2010. Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. Ecology Letters. 13, 1358.

Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD, 2005. Does organic farming benefit biodiversity? Biological Conservation. 122, 113-130.

Holland JD, Bert DG, Fahrig L, 2004. Determining the Spatial Scale of Species' Response to Habitat. Bioscience. 54, 227-233.

Holland JD, Fahrig L, Cappuccino N, 2005. Body size affects the spatial scale of habitat–beetle interactions. Oikos. 110(1), 101-8.

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setälä H, Symstad AJ, Vandermeer J, Wardle DA, 2005. Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge. Ecological Monographs. 75, 3-35.

International Competence Centre for Organic Agriculture, 2014. Report on BIOFACH INDIA together with INDIA ORGANIC 2014. http://www.iccoa.org/download/BioFach_Report_2014.pdf. Accessed on August 2017

International Rice Research Institute, 2013. http://irri.org/index.php?option=com_content&view=article&id=479:44-new-rice-varieties-in-asia-and-africa&catid=39:media-releases&Itemid=944. Accessed on November 2017

Iverson AL, Marín LE, Ennis KK, Ennis KK, Gonthier DJ, Barrie BTC, Remfert JL, Cardinale BJ, Perfecto I, 2014. Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis. Journal of Applied Ecology. 51, 1593-1602.

Jackson HB, Fahrig L, 2012. What size is a biologically relevant landscape? Landscape Ecology. 27, 929-941.

Jackson HB, Fahrig L, 2015. Are ecologists conducting research at the optimal scale? Global Ecology and Biogeography. 24, 52-63.

Jackson ND, Fahrig L, 2014. Landscape context affects genetic diversity at a much larger spatial extent than population abundance. Ecology. 95, 871-881.

Johnson C, Balmford A, Brook B, Buettel J, Galetti M, Lei G, Wilmshurst J, 2017. Biodiversity losses and conservation responses in the Anthropocene. Science. 356, 270-274.

Jones CG, Lawton JH, Shachak M, 1997. Positive and Negative Effects of Organisms as Physical Ecosystem Engineers. Ecology. 78, 1946-1957.

Kerala Agricultural Statistics, 2013. Department of Agriculture, Thiruvananthapuram. Facts and figures of agriculture in Kerala. http://keralaagriculture.gov.in/pdf/fact_figures_25062014.pdf. Accessed on June 2017

Kerala Conservation of Paddy Land and Wetland Act, 2008. https://archive.india.gov.in/allimpfrms/allacts/2886.pdf. Accessed on August 2017

Kerala Department of Environment and Climate Change, 2014. Response to climate change: strategy and action. Government of Kerala Thiruvananthapuram. www.indiaenvironmentportal.org.in/files/file/kerala%20state%20action%20plan%20on%20climate%20change.pdf. Accessed on June 2017

Kerala Department of Soil Survey and Soil Conservation, http://www.keralasoils.gov.in/index.php/kerala-at-a-glance Accessed on June 2017

Kerala Forest and Wildlife Department, http://www.forest.kerala.gov.in/index.php/forest/kerala-state-profile. Accessed on June 2017.

Kittusamy G, Kandaswamy C, Kandan N, Subramanian M, 2014. Pesticide Residues in Two Frog Species in a Paddy Agroecosystem in Palakkad District, Kerala, India. Bulletin of Environmental Contamination and Toxicology. 93, 728-734.

Kretschmer H, Hoffmann J, 1997. Agrarlandschaft und Artenvielfalt. Forschungsreport. 2(97), 17-21.

Kumar BM, 2006. Land use in Kerala: changing scenarios and shifting paradigms. Journal of Tropical Agriculture. 43, 1-2.

Lawler SP. 2001. Rice fields as temporary wetlands: a review. Israel Journal of Zoology. 47(4), 513-528.

Lefcheck JS, Byrnes JEK, Isbell F, Gamfeldt L, Griffin JN, Eisenhauer N, Hensel MJS, Hector A, Cardinale BJ, Duffy JE, 2015. Biodiversity enhances ecosystem multifunctionality across trophic levels and habitats. Nature Communications. 6, 6936.

Lockwood JA, 1999. Agriculture and biodiversity: Finding our place in this world. Agriculture and Human Values. 16, 365-379.

Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime J, Hector A, Hooper D, Huston M, Raffaelli D, Schmid B, Tilman D, Wardle D, 2001. Ecology - Biodiversity and ecosystem functioning: Current knowledge and future challenges. Science. 294, 804-808.

Maclean J, Hardy B, Hettel G, 2013. Rice Almanac: Source book for one of the most important economic activities on earth. International Rice Research Institute.

Matson PA, Parton WJ, Power AG, Swift MJ, 1997. Agricultural intensification and ecosystem properties. Science. 277, 504-509.

McGarigal K, Ene E, 2013. Fragstats: Fragstats help-versoin 4.2. A spatial pattern analysis program for categorical maps.

Miguet P, Jackson HB, Jackson ND, Martin AE, Fahrig L, 2016. What determines the spatial extent of landscape effects on species? Landscape Ecology. 31, 1177-1194.

Millennium Ecosystem Assessment (Program), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Miyashita T, Amano T, Yamakita T, 2014. Effects of ecosystem diversity on species richness and ecosystem functioning and services: a general conceptualization. Integrative Observations and Assessments, 29-47.

Mora C, Sale PF, 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea. Marine Ecology Progress Series. 434, 251-266.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J, 2000. Biodiversity hotspots for conservation priorities. Nature. 403, 853-858.

Natuhara Y, 2013. Ecosystem services by paddy fields as substitutes of natural wetlands in Japan. Ecological Engineering. 56, 97-106.

Norris K, 2008. Agriculture and biodiversity conservation: opportunity knocks: Agriculture and biodiversity. Conservation Letters. 1, 2-11.

Norton L, Johnson P, Joys A, Stuart R, Chamberlain D, Feber R, Firbank L, Manley W, Wolfe M, Hart B, Mathews F, Macdonald D, Fuller RJ, 2009. Consequences of organic and non-organic farming practices for field, farm and landscape complexity. Agriculture, Ecosystems and Environment. 129, 221-227.

Nowakowski AJ, Otero Jiménez B, Allen M, Escobar MD, Donnelly MA, 2013. Landscape resistance to movement of the poison frog, *Oophaga pumilio*, in the lowlands of northeastern Costa Rica. Animal Conservation. 16(2), 188-197.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MH, Szoecs E, Wagner H, 2017. vegan: community ecology package. R package version 2.4-5. https://CRAN.R-project.org/package=vegan

Oliver I, 1996. Invertebrate Morphospecies as Surrogates for Species: A Case Study. Conservation Biology. 10, 99-109.

Olson DH, Leonard WP, Bury RB. (eds.), 1997. Sampling Amphibians in Lentic Habitats. Olympia, Washington, Society for Northwestern Vertebrate Biology.

Östman Ö, Ekbom B, Bengtsson J, 2001. Landscape heterogeneity and farming practice influence biological control. Basic and Applied Ecology. 2, 365-371.

Pearce D, 2007. Do we really care about Biodiversity? Environmental and Resource Economics. 37, 313-333.

Pereira HM, Leadley PW, Proença V, Alkemade R, Jörn PW, Scharlemann Fernandez-Manjarrés JF, Araújo MB, Balvanera P, Biggs, R, Cheung WWL, Chini L, Cooper HD, Gilman EL, Guénette S, Hurtt GC, Huntington HP, Mace GM, Oberdorff T, Revenga C, Rodrigues P, Scholes RJ, Sumaila UR, Walpole M, 2010. Scenarios for Global Biodiversity in the 21st Century. Science. 330, 1496-1501.

Phalan B, Balmford A, Green RE, Scharlemann JP, 2011 (b). Minimising the harm to biodiversity of producing more food globally. Food Policy. 36(1), S62-S71.

Phalan B, Green RE, Dicks LV, Dotta G, Feniuk C, Lamb A, Strassburg BB, Williams DR, zu Ermgassen EK, Balmford A, 2016. How can higher-yield farming help to spare nature? Science. 351, 450-451.

Phalan B, Onial M, Balmford A, Green RE, 2011(a). Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared. Science. 333, 1289-1291.

Pinheiro J, Bates D, DebRoy S, Sarkar D and R Core Team, 2017. _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-131, <URL: https://CRAN.R-project.org/package=nlme>.

