Socio-ecological assessment of ecosystem services in relation to biodiversity along a gradient from forest to agricultural landscape in West Java, Indonesia

（インドネシア西ジャワの森林−農業景観における
生物多様性に関連する生態系サービスの社会生態学的評価）

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Abstract

Ecosystem services provided by natural resources, whether in the form of food, fiber, or fuel, or in a more abstract or psychological form such as cultural and spiritual values, are vital to the livelihoods of resource-poor rural people, particularly those living in the developing countries of the humid tropics, where, historically, people have enjoyed services derived from ecosystems for free. These various ecosystem services are strongly influenced by the level of biodiversity in regions characterized by a complex of natural and human-made ecosystems. However, the conversion of natural forests to other uses and the intensification of agricultural activities threaten both the sustainable provision of ecosystem services and biodiversity conservation. Thus, there is an urgent need to establish landscape management plans that aim to simultaneously maintain ecosystem services, satisfy increasing demands for basic economic needs, and conserve biodiversity.

In the humid tropics, forest ecosystems are still the most important source of ecosystem services and biodiversity, but agricultural ecosystems are also necessary to produce food for rural peoples. Landscapes composed of both natural and human-modified ecosystems are thus essential to provide a complete bundle of ecosystem services to local people. To cope with current threats to ecosystem services and biodiversity associated with forest conversion and intensive agriculture, both natural and human-modified ecosystems must be maintained at the landscape scale. Furthermore, before suitable landscape management plans can be implemented, it is important to understand the roles of local people, who are key stakeholders that actively use, manage, and modify the landscape.

There is a growing demand for the incorporation of social dimensions into assessments of ecosystem services, which at present usually focus on the effects of ecosystems and biodiversity on human well-being. The incorporation of social dimensions will improve our understanding of the ways in which various ecosystems benefit society and, as well, of the many ways in which societies perceive and appreciate ecosystem services. It is crucial to integrate social and ecological aspects at the landscape scale between, on the one hand, the perception of ecosystem services by local people, who are key stakeholders, the actual ecosystem managers, and the victims of degradation of ecosystem services, and, on the other hand, biodiversity, which underlies the ecosystem functioning that provides ecosystem services. Nevertheless, such assessments are not yet being performed, although they are necessary to provide the basis on which to establish the actual landscape management plans that will both accommodate sustainable utilization of the multiple services provided by ecosystems and, at the same time, maintain biodiversity.

In this dissertation, I assess socio-ecological aspects of ecosystem services with special reference to biodiversity in a forest–agricultural landscape in West Java, Indonesia, with the aim of identifying suitable landscape management practices for ensuring the delivery of multiple ecosystem services and the resultant enhancement of human well-being. I use a socio-ecological approach that takes into account the preferences of the local people as represented by their perceptions of ecosystem services and associated landscape elements as sources of those services, as well as the species richness of the avian and insect pollinator communities that,

through their contributions to ecosystem functioning, also contribute to the ecosystem services. For this study, I chose to focus on birds and insect pollinators because they are sensitive to landscape conditions and because, as pollinators, predators, seed dispersers, and ecosystem engineers, they are key players in ecosystem functioning. I used total species richness and that of each functional group to quantify potential ecosystem services, because many studies have indicated that species richness is strongly and positively correlated with ecosystem services, and because functional diversity is also a proven predictor of ecosystem services. The specific objectives of my study were to (a) assess perceptional differences in the landscape elements used and perceived as sources of ecosystem services (Chapter 2); (b) assess the bird community and its functional diversity (Chapter 3); (c) assess the diversity of insect pollinators (Chapter 4); and (d) integrate the findings presented in chapters 2 to 4 with regard to their implications for the spatial arrangement of landscape elements to establish a conceptual plan for sustainable management of a human-dominated landscape that both enhances the provision of multiple ecosystem services and maintains biodiversity (Chapter 5).

The study site is located from 600 to 1300 m above sea level in Neogene hills in Cianjur District, West Java, Indonesia. The landscape gradient extends from remnant forest, to broad- and needle-leaved tree plantations, to mixed-tree and bamboo-dominated agroforests, and thence to upland fields, paddy fields, and village settlements. The majority of the local population is engaged in agricultural activities.

I collected data on the local people's perception of ecosystem services and which landscape elements they regard as the source of those services by using structured interview techniques. I sampled 138 households out of the total of 293 households engaged in agriculture that occupied the study site. To identify which socioeconomic factors affected their perceptions of ecosystem services, I analyzed the survey data with generalized linear models (GLMs) with a logit link function that followed a binomial distribution. Next, I evaluated how accessibility to the remnant forest in two categories, less than or greater than 1.5 km from the remnant forest, affected how the people perceived each landscape element as a source of each ecosystem service.

I collected data on the birds and insect pollinator communities at sampling points chosen to represent all environmental variations at the study site. Bird surveys were performed in accordance with a standardized observation method using point counts. I defined 112 plots and aimed to sample all landscape elements in proportion to their actual occurrence in the forest–agricultural landscape. Insect pollinators were collected by a commonly used passive sampling method using pan traps. I set up 316 plastic soup bowls painted with UV-bright yellow, white, blue, and red colors in 79 plots. For birds and insect pollinators, I calculated abundance, species richness, and Simpson's diversity index of all species in each plot, and compared their differences among landscape elements. I performed a non-metric multidimensional scaling (NMDS) analysis to investigate general species composition patterns among the different landscape elements. To quantify the effects of three environmental factors (landscape element types, vegetation covers and structures, and proximity to the remnant forest) on total species richness and that of each functional group, I used GLMs with a logarithmic link function that followed a Poisson distribution.

Results and discussion of the chapter 2 cannot be publicizing through internet because it has already been published in Ecosystem Services Journal (http://dx.doi.org/10.1016/j.ecoser.2014.04.003i) since May 6, 2014, Title: “Living close to forests enhances people's perception of ecosystem services in a forest–agricultural landscape of West Java, Indonesia”. Its publication through the Internet is not authorized under an agreement with the publisher.

Results and discussion of the chapter 3 has also been published in Agroforestry Systems Journal Vol. 87, Pages 1247–1260, since 18 July 2013, Title: “Effects of habitat type, vegetation structure, and proximity to forests on bird species richness in a forest–agricultural landscape of West Java, Indonesia”. Its publication through the Internet can only be permitted 12 months after official publication date (Authorized publication date: After 18 July 2014).

The insect pollinator community assessment results showed that species richness, diversity, and abundance were highest in the remnant forest and the mixed-tree agroforests, and lowest in upland fields and village settlements. Species compositions did not differ among landscape elements. However, there was a dramatic difference between the forest and village settlements, mainly because of a decline in the species richness and abundance of efficient pollinators such as bees and wasps in the latter, and their replacement by less efficient pollinators such as moths, butterflies, flies, and beetles. Vegetation cover particularly that of top canopy, tended to be more important than other factors in explaining the species richness of insect pollinators, even in fields where annual crops were cultivated. However, species richness of efficient pollinators (bees and wasps) was moderately affected by proximity to the forest. Even though landscape element differences were not a main factor influencing species richness of total insect pollinators, the remnant forest was likely the source of efficient pollinators, especially of bees. Among human-modified ecosystems, mixed-tree agroforests maintained the highest number of species of insect pollinators.

The results presented in Chapters 2 to 4 show that both local people’s perceptions of ecosystem services and the functional biodiversity of birds and insect pollinators generally decreased from the remnant forest to human-modified ecosystems. Therefore, to conserve the diversity of forest birds and efficient pollinators (bees and wasps) as well as to preserve services related to the regulation of water, soils, and the atmosphere that many of the local people perceive, protection of forests should be a priority. In addition, to reduce extractive activities that conflict with forest conservation, such as the capturing of birds to be sold as pets, the economic needs of people must be accommodated. Then, if people have access to the remnant forest, biodiversity conservation and the maintenance of various ecosystem services will be promoted.

To prevent extractive utilization of forest resources, alternative ways for rural people to earn income must be provided. For example, the expansion of agroforests in buffer zones around the forest combined with economic utilization of the planted trees and shrubs can reduce human pressure on the remnant forest. In fact, my study shows that mixed-tree agroforests play pronounced sociological and ecological roles that could be further enhanced by establishing them close to the remnant forest and by creating ecological corridors to the remnant forest through both broad- and needle-leaved tree plantations. Greater functional diversity of birds in the agroforests could be sustained by increasing tree density and by introducing tree species that attract bark-gleaning insectivores. The bamboo-dominated agroforests, which clearly not favored by many efficient pollinators or functional groups of birds, should be located far from the remnant forests. The addition of trees to provide canopy cover would attract insect pollinators to those various ecosystem elements.

Additional studies are needed that fully cover the landscape gradient from intact forest to intensively exploited agricultural lands and densely populated urban areas, and that directly evaluate the role of biodiversity in all landscape elements, in order to quantify the extent to which species diversity improves the delivery of ecosystem services. In combination with such additional results, the outcomes of the present study will contribute to the development of a generalized ecosystem-service-based landscape management plan that is adaptable to conditions in developing countries in the humid tropics.

Chapter 1

General Introduction

1.1. Background

Food, fiber, freshwater supply and other resources that people obtain from natural and modified ecosystem are defined as ecosystem services (Costanza et al., 1997; Daily, 1997). According to Constanza et al. (1997), ecosystem services are the benefits provided to humans through the transformations of resources (or environmental assets, including land, water, vegetation and atmosphere) into a flow of essential goods and services. The Millennium Ecosystem Assessment sponsored by the United Nations assessed the consequences of ecosystem changes for human well-being and provided a framework to identify and classify ecosystem services (Millennium Ecosystem Assessment, 2005). Millennium Ecosystem Assessment (2005) classified ecosystem services into provisioning services (such as food, wood, fiber, and pharmaceutical), regulating services (such as climate regulation, water purification, pollination, pest and disease regulation), cultural services (such as religious and cultural values, recreational and aesthetic values), and supporting services needed in providing all other ecosystem services (such as soil formation and nutrient cycling).

Ecosystem services provided by natural resources, whether in the form of provisioning services or in a more abstract such as regulating and supporting services or psychological form such as cultural services, are vital to the livelihoods of resource-poor rural people, particularly those living in the developing countries of the humid tropics (Kalaba et al., 2012; Persson et al., 2010). These various ecosystem services are strongly influenced by the level of biodiversity in regions (Ash et al., 2010; Norris, 2012). Biodiversity provides the basis for ecosystem to function well, and ecosystem functioning provides ecosystem services upon which all people fundamentally depend (Millennium Ecosystem Assessment, 2005; Ash et al., 2010). Biodiversity underpins a much wider range of services than just providing products such as foods and fibers; it provides much more services such as insects that pollinate crops and wild flowers, and the biologically rich landscapes provide aesthetical enjoyment and spiritual values (Millennium Ecosystem Assessment, 2005; Ash et al., 2010).

People in the humid tropical developing countries are highly dependent on their surrounding landscapes to acquire sufficient ecosystem services (Fagerholm et al., 2012). Historically, such people in humid tropical developing countries have enjoyed free ecosystem services derived from forest ecosystems and modified parts of the forest to acquire enough foods and fibers. Thus, these people had relied on biodiversity in their daily lives without realizing it. However, the conversion of natural forests to other uses and the intensification of agricultural activities influenced by the modern economy threaten both the sustainable provision of ecosystem services and biodiversity conservation (Jackson et al., 2007; Mooney et al., 2005; Sodhi et al., 2010a). It is well established that if the ecosystem services that are provided by biodiversity are not managed effectively, future option will become ever more restricted for rich and poor people alike (Ash et al., 2010). However, poor people tend to be most directly affected by the deterioration or loss of ecosystem services due to their high dependency on their surrounding landscapes, and often live in the regions of biodiversity hotspot (Ziegler et al., 2009; Sodhi et al., 2010a; 2010b). Thus, there is an urgent need to establish landscape management plans that aim to simultaneously maintain ecosystem services, satisfy increasing demands for basic economic needs, and conserve biodiversity.

In the humid tropics, forest ecosystems are still the most important source of ecosystem services and biodiversity (Sodhi et al., 2010a; 2010b), but agricultural ecosystems are also necessary to produce food for rural peoples (FAO, 2013). Landscapes composed of both natural and human-modified ecosystems are thus essential to provide a complete bundle of ecosystem services to local people (Millennium Ecosystem Assessment, 2005; Haines-Young and Potschin, 2007; Martín-López et al., 2012). To cope with current threats to ecosystem services and biodiversity associated with forest conversion and intensive agriculture, both natural and human-modified ecosystems must be maintained at the landscape scale (Müller et al., 2010). The landscape-scale approach is also important for biodiversity conservation. The coverage of forests designated for biodiversity conservation is still <10% of the entire area of tropical forest worldwide (Schmitt et al., 2009). Most protected areas in tropical regions are embedded within a matrix of human-modified landscapes (Chazdon et al., 2009), and placing increasing stresses on the ecosystem (DeFries et al., 2007). Much attention has therefore been paid recently to understanding the roles and effects of human-modified landscapes surrounding tropical forests in the conservation of forest biodiversity within and beyond protected areas (Chazdon et al., 2009; Gardner et al., 2009). Furthermore, before suitable landscape management plans can be implemented, it is important to understand the roles of local people (Silvano et al., 2005). As farmers, pastoralists, and horticulturalists, local people are key stakeholders that actively use, manage, and modify the surrounding landscape. Therefore, local residents need to be included in formal landscape assessment and management procedures (Campos et al., 2012; Gunawan et al., 2004a).

Currently, there is a growing demand for the incorporation of social dimensions into assessments of ecosystem services and biodiversity (Bryan et al., 2010; Kumar and Kumar, 2008). Actually, note back the time, studies on ecosystem services had started in early 1970s (King, 1966; Helliwell, 1969; Hueting, 1970; Odum and Odum, 1972; De Groot et al., 2002). Continuously, as the issue of biodiversity loss increased, studies on ecosystem services were associated to biodiversity (Hooper et al., 2005; Loreau et al., 2001; Swift et al., 2004). Recent studies on ecosystem services and biodiversity tend to be focused either on biophysical assessment (Bracken et al., 2008; Breitbach et al., 2009; Díaz et al., 2007; De Groot et al., 2010; De Bello et al., 2010; Luck et al., 2009), or on the economic valuation (Costanza et al., 1997; Fisher and Turner, 2008; García-LLorente et al., 2011; Martín-López et al., 2011; TEEB, 2010). However, few studies have attempted to address preferences towards ecosystem services and biodiversity from the perspective of human perceptions, attitudes, and beliefs (Martín-López et al., 2011; Vihervaara et al., 2010).

Since the assessment of ecosystem services and biodiversity are made by analyzing the effect of ecosystems and biodiversity on human well-being (Millennium Ecosystem Assessment, 2005), it is necessary to incorporate the social dimension. The incorporation of social dimensions in the ecosystem services and biodiversity assessment will improve our understandings of the ways in which various ecosystems benefit society and, as well, of the many ways in which societies perceive and appreciate ecosystem services and biodiversity (Anton et al., 2010; Menzel and Teng, 2010). The recognition that local people are key stakeholders of ecosystems that are modified and simultaneously affected by modification has led researchers to seek and address both social and ecological dimensions (Carpenter et al., 2009). It is thus crucial to integrate social and ecological aspects at the landscape scale between, on the one hand, the perception of ecosystem services by local people, who are the actual ecosystem managers and the victims of degradation of ecosystem services, and, on the other hand, biodiversity, which underlies the ecosystem functioning that provides ecosystem services. Integrated social-ecological assessments, therefore, aim to broaden the theoretical understanding of ecosystem structure and function by encompassing a more realistic framework within ecosystem with people as a central driving factors and members of ecosystem (Liu et al., 2007a; 2007b). Nevertheless, such socio-ecological assessments at the landscape scale are not yet being performed, although they are necessary to provide the basis on which to establish the actual landscape management plans that will both accommodate sustainable utilization of the multiple services provided by ecosystems and, at the same time, maintain biodiversity.

1.2. Problems identification and objectives

1.2.1. Problems identification

Based on the literature surveys in the background (Section 1.1), there are two prominent issues in assessment of ecosystem services and biodiversity. First, in the humid tropics, both natural and human-modified ecosystems are essential to provide a complete bundle of ecosystem services to local people (Millennium Ecosystem Assessment, 2005; Haines-Young and Potschin, 2007; Martín-López et al., 2012), thus the assessment of ecosystem services and biodiversity must be performed at the landscape scale (Müller et al., 2010). Second, since the assessments are made by analyzing the effect of ecosystems and biodiversity on human well-being (Millennium Ecosystem Assessment, 2005), it is necessary to incorporate the social dimension. Hence, the two issues have led to the need of the integration of social and ecological dimensions at the landscape scale.

1.2.2. Objectives

In this dissertation, I assess socio-ecological aspects of ecosystem services in relation to biodiversity in a forest–agricultural landscape in West Java, Indonesia, with the aim of identifying suitable landscape management practices for ensuring the delivery of multiple ecosystem services and the resultant enhancement of human well-being. I use a socio-ecological approach that takes into account the preferences of the local people as represented by their perceptions of ecosystem services and associated landscape elements as sources of those services, as well as the species richness of the avian and insect pollinator communities that, through their contributions to ecosystem functioning, also contribute to the ecosystem services. For this study, rural people preference is represented by their perceptions, because it refers to the cognitive aspect of the reception of visual stimuli and an implicit categorization underlying people's interpretation of the surrounding landscape through their experiences and preferences in utilizing and modifying their surroundings (Berkes, 1999; Campos et al., 2012). Then, I chose to focus on birds and insect pollinators because they are sensitive to landscape conditions and because, as pollinators, predators, seed dispersers, and ecosystem engineers, they are key players in ecosystem functioning (Sekercioglu, 2006; Tscharntke et al., 2008). I used total species richness and that of each functional group to quantify potential ecosystem services, because many studies have indicated that species richness is strongly and positively correlated with ecosystem services (Chapin et al., 2000; Hooper et al., 2005; Loreau et al., 2001; Mertz et al., 2007), and because functional diversity is also a proven predictor of ecosystem services (Diaz and Cabido, 2001; Philpott et al., 2009; Tilman et al., 1997).

1.3. Framework of study

The scope of study in this dissertation covers social and ecological assessments of ecosystem services in relation to biodiversity (**Figure 1.1**). The socio-ecological approach is more in a sense of multidisciplinary and to some extent interdisciplinary approaches of social and ecological dimensions of ecosystem services and biodiversity. The assessment in this study is defined as the process of analyzing the effect of ecosystems and biodiversity on human well-being as a basis for landscape management based on empirical socio-ecological data. The term "analyzing" refers to the process of estimating and evaluating the relevant information quantitatively and qualitatively in order to elucidate an appropriate spatial arrangement and a practical measure for landscape management from social and ecological aspects of ecosystem services.

