Agro-ecological Analysis of Distribution Patterns of Tree in Paddy Field Landscapes in Northeast Thailand

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(東北タイの水田域に分布する樹木の時空間的変異に関する農業生態学的解析)

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CONTENTS

CHAPTER 1

General introduction

1.1 Background of this study

The primary scientific question that is addressed in this study is how to obtain a sustainable agriculture. Specifically, to clarify how the relationship between productivity and diversity is harmonized in agricultural landscapes.

In recent decades, agroforestry systems and traditional agricultural landscapes have been recognized as a significant source of biological diversity (Pimentel et al., 1992). At the same time, the attempt to protect biodiversity in national parks that cover only 3.2% of the world's land area (Reid and Miller, 1989) has been shifting towards the 95% of the terrestrial environment that is covered by human settlements, managed agricultural land, and other non-pristine forest ecosystems (Western and Pearl, 1989).

From the past century, the increase in crop productivity due to agricultural intensification and its consequence of local biodiversity decline has led to the idea that the relationship between productivity and diversity is a competitive one. However, there is no need to sacrifice biological diversity for crops. In fact, biodiversity increases stability of vegetation in terms of resistance and rehabilitation (Tilman and Downing, 1994), a mutual relationship. To balance agricultural productivity and biological diversity, two contrasting models have been designated. Land sparing, which separated land for conservation from land for crops, and land sharing, which integrates the two purposes on the same land (Phalan et al., 2011). Among them, the traditional agricultural landscapes– a land sharing system, have long been recognized to be sustainable, and benefits both human and nature (McNeely, 1995; Miller and Hobbs, 2001). This study does not attempt to discuss which model is better, but simply provides an introductory of a traditional land sharing system, aiming toward a sustainable agriculture.

All over the world, trees in farming system is not an unusual subject, such as the case in central India (Viswanath et al. 2000), in Ethiopia (Pamela et al. 2003), in Australia (Printsley et al. 1992). In many Asian countries, paddy rice fields are a monoculture of a staple crop but also harbor a variety of trees, which provide timber, fuel, fodder, food, medicine as well as play a role in maintaining soil fertility, protecting from soil erosion (Grandstaff et al., 1986; Watanabe, 1990; Prachaiyo, 2000; Vityakon, 2001; Vityakon et al., 2004; Kosaka et al., 2006; Natuhara et al., 2012; Miyagawa et al., 2013; Pham et al., 2015). In particular, hundreds of different tree species have been recorded in paddy field landscapes in rural areas in Laos and Northeast Thailand (54 species by Grandstaff et al., 1996; 137 species by Kosaka et al., 2006; 61 species by Natuhara et al., 2012; 79 species by Pham et al., 2015). Tree species diversity leads to the abundance of many other organisms. Not only do trees provide habitats for wildlife, but they also provide shadow and litter that help maintain the favorable condition for several litter-inhabiting soil macro-fauna such as spiders and orthopterans (Choosai et al., 2009). In such a way, it is proved that well-managed systems contain as much abundant biological resources as natural ones.

Field surveys were conducted in an extensive area of agricultural landscapes in Northeast Thailand. The background of rice growing history as well as characteristics of the study area is summarized here.

Often known as "Isan" (means "northeast" in the Thai language), the northeastern region of Thailand located on the Korat Plateau, from the latitude 14º7' N to 18º26' N and longitude 100º54' E to 105º37' E. Bordered by the Mekong River to the north and east (also is the border between Thailand and Laos), and by Cambodia to the southeast, Isan is separated from Central Thailand by the Phetchabun mountain range to the west. The average temperature range is from 19.6ºC to 30.2ºC. There are three seasons: the rainy season from May to October with average annual precipitation varies from 1270mm to 2000mm; the cool season from October to February and the hot season from February to May with the peak temperature may reach 43.9ºC in April (Thai

Meteorological Department, 2012).

Agriculture is the main economic activity and rice is the main staple crop. Unlike other regions, the northeast has an undulating topography, instable precipitation and an exceptionally hot and dry climate. Dry and saline soil conditions of the northeast make this region face difficulty in suiting upland crops other than sugarcane or cassava (Prachaiyo, 2000). Under those unfavorable conditions, the average rice yield in the region is the lowest in Thailand, despite its being the second largest rice growing area in the country (Adulavidhaya and Tsuchiya, 1986). Rain-fed paddy took up to 85% of total paddy lands, while irrigated paddy cover 15% of total paddy lands in wet season (Thanawong et al., 2014). In dry season, the number decreased in half to 7.5% of total paddy lands that were irrigated for rice cultivation (Thanawong et al., 2014). The low performances of irrigated rice in dry season both in economic and environmental terms (Thanawong et al., 2014) made farmers choose to engage in other activities rather than invest in irrigation. The increased use of agricultural machinery and the replacement of traditional transplanting by direct seeding are helpful means to adapt with the labor-lacking situation caused by the massive seasonal out-migration. Farmers in the northeast have the tradition of cultivate rice mostly in wet season, and diversified their rural livelihood systems from different sources such as trees plantation (ADB, 2012).

When clearing forest to establish paddy fields, farmers selectively removed a number of trees, then connecting termite mounds and trees that they wished to retain to build the levee (Grandstaff et al., 1986; Pham et al., 2015). Thus, paddy rice fields in the northeast are often composed of many small plots, with many standing trees and termite mounds scattered around (Grandstaff et al., 1986; Fukui, 1993). Those trees play an important role in sustaining local livelihoods, providing biomass energy, as well as limiting the decrease in forestland (Takaya and Tomosugi 1972; Grandstaff et al. 1986; Watanabe 1990; Prachaiyo 2000; Vityakon 2001; Vityakon et al. 2004; Kosaka et al. 2006; Natuhara et al. 2012; Miyagawa et al. 2013; Nansaior et al. 2013; Pham et al. 2015). By harboring a variety of trees, paddy rice fields might be a potential land sharing system that capable of satisfying both the productivity and diversity, with appropriate attention and management.

Recently, a few description studies on distribution and species composition of trees (Kosaka et al 2006; Natuhara et al 2012) in those unique landscapes have been conducted. Several reports about the trees density in paddy fields had pinpointed the declining trend of trees over time (Grandstaff et al., 1986; Watanabe, 1990; Prachaiyo, 2000). However, there were no comprehensive report on the exact number of those reducing trees, as well as a quantitative comparison of both tree density and species richness between landscapes so far. There were also studies that dealt with a large spatial scale of an extensive area (e.g., Watanabe et al., 2014), but lack of correlating discussion with the qualitative data. Due to those limitations in previous studies, it has been difficult to calculate the speed of reduction as well as to give any specific countermeasures for this issue.

1.2 Objectives of this study

Regarding the background of the studied area, this study focuses on the biological diversity of tree species in paddy fields. Specifically, it examines the distribution patterns of trees in relation to agro-ecological settings and evaluates the effects of agricultural intensification on trees diversity. Further, it discusses the feasibility of a paddy field-based land sharing system for sustainable agriculture.

This study was the first to comprehensively assess the variation of woody plant community at regional scale, as well as discussing the causes from the viewpoint of local knowledge. Another unique point in this study is that it examines the specific impact of agricultural intensification on the diversity of woody plant community in paddy fields. This is important when we consider the rapidly changing in agricultural practices of Northeast Thailand in particular and of rural agricultural landscapes in general.

Thus, the objective of this study is to clarify (1) distribution patterns of trees in paddy field landscapes in relation to agro-ecological settings, (2) relationship between historical changes of landscape structure and density of trees, (3) impact of agricultural intensification on density and species diversity of trees; along with considering the possibility of the paddy-field based land sharing system for sustainable agriculture in the region.

1.3 Overview of dissertation

There are six chapters that formed the structure of this dissertation:

Chapter 1 provides a general introduction to the background, logic, and objective of this study.

Chapter 2, 3, and 4 are three case studies. Chapter 2 discusses the variation in distribution patterns of trees in paddy field landscapes, in the extensive area of Northeast Thailand. Chapter 3 is an intensive survey on the historical change of land use-land cover type and trees distribution in 3 studied villages. Chapter 4 examines the specific effect of land consolidation during agricultural intensification on the density and species diversity of trees, with different level of mechanization in those 3 villages.

Chapter 5 describes the utility and management of trees in paddy field landscapes.

Species diversity and variation of species composition between microhabitats and regions are also compared in this chapter.

In addition to the discussion in each previous chapters, the general discussion in chapter 6 will review the possibility of a paddy field-based agroforestry system for sustainable agriculture and resource utilization in this unique human-managed ecosystem. Finally, the need of comparing studies between different regional contexts will also be discussed.

CHAPTER 2

Variation in distribution patterns of trees in paddy fields

2.1 Introduction

To meet rising demands for food at the lowest possible cost to biodiversity, two contrasting methods have been employed: land sharing and land sparing (Phalan et al., 2011). Land sparing has been implemented in the form of demarcation between monoculture fields and protected areas (e.g., ADB and UNEP, 2004). However, land demarcation, often conducted through top-down decision-making, may not be consistent with the local land-use customs (e.g., Wester and Yongvanit, 2005). Small-scale farmers have elaborated on various forms of land sharing using some forms of agroforestry and organic farming (Phalan et al., 2011), which have been evaluated in terms of sustainable food production, socioeconomic benefits, and ecological services (e.g., Nair et al., 2005).

Paddy fields are primarily used as agricultural land for staple crop production in mainland Southeast Asian countries (ADB and UNEP, 2004) and also harbor a variety of trees that play multifunctional roles in local livelihoods (Takaya and Tomosugi, 1972; Grandstaff et al., 1986; Watanabe, 1990; Prachaiyo, 2000; Vityakon, 2001; Vityakon et al., 2004; Kosaka et al., 2006; Natuhara et al., 2012; Miyagawa et al., 2013). Previous studies on paddy-based land sharing were primarily conducted in a small number of villages or in experimental fields. As deforestation has rapidly progressed in Southeast Asia's mainland (ADB and UNEP, 2004), one must compile the latest information on tree distribution in the local land sharing system on a regional scale—information not represented in forestry statistics.

In the northeast region of Thailand in 2008, the percentage of remaining forest area was the lowest in the country, i.e., only 16.32% of the total area (Royal Forest Department, 2014). Soil erosion and salinization have also become problems over most of the region due to land clearing and intensive farming (Prachaiyo, 2000).