Ponzetti JM, McCune B, 2001. Biotic Soil Crusts of Oregon's Shrub Steppe: Community Composition in Relation to Soil Chemistry, Climate, and Livestock Activity. The Bryologist. 104, 212-225.

Porej D, Micacchion M, Hetherington TE, 2004. Core terrestrial habitat for conservation of local populations of salamanders and wood frogs in agricultural landscapes. Biological Conservation. 120(3), 399-409.

Priyanga M, Venkataraman R, 2017. Opportunities and constraints in organic rice marketing-a study in Sirkazhi block of Nagapattinam district. International Research Journal of Agricultural Economics and Statistics. 8(1), 37-42.

R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ramankutty N, Foley JA, Norman J, McSweeney K, 2002. The Global Distribution of Cultivable Lands: Current Patterns and Sensitivity to Possible Climate Change. Global Ecology and Biogeography. 11, 377-392.

Randall NP, James KL, 2012. The effectiveness of integrated farm management, organic farming and agri-environment schemes for conserving biodiversity in temperate Europe - A Systematic Map. Environmental Evidence. 1, 4-4.

Relyea RA, 2005. The Impact of Insecticides and Herbicides on the Biodiversity and Productivity of Aquatic Communities. Ecological Applications. 15, 618-627.

Ricci B, Franck P, Valantin-Morison M, Bohan DA, Lavigne C, 2013. Do species population parameters and landscape characteristics affect the relationship between local population abundance and surrounding habitat amount? Ecological Complexity. 15, 62-70.

Roschewitz I, Gabriel D, Tscharntke T, Thies C, 2005. The Effects of Landscape Complexity on Arable Weed Species Diversity in Organic and Conventional Farming. Journal of Applied Ecology. 42, 873-882.

Schneider MK, Lüscher G, Jeanneret P, Arndorfer M, Ammari Y, Bailey D, Balázs K, Báldi A, Choisis JP, Dennis P, Eiter S, Fjellstad W, Fraser MD, Frank T, Friedel JK, Garchi S, Geijzendorffer IR, Gomiero T, Gonzalez-Bornay G, Hector A, Jerkovich G, Jongman RHG, Kakudidi E, Kainz M, Kovács-Hostyánszki A, Moreno G, Nkwiine C, Opio J, Oschatz ML, Paoletti MG, Pointereau P, Pulido FJ, Sarthou JP, Siebrecht N, Sommaggio D, Turnbull LA, Wolfrum S, Herzog F, 2014. Gains to species diversity in organically farmed fields are not propagated at the farm level. Nature Communications. 5, 4151.

Schuler J, Sattler C, Helmecke A, Zander P, Uthes S, Bachinger J, Stein-Bachinger K, 2013. The economic efficiency of conservation measures for amphibians in organic farming–Results from bio-economic modelling. Journal of Environmental Management. 114, 404-413.

Seufert V, Ramankutty N, Foley J, 2012. Comparing the yields of organic and conventional agriculture. Nature. 485, 229.

Shibahara F. 2010. Support system for farmers practicing environmentally conscious agriculture: Its effects and future problems. Journal of Japan Society on Water Environment (Japan). 33, 45-48.

Sruthi SN, Shyleshchandran MS, Mathew SP, Ramasamy EV, 2017. Contamination from organochlorine pesticides (OCPs) in agricultural soils of Kuttanad agroecosystem in India and related potential health risk. Environmental Science and Pollution Research. 24, 969-978.

Stanhill G, 1990. The comparative productivity of organic agriculture. Agriculture, Ecosystems and Environment. 30, 1-26.

Stolze M, Lampkin N, 2009. Policy for organic farming: Rationale and concepts. Food Policy. 34, 237-244.

Sutherland WJ, editor. 2006. Ecological Census Techniques: A Handbook. Cambridge University Press, Cambridge, UK; New York.

Taylor B, Skelly D, Demarchis LK, Slade, M.D, Galusha, D, Rabinowitz, P.M, 2005. Proximity to Pollution Sources and Risk of Amphibian Limb Malformation. Environmental Health Perspectives. 113, 1497-1501.