Ecosystem services in this dissertation are defined as benefits obtained by people from various resources and ecological processes that are supplied by ecosystem (after the Millennium Ecosystem Assessment, 2005). Following the definition from Millennium

Ecosystem Assessment (2005), ecosystem services in this dissertation are categorized mainly into two as direct or provisioning, and indirect (regulating, cultural, and supporting) services.

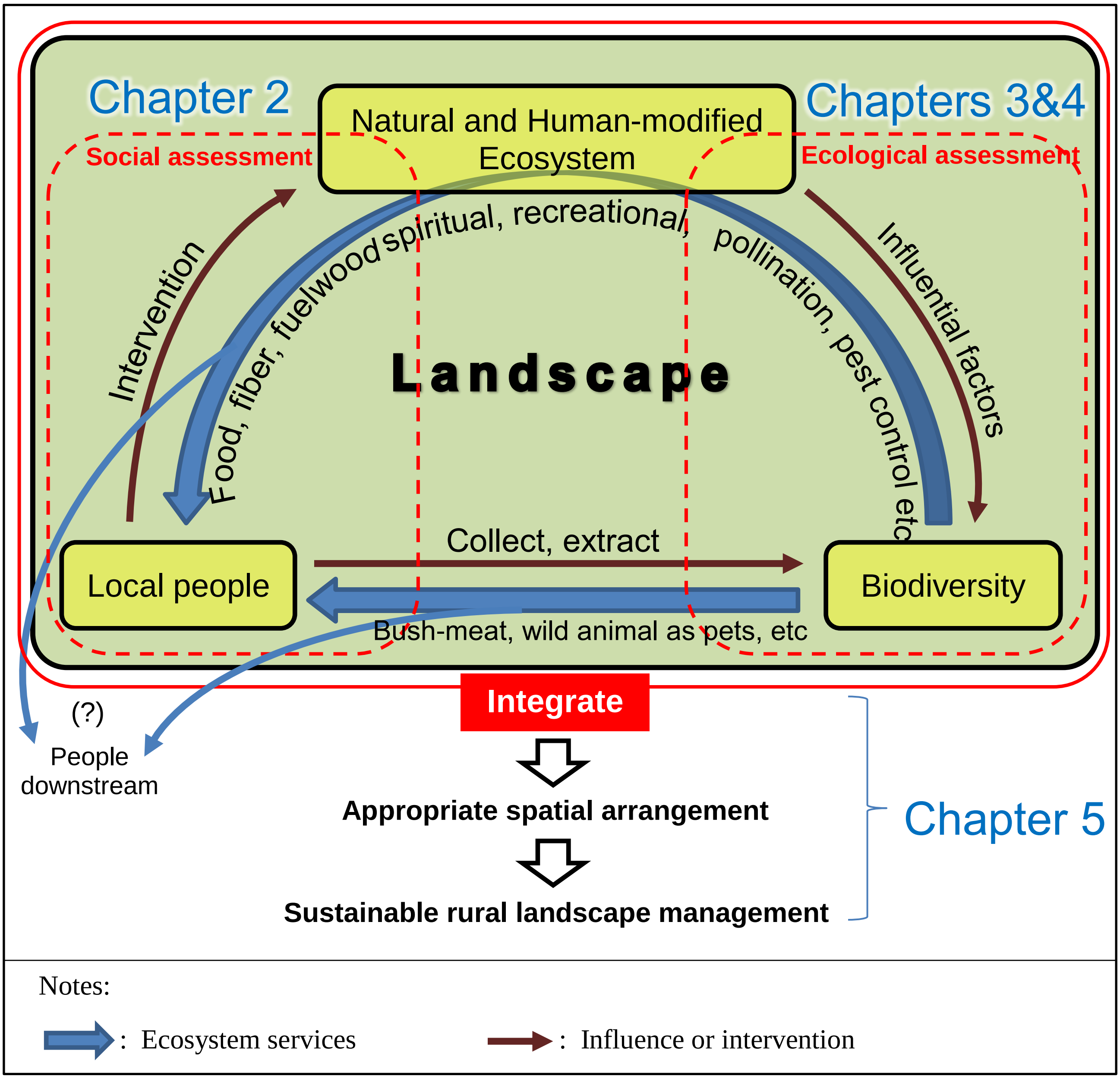


Figure 1.1 The framework of study and structure of dissertation

As mentioned in the background (Section 1.1), local people have enjoyed free services derived from forest ecosystems and modified parts of the forest to acquire enough foods and fibers based on their preferences (**Figure 1.1**). Consequently they have been forming their living landscapes. In order to assess ecosystem services, it is necessary to understand the ways society benefits from various ecosystems and, thus, the many ways that societies appreciate and perceive ecosystem services (Anton et al., 2010; Menzel and Teng, 2010). Understanding the perception of ecosystem services by local people—as the key stakeholders, actual managers, and victims of the degradation of ecosystem services—is crucial for identifying ecosystem services that are highly appreciated and preferable (Martín-López et al., 2012). In the assessment of social aspect in this dissertation, I cover as many categories of ecosystem services as possible from direct services such as foods and fibers to indirect services such as air and water regulation, pollination, and cultural value of a landscape. By gathering and analyzing the whole type of ecosystem services, it will help to establish sustainable rural landscape management with alternative sources of preferable ecosystem services for maintaining the livelihoods of people living in humid tropical developing countries that will both contribute to fulfilling conservation objectives and reducing poverty.

Biodiversity provides the basis for ecosystems and the services they provide, upon which people fundamentally depend (**Figure 1.1**). Since biodiversity underpins a wide range of services, biodiversity is incorporated as the ecological aspect in this dissertation in order to ensure sufficient services from the ecosystem. Among various ecosystem services closely related to biodiversity, I focus on biological regulating services and use relevant taxa (birds and insect pollinators) that are strongly influenced by landscape configuration as well as local environmental conditions, in order to understand an appropriate spatial arrangement of natural and human-modified ecosystems to establish sustainable rural landscape management. I adopt indirect assessment in ecological aspect assuming positive correlation between biodiversity and degrees of ecosystem services. Species richness of the total and each functional group of birds and insect pollinators among different landscape elements across the gradient of forest–agricultural landscape are the parameters of biodiversity used in this dissertation. Bird functional grouping are based on habitat specialization types and feeding guilds to indicate ecosystem functioning by acting as pollinators, predators, seed dispersers, and ecosystem engineers. Insect pollinators are classified into efficient and less efficient pollinators to further focus indicating the pollination services. The influence of local and landscape factors to the species richness and that of in each functional group of bird and insect pollinators are quantitatively analyzed in this dissertations, as the information to elucidate an appropriate spatial arrangement for sustainable rural landscape management that ensures sufficient supply of multiple services provided by ecosystems, and, at the same time, maintain biodiversity (**Figure 1.1**).

In this dissertation, ecosystem is defined as each landscape element found in a gradient from forest to agricultural landscape in West Java, Indonesia. The forest–agricultural landscape of the study is that commonly found in Indonesia.

Based on the aforementioned framework, in details this study was to:

(a) Assess perceptional differences among landscape elements used and perceived as sources of ecosystem services

- Identify what types of ecosystem services and associated landscape elements as sources of services are actually utilized and perceived by rural people
- Quantify how particular socioeconomic factors affect the perception of ecosystem services
- Assess changes of perceived landscape elements as sources of each ecosystem service along a gradient from forest to agricultural landscape

(b) Assess the diversity of birds

- Investigate general patterns of bird species composition and diversity among landscape element types

- Quantify environmental factors (landscape element types, vegetation covers and structures, and proximity to the remnant forest) determining total species richness and that of endemic species, each habitat specialization type, and each feeding guild group

(c) Assess the diversity of insect pollinators

- Investigate general patterns of insect pollinators' species composition and diversity among landscape element types
- Quantify environmental factors (landscape element types, vegetation covers and structures, and proximity to the remnant forest) determining total species richness and that of efficient (bees and wasps) and less efficient pollinators (moths, butterflies, flies, and beetles)

(d) Integrate the findings of social and ecological assessments with regard to their implications for the spatial arrangement of landscape elements to establish a conceptual plan for sustainable management of a human-dominated landscape that both enhances the provision of multiple ecosystem services and maintains biodiversity

1.4. Expected results

It is expected that the results of this dissertation can elucidate changing patterns of rural people's perceptions, species compositions and diversity of birds and insect pollinators along the gradient from forest to agricultural landscape as a basis for actual landscape management plans in a human-dominated landscape that will accommodate sustainable utilization of the multiple services provided by ecosystems and, at the same time, maintain biodiversity. This study is also expected to contribute in the harmonization between nature and human well-being in Indonesia where ecosystem services and biodiversity play an essential role in poverty alleviation.

1.5. Structure of dissertation

Overall, this dissertation consists of five chapters. The first chapter (this chapter) describes background of the study and elaborates the research problem, which is the need to integrate social and ecological assessments of ecosystem services at the landscape scale. In this chapter, the framework of the study is also developed and research methods are presented.

Following the introduction chapter, the next three chapters describe the socio-ecological assessment of ecosystem services at the landscape level (**Figure 1.1**). Chapter 2 describes the social dimension, which assesses the local people perceptional differences in the landscape elements used and perceived as sources of ecosystem services. In more details, the Chapter 2 describes what types of ecosystem services and associated landscape elements as source of services are actually utilized and perceived by rural people, and influential socio-economic factors of individual people determining the degree of perceived ecosystem services, and the difference of utilized and perceived landscape elements as sources of ecosystem services. Chapters 3 and 4 describe the ecological dimension, which assesses the diversity of bird community (Chapter 3) and insect pollinators (Chapter 4). These two chapters describe general patterns of bird and insect pollinator species composition and diversity among landscape element types, and influential environmental factors determining the species richness of birds and insect pollinators.

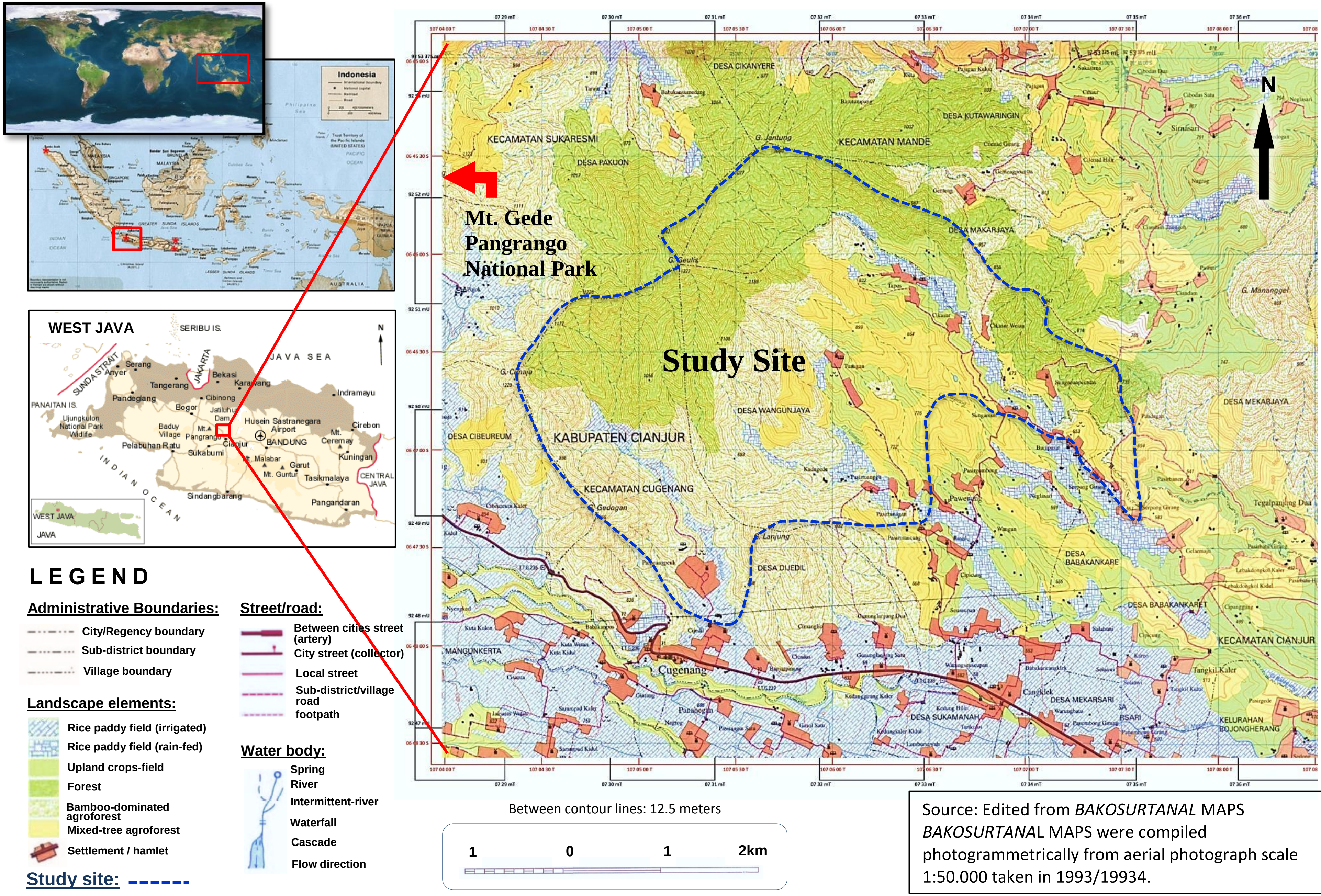
The last chapter (Chapter 5) provides the general discussion, integration, conclusions, and recommendations. This last chapter integrates the findings revealed in the chapters 2, 3 and 4 with regard to their implications for the spatial arrangement of landscape elements to provide recommendations in establishing a conceptual plan for sustainable management of a human-dominated landscape that both enhances the provision of multiple ecosystem services and maintains biodiversity.

1.6. Materials and methods

1.6.1. Study area

The study was conducted in a forest–agricultural landscape in West Java, Indonesia (lat. 06°45′28″ to 06°47′53″S, long. 107°04′18″ to 107°07′39″E), about 7 km from Gunung Gede Pangrango National Park, which has been declared by UNESCO as part of the World Network of Biosphere Reserves (**Figure 1.2**). The site is located at an elevation of 600 to 1300 m above sea level on Neogene hills. The mean daily temperature is about 22 °C and the daily maximum temperature ranges from 25 to 30 °C. The annual precipitation is approximately 2000 mm, with a rainy season (October to June) and short dry season (July to September). The forest–agricultural landscape of the study area consists mainly of remnant forest, tree plantations, agroforests, agricultural areas, and residential areas. The majority of the population is engaged in agricultural related activities. In about eighteen small settlement areas (hamlets) there are around 293 heads of households engaged in agriculture as their main or secondary occupation. Although, besides farming, some of them also engaged in other off farm activities, such as small-scale trade, construction labor during the dry season, and other jobs particularly during slow season on their farms. Most of them also raised livestock such as sheep, goat, chicken or water buffalo.

The remnant forest is located mainly on hilltops and covered an area of about 280 ha. The forest is not protected, but it is conserved under the management of the Regional State-owned Forest Enterprise (Perum Perhutani) of Cianjur (PP KPH Cianjur 2011a). The forest vegetation is typical Javanese lowland and montane forest dominated by *Schima wallichii*, *Dysoxylum* spp., and *Sterculia coccinea*, to a height of over 30 m (**Table 1.1**). The dominant species in the mid- and understory are mainly *Calliandra calothyrsus*, an exotic species planted as a buffer to protect the forest and provide fuelwood for local residents, and *Oreocnide rubescens*, a species representative of secondary forests. This indicated that the forest had been influenced by human activities such as selective logging and exotic species



Source: Edited from *BAKOSURTANAL* MAPS
BAKOSURTANAL MAPS were compiled photogrammetrically from aerial photograph scale 1:50.000 taken in 1993/19934.

Figure 1.2 Study site

Table 1.1 Vegetation characteristics based on means (± standard deviations) per sampling plot in each landscape element type (F: remnant forest, BP: broad-leaved plantation, NP: needle-leaved plantation, MT: mixed-tree agroforest, BT: bamboo-dominated agroforest, H: village settlement, U: upland crop field, P: rice paddy field)

Variable	Landscape element type							
	F (*n* = 22)	BP (*n* = 13)	NP (*n* = 11)	MT (*n* = 13)	BT (*n* = 13)	H (n = 13)	U (*n* = 12)	P (*n* = 15)
% vegetation cover:								
- Understory (<4.5 m high)	28.0 ± 9.0	41.9 ± 8.1	40.0 ± 8.1	32.7 ± 7.0	32.7 ± 6.0	30.8 ± 4.0	32.5 ± 6.2	77.3 ± 7.5
- Midstory (4.5 to 15 m high)	32.9 ± 6.5	29.6 ± 9.5	29.1 ± 10.4	47.3 ± 10.3	60.4 ± 9.9	28.5 ± 4.3	61.25 ± 9.8	19.0 ± 5.1
- Canopy (15 to 30 m high)	59.3 ± 7.6	48.9 ± 8.9	47.7 ± 9.8	22.3 ± 15.8	3.9 ± 6.8	–	2.9 ± 5.4	–
- Emergent (>30 m high)	4.6 ± 8.4	–	–	–	–	–	–	–
Tallest tree height (m)	29.2 ± 2.5	26.8 ± 1.8	26.8 ± 1.8	22.9 ± 4.1	16.9 ± 2.3	14.0 ± 2.2	7.6 ± 2.3	8.9 ± 2.0

invasion from the forest edge. Nevertheless, the forest still seemed to function as a native forest habitat, as indicated by the presence of many primates, such as the silvery gibbon (*Hylobates moloch*), Javan surili (*Presbytis comata*), and Javan lutung (*Trachypithecus auratus*), and other large mammals such as the Javan leopard, leopard cat, Java mouse-deer, and black giant squirrel, all of which were found during field observations in the forest; most of these are listed as critically endangered or near-threatened species (IUCN 2012) and are protected by Indonesian government regulation No. 7/1999 (PP KPH Cianjur 2011b). Therefore, I considered the forest as a quasi-natural remnant forest.