The objective of this study was to test the hypothesis that trees in paddy fields are not randomly dispersed, but rather depend on the villages' history of land use and the local demographics, landforms, microhabitat, in the extensive area of Northeast Thailand. To deal with a large spatial scale, satellite images and remote sensing were used, but differed with the methodology of previous researches (e.g. Watanabe et al., 2014), in this study the distribution of trees in paddy fields were classified into 2 types, according to their microhabitat location: in the paddy floor and on the paddy levee. Effects of the factors influencing the trees density were also analyzed and discussed separately for each microhabitat, respectively.

2.2 Materials and methods

The northeast region of Thailand (14°7’–18°26’N, 100°54’–105°37’E) was home to 21,953,183 people in 2006 (National Statistical Office, 2014) and covers an area of 168,854 km^2 (Fig. 2.1a and b).

Twenty villages from 11 provinces (Fig. 2.1b) were classified into two groups according to their landform: 6 were located on the floodplain and 14 were on the low terrace (Tables 2.1 and 2.2).

Satellite images obtained through free images of Google Earth version 7.1.2.1041 (images taken from 2001-2013, provided by Digital Globe; (Table 2.3)) were analyzed to measure the tree distribution patterns using the Quantum GIS software version 1.6.0. Three plots, varying from 10 to 100 ha each with increasing density of trees (sparse, medium, and dense) were selected in paddy field areas of each village by visual examination of the images. The plots were selected within a 2 km radius from the center of each village. Paddy fields were distinguished in the images by the netlike appearance of levees (Fig. 2.2a and b). The length of the paddy levees was also measured using the Calculate Geometry tool of ArcView GIS 10.

The tree distribution patterns of each plot were analyzed. Number of tree crowns were counted separately according to their microhabitats (Fig. 2.2b). Due to difficulties in distinguishing trees standing either singly or in small groups from the satellite images, the number of tree crowns (either of single tree or of cohesive trees; Fig. 2.2c and d) was counted for calculating the tree-unit density on behalf of the tree-individual density. The microhabitat of each tree was recorded by determining the location of each tree crown either in the paddy floor where rice plants were grown or on the paddy levees (Fig. 2.2b). The tree-unit density was thus calculated for both the floor and levee, which equaled the total tree density. This process was repeated three times for each village.

Field surveys were conducted in 2 villages (V3 and V4) in March 2012, 16 (V5–V20) in August 2012, 2 (V1 and V2) in May 2013, and all 20 villages (V1–V20) in December 2013. The village headmen and accompanying persons were interviewed in a semi-structured manner regarding the period of land use since village establishment, the former land cover and vegetation, the process of reclamation, the current population and number of households.

Tree-unit densities were compared using a one-way ANOVA, and Pearson's correlation coefficients were calculated between tree-unit density and the period of land use, the number of households, the human population, and the levee lengths per paddy area using Excel Statistics 2012.

2.3 Results

Factors influencing the tree-unit density in paddy fields

In total, the average tree-unit density of the study area was 6.27 unit/ha (SD = 2.54), ranging from 2.01 to 10.10 (unit/ha) between sites (Table 2.3). Therein, the average tree-unit density in the floors was significantly lower than the average tree-unit density on the levees: the former was 0.97 unit/ha (SD = 0.48), ranging from 0.18 to 1.86 (unit/ha), while the latter was 5.30 unit/ha (SD = 2.39), ranging from 1.65 to 8.98 (unit/ha) (Table 2.3). The average levee length per paddy area was 475.25 m/ha (SD = 166.35), ranging from 220.56 to 724.84 (m/ha) (Table 2.3).

Total tree-unit density had a strong correlation with the tree-unit density on the levee ($r = 0.983$, $p < 0.01$), while no significant correlation was found between tree-unit density and the period of land use, the number of households, or the human population size (Table 2.4). However, the levee length per paddy area was positively correlated with both the total tree-unit density ($r = 0.684$, $p < 0.01$) and the tree-unit density on the levee ($r = 0.699$, $p < 0.01$; Table 2.4).

Tree-unit density in the floor was significantly lower ($p < 0.05$) in the villages on the floodplain (0.61 unit/ha) compared to those on the low terrace (1.13 unit/ha); however, the tree-unit density on the levees was higher ($p < 0.05$) in the villages on the floodplain (6.89 unit/ha) than on the low terrace (4.62 unit/ha). The ratio of tree-unit density on the levees to total density was significantly higher ($p < 0.01$) on the floodplain (0.92) than on the low terrace (0.80).

2.4 Discussion

Paddy fields have expanded along with increased water availability to the low terrace in Northeast Thailand from the lowland floodplain (Walsh et al., 2001; Crews-Meyer, 2004; Vityakon, 2004). When the forest was converted to paddy fields, trees were selectively removed to prevent a reduction in rice yield, and levees were built by connecting termite mounds and the trees that farmers wished to retain. Both labor availability and wood use affect the speed of the paddy conversion process (Grandstaff et al., 1986). Trees in floors gradually decreased due to natural death in submerged conditions or cutting to facilitate agricultural activities. Nevertheless, the results in this study showed a weak relationship of trees density with period of land use and demography. This might due to the fact that some trees survived or were newly planted on levees (Grandstaff et al., 1986). As a result, tree-unit density on the levees is currently higher than in the floors and is correlated with the total tree-unit density (Table 2.4). This trend is more obvious in the villages on the floodplain, where the early introduction of agricultural machinery and the direct seeding of crops have reduced the number of trees in the floors and left levees as the only place for tree plantations.

Tree-unit density in the study sites was smaller than the mean of 12.1 unit/ha (ranging from 0.8 to 44.6) reported by Watanabe et al. (2014) who analyzed 203 grid cells of satellite images (2003–2007) covering all of Northeast Thailand. Although the individual-tree densities of the study sites were larger than the measured unit-tree densities, which often consist of more than one tree (Fig. 2.2c), the individual-tree densities found here were smaller than the 30–149 trees/ha reported in Northeast Thailand 20 years ago (Watanabe et al., 1990). A correlation between the total tree-unit density and the levee length per paddy area (Table 2.4) suggested a future decline in the number of trees because of the ongoing land consolidation for expanding field plot areas due to the removal of levees in Northeast Thailand.

2.5 Conclusions

Forestry statistics revealed a rapid decrease in forest area due to the expansion of agricultural land, but did not reflect the existence of multiple tree resources in the paddy fields of Northeast Thailand. The density and distribution patterns of trees were not affected by the villages' history or local demographics, but the tree-unit density was correlated with density on the levee and with levee length per unit paddy area. Also, by analyzing the tree-unit density separately in 2 microhabitats, the mutual effects of landform and microhabitats on unit density of trees were clarified. This finding implies that factors influencing the spatial variation of tree density in paddy field differs greatly depending on tree microhabitats, due to their different characteristics.

Table 2.1 Characteristics of study sites in Northeast Thailand

No	Village name	Province	Landform	Elevat-ion (m)	Period of land use (years)	No. of House-hold (2012)	Population (2012)	Main income sources*
V1	Ba Thoong	Sakon Nakhon	floodplain	165	130	100	440	Agriculture (rice), Work out
V2	Don Muang	Nakon Phanom	floodplain	148	110	152	650	Agriculture (rice), Work out
V3	Dong Na Thao	Nong Khai	floodplain	167	30	168	612	Agriculture (rice, sugarcane), Forestry (rubber, eucalypt)
V4	Na Hee	Nong Khai	floodplain	162	300	190	822	Agriculture (rice), Forestry (eucalypt), Others
V5	Lao Nokchum	Khon Kaen	floodplain	153	300	193	700	Agriculture (rice), Work out
V6	Tha Tum	Mahasarakham	floodplain	142	100	206	747	Others, Agriculture (rice), Work out
V7	Chan Tai	Sisaket	low terrace	142	300	72	358	Others
V8	Don Pa Muang	Yasothon	low terrace	165	70	114	587	Agriculture (rice, sugarcane, cassava), Forestry (rubber), Work out
V9	Huai Kaeng	Yasothon	low terrace	157	110	179	623	Agriculture (rice, cattle), Others
V10	Muang	Yasothon	low terrace	124	500	150	600	Agriculture (rice, peanut), Work out
V11	Muang Tao	Mahasarakham	low terrace	135	500	64	292	Agriculture (rice, cassava), Forestry (eucalypt)
V12	Na Kao	Surin	low terrace	152	200	227	945	Agriculture (rice), Work out
V13	Non Nam Nguong	Roi Et	low terrace	171	250	136	630	Agriculture (tobacco, rice)
V14	Non Sai	Sisaket	low terrace	138	150	68	300	Forestry (rubber), Agriculture (rice), Work out
V15	Nong Sao	Roi Et	low terrace	132	150	185	1000	Work out, Agriculture (rice)
V16	Phon Than	Yasothon	low terrace	128	1000	192	457	Agriculture (rice, cassava), Work out
V17	Prakhon Chai	Buriram	low terrace	165	60	423	1862	Work out, Forestry (eucalypt, rubber)
V18	Sa Nom	Surin	low terrace	182	500	216	914	Agriculture (rice), Others
V19	Si Chompu	Khon Kaen	low terrace	205	100	110	1000	Agriculture (sugarcane, rice), Work out
V20	Tha Hai	Ubonrachathani	low terrace	118	300	131	704	Agriculture (rice, cassava), Forestry (rubber), Work out

* Others including retailing commodities, selling handicrafts or working as a carpenter.

Table 2.2 Characteristics of the two landform types at study sites in Northeast Thailand.

Landform	Floodplain	Low terrace
Terrain[a)]	Level to nearly level lowland along the river, sometimes subject to flooding	Level to undulating land, relatively high elevation compared to floodplain
Soil condition[a)]	Poorly drained alluvial clayey soil on recent alluvium	Low-humic gley soil, mostly loam and sand, on semi recent and old alluvium
Soil fertility[a)]	High to moderate	Moderate to low
Rice productivity[b)]	High to moderate	Moderate to low
Cropping systems[b)]	The reclaimed earliest, recently introduced direct seeding system and agricultural machinery	Reclaimed later than the floodplain; use a manual transplanting system, is abandoned in cases of water shortage

a) Land Development Department (1972).

b) Vityakon (2001), field interviews, and observations.