Tews J, Brose U, Grimm V, Tielbörger K, Wichmann MC, Schwager M, Jeltsch F, 2004. Animal Species Diversity Driven by Habitat Heterogeneity/Diversity: The Importance of Keystone Structures. Journal of Biogeography. 31, 79-92.

The IUCN Red List of Threatened Species, 2017. Version 2017-3. <www.iucnredlist.org>. Accessed on June 2017.

Thomas F, Folgarait P, Lavelle P, Rossi JP, 2004. Soil macrofaunal communities along an abandoned rice field chronosequence in Northern Argentina. Applied Soil Ecology. 27, 23-29.

Tilman D, 1999. Global Environmental Impacts of Agricultural Expansion: The Need for Sustainable and Efficient Practices. Proceedings of the National Academy of Sciences of the United States of America. 96, 5995-6000.

Tilman D, Clark M, 2014. Global diets link environmental sustainability and human health. Nature. 515, 518-522.

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

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

Tscharntke T, Steffan-Dewenter I, Kruess A, Thies C, 2002. Contribution of Small Habitat Fragments to Conservation of Insect Communities of Grassland-Cropland Landscapes. Ecological Applications. 12, 354-363.

Tuck SL, Winqvist C, Mota F, Ahnström J, Turnbull LA, Bengtsson J, 2014. Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. Journal of Applied Ecology. 51, 746-755.

Venables WN, Ripley BD, 2002. Modern Applied Statistics with S. Fourth Edition. Springer Science & Business Media. ISBN 0-387-95457-0

Viswanathan PK, 2014. The Rationalization of Agriculture in Kerala: Implications for the Natural Environment, Agro-ecosystems and Livelihoods. Agrarian South: Journal of Political Economy. 3, 63-107.

Wickham H, 2009. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Willig MR, 2011. Biodiversity and productivity. Science. 333, 1709.

Winqvist C, Bengtsson J, Aavik T, Berendse F, Clement LW, Eggers S, Fischer C, Flohre A, Geiger F, Liira J, Pärt T, Thies C, Tscharntke T, Weisser WW, Bommarco R, 2011. Mixed effects of organic farming and landscape complexity on farmland biodiversity and biological control potential across Europe. Journal of Applied Ecology. 48, 570-579.

Appendix 1. Data sheet

Datasheet used to collect farm level data with the help of farmer.

Field Code: _______________ Organic/conventional

Date of survey: ____________________ Survey done by: _________________________________

Name of Landowner: ____

Location (Panchayat & district): ____

Phone No.: ________________________ Address: ______________________________________

GPS points of household: ______________________ of field(s): __________________________

<u>Total farm holdings</u>:

Area of total farm (landowner estimate): Owned: _______cents Rented: __________ cents

Number of individual fields in total farm: Owned: _____________ Rented: ________________

Average size of each field: Owned: _______________ Rented: ________________

Area of rice cultivated:

<u>Field Chosen for Sampling</u>:

Size of field: ___________ cents

Certified? Yes / No Year of certification: _____ Certification agency: _________________

No. of years that you have cultivated this field: _______ No. of years cultivated organically __

No. of crop seasons: ________________________

Cultivated rice crop variety: ___________________ Related varieties: __________________

Crop age (days since sowing): ___________________ Soil type: _________________________

Days since last fertilizer application: _______________ Type applied: __________________

<u>Time period (months) of cultivation:</u>

Land preparation	Sowing	Harvest (expected date)

What inputs (fertilizer, pesticides, manures, etc.) have you used (amount and time over past year)

Input	Amount (weight/percentage)	Time (year/month)

Productivity of rice per unit area in field?

Is there a fallow period? Yes/NoWhen? ______________________________

What crops, other than paddy, are cultivated in the same field and when?

Other crops	Period cultivated

What is the distance to nearest conventional field? ___________________m

Do you share water with conventional farms?   Yes / No Explain: _____________

____

Management questions: harvesting machinery?

Planting (machines vs hand)

Field Sketch (if possible, show general location of fields, hedgerows, uncultivated areas, homegardens, indicate conventional/organic if known)

Photograph #: __________

GPS #: _______________

Notes:

Field Productivity – Weekly Call Log

(Call farmer each week at the same time, and fill in one row of the table)

Date	Total amount of rice harvested in past week (bags? Kg?)	Amount sold	Type of rice (hulled, raw, dried, etc.)