The landscape elements adjacent to the remnant forest are two types of mature tree plantations (mostly more than 15 years old) managed by the Regional State-owned Forest Enterprise of Cianjur (PP KPH Cianjur 2011a). One type is a broad-leaved plantation dominated by *Altingia excelsa* and *Maesopsis eminii* and the native tree *Schima wallichii* used for timber production. The other type is a needle-leaved plantation dominated mainly by pine (*Pinus merkusii*) not only for timber use, but also for turpentine collection. However, broad-leaved tree species are sometimes planted in this type of plantation. Because the two plantations are mature and managed extensively, the mid- and understory vegetation was well developed (**Table 1.1**), but similar to the case of the remnant forest they are dominated by *Calliandra calothyrsus*, with other secondary-grown trees such as *Macaranga rhizinoides*.

Human-dominated landscapes are located at lower parts of the tree plantations. Small settlement areas (hamlets) are scattered along foothills of dissected valleys from up to downstream. Rice paddy fields are located on the bottoms of these valleys. Some of rice paddy fields are rain–fed and mostly harvested two times in a year; and some others are irrigated which can be harvested up to three times in a year. The vegetation structure of rice paddy fields is simple; most of the area is open with some crops, shrubs, and trees on the dike. Then, agroforests are another landscape element on the hillslopes, which are common agroforestry systems in West Java, Indonesia, and are locally called *talun* or *kebon* *tatangkalan* (Christanty et al. 1996; Parikesit et al. 2005). In general, Javan agroforests consist of trees that produce fruits, vegetable crops, industrial crops such as coffee and cloves, timber, and bamboos used for various purposes, including as construction materials, fuel, and support for climbing crops (Okubo et al. 2010). However, crop composition varies among gardens; because the gardens are privately owned, the types of crops cultivated are determined by each owner's preferences (Okubo et al. 2010, 2012). In accordance with the definition of Okubo et al. (2010), the agroforests in my study area are classified into bamboo-dominated and mixed-tree agroforests on the basis of plant species composition. The bamboo-dominated agroforests are dominated by mostly bamboos (*Gigantochloa apus* and *Gigantochloa verticillata*) and some timber and fruit trees (*Maesopsis eminii* and *Artocarpus heterophylla*), whereas the mixed-tree agroforests are dominated by fruit trees (*Parkia speciosa*, *Durio zibethinus*, *Nephelium lappaceum*, *Persea americana*), fast-growing timber trees (*Paraserianthes falcataria* and *Maesopsis eminii*), and industrial crops such as cloves and coffee. The vegetation structure of the bamboo-dominated agroforests is relatively simple, and the vegetation height is lower than remnant forest and tree plantations (**Table 1.1**). Upland crop fields are intermixed with agroforests on hillslopes. Local people mainly cultivate upland rice and a mixture of garlic (*Allium sativum*), chives (*Allium schoenoprasum*), chili (*Capsicum annuum* and *C. frutescens*), black nightshade (*Solanum nigrum*), maize (*Zea mays*), groundnut (*Arachis hypogaea*), cassava (*Manihot esculenta*), and banana (*Musa* spp.). Some timber and fruit trees (such as Paraserianthes falcataria, Artocarpus heterophylla, and Parkia speciosa) on the side parts of the lands plant some upland crop fields. Although small amounts of chemical fertilizers and pesticides are used, the upland areas under cultivation are not intensively managed. The vegetation structure of rice paddy and upland crops fields are the most simple and mostly consist of open area and the vegetation height of both landscape element types are the lowest (**Table 1.1**).

1.6.2. Methods for social aspect on rural people's perception towards ecosystem services and associated landscape elements as source of ecosystem services

1.6.2.1. Data collection

Data on rural people's perceptions of ecosystem services were collected by means of structured interviews with the local population. The population was sampled by means of simple random sampling from a list of the heads of households engaged in agriculture as their main or secondary occupation. From the total of 293 households in the study site, I sampled 138 households (47%). The sample was distributed among the 18 clusters of houses (hereafter, "hamlets") in the study area in proportion to their residential area (**Figure 1.3**). From 4 to 13 sampled respondents were randomly distributed in each hamlet.

Most of the heads of the sampled households were men (5 women and 135 men), and the age range was 30 to 76 years (mostly 40 to 60). Most of the respondents (80%) were originally born in the same hamlet or village, but all of them had lived in the present hamlet or village for more than 10 years. Twelve percent did not have any formal education, 77% had attended elementary school, and 11% had a higher education level. Fifty-seven percent of the respondents devoted themselves to agricultural activities as their main source of income; among them, 15% were agricultural laborers. The other respondents engaged in small-scale trade (25%), construction labor during the dry season (i.e., slow season on their farms; 12%), and other jobs (5%). Almost all (95%) owned agricultural lands (e.g., paddy fields and upland crop fields), ranging from 0.02 to 1.5 ha in area. Sixty-eight percent owned agroforests (0.1 to 3 ha), and 55% raised livestock, with each having two to six head of sheep, goat, and/or water buffalo.

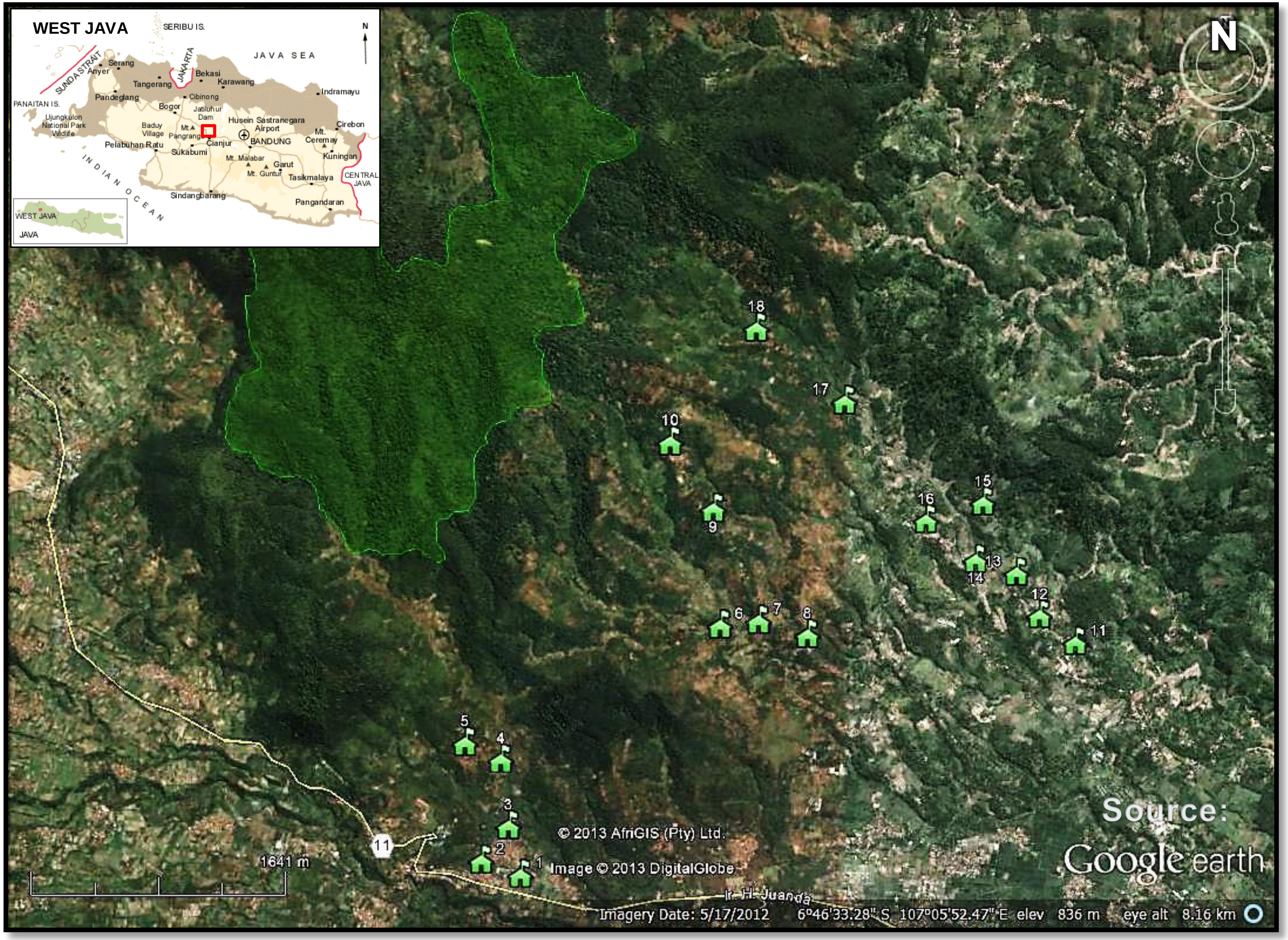


Figure 1.3 Location of interview survey to the local people in 18 hamlets

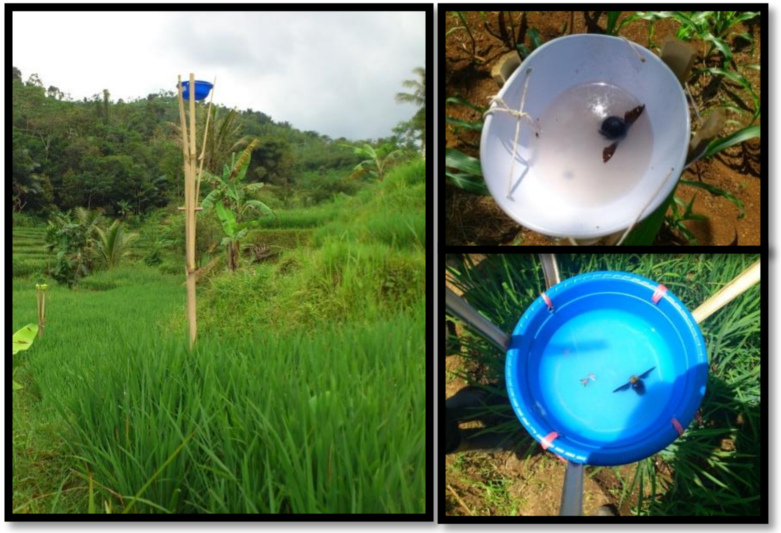
Before beginning face-to-face structured interviews, I conducted semi-structured interviews with 12 key informants (e.g., heads of hamlets, knowledgeable farmers) from different hamlets in order to identify ecosystem services that were actually beneficial and appreciated by local people, as well as the landscape elements that provide each ecosystem service. Based on previous studies (e.g., De Groot et al., 2002; Fisher et al., 2009; Millennium Ecosystem Assessment, 2005; Wallace, 2007) and results from the key-informant interviews, the ecosystem services and landscape elements were formulated for the face-to-face interviews. A total of 23 direct and indirect ecosystem services were identified. Direct ecosystem services represent the goods and resources used from their surrounding landscapes, such as food, fodder, energy, timber, craft materials, and medicinal materials. Indirect services represent the more abstract services that people perceived, such as regulation of climate, air, water, and soil; protection from erosion, landslides, flooding, and strong winds; provision of habitat for pollinators, natural enemies of crop pests, and seed dispersers (particularly for fruits trees); a place for observing wildlife and participating in games, sports, and other forms of recreation; and the enhancement of spiritual, cultural, and aesthetic values. To test the suitability of the structured interview design, I conducted a pretest of the interview in randomly selected clusters of houses.

The face-to-face interviews were conducted while visiting each respondent's house from September 2011 until February 2012 (**Figure 1.4a**). Each respondent was asked a set of questions related to his/her appreciation of the 23 ecosystem services as well as which landscape elements were the sources of each ecosystem service. The answer for whether an ecosystem service was appreciated was binary (yes or no, with "not sure" counted as no). For each direct ecosystem service that a respondent appreciated, I asked him/her to identify the landscape elements (remnant forest, tree plantation, agroforest, and agricultural land) that provide that service; respondents were allowed to choose more than one. In the case of indirect services, I asked each respondent what the important or necessary places were to obtain the benefit. In addition to the questions related to ecosystem services, I collected the following information for each sampled household: the area of agricultural lands and agroforests; the number of livestock; and the individual attributes of age, sex, educational background, place of origin, duration in the present hamlet, and main and secondary occupations. During the interviews, ecosystem services were always referred to as “the benefits that you can get from the surrounding landscape elements (including forest)” to make the term more understandable and to avoid educational biases (as done by Martín-López et al., 2012). In addition, to minimize the bias from the tendency of people telling us what they thought I wanted to hear (Sheil and Wunder, 2002; Sodhi et al., 2010b), I asked questions about their daily natural resource use and dependency on the surrounding landscape. I did not have preconceived expectations and considered that people would be unaware of ecosystem services (Kremen et al., 2008; Sodhi et al., 2010b). All the interviews were conducted in *Bahasa Sunda* (local language for the people in West Java) in order to ensure locally relevant answers to the questions. Local words were also used to avoid technical terminology.

To identify the geographic locations of each hamlet in the context of the gradient from forest to agricultural landscape, I chose proximity to the remnant forest as an indicator of accessibility to forest resources. I used a land-use map derived from an orthorectified QuickBird satellite image (0.6-m resolution in the pan-sharpened image) taken on 9 September 2011 to calculate the distance to the remnant forest, which was measured as the closest distance from the edge of each hamlet to the nearest forest margin.

(a)

(b)



(c)

Figure 1.4 Field sampling of: **(a)** interview survey to the local people; **(b)** bird survey; **(c)** pan traps

1.6.2.2. Data analysis

To elucidate which socioeconomic factors affect people's perceptions of ecosystem services, I chose generalized linear models (GLMs) with a logit (logistic regression) link function that followed a binomial distribution. I set the number of all perceived ecosystem services and the perceived direct and indirect ecosystem services as separate response variables. Explanatory variables were place of origin (i.e., born in the present village or hamlet or not), residential location (name of hamlet), level of formal education, and main occupation as nominal variables, as well as age (years), area of agroforest (ha) and agricultural land (ha) owned, and the number of ruminant livestock owned. To allow for uncertainty in the choice of the best model, I opted for multi-model inference and model averaging based on the Akaike information criterion corrected for small sample bias (AICc; Burnham and Anderson, 2002). For each analysis, the full model, null model, and models with all valid combinations of the explanatory variables were generated, and I then computed the ΔAICc values, which showed the difference between the value for the best model (i.e., with the smallest AICc) and those for the remaining models. Model-averaged estimated coefficients (AECs) for the explanatory variables were obtained by computing the means and standard errors of the estimates weighted by the Akaike weight of each plausible model. The Akaike weight is an indicator of the strength of evidence that the selected model is convincingly the best. The sum of the Akaike weights of models that included a particular parameter was used as the weight of evidence of the relative importance of that variable (IoV). To identify the effect of multicollinearity, I also calculated the variance inflation factor (VIF) value for each explanatory variable included in the model. If a variable had a VIF >10 in a model, then the models including that variable were excluded from model averaging.

Next, I evaluated how the accessibility of the remnant forest affects which landscape elements are perceived as the source of each ecosystem service among different local people. Respondents were classified into two groups based on proximity of their hamlet to the remnant forest, with a threshold distance of 1.5 km, which was chosen to divide the number of the respondents evenly between the groups. The “close” group consisted of 71 respondents, and the “far” group consisted of 67 respondents. Fisher’s exact test was used to compare the differences in the proportion of perceived landscape elements for each ecosystem service between the two groups.

All statistical analyses in the social aspect of this study were performed with R software version 2.15.1 (R Development Core Team, 2012), with additional functions provided by the R package MuMIn for GLM and multi-model inference and model averaging.

1.6.3. Methods for ecological aspect on birds and insect pollinators

1.6.3.1. Data collection

a. Bird survey

Bird surveys were performed from 10 October 2011 to 28 March 2012 in accordance with a standardized observation method using point counts proposed by Bibby et al. (2000). I defined 112 sampling plots of point counts arbitrarily from a map derived from an orthorectified QuickBird satellite image (0.6 m resolution in pan-sharpen image) taken on 9 September 2011, and I aimed to sample all landscape element types in proportion to their actual occurrences in the forest–agricultural landscape. The sampling plots were at least 200 m apart from each other. Admittedly, a distance of 200 m to the nearest sampling plot may not have always been sufficient to ensure data independence. I therefore recorded only birds within a radius of 50 m of the center of each sampling plot, and I ensured that I did not double-count birds that were identifiable as moving between two plots. I surveyed 112 plots, consisted of 22 plots in the remnant forests (hereafter referred to as F); 13 in the broad-leaved plantations (BP); 11 in the needle-leaved plantations (NP); 13 in the mixed-tree agroforests (MT); 13 in the bamboo-dominated agroforests (BT); 12 in upland crop fields (U); 15 in rice paddy fields (P); and 13 in settlements or hamlets (H) (**Figure 1.5**).