Table 2.3 Tree-unit density and ratio of levee length per paddy area at study sites.

Village No.	Satellite image year	Density in floor (ha^{-1})	SD	Density on levee (ha^{-1})	SD	Total density (ha^{-1})	SD	Levee length/paddy area (m/ha)	SD
V1	2006	0.66	0.45	7.09	5.79	7.75	6.24	692.7	31.55
V2	2006	1.03	1.03	8.88	6.77	9.92	7.71	662.98	129.71
V3	2011	0.91	0.43	7.15	1.58	8.06	1.95	703.83	129.82
V4	2011	0.38	0.14	7.35	0.75	7.73	0.79	544.16	66.53
V5	2004	0.48	0.38	8.98	4.17	9.46	3.83	438.88	29.13
V6	2003	0.18	0.05	1.88	0.69	2.06	0.74	252.44	24.01
V7	2009	1.86	0.91	3.06	0.50	4.92	1.21	289.3	12.31
V8	2003	0.56	0.22	2.61	2.95	3.16	3.13	329.01	457.43
V9	2011	1.71	1.10	6.96	1.34	8.67	2.39	511.45	30.83
V10	2013	1.72	0.68	8.38	2.48	10.1	2.44	451.73	22.56
V11	2006	0.36	0.35	1.65	1.40	2.01	1.74	220.56	38.94
V12	2006	1.04	0.18	2.64	0.82	3.68	1.00	303.87	36.19
V13	2010	1.15	0.27	6.58	2.34	7.73	2.59	569.29	56.45
V14	2007	1.10	0.23	3.50	1.26	4.60	1.49	312.7	42.24
V15	2006	0.75	0.34	3.53	2.82	4.29	3.16	292.78	213.53
V16	2007	1.48	0.81	6.78	2.05	8.25	2.83	521.52	40.01
V17	2004	1.21	1.44	3.42	0.91	4.63	2.35	434.09	52.78
V18	2001	0.87	0.43	4.40	3.38	5.27	3.77	669.15	237.55
V19	2010	0.82	0.88	5.25	4.75	6.07	5.58	579.75	55.5
V20	2012	1.24	1.21	5.86	1.21	7.10	0.77	724.84	338.87
Mean		0.97 a*		5.30 b		6.27 b		475.25	
SD		0.48		2.39		2.54		166.35	

* Values followed by the same letter are not significantly different at 5% level based on One way ANOVA test.

Table 2.4 Correlation coefficient between tree-unit density and period of land use, number of household, population and ratio of levee length per paddy area at study sites (n = 20) in Northeast Thailand

	Density in floor	Density on levee	Total density
Total density	0.400	0.983**	–
Period of land use	0.246	0.138	0.176
Number of household	0.012	-0.006	-0.003
Population	-0.063	-0.120	-0.125
Levee length / paddy area	0.142	0.699**	0.684**

**$p<0.01$

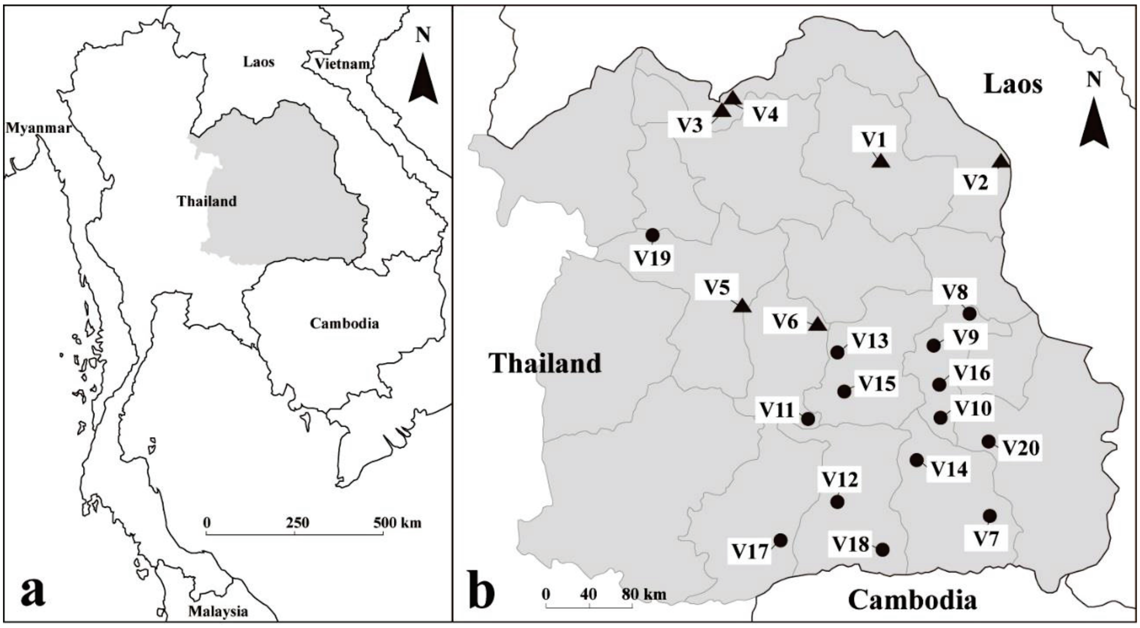

Fig. 2.1. Map of the study sites. (a) Area of Northeast Thailand (gray area) and (b) location of 20 selected villages. Six villages were located on the floodplain (V1–V6, triangle) and 14 were on the low terrace (V7–V20, circle).

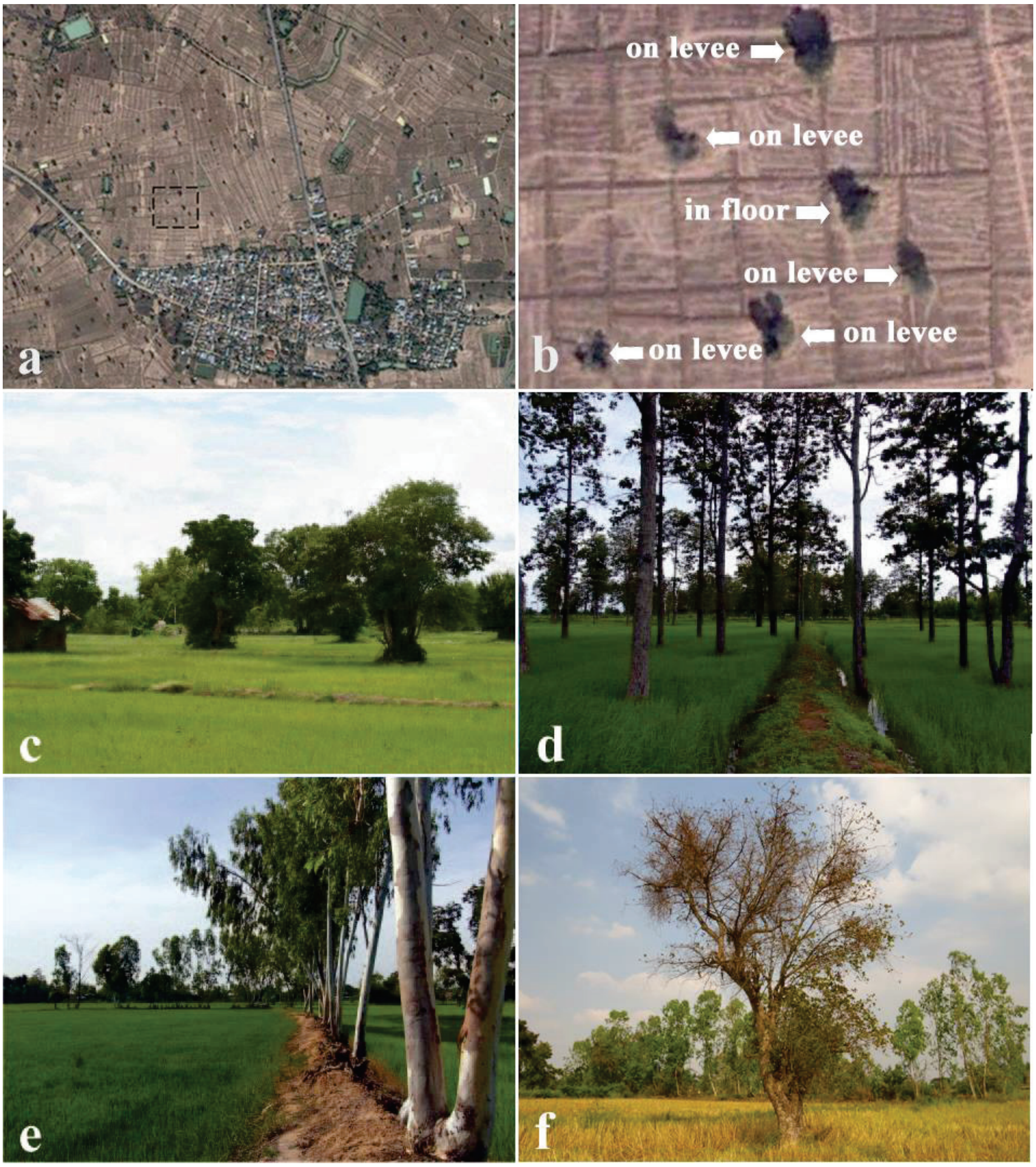

Fig. 2.2. Trees in the paddy field landscape in Northeast Thailand. (a) Paddy fields surrounding the village settlement area are shown in a satellite image; (b) an enlarged version of the square frame image in (a), where a tree-unit is described as either in the paddy floor or on the levee; (c) tree-units of *Tamarindus indica*, *Azadirachta indica* var. *siamensis*, and *Streblus asper*, among others, on termite mounds in a paddy field; (d)

Dipterocarpus spp. and *Shorea* spp. in floors and on levees; (e) coppicing eucalypts planted on levees; and (f) pollarding for fuelwood collection from *Mitragyna diversifolia* in a paddy field. Images (a) and (b) were obtained from Google Earth in 2014.