Appendix 2. List of amphibians and arthropods

Total abundance of amphibians, arthropods and Odonates in organic and conventional fields

Amphibian species	*conventional*	*organic*	*IUCN Status*
Clinotarsus curtipes	1	0	Near threatened
Duttaphrynus melanostictus	3	3	Least concern
Duttaphrynus scaber	4	2	Least concern
Euphlyctis cyanophlyctis	75	115	Least concern
Fejervaria sp. A	538	558	
Fejervaria sp. B	100	95	
Hoplobatrachus tigerinus	355	555	Least concern
Indosylvirana aurantiaca	48	125	Vulnerable
Microhyla ornata	105	90	Least concern
Microhyla sp.	53	26	
Polypedates maculatus	49	51	Least concern
Polypedates occidentalis	0	1	Data deficient
Pseudophilautus kani	1	2	Least concern
Sphaerotheca breviceps	1	1	Least concern
Uperodon taprobanicus	2	0	Least concern
Uperodon variegatus	1	7	Least concern

Arthropod orders	*Conventional*	*Organic*
Araneae	552	609
Blattodea	0	6
Coleoptera	947	1120
Decapoda	1	1
Dermaptera	3	5
Diptera	3447	3623
Ephemeroptera	22	152
Hemiptera	3436	3957

Hymenoptera	1085	1455
Lepidoptera	822	870
Mantodea	1	1
Neuroptera	0	6
Orthoptera	1132	1253
Phasmatodea	8	4
Polydesmida	7	10
Thysanoptera	4	9

Odonate group	***Conventional***	***Organic***
Damselfly	338	375
Dragonfly	216	221
Total	554	596

Appendix 3. Sentinel 2 imagery data

Sentinel-2 imagery details for the six images used in the analysis showing entity ID, date and center latitude and longitude.

Image No	Entity ID	Date	Center Latitude and Longitude
1	L1C_T43PFN_A008739_20170223T051515	16/02/2017	11°15'36.57"N 76°25'08.59"E
2	L1C_T43PFP_A008639_20170216T053443	16/02/2017	12°09'51.89"N 76°25'25.23"E
3	L1C_T43PFM_A008639_20170216T053443	16/02/2017	11°15'36.57"N 76°25'08.59"E
4	L1C_T43PEN_A008639_20170216T053443	16/02/2017	11°15'47.23"N 75°30'10.11"E
5	L1C_T43PFN_A008639_20170216T053443	16/02/2017	10°21'21.03"N 76°24'53.32"E
6	L1C_T43PFM_A008453_20170203T051647	03/02/2017	10°21'21.03"N 76°24'53.32"E

Appendix 4. Image validation data

Validation data tables (in percentages) for six of the Sentinel 2 images used in the study. Validation data are columns and training data are rows. Reported overall accuracy and Kappa coefficient.

Image 1 Validation Overall Accuracy = (1752/1961) 89.3422%; Kappa Coefficient = 0.8469

Class	Water	Buildings	Barren	Paddy	Forests	Total
Unclassified	6.97	5.71	5.54	0.66	1.64	3.42
Water	92.62	0.00	0.00	0.00	0.00	11.52
Buildings	0.41	88.57	9.33	0.00	0.00	12.75
Barren	0.00	4.08	76.09	16.56	3.58	16.88
Paddy	0.00	0.41	6.12	82.78	0.41	7.70
Forests	0.00	1.22	2.92	0.00	94.38	47.73
Total	100.00	100.00	100.00	100.00	100.00	100

Image 2 Validation Overall Accuracy = (3281/3612) 90.8361%; Kappa Coefficient = 0.8514

Class	Water	Buildings	Barren	Cropland	Forest	Total
Unclassified	1.28	20.11	8.67	4.03	4.21	5.23
Water	98.72	0.00	0.00	0.00	0.00	2.13
Buildings	0.00	75.86	1.33	0.58	0.05	3.96
Barren	0.00	2.30	85.00	8.54	0.30	9.80
Paddy	0.00	1.72	1.67	85.99	0.25	25.17
Forests	0.00	0.00	3.33	0.86	95.19	53.71
Total	100.00	100.00	100.00	100.00	100.00	100.00