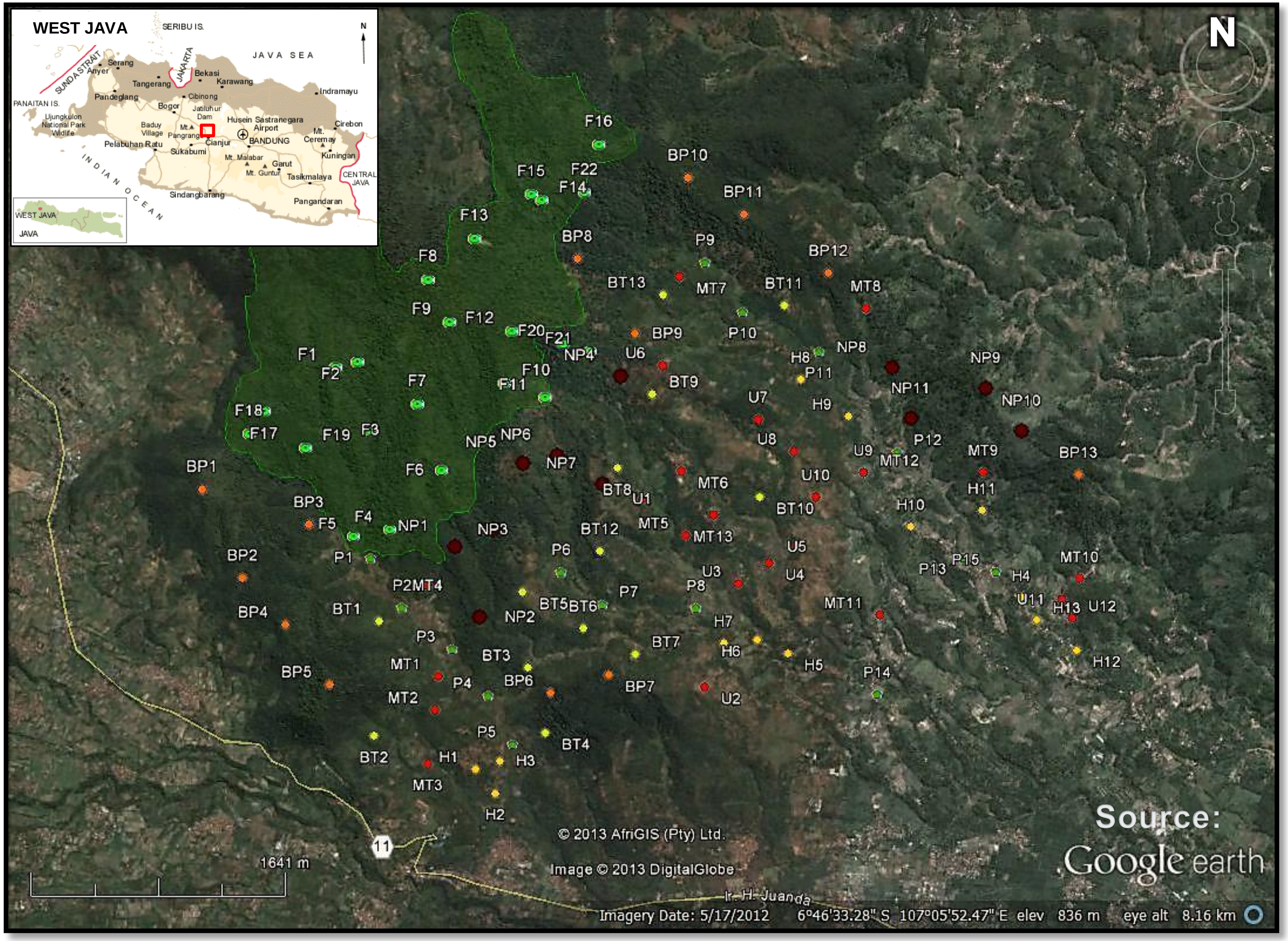


Figure 1.5 Plots of bird survey in each landscape elements (F: remnant forest; BP: broad-leaved plantation; NP: needle-leaved plantation; MT: mixed-tree agroforest; BT: bamboo-dominated agroforest; U: upland crop field; P: rice paddy field; H: settlement/hamlet)

All bird surveys were conducted from 06:00 to 09:30 h, but only when the weather was fine (e.g., no precipitation or strong wind). All bird samplings were conducted by the same two experienced bird experts and the author (D. Muhamad) with the help of local villagers (**Figure 1.4b**). For each plot, all visual and acoustic detections within a period of 20 min were recorded. A digital rangefinder was used to measure and estimate distance, and all observations beyond 50-m radius were discarded in the analysis of each site. To avoid hour-counting bias in the sampling (Leyequién et al. 2009), I alternated the order of the point counts at every visit, with a total of six visits to every plot. The observers did not count birds that were flying over or through the count areas. The bird nomenclature followed that of MacKinnon et al. (2010) and Sukmantoro et al. (2007).

Although mist-netting has been recommended for surveying tropical understory birds, especially cryptic species (Arriaga-Weiss et al. 2008), I considered its use impractical for this study. I admit that visibility differences among the landscape element types could have biased my data, but I attempted to minimize this bias by using no more than a 50-m radius of observation in each sampling plot, by scanning dense vegetation extensively, and by identifying calling birds. Moreover, because there were open areas in all landscape element types, I could clearly see the boundaries of all of the sampling areas. Use of this fixed area survey method can make cross-habitat comparisons possible and reduces the biases that result from uneven visibility (Thiollay 1997; Sekercioglu 2002).

b. Insect pollinators' sampling

Insect pollinators were collected by a common passive sampling method using pan traps (Kearns and Inouye, 1993; Southwood and Henderson, 2000, Dafni et al. 2005; sampling protocol in The Bee Inventory Plot, available online). According to Westphal et al. (2008) pan traps is an efficient methods in natural as well as human-modified landscape elements even compared to other sampling methods such as transect methods using swift net, observation plots, and trap nets. Data collections for insect pollinators were performed from 11 June 2012 to 9 September 2012, which was still within the flowering periods of the most mass-flowering crops and fruiting trees in Indonesia.

I set up yellow, white, blue, and red pan traps, which represented prevailing floral colors in my study site to account for different color preferences of insect pollinators (Toler et al., 2005; Campbell et al., 2007; Westphal et al., 2008). Since pan traps have a higher efficiency when they are UV-bright (Stephen and Rao, 2005), I painted 500-mL plastic soup bowl with UV-bright yellow, white, blue, and red. I established 316 pan traps in 79 plots put in the same location of plots for bird survey. Each plots containing 4 different colors bowls at a distance of 5 m. There were 8 plots in F, 6 in BP, 9 in NP, 12 in MT, 13 in BT, 11 in U, 13 in P, 7 in H (**Figure 1.6**). Pan traps were mounted on a bamboo pole in understory vegetation (± 1.5 m high), filled with 400 mL of water and a drop of detergent and flower scent of cloth's deodorizer, then left active for 48 hours (**Figure 1.4c**). I collected the specimens of insect pollinators from pan traps in every 24 hours and at the same time I changed the water in the pan traps with the new ones. The collected specimens were temporarily stored in 70% ethanol until pinned for identification. Specimens' identification was performed in Zoology Division (Museum of *Zoologicum Bogoriense*), Research Center for Biology, Indonesian Institute of Science (LIPI or *Lembaga Ilmu Pengetahuan Indonesia*).

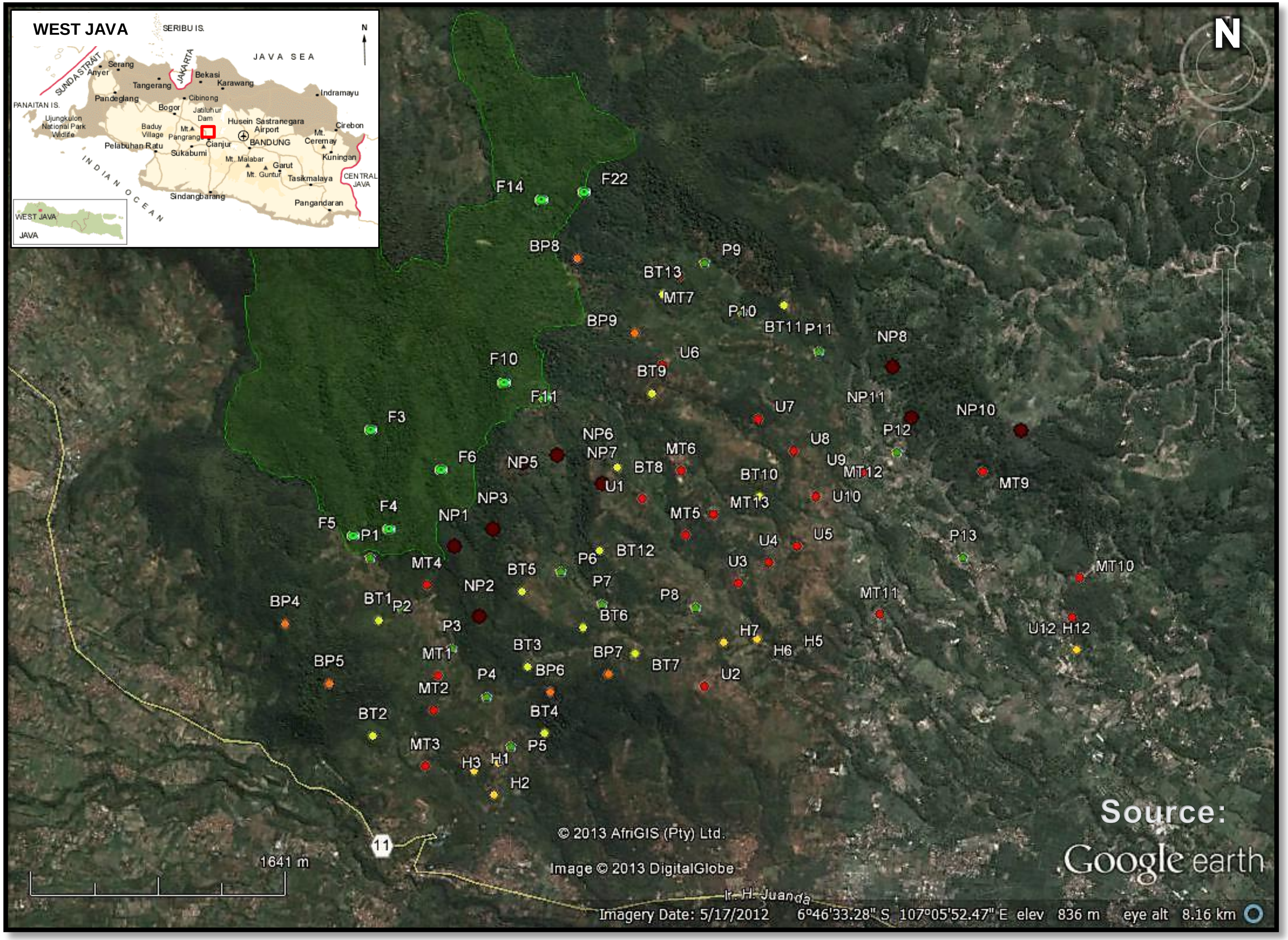


Figure 1.6 Plots of insect pollinators sampling in each landscape elements (F: remnant forest; BP: broad-leaved plantation; NP: needle-leaved plantation; MT: mixed-tree agroforest; BT: bamboo-dominated agroforest; U: upland crop field; P: rice paddy field; H: settlement/hamlet)

c. Vegetation survey

Birds respond well to variations in vegetation cover and structure (Hughes et al. 2002; Sekercioglu 2002; Walther 2002; Sodhi et al. 2005) as well as insect pollinators to floral resources (Borror et al. 1989; Michener, 2000) and to the changes in plant species composition represented by different types of landscape elements. I therefore measured vegetation cover and structure within circles of the same radius as the bird-sampling plots (50 m). Within these areas, I visually estimated the overhead percentage foliage covers of emergent layers (>30 m high), canopy (30 to 15 m), midstory (4.5 to 15 m), and understory (<4.5 m). At the sampling points, I visually estimated foliage cover by making an imaginary circle divided into quadrants representing the four cardinal directions (i.e., north, south, east, and west); the readings from each quadrant were averaged for each sampling plot. I also measured the height of the tallest tree in each plot, and I inventoried the dominant species in each point count. As the results of vegetation survey, average of each sampling plot describing vegetation characteristics in each landscape element type were presented in **Table 1.1**.

d. Proximity to nearest forest margin

As the major important landscape-scale determinant of species richness (Tscharntke et al. 2008) of birds (Anand et al. 2008; Estrada et al. 1997; Greenberg et al. 1997b; Laurance 2007; Luck and Daily 2003; Naidoo 2004; Zurita and Bellocq, 2010) and insect pollinators (Kremen et al., 2002; Klein et al., 2003a; 2006; Olschewski et al. 2006; Ricketts et al., 2004; 2008; Steffan-Dewenter et al. 2002), I used the QuickBird map mentioned above to measure the proximity to the nearest forest margin as the distance from the edge of each sampling plot to the nearest remnant forest margin. In the case of sampling plots in the remnant forest, I measured the distances to the nearest forest margin as negative values to account for any edge effect. The range of proximities to the nearest forest margin was –1.0 to –0.1 km for the sampling plots in F, 0.1 to 2.0 km for BP, 0.2 to 1.8 km for NP, 0.2 to 2.9 km for MT, 0.4 to 1.6 km for BT, 0.4 to 3.0 km for U, 0.1 to 3.1 km for P, and 1.1 to 3.2 km for H.

e. Functional groups of bird and insect pollinator species

I classified the observed bird species into several functional groups on the basis of biogeographical distribution, habitat specialization, and primary diet (feeding guild). To assign the bird species to these functional groups, I extracted the information from a bird field guidebook by MacKinnon et al. (2010) and a list of birds in Indonesia by Sukmantoro et al. (2007). For biogeographical distribution, I extracted data on the species endemic to Indonesia in order to assess the conservation value of quasi-natural (the remnant forest) and other elements in human-dominated landscape. For habitat specialization, I classified all species into forest specialists (primarily preferring forest interiors), forest-edge species (preferring forest edges, gaps, or woodlands), forest generalists (preferring forests, forest edges, and woodlands, and often visiting cultivated areas), and open-habitat generalists (primarily preferring open areas, grasslands, shrubs, cultivated areas, or settled areas). For feeding guilds, I classified all species into carnivores, frugivores, granivores, nectarivores, insectivores, or omnivores. Because the number of insectivorous bird species was much higher than that of other feeding guilds and included many different functional groups (as determined by behavior when foraging), I further classified insectivores into subgroups, namely bark-gleaning, canopy-foliage-gleaning, understory-foliage-gleaning, ground-gleaning, and sallying insectivores.

For insect pollinators, I classified all species into several groups based on their taxonomy in relation to their efficiency in pollination. I grouped the order Hymenoptera of bees (superfamily Apoidea) and wasps (suborder Apocrita that is neither bees nor ants) as efficient insect pollinators, with bees as the most efficient of all. Bees are typically fuzzy and carry an electrostatic charge. Both features help pollen grains adhere to their bodies, but they also have specialized pollen-carrying structures. In most bees, this takes the form of a structure known as the scopa, such as of megachilid bees; or corbicula or “polen basket” in honeybees and their relatives (McGregor, 2011). Wasps are also responsible for the pollination of several plants species, being important pollen vectors and, in some cases, efficient pollinators even more than bees (FAO, 1995; McGregor, 2011; Momose et al., 1998). Although the majority of wasps are predatory that preys on other insects, as adults, wasps may use nectar and pollen for food and pollinate as a result of their feeding such as paper wasps and potter wasps (McGregor, 2011). Furthermore, I devided the efficient insect pollinators into pollinators known to be mostly pollinating annual and perennial crops, and others. For bees, I classified them into solitary and social ones, because these groups of bees have different efficiency in pollinating activities; solitary bees are often oligoleges that make them more efficient pollinator than social bees, because they only gather pollen from one or a few species/genera of plants, unlike social honeybees, which are generalists. Other insect pollinators such as the order of Coleoptera (beetles), Lepidoptera (butterflies and moths), and Diptera (flies), which are known to be less active on visiting flowers to consume nectar, pollen, and other flower parts (FAO, 1995; McGregor, 2011), were classified as less efficient insect pollinators. In order for the groupings, I referred to Borror et al. (1989), FAO (1995) and McGregor (2011).

1.6.3.2. Data analysis

For each sampling plot of bird survey, I merged the data from six observation times by summing the abundance of each bird species. Similarly, for each sampling plot of insect pollinator sampling, I merged the data collected from the two times of every 24 hours collection and from the four different colors of pan traps by summing the abundance of each insect pollinator’s species. For the bird community analysis, I calculated the abundance and species richness of all observed birds, species endemic to Indonesia, each habitat specialization group, and each feeding guild, as well as of each subgroup of insectivores. For the insect pollinator analysis, I calculated the abundance and species richness of all identified species, efficient and less efficient insect pollinators, bees, social and solitary bees, and efficient pollinators on crops. I also calculated Simpson's diversity index for all species of both birds and insect pollinators for each plot, as follows:

$$\text{Simpson's diversity index} = 1 - \sum_{i=1}^{N} P_i^2$$

where P_i is the relative individual density (the proportion of the total number of individuals accounted for by a species) for species *i* in a sampling plot, for a total of *N* species.

To determine the general status of each bird and insect pollinator diversity, I first compared the species richness and Simpson's diversity index of the total number of species and the species richness values of ecological groups among all landscape element types by using the Kruskal-Wallis test followed by a Wilcoxon pairwise test. Because there were limitations on the sampling, some species were not observed. I thus estimated the true species richness for the whole study site and for each landscape element type by using three different non-parametric species estimators, namely first- and second-order jackknifes and a bootstrap (Palmer 1990). These estimators account for heterogeneity in the probability of detecting different species in different habitat types, and they are appropriate for point-count data on species-rich communities in heterogeneous landscapes (Boulinier et al. 1998).

Second, I performed a non-metric multidimensional scaling (NMDS) by using a table of species and sampling plots with the abundances in each in order to investigate the general patterns of bird and insect pollinator species composition in the remnant forest and other human-modified ecosystems. The NMDS is considered to be the most effective ordination method for ecological community data, whereby sample units are positioned according to the association among species and are not constrained by previously selected environmental variables (McCune and Grace 2002; Peh et al. 2006). It is also commonly regarded as the most robust unconstrained ordination method in community ecology (Minchin 1987). For both bird community and insect pollinator, I used random starting configurations and the Sørensen (Bray-Curtis) dissimilarity index as a distance measure (Bray and Curtis 1957).

To quantify the simultaneous effects of all three determinant factors (landscape element type, vegetation cover and structure, and proximity to forest margins) on the total species richness and that of each functional group in bird community as well as in insect pollinators, I chose generalized linear models (GLMs) with a logarithmic link function that followed a Poisson distribution. For the analysis of bird community, I set richness values for all species, species endemic to Indonesia, forest specialists, open-habitat generalists, each of six feeding guild groups, and each of five subgroups of insectivores as response variables separately. As for the analysis of insect pollinators, I set richness values for all species, efficient and less efficient insect pollinators, bees, social and solitary bees, and efficient crop pollinators as response variables separately. I used the same explanatory variables for both bird community and insect pollinators, which consisted of landscape element type as a nominal variable; proximity to the nearest forest margin (km); percentage vegetation covers in the canopy, midstory, and understory layers. The height of the tallest tree was excluded in the analysis because of the effect of multicollinearity.

To incorporate spatial autocorrelations, I applied a trend surface analysis in all GLMs (Legendre 1993) for birds and insect pollinators. This analysis has two primary aims. The first is to guard against false correlations between species and environmental determinant factors, as may arise when an unmeasured environmental factor causes a common spatial structure in the species and in the measured environmental variables. The second is to determine whether there is a substantial amount of broad-scale spatially structured variation in the species data that is unexplained by the measured environmental variables. In accordance with the method of Lichstein et al. (2002), I added all nine third-degree polynominal terms of the geographic coordinates (x, y, x^2, y^2, xy, x^3, y^3, x^2y, and xy^2, where x and y are longitude and latitude, respectively) of each sampling plot as explanatory variables in the GLM, together with environmental variables. Before the analysis, the geographic coordinates of longitude and latitude for each sampling plot were centered on their respective means to reduce collinearity with higher order terms (Lichstein et al. 2002).