CHAPTER 3

Historical changes of landscape structure and distribution of trees in paddy fields

3.1 Introduction

Whereas conservation of traditional landscapes remains one of the main issues in current landscape ecology (Palang and Fry, 2003), the fact that those landscapes are disappearing due to urbanization, agricultural modernization and abandonment has reached an alarming level. Beside resources loss, it is common knowledge that ongoing landscape transformation threaten species diversity and caused consequences for the ecosystems. But to understand specifically the mechanism of how landscape transformation affects the ecosystem as well as the corresponding species is very important in pursuance of conserving those traditional ones.

Paddy fields with many standing trees located either in paddy floor or on paddy levee is the typical landscape of rural areas in Northeast Thailand. So far, studies on trees in this landscape have showed a wide range of variation in density of trees, locally and regionally. Also, period of land use was often discussed in previous researches as a factor that influence tree density: the older the paddy land, the fewer the numbers of tree; without showing any specific evidences. In recent years, trees in paddy fields have been reducing rapidly by land consolidation caused by modernization of rice cultivation, without any development strategies and management measures (Vityakon et al., 2004). Meanwhile, severe deforestation in the region causes a decline of forest products such as charcoal or firewood, pressure more on using trees in paddy fields. Thus, it has become an urgent subject to learn from the past of the landscape, in order to plan strategies for sustainable conservation of the future one.

This research was conducted to find out precisely how the chronological factor and land use changes impact the density and structure of tree distribution in paddy field. We hypothesize that:

1. Landscape transformation has affected spatial structure of tree distribution in paddy field.
2. Trend of changes in tree density depended on the length of land use practice for rice cultivation.

To test these hypotheses, data of land use changes together with density of tree in paddy were collected in a time series during 1975-2014 in three different rural landscapes, in the northeast region of Thailand.

3.2 Materials and methods

The field survey was conducted at three villages: Phon Than, Lao Nokchum and Si Chompu, all located in the northeast of Thailand. Although located in the same northeast region, the three target villages have dissimilar features. Phon Than and Si Chompu are both classified as low terrace region with easily access to water resources (about 300-900m apart from central village). Because of consisting of mostly denudation surface, and with a long history of land use, Phon Than has apparently lower elevation than Si Chompu (see Table 2.1 in Chapter 2). On the other hand, Lao Nokchum located right next to the meander of Chi river, one in two main rivers in the northeast, and rice fields here are often partly flooded in peak time of rainy season from May to October. All three villages have a long period of rice cultivation, from the oldest 1000-year Phon Than to the 300-year Lao Nokchum and the newest Si Chompu with also more than 100 years of history. Through interview the village headman, we acknowledged that in all three villages, there has been the history of growing eucalypt, and in recent decades, a project of integrated growing eucalypt on paddy levee has been implemented.

The landscape surrounding each target village was analyzed using Geographical Information Systems (Quantum GIS 1.6.0 and ArcView GIS 10). For each village, three maps representing different time layers were analyzed. Aerial photographs obtained from

Royal Thai Survey Department (provided as monochrome; 1:15,000; images taken on 7 Nov 1975; 18 Dec 1975; 6 Oct 1976; 14 Jan 1991; 2 Nov 1992 and 12 Nov 1992) and satellite images obtained through free images of Google Earth version 7.1.2.1041 (images taken on 10 Apr 2013; 13 Jan 2014 and 15 May 2014 provided by Digital Globe) were used for measuring the tree distribution patterns and the area of respective land use types (paddy fields, other crop fields, open water, forest patches and village settlement areas). Classification of each type was described in Table 3.1. At each target village, the landscape was analyzed at 1 km spatial scale by 1-km radius circle, chosen to include the whole settlement of the target village and the surrounding paddy fields (Fig. 3.1). For measuring level of the urbanization, geographic information of well-constructed main roads were also recorded.

Paddy field was recognized from other crop fields in the images by the netlike appearance of levees, which is man-made earthen ridges used as footpath, property boundary, or space for planting trees (Fukamachi et al., 2005). The length of paddy levee was also measured using the Calculate Geometry of ArcView GIS 10. From satellite image and aerial photographs, it is difficult to identified exactly numbers of each individual tree. Thus, each canopy of tree was considered one tree-unit on behalf of tree-individual density. Density of tree in two different microhabitats: in the paddy floor and on the levee were then calculated, by divided the counted numbers of trees in each microhabitat for total area of paddy field, respectively.

Annual rates of change were calculated for each type of land use as the percentage of change, divided by the number of years disconnecting the pairs of time layers being compared. Beside proportions change, the changes in landscape structure were followed over the three decades for each layer by computing three landscape metrics: the Number of Patches (the total number of all recorded land use patches except paddy fields; NP), the Mean patch size (MPS) and the Shannon's Diversity index (SHDI) (Turner and Gardner, 1991). Data of paddy patches were neglected to exclude the dominant effect.

3.3 Results

3.3.1 Landscape transformation

The annual rate of land use change and main road change over each period is described in Table 3.2, separately in each landscapes and in average of three landscapes. In average, forest areas have been reducing continuously at rate of -2.15% during 1975-2014. Whereas village settlement and main road showed a gradually increasing rate of 2.04 and 2.17%, respectively. Paddy field areas was not changed from 1975 to 2014. The constantly decline of the levee length per paddy area (-1.05%) showed the ongoing land readjustment for expanding field plot areas by removing levees (Table 3.2).

Land cover proportion changes were estimated from the analysis of the time series during 1975-2014 (Fig. 3.2). Paddy field is the most dominant land cover, with an average of approximately 70% the proportion in all three landscapes in any time layers, and up to 90% in Phon Than in all three time series. Remnant forest has a general negative trend of change. In 1975-1976, Lao Nokchum had the proportion of remnant forest cover of 14.1%, but drastically decreased to 5.1 % in 2013-2014. There were a slight increase in forest cover in Si Chompu from 1991-1992 to 2013-2014 (from 1.2% to 1.6%). Phon Than had the lowest proportion of forest cover, of 2.0% in 1975-1976, and had decline further to 0.6% in 2013-2014. In contrast, village settlement had expanded gradually over time. Open water and other fields showed different trends in three landscapes. In the flood plain Lao Nokchum, both had positively increased. In the low terraces Si Chompu and Phon Than, area of open water had both decreased. Other land uses in Si Chompu decreased over time but in Phon Than, it first decreased from 1975-1976 to 1991-1992 then increased in the later period. In average, forest areas have been reducing continuously in both two period of time series. Whereas village settlement and main road showed a gradually increasing in both period. Paddy areas increased in the former period:

1975-1976 to 1991-1992 but then declined in the later one: 1991-1992 to 2013-2014. The constantly decline of the levee length per paddy area showed the ongoing land consolidation for expanding field plot areas by removing levees (Fig 3.2).

The increase in number of patches and the decrease in mean patch size imply that the landscape has become more fragmented (Fig. 3.3a, b). Thus it is obvious that Lao Nokchum landscape is significantly more fragmented than the other two villages. In general, the land use diversity in the landscape has been decreasing between 1975-1976 and 1991-1992, but since 1991-1992, it had managed to recover slightly (Fig. 3.3c). However, the landscape diversity index is clearly lower in Phon Than (Fig. 3.3c), indicated the unequal in proportion of land use types here.

3.3.2 Historical changes of tree-unit density

Both of the tree density in the floor and on the levee was highest in the 1000 years old landscape Phon Than, regardless of time layers (Table 3.3). However, the variation of tree density between landscapes were getting smaller over time (Fig. 3.4).

In the recorded time series, trend of changes in tree density differed between three studied villages, as well as among different types of tree density within each village (Fig. 3.4). In general, tree density in the floor decreased over two periods, except its slightly increasing from 1991-1992 to 2013-2014 in Phon Than. Tree density on the levee showed signs of risen from 1975-1976 to 1991-1992 in Lao Nokchum and from 1991-1992 to 2013-2014 in Si Chompu (Fig. 3.4).

3.4 Discussion

The continuously reducing of forest areas reflected the fact of severe deforestation, happening in recent decades in the region. Whereas expansion of village settlement and well-constructed road were corresponded with the rapid development of the economic and urbanization. Those human activities caused consequences to the landscape changes, which then affected tree density in paddy fields. However, this decline just happened recently, in compare with the history of hundreds or thousands years of villages, thus lead to the weak correlation between trees density and period of land use in chapter 2.

When forest was converted to paddy field, some trees were left standing for used in various ways (Grandstaff et al., 1986). Trees in floor then reduce over time universally due to natural death when flooding field or cutting for used, which was proved in this study (Fig. 3.4). At the same time, trees survived or were newly planted on levees (Grandstaff et al., 1986), resulting in higher proportion of tree density on levee compare with that of tree density in floor (Fig. 3.4). This explain why despite the repeatedly reducing of the levee length per paddy area ratio (Table 3.2), the levee density was not kept reducing. Farmers prefer a paddy field with trees rather than no tree, hence decided to preserve some species that thought to be valuable, and even planted new ones on paddy levees, as we acknowledged through field surveys.

Besides, landscape structure might also play an important part in decision of future tree density. When landscape structure were dominated by paddy fields and originally had high tree density, it would then lead to higher ratio of natural generated saplings and less affected by human interference. This explain why there was increasing trend of trees in the field from 1991-1992 to 2013-2014 in Phon Than (Fig. 3.4), as this village landscape had the largest paddy areas proportion (Fig. 3.2). On the contrary, landscapes with initially few tree would then reflected evidently the effect of human activities. Nevertheless, only in low terrace Si Chompu with more suitable conditions for application of trees planting than flood plain Lao Nokchum, had an increasing trend of tree density on the levee until 2013-2014 (Fig. 3.4).

3.5 Conclusion

Despite the general consensus that trees would gradually reduce as time pass, the dissimilar trend of changes recorded in three landscapes and the fact that the oldest village had the highest tree density implied that period of land use was not a factor that directly influences trees density in paddy fields. In a long term, although the tree density was not affected by chronological factor, there is no guarantee that the species richness was also maintained. In pursuance of further discussing, it is necessary to examine the short term impact of landscape change (e.g. land consolidation in paddy fields) to both density and species diversity of trees.