Image 3 Validation Overall Accuracy = (3878/4540) 85.4185%; Kappa Coefficient = 0.7867

Class	Water	Buildings	Barren	Paddy	Forests	Total
Unclassified	3.27	20.07	2.47	1.63	0.78	2.62
Water	94.81	0.00	0.00	0.00	0.00	10.86
Buildings	0.00	58.78	2.47	1.70	0.20	4.38
Barren	0.19	9.32	84.81	7.39	0.39	8.35
Paddy	1.73	11.83	10.25	74.01	4.05	26.34
Forests	0.00	0.00	0.00	15.27	94.59	47.44
Total	100.00	100.00	100.00	100.00	100.00	100.00

Image 4 Validation Overall Accuracy = (3118/3656) 85.2845%; Kappa Coefficient = 0.8065

Class	Water	Buildings	Barren	Paddy	Forests	Total
Unclassified	1.70	8.48	7.74	2.86	7.43	5.20
Water	98.07	0.00	0.00	0.00	0.00	23.69
Buildings	0.00	80.21	0.57	4.29	0.00	7.17
Barren	0.00	5.30	71.92	3.38	0.22	8.07
Paddy	0.23	6.01	18.05	86.09	11.30	24.59
Forests	0.00	0.00	1.72	3.38	81.05	31.29
Total	100.00	100.00	100.00	100.00	100.00	100.00

Image 5 Validation Overall Accuracy = (2788/3393) 82.1692%; Kappa Coefficient = 0.7660

Class	Water	Buildings	Barren	Paddy	Forests	Total
Unclassified	4.87	21.41	14.04	1.45	2.46	5.13
Water	94.18	0.00	0.00	0.00	0.00	17.65
Paddy	0.00	1.83	2.13	76.63	2.58	32.15
Buildings	0.47	66.67	19.57	0.72	0.12	8.19
Barren	0.47	10.09	62.13	18.60	0.62	13.09
Forests	0.00	0.00	2.13	2.60	94.22	23.78
Total	100.00	100.00	100.00	100.00	100.00	100

Image 6 Validation Overall Accuracy = (3614/4317) 83.7155%; Kappa Coefficient = 0.7894

Class	Water	Buildings	Barren	Paddy	Forests	Total
Unclassified	1.57	35.47	26.36	1.50	1.56	7.20
Water	98.34	0.00	0.00	0.00	0.00	27.52
Buildings	0.00	56.06	32.56	3.01	0.17	9.43
Barren	0.00	0.92	30.75	5.13	0.78	4.40
Paddy	0.08	6.86	10.08	89.92	6.93	27.03
Forests	0.00	0.69	0.26	0.44	90.55	24.42
Total	100.00	100.00	100.00	100.00	100.00	100

Appendix 5. Effective radius values

Slope, p-values and adjusted R2 values used in the analysis of the effective radii for amphibians, arthropods, Odonates and productivity.

Group	Radius	Slope	p-value	Adj_R^2
Amphibian	250	-0.00667	0.0316	0.120
Amphibian	500	-0.00717	0.0301	0.123
Amphibian	1000	-0.00665	0.0523	0.093
Amphibian	1500	-0.0058	0.102	0.058
Amphibian	2000	-0.00499	0.1757	0.03
Arthropod	250	-0.00236	0.482	-0.017
Arthropod	500	-0.00165	0.646	-0.027
Arthropod	1000	-0.0026	0.479	-0.016
Arthropod	1500	-0.00344	0.362	-0.004
Arthropod	2000	-0.00373	0.335	-0.001
Productivity	250	0.006515	0.00233	0.26
Productivity	500	0.006836	0.00298	0.248
Productivity	1000	0.007932	0.000639	0.322
Productivity	1500	0.008133	0.000673	0.319
Productivity	2000	0.00825	0.000839	0.309
Odonates	250	-0.0016	0.74	-0.031
Odonates	500	-2.1E-05	0.997	-0.034
Odonates	1000	-0.00255	0.628	-0.026
Odonates	1500	-0.0034	0.53	-0.02
Odonates	2000	-0.00318	0.568	-0.023