To allow for uncertainty in the choice of the best model, I opted for multi-model inference and model averaging based on the Akaike information criterion corrected for small sample bias (AICc; Burnham and Anderson 2002). For each analysis, the full model, the null model, and models with all valid combinations of the explanatory variables were generated, and ΔAICc values that showed the difference between the values for the best model (i.e., with the smallest AICc) and those for the remaining models were computed. Model-averaged estimated coefficients (AECs) for the explanatory variables were obtained by computing the means and standard errors of the estimates weighted by the Akaike weight of each plausible model. The Akaike weight is an indicator of the strength of evidence that the selected best model is convincingly the best. The sum of the Akaike weights of models that included a particular parameter was used as the weight of evidence of the relative importance of that variable (IoV). To identify the effect of multicollinearity I also calculated VIF (variance inflation factor) values for each explanatory variable included in the model. If a variable showed a VIF of >10 in a model, the models including the variable were excluded from model averaging. Because of this effect of multicollinearity, the height of the tallest tree was excluded in the analysis.

All the numerical analyses in the ecological aspect in this study were performed with R software version 2.15.1 (R Development Core Team 2012), with additional function provided by the R package vegan for NMDS, and MuMIn and DAAG for GLM, and multi-model inference and model averaging.

1.6.4. Methods for integration of social and ecological aspects

In this dissertation, I adopted the widely used Driving Force or Driver – Pressures – State – Impact – Response (DPSIR) framework (European Environment Agency/EEA, 1999) to integrate the social and ecological assessments. I used the DPSIR concept because it provides a structure in which biophysical and societal indicators can be analyzed to set and evaluate targets and give a clear picture of progress in a number of policy areas (EEA, 1999; Rounsevell et al., 2010). Now, the DPSIR framework has been applied in ecosystem service assessment and biodiversity monitoring to capture and describe the relationships between society and the environment (Feld, et al. 2010).

As the basis for the integration of socio-ecological assessment using DPSIR framework, first I made the synthesis based on summaries from the results presented in Chapters 2, 3, and 4 that can help to understand what sorts of human-modified landscapes with fragmented forest remnants in developing country like Indonesia to maintain biodiversity while fulfilling the demands of local people for multiple ecosystem services and reducing poverty. The DPSIR framework itself, assumes cause–effect relationships between interacting components of social and ecological systems (Maxim et al. 2009; Rounsevell et al., 2010). Maxim et al. (2009) and Rounsevell et al. (2010) further explained that *Drivers* are the underlying causes of environmental change that are exogenous to the system or region in question, for example global and national social and economic developments. They reflect either past, present or future conditions that cause changes to ecosystem. *Pressures* are endogenous variables that quantity the effect of drivers within a system or region (Rounsevell et al., 2010), for examples regional population, land covers, or deforestation. What is defined as exogenous driver and endogenous pressure clearly depends on the location of the social-ecological system boundaries. Changing the location of this boundary by, for example, changing the spatial scale of observation may result in an exogenous driver becoming endogenous pressure. The notion of driver or a pressure is very much dependent, therefore, on the geographic extent of the system being considered (Rounsevell et al., 2010). Then, *State* variable represent the sensitivity of the system/sector to the pressure variables (Maxim et al., 2009). In this case, state involves the definition and quantification of all those elements relevant to the supply of the ecosystem service by biological organisms (ecological aspect) and the demand for ecosystem services from people (social aspect) (Rounsevell et al., 2010). Thus, states are made up of variables that describe the whole of the socioecological system. As for the *Impact*, it is a measure of whether the changes in the state variables have a negative or positive effect on individuals, society and/or environmental resources (Maxim et al., 2009; Rounsevell et al., 2010). In this dissertation, the negative or positive effect of are measured in relation to capacity to provide a given ecosystem service. Finally, *Responses* are through planned policy and management which aim to minimize negative impacts (or maximize positive impacts/benefits) by acting on the socio-economic pressure variables or directly on the state variables (Rounsevell et al., 2010). The different routes to minimizing impacts reflect different generic types of response strategies (Maxim et al., 2009; Rounsevell et al., 2010). Examples of this include policy measures to restrict rural development or restriction of people to enter or close the forest.

Chapter 2

Social aspect on rural people's perception towards ecosystem services and associated landscape elements as source of ecosystem services

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Title: "Living close to forests enhances people's perception of ecosystem services in a forest–agricultural landscape of West Java, Indonesia".

Authors: Muhamad, D., Okubo S., Harashina, K., Parikesit, Gunawan, B., Takeuchi, K.

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Chapter 3

Ecological aspect on the diversity of bird community

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Title: "Effects of habitat type, vegetation structure, and proximity to forests on bird species richness in a forest–agricultural landscape of West Java, Indonesia"

Authors: Muhamad, D., Okubo, S., Miyashita, T., Parikesit, Takeuchi, K.

Chapter 4
Ecological aspect on the diversity of insect pollinators

4.1. Introduction

Pollination is an ecological process essential for the maintenance of the viability and diversity of flowering plants and provides important ecosystem services to humans (Kevan, 1999; Klein et al., 2007; Vergara and Badano, 2009). In the world, an estimated 70% of the different types of world crops that are directly used for human consumption are dependent on animal-mediated pollination to some extent (Klein et al., 2007), and a conservative estimate of the value of this pollination service was $200 billion for 2005 (Gallai et al., 2009). There are also empirical evidences to support that the diversity of insect pollinator assemblages influences the reproduction and diversity of wild flowering plants (Biesmeijer et al., 2006), of which 87.5% are estimated to be animal pollinated worldwide (Bates et al., 2011; Ollerton et al., 2011). Insects, particularly bees, are thought as the most important group of pollinators worldwide (FAO, 2005; Klein et al., 2007; Kremen et al., 2007). The recent well documented declines in North America and Europe of the managed European honeybee (*Apis melifera*) and other insect pollinators, sometimes termed the 'pollination crisis', have been the subject of considerable media, public, political, and academic attention (Bates et al., 2011; Potts et al., 2010; Biesmeijer et al., 2006). Nevertheless, whether these declines will cause significant declines in crop and wild plant populations is the subject of some debate (Bates et al., 2011) and most authorities agree that this is an issue of global concern that deserves further research (Ghazoul, 2005; Ghazoul et al., 2010).

Although most flowering plants are generalists in terms of their pollination requirements, the global issue of pollination crisis had to be taking seriously. As natural ecosystems are continuously modified by human to fulfill their needs, there are increasing reports that insect pollinators are threatened by human landscape-modifications (Kremen and Ricketts, 2000; Ricketts, 2004). Particularly in humid tropical developing countries such as Indonesia, where most natural forest areas are embedded within a matrix of human-modified landscapes, this makes biodiversity in such regions likely to be influenced by surrounding human activities (Chazdon et al., 2009). In addition, the forest conversion to other uses and agriculture intensification are high, whereas people demands for foods and fibers are also high, therefore, this issue on pollination crisis cannot be taking for granted.

Loss of natural forests within human-dominated tropical landscapes may be of particular importance, because crop pollination by insect species is provided locally within a landscape, constrained by foraging range of pollinator species such as bees or wasps or beetles (Ricketts, 2004). It is well recognized that tropical forests provide a source of diverse bees and other taxa of insect pollinator communities, which enhance pollination of nearby crops (Ricketts, 2004). Maintaining pollinator habitats and pollinator diversity within human-modified landscape, therefore, is essential to ensure high ecosystem services including demands of food production, quality, and security.

Many studies have examined the roles and effects of human-modified tropical landscapes in the maintenance of insect pollinators. Previous studies have revealed that high levels of insect pollinator diversity are maintained in human-modified landscape elements, such as unshaded cacao monocultures and coffee plantations (Vergara and Badano, 2009; Klein et al., 2008) and shaded cacao and coffee agroforests (Tscharntke et al., 2008; Klein et al., 2003a; Hoehn, et al., 2008), although these landscape elements often have different species assemblages and lower species richness than those of the original forests (De Beenhouwer et al., 2013; Lonsdorf, et al., 2009; Tscharntke et al., 2008). Among different human-modified landscape elements, tropical agroforests that have vegetation structures similar to those of the original forests have been highlighted as alternative habitats for insect pollinators if they are close to the natural ecosystem (Kremen et al., 2002; Klein et al., 2003; 2006; 2008; Ricket et al., 2004; Olschewski et al., 2006; Tscharntke et al., 2008). Synthesizing 23 case studies, Ricketts et al. (2008) found general 'consensus': decline in pollinator abundance in crop fields with increasing isolation from natural or semi-natural landscape element. It appears that in human-dominated tropical landscapes, proximity to the nearest forest has shown to be a major configuration effect (Tscharntke et al., 2008).

Apart from human-modified landscape element types and proximity to natural forests, vegetation structure is also considered as an important environmental factor determining insect pollinator diversity and composition (Klein et al., 2003a; 2003b; 2006; Schulze et al., 2004; Bos et al., 2007; Tscharntke et al., 2008). In relation with insect pollinators, the vegetation structure represents the abundance and distribution of flower resources (Williams and Kremen, 2007; Tylianakis et al., 2008), species richness of flowering plants (Ghazoul 2006; Potts et al., 2006), availability of nesting sites and materials (Shuler et al., 2005; Kim et al., 2006) and light levels (Klein et al., 2003a; 2003b). Therefore, resource availability represented by variation in vegetation structure, the area or landscape element types, and isolation of natural habitats or proximity to nearest forests are key factors that may interact to determine insect pollinator composition and diversity in human-modified landscapes. Although some studies have quantified the combined effects of landscape element-type differences and proximity to forests (such as, Tscharntke et al. 2008), landscape element type differences and vegetation structure (such as, Lonsdorf et al. 2009), and vegetation structure differences and proximity to forest (such as, Klein et al., 2003; 2006), to my knowledge there have been no comparisons of different kinds of human-modified landscape element simultaneously with vegetation structure and proximity to forests in a gradient from forest to agricultural landscapes. This sort of integrated information would help to implement landscape management for maintaining insect pollinator diversity, as well as maintaining sufficient supply of foods and other ecosystem services.

This fourth chapter described the influences of all three environmental factors (landscape element type, vegetation structure, and proximity to the nearest forests) on the total insect pollinator species richness and species richness of various functional groups by comparison among different landscape elements in a human-modified landscape. By using the case of a forest to agricultural landscape with a highly fragmented forest remnant in West Java, Indonesia, the detailed objectives of this chapter are: (1) to understand the general patterns of insect pollinator species composition and diversity in a fragmented forest remnant and its surrounding landscape elements such as tree plantations, agroforests, agricultural lands, and settlements; and (2) to quantify the influences of landscape element type, vegetation structure, and proximity to forests on the total species richness and that of less efficient, efficient, and most efficient (bee) pollinators, solitary and social bees and wasps, and insect pollinator that mostly pollinating annual and perennial crops.

4.2. Results

4.2.1. General description of insect pollinator community

A total of 453 individual of 30 species of insect pollinators from 21 families were observed in the 79 plots of pan traps (**Table 4.1**). The most commonly found insect pollinators were (in descending order): *Onthophagus sp.*, *Apis cerana indica*, *Amegilla cingulata*, and *Apis dorsata*, all of which were recorded in all landscape element types. In total, there were 8 species of bees, 7 of wasps, 7 of beetle, 4 of moths/butterflies, and 4 of flies. The 8 bee species consisted of 3 social honeybees and 5 solitary bees. The 7 wasp species consisted of 4 social wasps and 3 solitary wasps. The 8 bee species, 3 wasps, 5 beetles, 1 moth/butterfly, and 4 flies are efficient crop pollinators, which are known to mostly pollinate annual and perennial crops (**Table 4.1**). Among all insect pollinators, there were 7 wasps, 3 beetles, and 1 fly that also functions as pest controllers. The species prey on crop pests. Most wasps feed their larvae with caterpillars, and ladybug beetle (*Coccinella* sp.) preys on mites. There was one predatory wasp (*Philanthus* sp.) that preys on bees for their larvae.

When I compared species richness, diversity, and abundance among the eight landscape element types (**Table 4.2**), species richness, abundance, and Simpson's diversity index based on the mean values for the sampling plots in each landscape element type differed significantly between F and MT (highest) and H (lowest). For species richness, the values of BP and NP were high-intermediate and that of BT, U, and P were low-intermediate between those for F and MT, and P, and did not differ significantly from each other. For total abundance in each sampling plot, BP, NP and P were high-intermediate and BT and U were low-intermediate for F and MT, and P, and did not differ significantly from each other. For Simpson's diversity index, BP, NP, BT, P and U were intermediate between MT and F, and H, and did not differ significantly from each other. The results of the species richness estimation based on the first- and second-order jackknife and bootstrap methods revealed that the insect pollinator community in the surveyed plots was almost completely recorded (99.9% in total for all landscape element types) (**Table 4.3**). When calculated for each landscape element type, it was lowest in H (81.8%) followed by P (82.9%), U (96.7%) and F (99.5%), indicating that the observed species richness in H and P was a little underestimated compared with those of the other landscape element types (**Table 4.3**).

Species richness of efficient and crop pollinators was highest in F followed by MT, and declined in H, whereas that of less-efficient and non-crop pollinators increased, particularly in H (**Figure 4.1a**). For the subgroups in the efficient pollinator group, a large decline in the species richness of crop pollinators was obvious between F and H. For the subgroups in the less efficient pollinator group, species richness of crop pollinators was low in F and H, and high in U and P (**Figure 4.1b**).

Table 4.1 List of all 30 insect pollinator species observed in 79 sampling plots using the pan-traps method, with percent frequencies of sampling plots where each species was found in each landscape element type (F: remnant forest, BP: broad-leaved plantation, NP: needle-leaved plantation, MT: mixed-tree agroforest, BT: bamboo-dominated agroforest, H: village settlement; U: upland crop field, P: rice paddy field)

Insect Pollinator	Family	Pollinator Category [a]	Landscape element type								
			F (*n* =8)	BP (*n*=6)	NP (*n*=9)	MT (*n*=12)	BT (*n*=13)	H (*n*=7)	U (*n*=11)	P (*n*=13)	**All (*n*=79)**
Bee:											
*Amegilla cingulata*91(blue banded bee) *, [SL]	Apidae	EP	0.75	0.50	0.33	0.50	0.31	0.15	0.18	0.14	**0.34**
Apis cerana indica (asiatic honey bee) *, [SC]	Apidae	EP	0.75	0.50	0.33	0.58	0.23	0.23	0.36	0.29	**0.39**
Apis dorsata (giant honey bee) *, [SC]	Apidae	EP	0.88	0.33	0.22	0.33	0.15	0.00	0.09	0.14	**0.24**
Xylocopa latipes (carpenter bee) *, [SL]	Apidae	EP	0.63	0.33	0.67	0.33	0.54	0.23	0.09	0.00	**0.35**
Xylocopa caerulea (carpenter bee) *, [SL]	Apidae	EP	0.38	0.17	0.11	0.25	0.15	0.15	0.00	0.00	**0.15**
Xylocopa confusa (carpenter bee) *, [SL]	Apidae	EP	0.38	0.33	0.11	0.17	0.15	0.08	0.00	0.00	**0.14**
Megachile sp.(leafcutter bee) *, [SL]	Megachilidae	EP	0.50	0.17	0.22	0.50	0.08	0.31	0.00	0.00	**0.23**
Nomia sp. (sweat bee) *, [SC]	Halictidae	EP	0.50	0.33	0.22	0.25	0.15	0.46	0.36	0.00	**0.29**

Insect Pollinator	Family	Pollinator Category [a]	Landscape element type								
			F (*n* =8)	BP (*n*=6)	NP (*n*=9)	MT (*n*=12)	BT (*n*=13)	H (*n*=7)	U (*n*=11)	P (*n*=13)	**All (*n*=79)**
Wasp:											
Campsomeris leefmansi (scoliid wasp) [SL, C]	Scoliidae	EP	0.63	0.33	0.44	0.00	0.00	0.00	0.00	0.14	**0.15**
Scolia sp. (scoliid wasp) [SL, C]	Scoliidae	EP	0.00	0.00	0.11	0.17	0.23	0.31	0.00	0.29	**0.15**
Polistes sagittarius (banded paper wasp) *, [SC, C]	Vespidae	EP	0.38	0.00	0.00	0.17	0.31	0.00	0.18	0.00	**0.14**
Ropalidia mathematica (small brown paper wasp) *, [SC, C]	Vespidae	EP	0.00	0.17	0.00	0.08	0.15	0.00	0.09	0.00	**0.06**
Allorhyncium argentatum (Indomalayan potter wasp) [SC, C]	Vespidae	EP	0.00	0.00	0.00	0.25	0.23	0.00	0.00	0.29	**0.10**
Eumenes architect (mason wasp) [SC, C]	Vespidae	EP	0.00	0.50	0.00	0.08	0.31	0.00	0.36	0.29	**0.18**
Philanthus sp. (beewolves) [SL, R]	Crabronidae	EP	0.00	0.00	0.33	0.17	0.00	0.54	0.18	0.00	**0.18**
Beetle:											
Onthophagus sp. (scarab beetle) *, [C]	Scarabaeidae	LEP	0.63	0.67	0.56	0.50	0.54	0.62	0.64	0.29	**0.56**
Megapenthes sp. (click beetle)	Elateridae	LEP	0.00	0.33	0.00	0.25	0.15	0.00	0.00	0.00	**0.09**
Coccinella sp. (ladybird) [C]	Coccinellidae	LEP	0.25	0.50	0.22	0.33	0.15	0.00	0.36	0.14	**0.23**
Aspidomorpha sp. (leafbeetle) *	Chrysomelidae	LEP	0.00	0.17	0.11	0.25	0.15	0.00	0.00	0.00	**0.09**
Curculioninae (flower weevils) *	Curculionidae	LEP	0.00	0.00	0.00	0.08	0.08	0.00	0.09	0.00	**0.04**
Cybocephalis sp. (sap/pollen beetle) *	Nitidulidae	LEP	0.00	0.00	0.00	0.00	0.00	0.46	0.18	0.00	**0.10**

Insect Pollinator	Family	Pollinator Category [a]	Landscape element type								
			F (*n* =8)	BP (*n*=6)	NP (*n*=9)	MT (*n*=12)	BT (*n*=13)	H (*n*=7)	U (*n*=11)	P (*n*=13)	**All (*n*=79)**
Staphylinidae (rove beetle) *, C	Staphylinidae	LEP	0.00	0.00	0.00	0.00	0.00	0.31	0.36	0.00	**0.10**
Moth/butterfly:											
Helicoverpa sp. (owlet moths)	Noctuidae	LEP	0.00	0.00	0.00	0.17	0.00	0.15	0.27	0.00	**0.09**
Hesperiinae (grass skippers) *	Hesperiidae	LEP	0.00	0.00	0.22	0.25	0.00	0.00	0.00	0.00	**0.06**
Pieris sp. (sulphur/garden white)	Pieridae	LEP	0.00	0.17	0.00	0.42	0.08	0.00	0.27	0.43	**0.16**
Euploea sp. (brush-footed butterflies)	Nymphalidae	LEP	0.00	0.50	0.33	0.33	0.54	0.38	0.00	0.57	**0.33**
Fly:											
Syrphus sp. (hoverfly) *, C	Syrphidae	LEP	0.00	0.00	0.00	0.00	0.31	0.00	0.18	0.00	**0.08**
Drosophila sp. (vinegar flies) *	Drosophilidae	LEP	0.00	0.33	0.67	0.50	0.00	0.85	0.55	0.29	**0.42**
Chrysomya sp. (blowfly) *	Calliphoridae	LEP	0.50	0.00	0.22	0.25	0.46	0.23	0.09	0.00	**0.24**
Tabanidae (horsefly) *, C	Tabanidae	LEP	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	**0.05**

* Efficient crop pollinators; [SL] solitary bee or solitary wasp; [SC] social bee or social wasp; [C] also provide function as pest controllers; [R] predatory wasp that prey on bees (all of these functional grouping based on FAO, 1995; McGregor, 2011; Momose et al., 1998).