Table 3.1 Land use classification scheme

Land cover types	Description
Remnant forest	remnants from primary or secondary forest, tree plantations or land-cover with high density of trees
Settlement	houses, schools, buildings, factories, temples, human constructions including small huts in paddy field
Open water	river streams, ponds, water canals
Paddy field	agricultural lands where rice crops are cultivated
Other land use	upland fields, vegetable gardens, grassland, agricultural lands other than paddy fields
Main road	roads that are accessible by cars
Paddy levee	the net-like images of earthen ridges surrounding paddy fields

Table 3.2 Annual rates of changes in land use and main road during 1975-2014 (%)

Village	Remnant forest	Village settlement	Open water	Other land use	Paddy field	Main road	Levee length/ paddy area
Phon Than	-1.85	0.57	1.15	5.23	-0.05	0.97	-0.86
Lao Nokchum	-1.68	2.33	0.71	0.34	0.17	3.47	-0.89
Si Chompu	-1.68	1.72	-0.83	-1.03	0.06	1.69	-2.56
Average	-2.15	2.04	0.89	1.16	0.00	2.17	-1.05

Table 3.3 Tree-unit density (unit/ha) in three studied villages in three time layers

	Tree-unit density in floor			Tree-unit density on levee		
	1975-1976	1991-1992	2013-2014	1975-1976	1991-1992	2013-2014
Phon Than	3.09	1.72	1.75	12.84	9.98	7.37
Lao Nokchum	0.55	0.49	0.22	3.24	4.77	6.63
Si Chompu	1.49	0.85	0.63	3.72	3.52	6.46

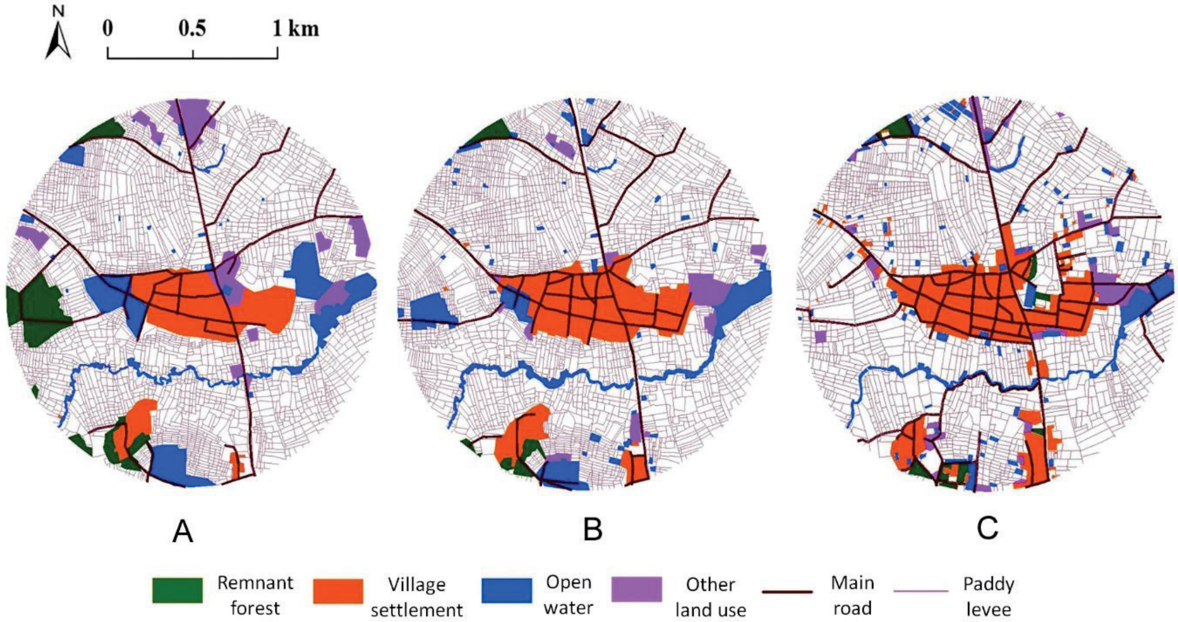

Fig. 3.1 Example land use map of Si Chompu, representing four time periods: (A) 1975-1976, (B) 1991-1992, (C) 2000s, and (D) 2013-2014. Each circle has the radius of 1 km.

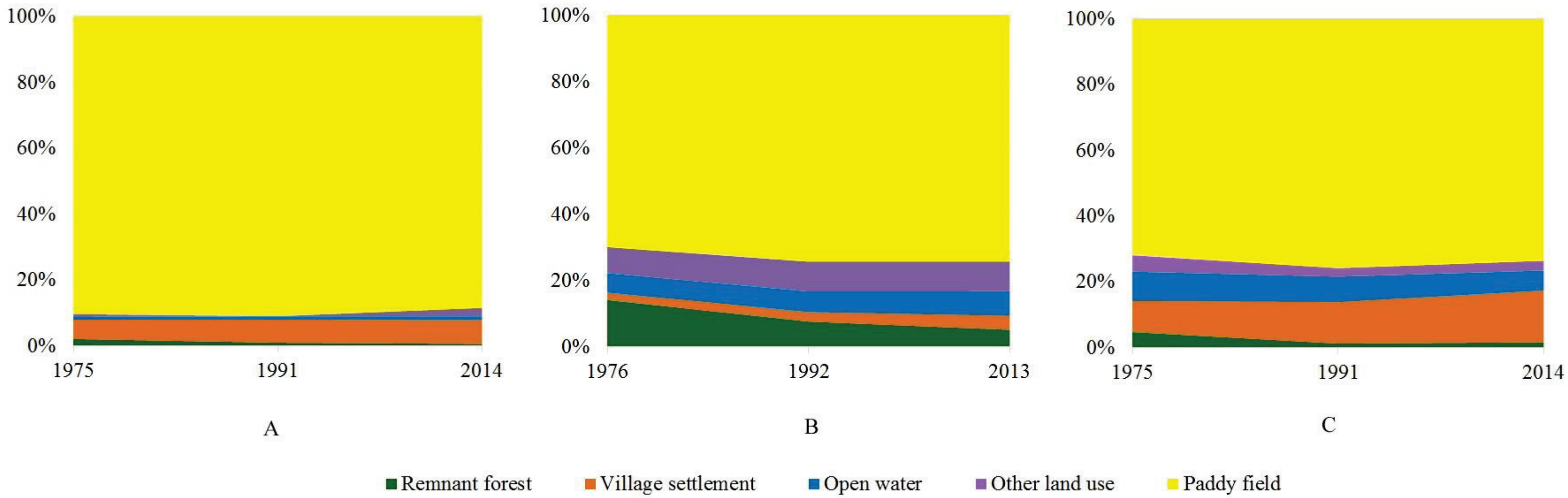

Fig. 3.2 Land use proportions change from 1975-2000s in three villages: (A) Phon Than, (B) Lao Nokchum, and (C) Si Chompu.

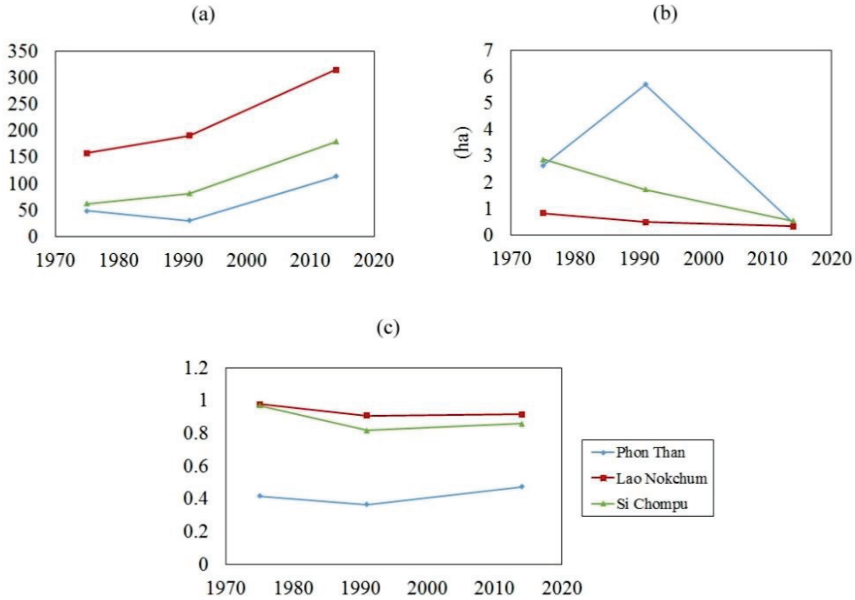

Fig. 3.3 Changes in landscape structure measured by three landscape indices from the time series in three landscapes. (a) Number of patches (NP); (b) Mean patch size (MPS); Shannon's Diversity index (SHDI).

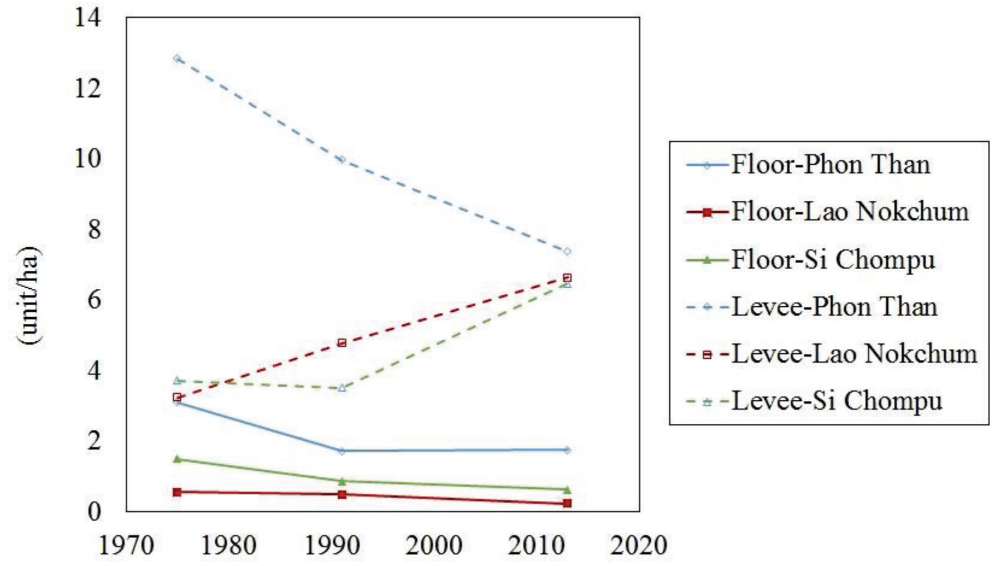

Fig. 3.4 Historical changes of the unit density of trees in the floor (Floor), and of trees on the levee (Levee), in three landscapes over the time series.

CHAPTER 4

Effect of land consolidation on density and species diversity of trees in paddy fields

4.1 Introduction

The conservation of landscapes that are capable of harmonizing the needs of both human society and nature has become a pressing concern, as the human population and the decline of biodiversity have both risen dramatically. However, these landscapes are rapidly disappearing due to the incorporation of industrialization into traditional agricultural practices (Natori et al., 2011). From the latter half of the 20th century, agricultural intensification has occurred around the globe and has resulted in a severe reduction in local biodiversity and an increased risk of global extinction for many species (Norris, 2008). The increased application of chemicals and machinery has helped to temporarily obtain higher crop yields, but inappropriate intensive farming might lead to the permanent degradation of ecosystems (Tilman, 2002; Norris, 2008). The balance of diversity and productivity has been broken, and sustainability is no longer assured.

So far, studies on trees in paddy fields have been limited mostly in their quantitative density, but lack of qualitative report on species diversity. Although tree species diversity are much lower than herbaceous plant species, trees provide habitat for hundreds or thousands of species such as bee, birds, termites, etc. (Grandstaff et al., 1986; Kokubo et al., 2015). Hence, abundant trees species lead to diversity of a larger variety of organisms. Due to both benefits of trees to human and nature which are capable of balancing productivity and diversity, this study focus on diversity of trees in paddy fields.

In the past, there were reports that size of individual farms was associated with the density of trees: larger farmlands holding usually had more trees than smaller ones (Vityakon, 1996). Nevertheless, the positive relationship of tree density with farm size may not imply the same trend for species richness. In contrast, several studies have pinpointed that together with the development stages of rice cultivation, a diverse mix of remnant tree species scattered in paddy fields is gradually replaced by a few planted one (Grandstaff et al., 1986; Kosaka et al., 2006) or by the eucalypts plantation on the levee (Funahashi and Kosaka, 2015). Besides, a research regarding tree species diversity in western Kenyan farms has concluded that though farm size had a positive relationship with tree diversity, the same area would be more abundance if it was composed of many smaller plots (Kindt et al., 2004). Whereas relationship of trees diversity and size of field plot remain unclear, farmers continue to expanding their plot size to adopt the use of agricultural machinery (Grandstaff et al., 2008).

Besides the use of machinery and the increase in field size, agricultural intensification also involving the intensive use of chemical fertilizers and changes in cultivation practices from transplanting to direct seeding under mechanized plowing or puddling (Miyagawa et al., 2011), which have entailed important landscape changes. A number of studies on density of these trees in different period have coincidentally reflected a declining trend in the average tree density over time: Watanabe (1990) reported a tree density varies from site to site ranging from 30 to 149 tree/ha; Prachaiyo (2000) recorded an average density of 15 tree/ha, varies between 4 and 24 trees/ha; and Pham et al., (2015) found an average density of 6.27 tree-unit/ha, ranging from 2.01 to 10.10 (tree-unit/ha). Trees gradually reduce over time is common knowledge (Grandstaff et al., 1986), however it is coincidently correlated with the development of intensive agriculture. Thus, this study were conducted to find out the impact of landscape transformation due to agricultural intensification on tree density and species diversity in paddy fields.

In this study, we analyzed the distribution pattern of trees in different agricultural areas in rural landscapes of Northeast Thailand to determine how the process of agricultural intensification affects the density and species diversity of trees. Specifically, we examined the hypotheses that (i) there is relationship between the average plot size and the density and species diversity of trees, and (ii) agricultural intensification has affected tree diversity due to land consolidation that occurred in the past.

4.2 Materials and Methods

Study area

The study was conducted in the northeast region of Thailand (14º7–18º26’N, 100º54’–105º37’E) (Fig. 4.1a). Like many other parts of the country, rice cultivation is the most important crop grown in the study area. Due to the dry and saline soil conditions, as well as a lack of water, the average rice yield in the region is the lowest in Thailand, despite its being the second largest rice growing area in the country (Adulavidhaya and Tsuchiya, 1986). Following the fourth National Economic and Social Development Plan (NESDP) of Thailand in 1976, modern agricultural technologies were introduced to the northeast region (Soni and Ou, 2010). However, it is only since 1985 that a structural shift in agricultural production in the region began to occur (Thepent and Chamsing, 2009). Biodiversity in paddy fields was affected when agricultural machines were introduced and gradually replaced traditional management methods, as well as by urbanization and land consolidation (Miyagawa et al., 2011). The percentage of households using a two-wheeled tractor in the northeast started to increase (7% in 1983, 54% in 1993, 89% in 2003; Grandstaff et al., 2008). The increased use of agricultural machinery also led to further land consolidation to increase the size of paddy plots. The use of machinery has become an important change in agricultural production systems, with nearly 100% of households now using tractors (either four- or two-wheeled), instead of animal power.

Geographical data and field survey

Three different landscapes surrounding 3 villages: Phon Than, Lao Nokchum, and Si Chompu were chosen (Fig. 4.1b). Each landscape is a mosaic of paddy fields, upland fields, remnant forest and human settlements, typical for the rural landscape of the northeast. Their topography ranged from a flood plain to a low terrace, with soil fertility varying from high to low, respectively (Pham et al., 2015). All three landscapes have a long history of rice cultivation, ranging from 100 to 1000 years. Three different time series during 1975–2014 were created for each landscape using aerial photographs obtained from Royal Thai Survey Department and satellite images obtained through free images of Google Earth version 7.1.2.1041 (see details in previous chapter). These time series were selected to represent three different stages of the mechanization of agriculture: 0% (1975-1976), 50% (1991-1992), and 100% (2013-2014) (see Grandstaff et al., 2008 for details). Within a 1-km radius circle of each study landscape, we identified paddy fields that were or were not under land consolidation by comparing the net-like image of paddy levees (the earthen ridges surrounding paddy fields) in the different time series (Fig. 4.2). We divided paddy fields into two groups: land-consolidation (LC) paddies (there were changes in the average paddy plot size and length of paddy levee) and no-land-consolidation (NLC) paddies (there were no such changes).

In each studied landscape, there were three random replicates for each group; thus, there were nine target sites in three landscapes for each group and 18 target sites in total, with the area of each site varying from 0.7 to 1.6 ha. As the area of paddy land holdings in the region was relatively small (2.3 ha in 2000; Grandstaff et al., 2008; 2.4 ha in 2013; National Statistical Office, 2013), sites were selected to ensure that each site belonged to the same owner and had undergone similar management methods. Changes in the number of paddy plots, length of paddy levees, and tree distribution patterns were recorded in the three time series. The number of tree crowns (either of single tree or of cohesive trees) in each microhabitat (inside the paddy floor or on the paddy levee; Fig. 4.3a) was counted for calculating the tree-unit density on behalf of the tree-individual density (Pham et al., 2015). The site area and length of paddy levees were measured using Calculate Geometry in ArcView 10. The average plot size was then determined by dividing the total site area by the number of paddy plots. A field survey was conducted in March 2015 at 18 target sites to collect tree diversity data. Three measures, total individual trees (the total number of individual trees), individual tree density (the average number of individual trees per hectare), and species richness (the total number of trees species) with diameter at breast height (DBH) of more than 1 cm and height (H) of more than 1 m at each target site were recorded separately for each microhabitat, both in the floor and on the levee. The nomenclature of the tree species followed Smitinand and Larsen (1970-1996) and Santisuk and Larsen (1997-2013). Interviews about the land management history with the field owners were also conducted.

Analysis

To test whether LC paddies differed from NLC paddies, an analysis of variance (ANOVA) was performed. Means were compared by Fisher tests. To examine the relationship of plot size to tree diversity, Pearson's correlation coefficients were calculated for all 18 studied sites and the LC group in each time series. We calculated the mean alpha diversity for each microhabitat in each group as the mean number of species per site (i.e., across nine sites per group; equal to the mean value of species richness). Gamma diversity for each microhabitat in each group was the total number of species identified across all the sites in the group. Beta diversity was the difference between gamma diversity and mean alpha diversity (Crist et al., 2003). All statistical analyses were performed using Excel Statistics 2012.

4.3 Results

4.3.1 Tree species diversity

A total of 334 individual trees belong to 46 tree species were recorded at field survey. Diversity tended to be highest in trees on the levees in the LC group, regardless of the parameter considered, whereas it tended to be lowest in trees in the floors in the NLC group (Table 4.1). The mean number of individual trees was much higher on the levees in the LC group (17.0 trees) than in the floors in the NLC group (1.4 trees) (Table 4.1). The mean number of individual trees was intermediate on the levees in the NLC group and in the floors in the LC group (13.0 and 5.7, respectively). The mean individual tree density followed the same trend, with 14.6 tree/ha on the levees in the LC group, 1.3 tree/ha in the floors in the NLC, and 12.8 and 5.9 tree/ha on the levees in the NLC group and in the floors in the LC group (Table 4.1).

The mean alpha diversity, or mean species richness, was nearly five times higher on the levees in the LC group (4.9 species) than in the floors in the NLC group (1.0 species), and it was intermediate at the other two locations (3.7 on the levees in the NLC group, and 2.1 in the floors in the LC group) (Table 4.1). The total number of species across all sites (gamma diversity) was also at a maximum on the levees in the LC group (44 species), with 33 species on the levees in the NLC group, 19 species in the floors in the LC group, and only 9 species in the floors in the NLC groups. Overall, the trend of the low local mean alpha diversity and high regional beta diversity found in both groups explained for the high variation on all diversity measures among sites.

4.3.2 Relationship between paddy plot size and the density and species diversity of trees

An analysis of the landscape changes between 1975 and 2014 showed that the process of agricultural intensification has been rapid. The average plot size of LC paddies in 1975-1976 and in 1991-1992 (0.11 and 0.14 ha, respectively) was significant smaller than that of NLC paddies (0.44 ha); while it was intermediate in LC paddies in 2013-2014 (0.33 ha) (Table 4.2). The average levee length per paddy area was highest at LC sites in 1976 (895.4 m/ha), lowest at LC sites in 2013-2014 (600.5 m/ha), and intermediate at LC sites in 1992 (817.2 m/ha) and at NLC sites (676.4 m/ha) (Table 4.2).