[a] General categorization of pollinator in this dissertation into: **EP**: efficient insect pollinators that consisted of bees and wasps; and **LEP**: less efficient insect pollinator that consisted of beetles, moths/butterflies, and flies.

Table 4.2 Insect pollinator species richness, abundance, and Simpson's diversity index based on means (± standard deviations) per sampling plot in each landscape element type (F: remnant forest, BP: broad-leaved plantation, NP: needle-leaved plantation, MT: mixed-tree agroforest, BT: bamboo-dominated agroforest, P: rice paddy field; U: upland crop field, H: village settlement), with Kruskal-Wallis comparisons (*H*) followed by Wilcoxon pairwise test. Different letters within the same row indicate significant differences ($P < 0.05$)

Variable	Landscape element type								*H* value
	F (*n* = 8)	BP (*n* = 6)	NP (*n* = 9)	MT (*n* = 12)	BT (*n* = 13)	P(*n* = 13)	U(*n* = 11)	H(*n* = 7)	
Species richness	7.1 ± 1.4***a***	6.3 ± 2.0***ab***	5.4 ± 1.0***ab***	7.2 ± 1.1***a***	5.4 ± 1.6***bc***	5.8 ± 0.9***bc***	4.9 ± 1.4***cd***	3.3 ± 0.9***d***	33.51***
Abundance	14.2 ± 3.3***a***	11.0 ± 5.4***ab***	10.6 ± 3.2***ab***	13.8 ± 3.9***a***	9.3 ± 2.4***bc***	11.9 ± 2.8***ab***	9.4 ± 2.7***bc***	5.1 ± 1.6***c***	31.40***
Simpson's diversity	0.83 ± 0.03***a***	0.80 ± 0.05***ab***	0.75 ± 0.05***ab***	0.82 ± 0.03***a***	0.77 ± 0.08***ab***	0.73 ± 0.07***ab***	0.71 ± 0.09***b***	0.58 ± 0.18***c***	34.70***

*** $P < 0.001$

Table 4.3 Overall observed insect pollinator species richness (S.obs) and estimated species richness (S.est) of all and each landscape elements

Landscape element type	Number of plots	Observed species richness (S.obs)	Estimated species richness (S.est)			Ratio of S.obs : S.est (%)			
			Jackknife 1	Jackknife 2	Bootstrap	Jackknife 1	Jackknife 2	Bootstrap	**Average**
All landscape element types	**79**	**30**	**30.0**	**30.0**	**30.1**	**100.0%**	**100.0%**	**99.7%**	**99.9 ± 0.2%**
Each of landscape element:									
- Remnant forest (F)	8	13	13.0	12.4	13.2	100.0%	100.0%	98.6%	**99.5 ± 0.8%**
- Broad-leaved plantation (BP)	6	18	22.2	21.8	20.4	81.2%	82.7%	88.4%	**84.1 ± 3.8%**
- Needle-leaved plantation (NP)	9	18	21.6	20.6	20.1	83.5%	87.4%	89.5%	**86.8 ± 3.0%**
- Mixed-tree agroforest (MT)	12	25	27.8	26.5	26.9	90.1%	94.5%	93.0%	**92.5 ± 2.2%**
- Bamboo-dominated agroforest (BT)	13	22	24.8	21.1	24.1	88.8%	100.0%	91.3%	**93.4 ± 5.9%**
- Rice paddy field (P)	11	19	23.5	24.0	21.4	80.7%	79.3%	88.8%	**82.9 ± 5.1%**
- Upland crop field (U)	13	17	17.9	16.4	17.8	94.8%	100.0%	95.3%	**96.7 ± 2.8%**
- Village settlement (H)	7	12	15.4	14.7	14.0	77.8%	81.6%	86.0%	**81.8 ± 4.1%**

Species richness estimates are using ±95% confidence interval

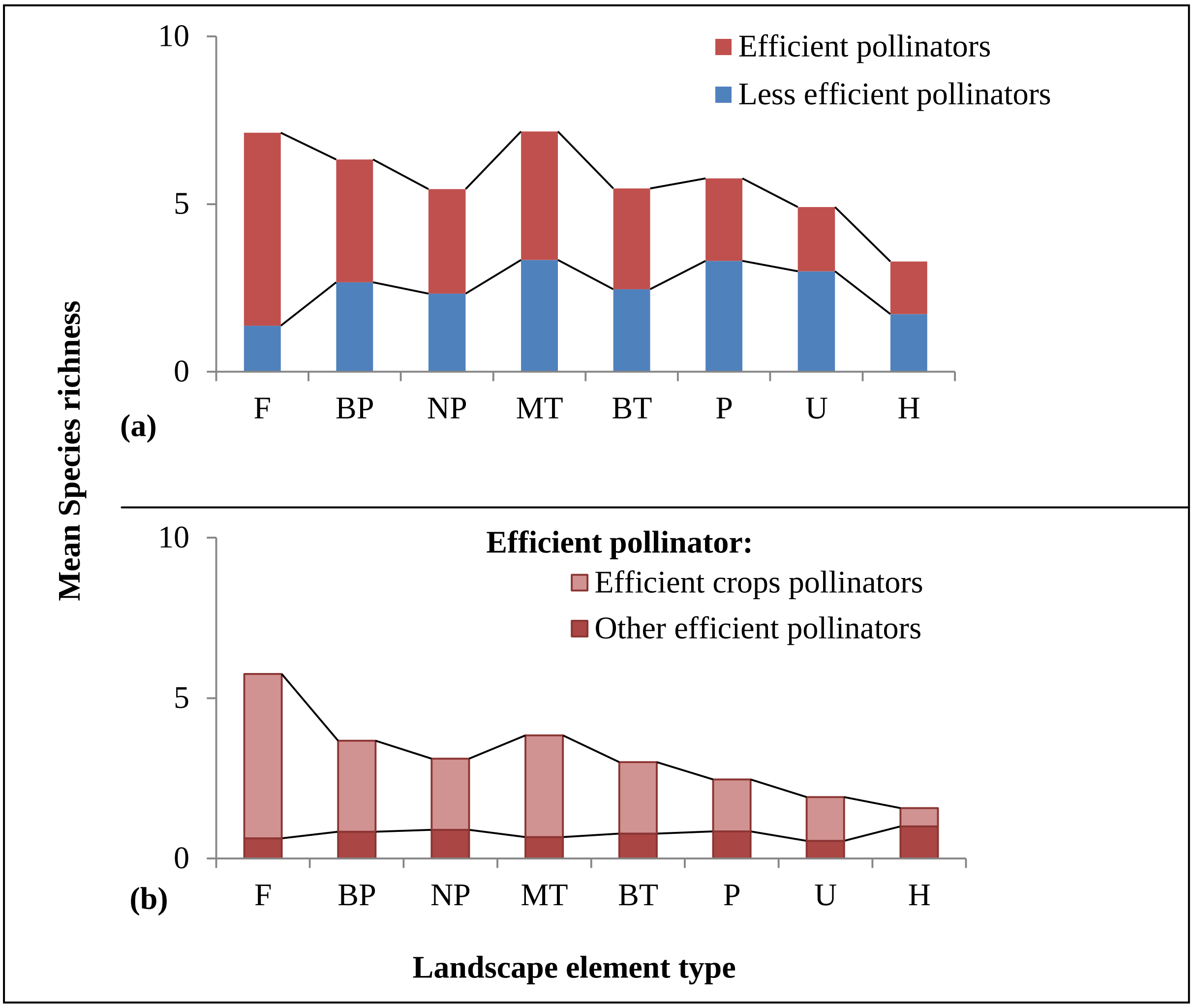
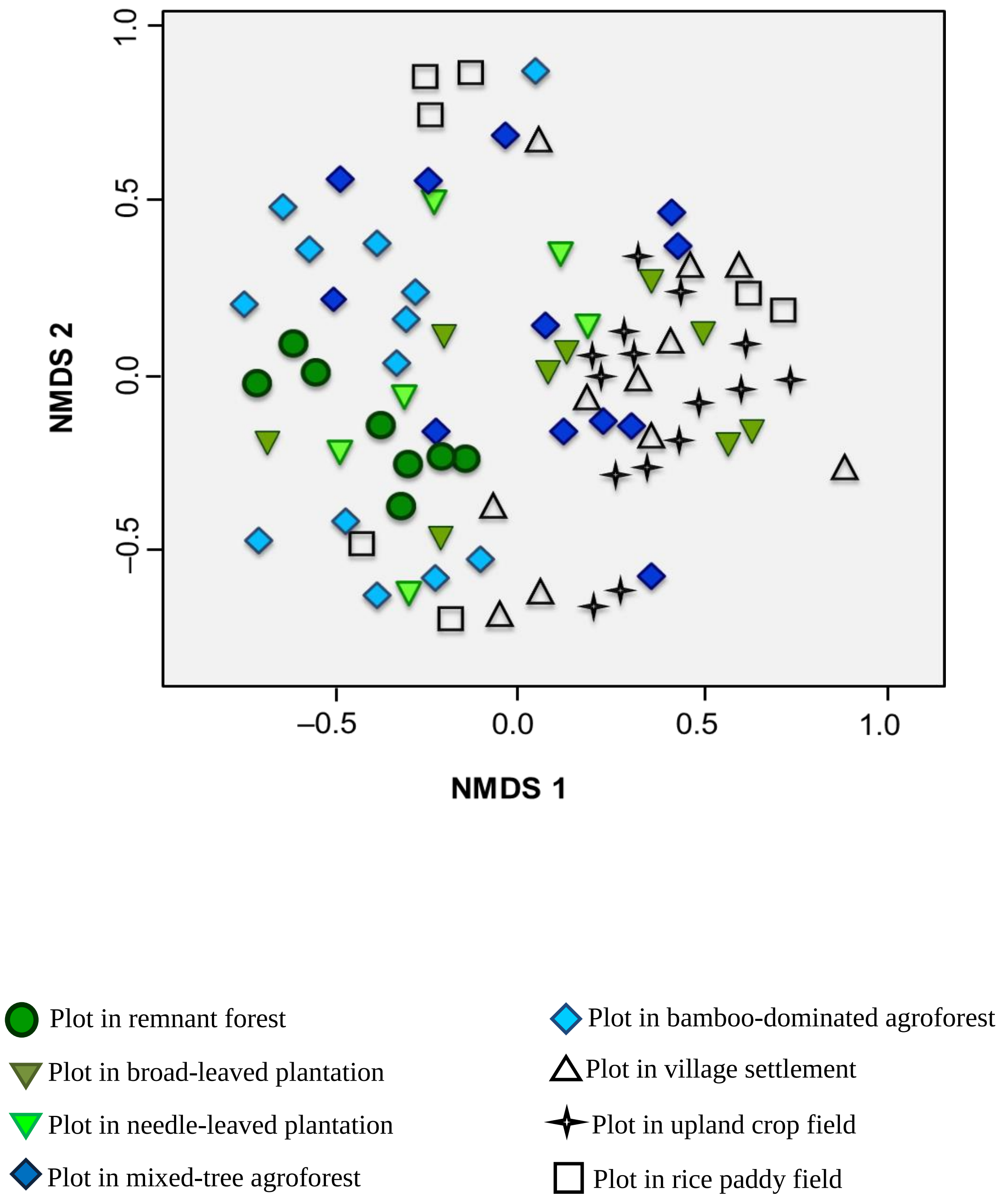


Figure 4.1 Functional diversity of insect pollinators, based on the mean number of species per sampling plot in each landscape element type (F: remnant forest; BP: broad-leaved plantation; NP: needle-leaved plantation; MT: mixed-tree agroforest; BT: bamboo-dominated agroforest; P: rice paddy field; U: upland crop field; H: village settlement) using (**a**) efficient and less efficient pollinators categories and (**b**) efficient crop pollinators and others

4.2.2. Insect pollinator species composition in different landscape element types

The whole dissimilarity in species composition was summarized into two dimensions by using NMDS analysis (**Figure 4.2**), although the stress value that represented the inverse degree of correspondence against the original distances among sampling plots was still high (0.23). Sample score plots with landscape element differences in ordination revealed no clear cluster of plots by landscape element type (**Figure 4.2a**). Even though, plots of F and P were distinguishable: plots of the two landscape element types were clustered separately with those of other element types, and were much closer to one another. However, plots of other landscape element types (BP, NP, MT, BP and H) were scattered among those of F and P. All plots in the remnant forest had negative scores on the first NMDS axis, while most plots of village settlement had positive scores (**Figure 4.2a**). These results imply that the first axis can be interpreted as an environmental gradient from forest interior to open landscape elements.

The species scores of efficient and less efficient pollinators represented differences of species composition (**Figure 4.2b**). All efficient pollinators (bees and wasps) had negative scores on the first NMDS axis except for one species (*Philanthus* sp.), which is a predatory wasp that preys on bees. Less efficient pollinators were distributed around the efficient ones.


NMDS 2
1.0
0.5
0.0
–0.5
–0.5
0.0
0.5
1.0
NMDS 1
Plot in remnant forest
Plot in broad-leaved plantation
Plot in needle-leaved plantation
Plot in mixed-tree agroforest
Plot in bamboo-dominated agroforest
Plot in village settlement
Plot in upland crop field
Plot in rice paddy field

(a)

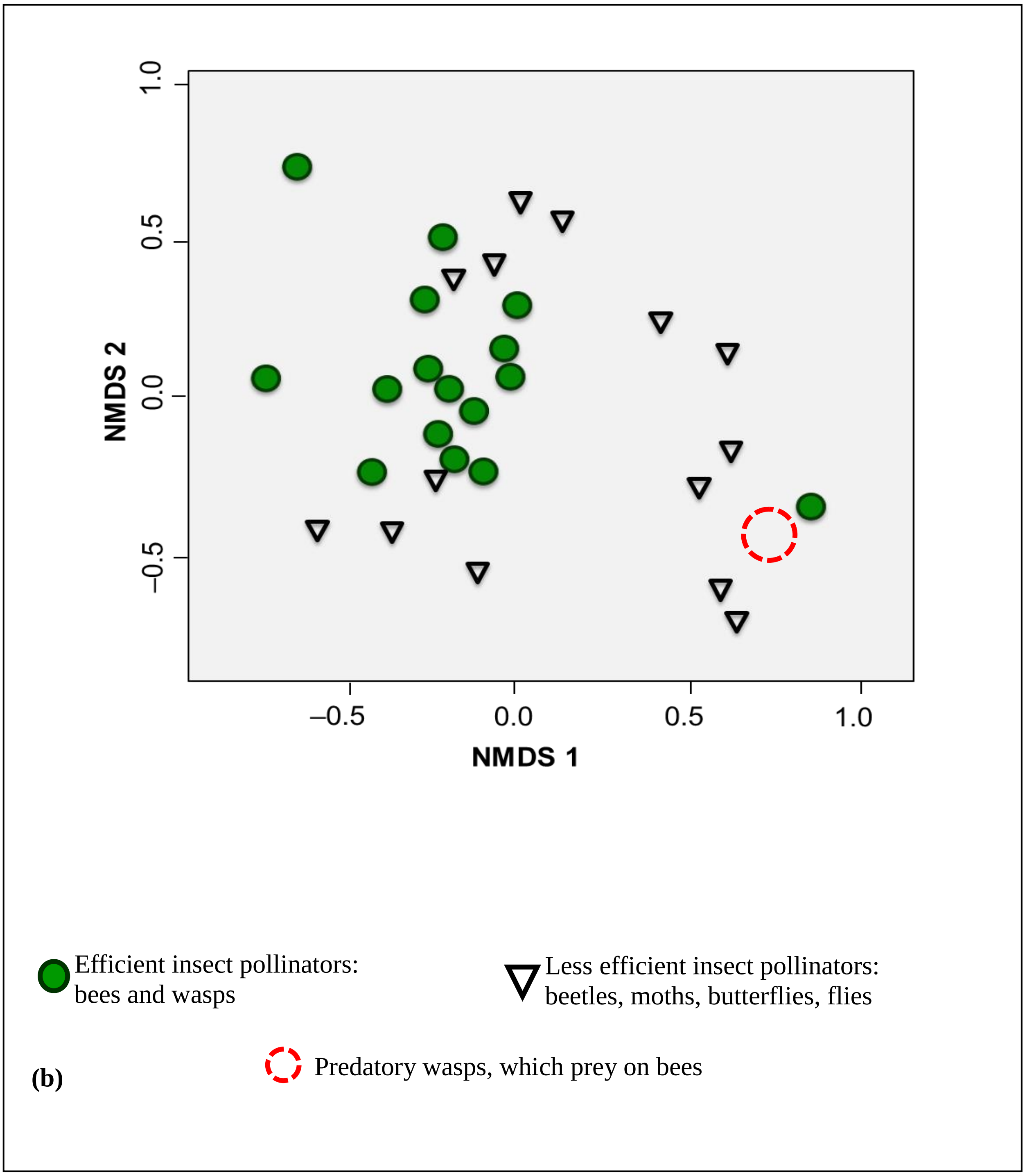


Figure 4.2 Two-dimensional ordination plots derived from non-metric multidimensional scaling (NMDS) of **(a)** site scores with landscape element types; **(b)** species scores with efficient pollinators' categories

4.2.3. Differences in factors determining various richness values

The results of a multi-model inference approach using the GLM revealed that environmental factors affected various richness values differently (**Tables 4.4** and **4.5**). Among environmental factors, vegetation cover tended to be more important than other factors in explaining many of the richness values in each functional group, as well as in all species combined. Proximity to forest also appeared to be important in explaining the species richness values as well.