The overall tree-unit density had a tendency to reduce over time, except on the levees in the NLC groups, where tree-unit density increased over time (Table 4.3). Tree-unit density tended to be higher on the levees in the LC group and lower in the floors in the NLC, irrespective of the time period. The difference among microhabitats within each group was not significant in 1975-1976, but was significant for both groups in 2013-2014 (Table 4.3). As with tree species diversity, tree-unit density showed a consistently high coefficient of variation among sites. The tree-unit on the levee per 100 m of paddy levee length was also calculated, and there found to be no significant differences between two groups of paddies (Table 4.3). However, LC paddies tend to have higher tree-unit on the levee than NLC paddies (Table 4.3). During 1975-2014, tree-unit on the levee in LC paddies was decreasing while it was increasing over time in NLC paddies (Table 4.3).

In general, there was no relationship between the paddy plot size and tree density or tree species diversity. Further analyses were performed for the LC sites to test the effects of land consolidation on tree density and species richness. We found that the tree-unit density was positively related to plot size in 1991-1992, whereas it was negatively related to plot size in 2013-2014 (Table 4.4). Individual tree density and species richness were not affected by the size of paddy plots in the past, but both were lower in the floors of larger plots in 2015 (Table 4.4).

4.4 Discussion

4.4.1 Variation of tree species diversity

The high variation of beta diversity (Table 4.1) might due to different topography (floodplain or low terrace) and soil fertility (high to moderate or moderate to low) of three selected landscapes (Pham et al., 2015). As several tree species have their own specific suitability to some particular sites (Prachaiyo, 2000), each landscape has several unique species that other does not have (e.g. *Phyllanthus taxodiifolius* is a ruderal species found only in Phon Than sites). Due to this general low similarity in species composition between landscapes, the variation in diversity among sites of LC and NLC paddies were relatively high.

Though undergone the land consolidation process, all the parameters of tree species diversity in LC paddies were still higher than in NLC paddies. This result implies that the impact of land consolidation on tree species diversity is not as strong as other landscape variables (e.g. topography, initial species diversity). Although there were no land consolidation at NLC sites from 1975 to 2014, the possibility is that introduction of machinery or changes in cultivation practices were also adopted here, due to the advantage of initial large plot size (interview results).

4.4.2 Effects of agricultural intensification on the density and species diversity of trees

The average plot size of LC paddy fields in the studied landscapes has undergone significant changes during 1975-2014, reflecting the landscape transformation that has occurred in the region and in the rest of Thailand due to the introduction of machinery in agriculture. In the past, Thailand's crop production increased as a result of expansion of the area under production (Thepent and Chamsing, 2009). Strategies were then introduced to increase agricultural production by increasing land productivity, which resulted in major changes in the paddy plot size from period 1991-1992 onward.

According to the background and the hypothesis, agricultural intensification has negative effects on tree species diversity. However, results obtained from remote sensing analysis and field survey showed that tree density and diversity in LC group was generally higher than that in NLC group (Table 4.1; 4.3). Initial low density of NLC group observed in 1975-1976 is probably due to large plot size. Although tree unit-density of paddy fields in both LC group and NLC group reduced over time, reduction rate is much higher in LC group (Table 4.3). Apparently, farming method has been changed not only in LC group but also in NLC group (e.g. use of machinery instead of animal power) during 1975-2014. Therefore, reduction of tree density over time was observed in both groups. It can be assumed that one of the main causes of higher reduction rate in LC group is land consolidation. When interview with the field owners, one common point is that the paddy plots that were previously smaller were expanded when started using plowing tractor or harvesting machine. On the other hand, due to the more favorable water conditions, the paddy plots in the lowlands were originally large enough to require no further expansion. This is in align with the case study of a village in Northeast Thailand, where alteration of paddy plots was the most efficient way to increase rice productivity in the highlands, where paddy plots were previously smaller (Watanabe et al., 2008).

The positive relationship between plot size and tree-unit density found in 1991-1992 for LC sites was due to the exceptionally high number of tree-units on the levee found at one site (23.3 unit/ha) in Phon Than in that period (Table 4.4). One explanation is that the site had a rather high tree-units density previously in 1975-1976 (36.4 unit/ha). When plot sizes increased drastically from 0.11 in 1975-1976 to 0.33 ha in 1991-1992, the tree-units was still remain. The dominant species on that site was *Dipterocarpus alatus* (interview results) and *Syzygium cumini* (field observation), which leaf litter were considered good for rice growth (Pham et al., 2015). However, according to interview, farmers that do not possess a harvesting machine have to line up for the rental one. The machine owner is reluctant to come to paddy fields with many trees due to obstacle in operating machinery, thus people prefer less and less tree in their fields. Consequently, together with the removal of paddy levees and expansion of plot sizes, the increased use of machinery reduced the number of trees, resulted in the negative association between plot size and tree-unit density in 2013-2014 (Table 4.4).

A study recently conducted at different crop fields (maize, soybean, forage crops, and wheat) in Canada revealed that farmlands with smaller field sizes had higher within-field biodiversity due to increase of landscape heterogeneity (Fahrig et al., 2015). Similarly, we also found that the individual density and species richness of trees in the floors were lower in paddy fields with larger plot sizes in 2015 (Table 4.4). However, the mechanism of the result is due to the different characteristic in succession of trees in each microhabitat. When machinery was introduced to replace animal power, trees in the floors became an obstacle (Fig. 4.3b). According to interview and field observation, small trees were removed immediately, whereas big trees were cut, and the stems were left to die when the fields flooded during the rainy season (Fig. 4.3c). The dead stems were then easy to remove in the following dry season. The long flooding period in rice cultivation makes it difficult for tree seedlings to regenerate and survive in the floor (Grandstaff et al., 1986). As a result, most trees in the floors were remnants from the predominant forest (Pham et al., 2015), and the large plot size of paddy fields after land consolidation reduced both their individual density and species diversity. On the other hand, only a few trees on the levees were cut to open routes for the newly introduced machinery to enter the fields.

The rest were mostly pollarded or coppiced (Pham, field observation). As the levees are often 0.4–1 m higher than the field surface, the coppiced stems were then able to survive flooding, and regrowth occurred rapidly (Fig. 4.3d). A limited selection of teak trees (*Tectona grandis*), with their high-value timber, and fast-growing eucalypt trees (*Eucalyptus camaldulensis*) were planted on the levees (Niskanen, 1998; Pham et al., 2015) to replace the few trees that were removed. Hence, trees on the levees are mostly planted and were not significantly affected by land consolidation.

Table 4.1 Diversity measures of woody plants for each group and microhabitat

Group	Microhabitat	Total individual trees		Individual tree density (per ha)		Species richness		Diversity indices		
		Mean	SD	Mean	SD	Mean	SD	Mean α	γ	β
LC	Floor	5.7	13.2	5.9	13.6	2.1 ab*	4.0	2.1	19	16.9
	Levee	17.0	15.2	14.6	12.5	4.9 a	2.8	4.9	44	39.1
NLC	Floor	1.4	2.7	1.3	2.1	1.0 b	1.8	1.0	9	8.0
	Levee	13.0	15.8	12.8	15.4	3.7 ab	3.2	3.7	33	29.3

*Values followed by the same letter in the same column are not significantly different at $p = 0.05$, $n = 9$

Table 4.2 Comparisons of the mean values of paddy plot size and levee length per paddy area between the no-land-consolidation paddies and the land-consolidation paddies.

	Land-consolidation group						No-land-consolidation group	
	1975-1976		1991-1992		2013-2014			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Paddy plot size (ha)	0.11b*	0.08	0.14 b	0.08	0.33 ab	0.14	0.44 a	0.48
Levee length per paddy area (m/ha)	895.4 a	185.3	817.2 ab	149.6	600.5 c	151.4	676.4 bc	238.7

*Values followed by the same letter in the same row are not significantly different at $p = 0.05$, n = 9.

Table 4.3 Comparison of tree-unit density (unit/ha) among groups of paddies and microhabitats

Group	Microhabitat	1975-1976		1991-1992		2013-2014	
		Mean	SD	Mean	SD	Mean	SD
LC	Floor	3.3	3.7	1.5	2.9	0.7 b*	1.0
	Levee	8.3	11.4	5.7	7.1	5.2 a	4.0
		(0.97)#	(1.40)	(0.84)	(13.0)	(0.85)	(0.59)
NLC	Floor	1.4	1.8	0.5	1.2	0.4 b	0.8
	Levee	2.2	2.2	2.8	2.4	5.1 a	4.9
		(0.34)	(0.37)	(0.41)	(0.37)	(0.71)	(0.47)

*Values followed by the same letter in the same column are not significantly different at $p = 0.05$. $n = 9$.