For total species richness, the best model was the model that included only a three-dimensional polynominal trend surface. Proximity to the forest was chosen in the subset of competing models (ΔAICc <2), and influenced negatively and significantly. Although vegetation cover had positive effects, the coefficient values were not significant and their relative IoVs were small (**Table 4.4**). Species richness of efficient pollinators was strongly and positively influenced by canopy cover and weakly influenced by midstory cover and proximity to forest. The richness of less efficient pollinators was positively and significantly influenced by midstory and understory cover. In contrast, the richness of bees, which represented the most efficient pollinators, was influenced negatively by canopy cover, and significantly and negatively by proximity to the forest. It was also affected by landscape element differences, although the IoV was small. Compared to the remnant forest, all other landscape element types had negative influence on the species richness of bees, although MT and BP did not show significant effects (**Table 4.4**). The lowest AEC was found in H followed by U and P.

Species richness of social bees was not affected by landscape element type, but instead by proximity to the nearest forest margin and vegetation cover: distance from the forest edge had a strong and negative effect, and vegetation cover had a weak positive effect except understory cover that had negative effect (**Table 4.5**). In contrast, the richness of solitary bee was determined again by landscape element type, with a moderate and negative effect of proximity to the nearest forest margin. Compared with remnant forest, all human-modified landscape element types contributed to decrease richness of solitary bees. Particularly P, U, and H had significantly larger coefficient values than other landscape elements.

Species richness of efficient crop pollinators was mostly and negatively affected by landscape element differences, and weakly and negatively by proximity to the forest and vegetation cover with small IoVs value (**Table 4.5**). NP, BT, P, and especially H that had a significant and high coefficient values contributed to decrease the species richness of efficient crop pollinators. MT had the lowest coefficient value followed by BP.

Table 4.4 Multi-model averaged estimates of coefficients (AECs) and relative importance of variables (IoVs) for environmental factors determining all (total) insect pollinator species richness and that of efficient and less efficient pollinator, and bee (most efficient pollinator. Data are not shown for the nine third-degree polynominal terms of the geographic coordinates

Environmental factors	Total insect pollinator species richness		Less efficient insect pollinator		Efficient insect pollinator		Bee (most efficient insect pollinator)	
	AEC	IoV	AEC	IoV	AEC	IoV	AEC	IoV
Proximity to forests	–0.159 ± 0.071*	0.31	0.069 ± 0.091	0.08	–0.209 ± 0.133	0.39	–0.331 ± 0.144*	0.70
Landscape element type [a]		–		–		–		0.11
- BP	–		–		–		–0. 551 ± 0.299	
- NP	–		–		–		–0.733 ± 0.278**	
- MT	–		–		–		–0.461 ± 0.236	
- BT	–		–		–		–0.961 ± 0.266***	
- P	–		–		–		–1.052 ± 0.273***	
- U	–		–		–		–1.444 ± 0.332***	
- H	–		–		–		–2.091 ± 0.526***	
% canopy cover	0.007 ± 0.003	0.41	–0.004 ± 0.003	0.09	0.009 ± 0.003**	0.95	–0.014 ± 0.013	0.89
% midstory cover	0.008 ± 0.005	0.38	0.011 ± 0.005*	0.80	0.006 ± 0.004	0.36	–0.014 ± 0.013	0.12
% understory cover	0.009 ± 0.005	0.28	0.012 ± 0.005*	0.80	–0.005 ± 0.004	0.07	–	–

[a] BP: broad-leaved plantation; NP: needle-leaved plantation; MT: mixed-tree agroforest; BT: bamboo-dominated agroforest; P: rice paddy field; U: upland crop field; H: village settlement. As the baseline for the nominal variable of landscape element type, remnant forest (F) does not appear.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 4.5 Multi-model averaged estimates of coefficients (AECs) and relative importance of variables (IoVs) for environmental factors determining insect pollinator species richness of social and solitary bee and efficient crop pollinators. Data are not shown for the nine third-degree polynominal terms of the geographic coordinates

Environmental factors	Social bee		Solitary bee		Efficient crop pollinator [b]	
	AEC	IoV	AEC	IoV	AEC	IoV
Proximity to forests	–0.606 ± 0.207**	0.88	–0.447 ± 0.262	0.42	–0.246 ± 0.158	0.28
Landscape element type [a]		–		0.83		0.84
- BP	–		–0.478 ± 0.430		–0. 556 ± 0.311	
- NP	–		–0.518 ± 0.389		–0.770 ± 0.300*	
- MT	–		–0.260 ± 0.405		–0.387 ± 0.286	
- BT	–		–0.634 ± 0.410		–0.758 ± 0.305*	
- P	–		–0.922 ±0.426*		–1.043 ± 0.385**	
- U	–		–2.083±0.703**		–1.206 ± 0.371**	
- H	–		–2.695 ± 1.089*		–2.089 ± 0.574***	
% canopy cover	0.005 ± 0.006	0.13	–	–	0.010 ± 0.006	0.21
% midstory cover	0.004 ± 0.007	0.04	–	–	0.010 ± 0.005*	0.16
% understory cover	–0.009 ± 0.007	0.27	–	–	–0.010 ± 0.012	0.05

[a] BP: broad-leaved plantation; NP: needle-leaved plantation; MT: mixed-tree agroforest; BT: bamboo-dominated agroforest; P: rice paddy field; U: upland crop field; H: village settlement. As the baseline for the nominal variable of landscape element type, remnant forest (F) does not appear. [b] EP species that has asterix mark (*)in **Table 4.1**.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

4.3. Discussion

4.3.1. Roles of human-modified landscapes in conservation of insect pollinators

The results showed that total species richness, abundance and diversity were maintained in human-modified landscape elements, particularly in mixed-tree agroforests (MT), except village settlement (H) and upland crop field (U), although these factors were highest in the remnant forest (F). These findings are similar to those of previous studies examining insect pollinator or bee community in tropical forests and surrounding human-modified landscape elements (Hoehn, et al., 2008; Kessler et al., 2009; Klein et al., 2003; 2006; 2008; Schulze et al., 2004; Tscharntke et al., 2008; Vergara and Badano, 2009). The human-modified landscape also showed a remarkable contribution to maintain total (gamma) diversity over the whole research site, particularly by mixed-tree agroforest. Of the total 30 species observed, about 83% (25 species) were recorded in the mixed-tree agroforest, whereas only 40% to 70% were recorded in all the other landscape element types including the remnant forest. A similar pattern was also observed by using estimated species richness values in each landscape element type (**Table 4.3**). Furthermore, in the category of efficient pollinators, almost all (93%) were recorded in the mixed-tree agroforest, whereas 47% to 87% were recorded in all the other landscape element types.

The NMDS result indicated that there was almost no strong difference of species composition among landscape element types, and then the GLM results revealed that insect pollinators were more sensitive to habitat characteristics such as vegetation cover rather than to landscape characteristics such as distance to natural ecosystems. Vegetation cover is identified as an important determinant factor of species diversity of insect pollinators in tropical landscapes with fragmented remnant forest (Donaldson et al. 2002). As discussed by Klein et al. (2010), vegetation structure represents abundance and distribution of flower resources (Williams and Kremen, 2007; Tylianakis et al., 2008), availability of nesting sites and materials (Shuler et al., 2005; Kim et al., 2006), and light intensity levels (Klein et al., 2003).

The NMDS results also indicated that the abundance of efficient pollinators (bees and wasps) declined, and was replaced with less efficient pollinators (beetles, moths/butterflies, and flies) along a gradient from the remnant forest to village settlement. This finding is consistent with those of other studies (Aguirre and Dirzo, 2008; Bates et al., 2011; Vargara and Badano, 2009). Although dense canopy cover was fragmented in the remnant forest because of selective logging, this forest may still provide suitable habitats for efficient pollinators that feed abundant floral resources and build their nests on forest trees (such as *Apis* spp. *Xylocopa* spp. and *Ropalidia* spp.). The GLM results also showed that species richness of efficient insect pollinators, particularly bees as the most efficient ones, decreased with increasing distance from forest as shown in previous studies (see Ricketts et al. 2008 and references therein). This result is not surprising, because efficient pollinators, especially bees are dependent on natural ecosystems as sources of floral resources and nesting sites (Klein et al., 2003; 2006; Tscharntke et al. 2008). Therefore, the protection of tropical natural forests should be prioritized to conserve efficient pollinator diversity (Kremen et al., 2002; Klein et al., 2003a; 2006; 2008; Ricket et al., 2004; Olschewski et al., 2006; Tscharntke et al., 2008).

4.3.2. Different responses of various functional categories of insect pollinators

Overall, the high proportion of social bees and efficient crop pollinators in the remnant forest and the drastic decline in this proportion from remnant forest to human-modified landscape elements is consistent with previous studies (Klein et al., 2003a; 2006; 2008; Olschewski et al., 2006; Ricketts et al., 2008; Tscharntke et al., 2008). Social bees in this study, which consisted of two honeybees (*Apis cerana indica* and *Apis dorsata*) and one sweat bee (*Nomia* sp.) live in colonies. Each colony has a single queen, many workers and, at certain stages in the colony cycle, drones. Social bees such as honeybees thus need an abundant and steady source of pollen to multiply. Therefore, as previously discussed in other studies (e.g., Klein et al., 2003a; 2006; 2008; Olschewski et al., 2006; Ricketts, 2004; Ricketts et al., 2008), the numbers of social bee species in this study was strongly influenced by proximity to the forest (**Table 4.5**), presumably because the remnant forest offers a wealth of suitable nesting sites and abundant floral resources for their colonies (Klein et al., 2003a; 2003b; 2006).

Solitary bee such as the carpenter bee (*Xylocopa* spp.) and leafcutter bee (*Megachile* spp.) are solitary in the sense that every female is fertile, and typically inhabits a nest she constructs herself. There are no worker bees for these species. Solitary bees typically produce neither honey nor beeswax. Solitary bees are often oligoleges that make them more important pollinator than social bees, because they only gather pollen from one or a few species/genera of plants, unlike social honeybees, which are generalists. Although there is bee known as nectar specialists, solitary bees have better pollination efficiency than social bees (FAO, 1995; McGregor, 2011).

From the results of the GLM, it appeared that proximity to the forest was not the main determinant factor, but different types of landscape element appeared to have more effect in decreasing the species richness of solitary bees. Rice paddy fields, upland crop fields, and village settlements appeared to reduce the species richness of solitary bees, while broad-leaved plantations and mixed tree agroforests had no significant and the lowest negative coefficient. The reason might be due to most solitary bees prefer a habitat with high light intensity, which indicates high availability of flowering herbs (Klein et al. 2002; 2003a; 2003b; 2006). That might be a reason why solitary bees in this study such as *Amegilla cingulate* and *Megachile* sp. were recorded in human-modified landscape elements that have less shaded and less humid, and offered some moderate open areas of mixed tree agroforest. According to previous studies, such less shaded and less humid habitats were favorable by solitary bees because it is the ideal habitat for their ground-nesting and often grown various herbaceous plants that provide pollen and nectar resources (Liow, et al., 2001; Klein et al. 2002; 2003a; 2003b). Similar pattern was also showed by the species richness of efficient crop pollinators, which was mostly influenced negatively by landscape element differences, and negative effects of mixed-tree agroforest and broad-leaved plantations were lower than other landscape element types. This finding again emphasizes the importance of human-modified landscapes, particularly broad-leaved plantations and mostly mixed-tree agroforest in supporting the remnant forest maintaining high diversity of solitary bees and efficient crop pollinators and also insect pollinators in general.

4.4. Conclusions

Results of this chapter indicate conforming results in the case of birds (Chapter 3): appropriate landscape management in human-modified landscape elements surrounding remnant forest could also conserve forest insect pollinator diversity to some degree. However, the remnant forest as a source of efficient pollinator diversity particularly bee communities has to be prioritized to conserve regional pollinator diversity in forest–agricultural landscapes.

I found no difference in species composition among landscape elements. However, species richness and abundance of efficient pollinators such as bees and wasps declined, and were replaced with less efficient pollinators such as moths, butterflies, flies, and beetles along a gradient from the remnant forest to village settlements. Vegetation cover particularly that of tree canopy, tended to be more important than other factors in explaining the species richness of insect pollinators, even in agricultural fields. However, species richness of efficient pollinators, particularly bees was affected by proximity to the forest. Among human-modified ecosystems, mixed-tree agroforests maintained highest number of species of insect pollinators in total and solitary bees and efficient crop pollinators.

Chapter 5

Integration of socio-ecological assessments and conclusions

5.1. Introduction

In the dissertation, socio-ecological assessment was performed in a forest–agricultural landscape of West Java, Indonesia to identify suitable landscape management practices for ensuring the delivery of multiple ecosystem services and maintenance of biodiversity. To identify the suitable landscape management, holistic approach and integration of social and ecological dimension is crucial rather than management of individual issues or dimension. From all the results presented from Chapters 2, 3, and 4, I recognized that: 1) local people depends on and benefits from the ecosystem through ecosystem services; 2) ecosystem services are directly and indirectly affected by multiple human uses and activities; and 3) the ecological and social components of a landscape interact in complex ways. There are some approaches to integrate multiple assessments of environmental multifunctionality or services in order to formulate the suitable management practices. In this study, first I made a synthesis based on the summaries of all the results presented in Chapters 2, 3, and 4, and then I adopted the widely used Driving Force or Driver–Pressures–State–Impact–Response (DPSIR) framework (EEA, 1999) to integrate the social and ecological assessments.

The abbreviation DPSIR stands for a conceptual framework for the description of the environmental problems and of their relationships with the social domain, in a policy meaningful way (Maxim, et al. 2009). According to Maxim et al. (2009), social and economic developments is the *drivers*, exert *pressures* on the environment and, as a consequence, the *state* of the environment changes; then this leads to *impact* on ecosystems, human health, and society, which may elicit a societal *response* that feeds back on driving forces, on state or on impacts through various mitigation, adaptation or curative actions (Gabrielsen and Bosch, 2003; Smeets and Weterings, 1999). Based on that, the DPSIR is described as a "causal framework for describing the interactions between society and the environment" (Maxim et al. 2009).

The concept of DPSIR is useful that it provides a structure in which a number of physical, biological, chemical and societal indicators can be analyzed to set and evaluate targets and give a clear picture of progress in a number of policy areas (EEA, 1999; Rounsevell et al., 2010). The DPSIR framework is applied in ecosystem service assessment and biodiversity monitoring to capture and describe the relationships between society and the environment (Feld, et al. 2010). Furthermore, Rounsevell et al. (2010) explained that an important strength of the DPSIR approach is that it emphasizes the role of human in nature by representing a system that includes societal (human) and ecological (biodiversity) subsystems in mutual interaction, consistent with the concept of Social-ecological system (Gallopin, 1991). Therefore, using the DPSIR framework I attempt to understand the complex socio-ecological interrelationship between human and ecosystem through the ecosystem services in order to formulate the suitable landscape management which ensures the provision of multiple ecosystem services and conserve biodiversity.

5.2. Integrations of social and ecological assessments

5.2.1. Synthesis of results in Chapters 2, 3, and 4

As the basis for the integration of socio-ecological assessment using DPSIR framework, first I made the synthesis based on summaries from the results presented in Chapters 2, 3, and 4 that can help to understand what sorts of human-modified landscapes with fragmented forest remnants in developing country like Indonesia to maintain biodiversity while fulfilling the demands of local people for multiple ecosystem services and reducing poverty (**Table 5.1**).

By understanding local people's perception on ecosystem services and landscape elements as their sources as well as environmental determinant factors of species richness of birds and insect pollinators, I attempted to elucidate what kinds of landscape elements should be maintained as sources of ecosystem services, particularly of provisioning, cultural, and physical regulating services based on local people's perception, and biological regulating services based on the species richness of birds and insect pollinators. For sources of provisioning services, there were some significant different appreciations between close and far groups of local villagers (see **Figure 2.3**), thus provisioning services were separately evaluated by the two different end users, those living close to forest and those living far to forest.

Results of the Chapter 2 clarified that the forest–agricultural landscape in total provides a bundle of ecosystem services for local people's livelihoods. Despite high appreciation on the remnant forest and mixed-tree agroforests as sources of many ecosystem services, no single landscape element could be a complete source of all provisioning services (**Table 5.1**). With no doubt, agricultural lands were actually perceived as the only source of provisioning services particularly of main food (**Figure 2.3**) regardless to local villagers who live close to and far from the remnant forest. For sources of provisioning services of fuelwood and timbers (building materials for houses and livestock-sheds), however, there was different appreciation between close and far groups of local villagers. People who live close to forest relied mostly on the remnant forest and tree plantations for acquiring fuelwood and timbers, while people who live far to forest mostly on agroforests (mixed-tree and bamboo dominated ones). This implies that agroforests could be alternative sources of the remnant forest for acquiring timbers and fuelwoods. Based on that, it is crucial to devising ways of earning income for the rural people through enhancement of agroforestry as buffer zones around forest and timber plantation and economic utilization of the planted trees and shrubs.

Table 5.1 Synthesis based on the summaries of results from the social and ecological assessments in Chapters 2, 3, and 4

Landscape element types	**Provisioning services**		**Cultural services**	**Regulating services**					
				Water regulation*	**Landslide protection***	**Pest controller**	**Seed disperser**	**Pollination**	
	Local people perceptions					Species richness of bird			Species richness of insect pollinator
	Live close to forest	Live far to forest				Insectivores	Frugivores	Crop pollinators	Bees & efficient pollinators
Remnant forest	√	–	√	√	√	√	√	√	√
Broad-leaved plantation	√	√	√	√	√	√ (+ close to forest & canopy cover)	√ (+ canopy cover)	–	√ (+ canopy cover & close to forest)
Needle-leaved plantation	√	√	√	√	√	√ (+ close to forest & canopy cover)	√ (+ canopy cover)	–	√ (+ canopy cover & close to forest)
Mixed-tree agroforest	–	√	–	√	√	√ (+ close to forest & canopy cover)	√ (+ canopy cover)	√	√ (+ canopy cover & close to forest)
Bamboo-dominated agroforest	–	√	–	√	√	√ (+ close to forest & canopy cover)	√ (+ canopy cover)	–	–
Upland crop field	√	√	–	–	–	–	–	–	–
Rice paddy field	√	√	–	–	–	–	–	–	–

Notes:

√ = Yes, that certain service is provided by that certain landscape element type;

– = No or small number and not significant value, that certain service is not provided by that certain landscape element type;
Other functional groups of birds and insects pollinators that provide regulating services which proved to be not affected by environmental factors are not shown in this table.

In the Chapter 2, I discussed that rural people in West Java had an appreciation of ecosystem services provided by forests particularly for indirect services such as physical regulation services of air, water, and soil, and also spiritual and cultural values that well perceived by not only the people who live close, but also by them who live far from forest. Particularly for spiritual and cultural services, it was provided from the remnant forest and tree plantations only (**Table 5.1**). That indicates there was no alternative source in providing spiritual and cultural services except the remnant forest and tree plantations. For the physical regulation services, local people's perceptions showed that those services were provided by the remnant forest, broad-leaved and needle-leaved plantations, and mixed-tree and bamboo-dominated agroforests (**Table 5.1**). These roles of natural and semi-natural ecosystems, particularly agroforests in providing many physical regulation services had also been intensively studied and proved by many studies (Anderson et al., 2009; Cassman, 1999; FAO, 2010; Forest Watch Indonesia and Global Forest Watch, 2002; Lee et al., 2003; Nair and Graetz, 2004; Nair et al., 2009; van Noordwijk et al., 1996). Therefore, conservation strategies that incorporate ecosystem services based on the fact that once rural people perceived well the value of forests, they might use the forest and other landscape elements sustainably.

In the Chapter 3, I discussed that protection of remnant forests should be prioritized and integrated with other landscape element types to conserve forest bird diversity that providing biological regulating services such as pest controllers by insectivores and seed dispersal by frugivores. Human-modified landscape elements such as tree plantations (owned by the forest enterprise) and agroforests (privately owned by local people) with appropriate vegetation composition and structure and proximity to remnant forest could support forest biodiversity conservation as well as species richness of insectivores and frugivores, while producing foods and fibers that are economically beneficial for local people (**Table 5.1**). In the Chapter 4, I further emphasized the importance of the protection of remnant forests for conserving crop pollinators, particularly bee community. Human-modified landscape elements such as tree plantations and particularly mixed-tree agroforests with appropriate canopy cover and vegetation that provide abundant floral resources could support maintenance of pollination services (**Table 5.1**).

5.2.2. Socio-ecological integration using DPSIR framework

The DPSIR approach requires the compilation of an appropriate list of indicators able to capture the complexities of the system interactions, in this case, between social (local people) and ecology (biodiversity: species richness of bird and insect pollinator) in a forest to agricultural landscape (**Figure 5.1**). However, despite the availability of DPSIR conceptual framework and a considerable body of literature on indicator currently developed (see Feld et al. 2009 for recent review on the indicators), Feld et al. (2010) explained that so far many indicators of ecosystem services and biodiversity do not meet the general suitability criteria. In this study, as previously explained from Chapters 1, 2, 3, and 4, I used the preferences of the local people, which were represented by their perceptions of ecosystem services and associated landscape elements as sources of those services, as well as the species richness of the avian and insect pollinator communities that, through their contributions to ecosystem functioning (indicate by the species richness of each bird's feeding guilds and pollinations efficiency for pollinators) that contribute to the ecosystem services as the indicators. Local people's perceptions about ecosystem services and their associated landscape elements were represented the social indicators and the species richness of bird and insect pollinator were represented the ecological indicators (**Figure 5.1**). Actually, some of the indicators I used in this study, such as the species richness of bird and insect pollinators including the species richness of each functional group from those two chosen taxa were also suggested by Feld et al. (2010) as indicators for DPSIR in relation to ecosystem services and biodiversity. Based on these indicators, the description of results presented in Chapter 2, 3, and 4 describe the current state of environment condition in this study site. This current state of environment might be change for a better or worse condition by certain drivers and pressures.

Although in this study I did not directly investigate the drivers of current state of environment in the study site, however, according to the collected information during interview to local people that driving force was basically the modern economy system at global scale that direct and indirectly affected the local social and economic condition of the people in study site had made them highly dependent on their surrounding landscape in providing natural resources to fulfill their daily needs, as well as for more abstract and psychological reasons, such as scenic beauty, wilderness for spiritual purposes, and stress relief. The current conditions of how the local people highly relied on multiple services provided by the ecosystem were also recorded in other areas, particularly developing countries (e.g., Dolisca et al., 2007; Fagerholm et al., 2012; Kramer et al., 1992; Silvano et al., 2005; Sodhi et al., 2010b; Stein et al., 1999). Historically, local people have enjoyed free services derived from forest ecosystems and modified parts of the forest to acquire enough foods and fibers based on their preferences, consequently forming their living landscapes. Then, as the drivers of social and economic increased, the people needs also increased; they modified more parts of the forest to acquire more resources. Based on my observation and collected information during the interview and bird and insect pollinators data collection, there are mainly two major pressures exert from the mentioned drivers that will make seriously impact to change the current state of landscape in the study site, which are deforestation, and simplification of vegetation structure related to agricultural intensification (**Figure 5.1**).

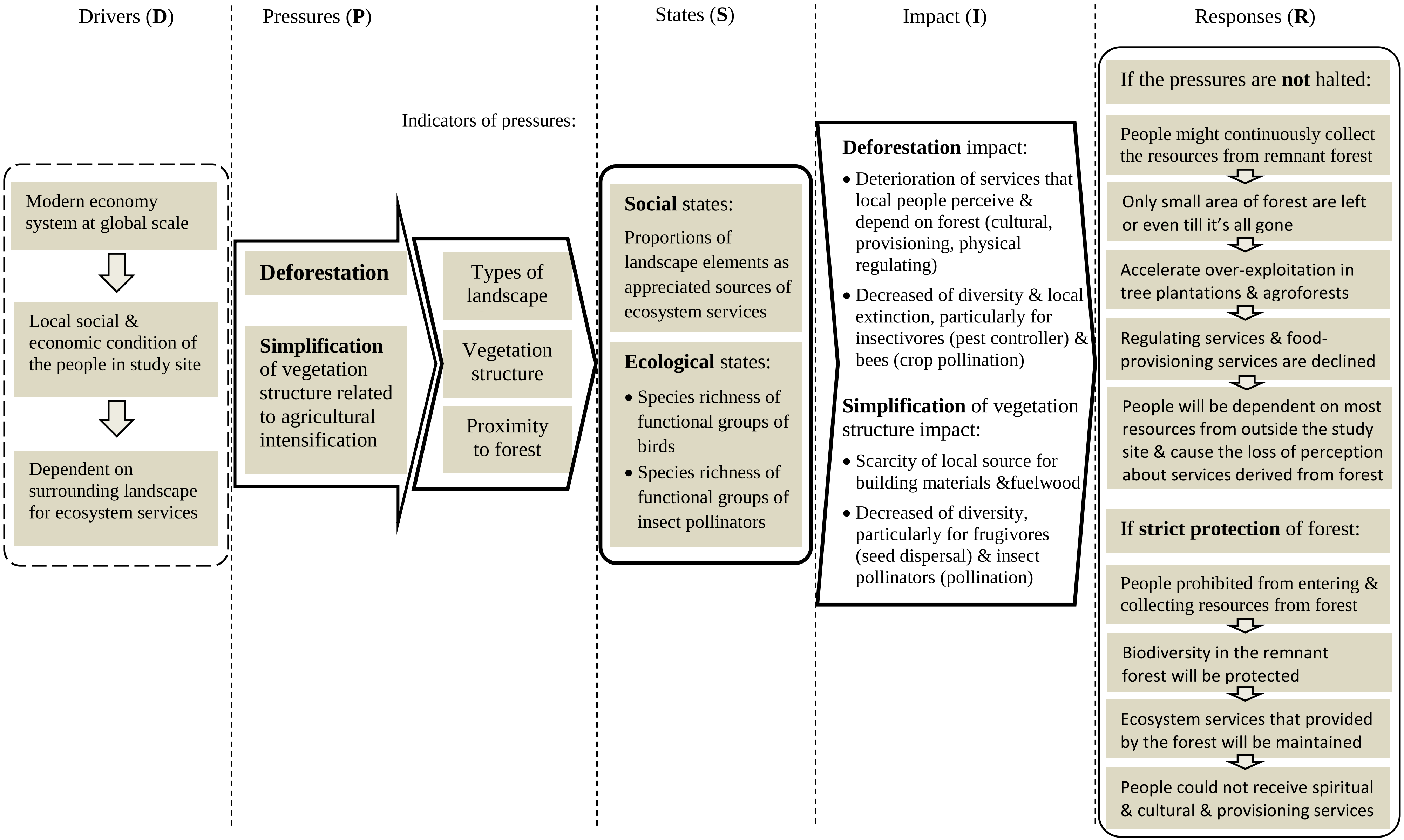


Figure 5.1 Socio-ecological integration using DPSIR framework in a forest to agricultural landscape, West Java, Indonesia

As presented in **Figure 5.1**, I set types of landscape elements, vegetation structures and proximity to the remnant forest as a compilation of indicators for pressures that govern the impacts and change the current states of ecosystem services. Degrees of these pressures to the current states were evaluated based on proportions of landscape elements as appreciated sources of ecosystem services for social states, and the results of GLMs for species richness of functional groups of birds and insect pollinators for ecological states of ecosystem service delivers.

The most influential pressure to the current state of environment is deforestation. As previously explained in the Chapter 2, the remnant forest provides many services from provisioning, cultural, to regulating services for the local people, and then the forest also increased people awareness about their surrounding as people who live close to the remnant forest perceived higher number of ecosystem services. The remnant forest is the most important habitat for bird species, particularly groups of species that providing important services such as insectivores (pest controllers), and for bees (the most efficient pollinators) and crop pollinators, and likely species source of spill-over effects to adjacent tree plantations and mixed-tree agroforests. Therefore, disturbance to the remnant forest, especially deforestation would surely make the major impact to the decrease or deterioration of services that local people perceive and depend on the remnant forest, such as a source of timber and fuelwood, spiritual values, game hunting, and scenic beauty, also air and water regulations, and landslide prevention. Another impact might be the decreased of diversity and local extinction, particularly for insectivores and bees that would make the pest controllers and crops pollination services decreased or deteriorated.

Simplification of vegetation structure and cover would also become the major pressure that will change the current state of environment. As previously explained in the Chapter 2, many people highly depend on multiple trees, bamboo and shrubs in remnant forest, tree plantations, and agroforests as major sources for building materials (timber and bamboos) and fuelwood (dry or falling branches). Complex vegetation structure enhanced the species richness of frugivores that provide seed dispersal service, and insect pollinators in general; the species richness of insect pollinators seemed increase even in upland crop fields if there was some canopy covers. Thus, simplifying vegetation structure might cause serious impact in the scarcity of local source for building materials and fuelwood, which was the major source of energy for people daily life in the study site. It would also make serious impact to decrease the diversity of frugivores and insect pollinators that lead to the decreasing or deteriorating of seed dispersal and general pollination services.

If the pressures of deforestation and simplification of vegetation structure are not halted, it will cause serious impacts and change the state of environment in the study site (**Figure 5.1**). As the responses people might continuously collect the resources from the remnant forest until only small area of forest are left or even till it's all gone. Loss of forest resources could accelerate over-exploitation in tree plantations and agroforests. Consequently regulating services might decline, and food-provisioning services might be suffered. Thus, the agricultural systems would be changed to use much chemical pesticides and fertilizers as happening in other areas in humid tropical developing countries (e.g., Jackson et al., 2007), so the people will be highly dependent on most resources from outside the study site. That likely to cause the loss of the perception about services derived from forest (Sodhi et al., 2010b) as well as the wisdom of knowledge about spiritual and cultural related to forest such as hunting games and traditional medicine.

On the contrary, if deforestation is controlled by strict protection of the remnant forest, it will also cause negative impacts in the change of environmental states (**Figure 5.1**). As the responses, local people might be disentangled from the remnant forest: they will be prohibited from entering and collecting resources from forest and even to live close to the forest.

Although the biodiversity condition in the remnant forest will be protected and many of ecosystem services that provided by the forest will also maintained, local people could not receive many other ecosystem services such as spiritual and cultural services and provisioning services, which are very important for their daily lives.

Based on the DPSIR framework (**Figure 5.1**), it seems that letting deforestation ongoing or contrary stopping it by making the remnant forest as protected area does not result in providing a bundle of ecosystem services to the local people. If the deforestation and vegetation structure simplification are continuously occurred in order to increase food supply, most of food provisioning services might increase, but other regulating and cultural services might decline. If complete protection of the remnant forest is implemented, regulating services will increase, but local people might decrease or lose many cultural and provisioning services of forest resources. Gbadegesin and Ayileka (2000) explained that the approach to protect forests had failed to take into account the interest of rural communities and did not involve them in making resource-related decisions. More recently, many conservationists have suggested a different approach, arguing that integrating local people is the most effective means of conserving the forest (Dolisca et al. 2007). The underpinning of this approach is that once local people see the value of forests, they may use it sustainably, thus also resulting in conservation benefits (Sodhi et al., 2010b). Therefore, based on the synthesis and DPSIR framework integration of social and ecological assessment that incorporate all landscape element types and local people is needed to provide appropriate landscape arrangement and management which ensure the provision of a bundle of ecosystem services, biodiversity conservation and in turn, the enhancement of human well-being.

5.3. Recommendations

The remnant forest had a great value for rural people in providing most of cultural services, many provisioning and regulating services, and then was proved to be the source of bird and insect pollinator diversity, particularly forest specialist and bees (most efficient pollinators) and crop pollinators. Therefore, to conserve the diversity of forest birds and efficient crop pollinators that maintained biological regulating services as well as to preserve services related to provisioning and regulation of water, soils, and the atmosphere that many of the local people perceive, protection of forests should be a priority. The remnant forest in this study area is not protected for biodiversity conservation and has undergone deforestation, fragmentation, and selective logging to fulfill timber demands, efforts to avoid further human disturbance and to rehabilitate complex-structured vegetation strata are necessary. In addition, to reduce extractive activities that conflict with forest conservation, such as the capturing of birds to be sold as pets, the economic needs of people must be accommodated. However, the protection of remnant forest does not mean complete disentanglement of local people from the forest. Conservation strategies that incorporate ecosystem services in landscape management should be established. Therefore, accessibility of local people to the forest should be facilitated. By allowing people to have access to the remnant forest, biodiversity conservation and the maintenance of various ecosystem services will be promoted. To implement it, extractive or destructive activities and utilization of resources (provisioning services or other services such as birds collecting to be sold as pet) should be avoided by the following measures:

- Allowing people to live close to the remnant forest through the intensive interaction between human and nature, because it is expected to improve local people’s sensitivity and awareness about their environments, and then to enhance the perception about the ecosystem and various services for daily livelihood.

- Providing non-formal education about the importance of sustainable use of resources and ecosystem service maintenance that will conserve the biodiversity and facilitate the knowledge transfer among people and among different generations about their traditional knowledge in spiritual value, medicine, agricultural practices such as traditional organic pesticide for example, which in turn ensure the continuous supply of multiple ecosystem services for the present and next generations.
- Devising ways of earning income for the rural people through enhancement of agroforestry by planting more tree species (combination of fruiting, timber, & native trees) as buffer zones around the remnant forest and tree plantation and economic utilization of the planted trees and shrubs so that reliance on forest for economic benefits and pressure on forest resource extraction are reduced and shifted to enhanced agroforests.

Since the two types of tree plantations (needle- and broad-leaved) are owned and managed by the Regional State-owned Forest Enterprise, similar as in the case of the remnant forest, accessibility to vital resources for local people has to be accommodated. Nonetheless, there are some suggestions to increase the biodiversity and ecosystem service to the Regional State-owned Forest Enterprise not to harvest the mature trees for timbers, instead to maintain the vegetation structure and cover by using REDD schemes or combining it with ecotourism activities that involving local people.

To further enhance the human-modified landscape surrounding the remnant forest, various types of tree composition with multistoried structure in the two types of tree plantations and the two types of agroforests might need to be maintained. Broad-leaved plantations with native trees used for timber production could be facilitated more to maintain avian community similar to that in the remnant forest and efficient pollinators such as bees. In the case of needle-leaved plantation, it can be improved by adding various tree-crop mixtures under the sparse canopy. The expansion of agroforests in buffer zones around the forest combined with economic utilization of the planted trees and shrubs could reduce human pressure on the remnant forest. In fact, my study shows that mixed-tree agroforests play pronounced sociological and ecological roles that could be further enhanced by establishing them close to the remnant forest through the broad- and needle-leaved tree plantations. Greater functional diversity of birds in the agroforests could be sustained by increasing tree density and by introducing tree species that attract bark-gleaning insectivores. Then, to enhance the economic benefits, the various annuals crops that are tolerant to canopy shade can be introduced. By keeping high diversity of plant species of different life forms and phenology that provide abundance source of floral resources, of which expected to attract more insect pollinators, including efficient pollinators.

Current form of bamboo-dominated agroforests, which are clearly not favored by many efficient pollinators or functional groups of birds, can be located far from the remnant forests. In addition, upland crops field and rice paddy field that mostly produced foods for local people and economically important are also need to be further improved. Many insect pollinators were attracted to upland crops fields because of the nectar and pollen from different cultivated annual crops. In order to sustain and improve the diversity of insect pollinators, frugivorous and insectivorous birds, adding tree covers within agricultural fields would attract insect pollinators to those ecosystem elements.

5.3. Concluded remarks and outlook

This study is one of the first attempts to assess the change the degree of ecosystem services from forest to agricultural landscape using a socio-ecological approach. Additional studies are needed that fully cover the landscape gradient from intact forest to intensively exploited agricultural lands and densely populated urban areas, and that directly evaluate the role of biodiversity in all landscape elements, in order to understand the importance of mosaic structure of landscape, to quantify the extent to which species diversity improves the delivery of ecosystem services, and the spillover effect of insectivores and insect pollinators from mixed-tree agroforests to agricultural lands. In combination with such additional results, the outcomes of the present study will contribute to the development of a generalized ecosystem-service-based landscape management plan that is adaptable to conditions in developing countries in the humid tropics.

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