#Values in parenthesis are tree-unit density per levee length (unit/100m)

Table 4.4 Correlation coefficients for the relationships of plot size with tree-unit density, individual tree density, and species richness

Plot size year	Tree density in floor				Tree density on levees				Species richness (2015)	
	Tree-unit density			Individual tree density	Tree-unit density			Individual tree density		
	1975-1976	1991-1992	2013-2014	2015	1975-1976	1991-1992	2013-2014	2015	Field	Levee
1975-1976	-0.11	-0.077	-0.301	-0.208	-0.096	-0.068	-0.253	-0.275	-0.264	-0.195
1991-1992	--	0.751*	-0.031	-0.203	--	0.744*	-0.348	-0.441	-0.234	-0.48
2013-2014	--	--	-0.847**	-0.772*	--	--	-0.741*	-0.433	-0.815**	-0.032

*$p < 0.05$; ** $p < 0.01$

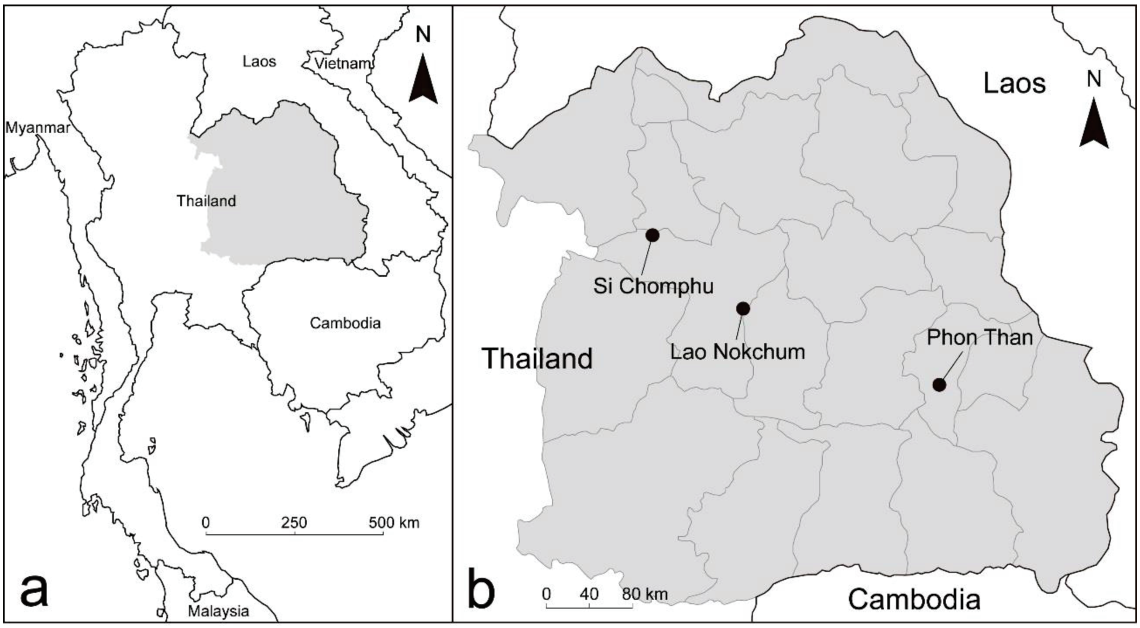

Fig. 4.1. Map of the study sites. (a) Area of Northeast Thailand (gray area) and (b) location of the three selected landscapes.

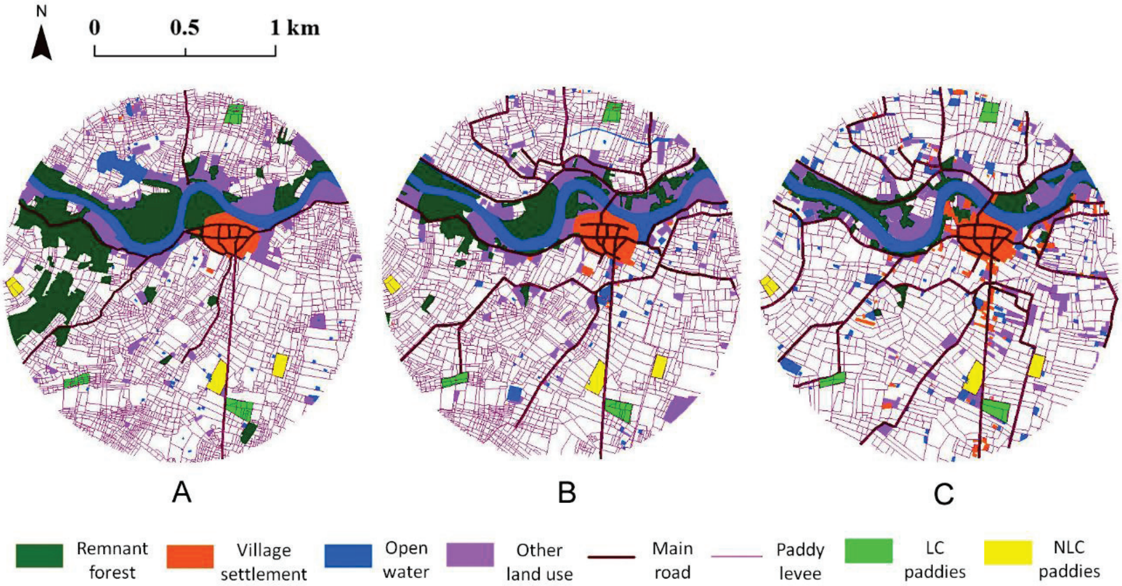

Fig. 4.2. Example land cover map of one of the 1-km² study landscapes representing three time periods: (A) 1975-1976, (B) 1991-1992, and (C) 2013-2014. LC = land-consolidation paddies and NLC = no-land-consolidation paddies.

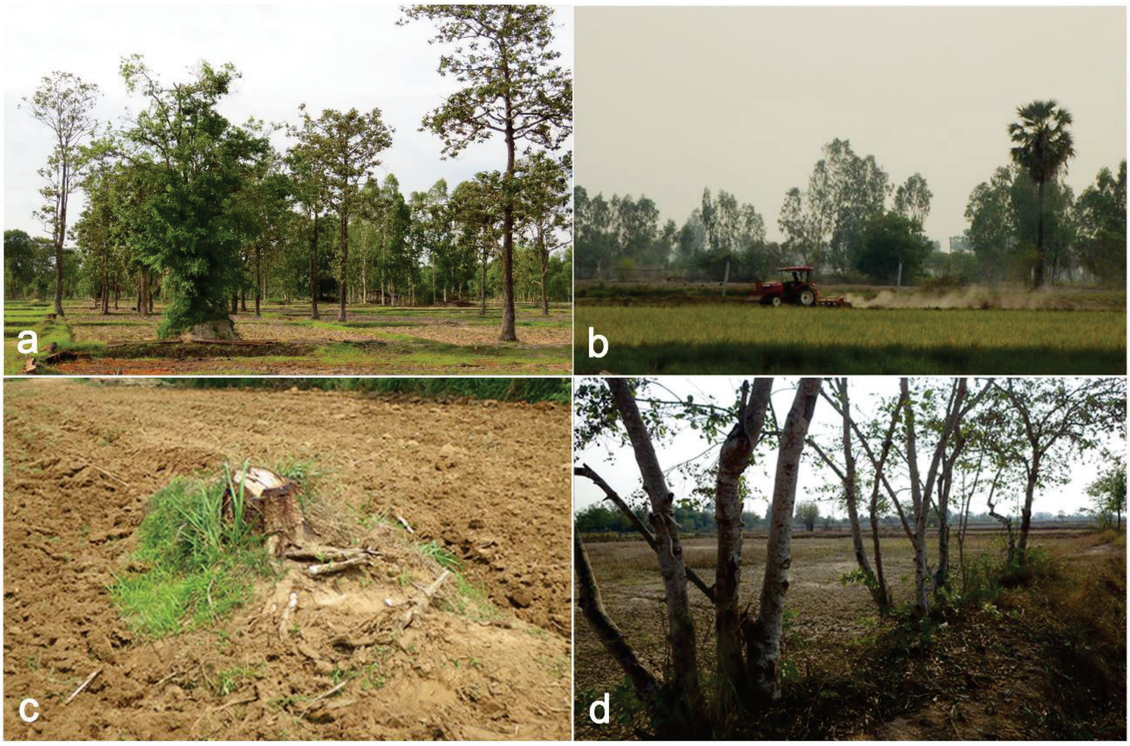

Fig. 4.3. Trees in the paddy field landscape in Northeast Thailand. (a) single and cohesive trees of *Lagerstromeia* sp. and *Diospyros* sp., located either in the floor or on the levee; (b) four-wheeled tractor plowing in an irrigated rice field; (c) stem of one big tree in the floor after it was cut; (d) coppiced *Combretum quadrangulare* naturally regenerated on levees.

CHAPTER 5

Utility, management and species composition of trees in paddy fields

5.1 Background and objectives

Although there have been numerous studies describing the species composition of trees in paddy fields and their utilization (Grandstaff et al., 1986; Watanabe et al., 1990; Prachaiyo 2000; Kosaka et al., 2006; Natuhara et al., 2012), discussions on roles of human in managing trees are still lacking. Besides variation of density, variation of species composition is also important to understand the variation in distribution patterns of trees. Thus the aim of this survey is to clarify the tree management practices that can be used for sustainable agriculture, as well as explaining the factors influencing variation in tree species composition.

To have an overall view, tree species and their utilities were first recorded in an extensive area of Northeast Thailand, and the uses of trees were compared at an inter-regional level to understand the relationship between human and the woody plant community in different backgrounds. Then an intensive survey of tree species composition were conducted in 3 selected villages, to discuss the variation in species composition of trees upon location of villages, and microhabitats.

5.2 Utility and management of trees

5.2.1 Field survey

Field surveys were conducted in 20 villages from 11 provinces of the extensive area of Northeast Thailand (Table 2.1 in Chapter 2). Two villages (V3 and V4) in March 2012, 16 villages (V5–V20) in August 2012, 2 villages (V1 and V2) in May 2013, and all 20 villages (V1–V20) in December 2013. The village headmen and accompanying persons were interviewed in a semi-structured manner regarding the use (either subsistence or commercial) and management (planting, protecting, or cutting) of trees in the paddy fields, the tree species with either positive or negative effects on rice growth, rice cultivation systems (i.e., cropping season, cultivars, usage of machines, pests, and natural disasters), fuel consumption, forest management, and other income sources such as cash crop production, the sale of non-timber forest products, or wage labor. To cross-check the interviewed information, tree species in the paddy fields were recorded by 30-min observation in the villages of V5–V20.

Field survey and interviews were conducted at Dong Khuai village, Vientiane, Laos (14^{th}, 15^{th} December 2011) to obtain the various uses of trees in paddy fields here. The data collected were used to compare with the utility of trees in Northeast Thailand. Nomenclature of the tree species followed that of Smitinand and Larsen (1970–1996) and

Santisuk and Larsen (1997–2013).

5.2.2 Utility and tree management practices

In total, 79 tree species representing 66 genera and 33 families were observed in the paddy fields of 16 villages (V5–V20).

According to the interview survey, the trees that have declined in the paddy fields mainly consist of *Dipterocarpaceae* and *Fabaceae*, and represent remnants of the original forest that was used as timber for house construction, charcoal, or fuelwood (Table 5.1). The trees that have been planted in the paddy fields are mango (*Mangifera indica*) and tamarind (*Tamarindus indica*) for fruit, and teak (*Tectona grandis*) and eucalypt (*Eucalyptus camaldulensis*) for timber (Table 5.1). Oil palm (*Elaeis guineensis*) was recently introduced on paddy levees as a cash-tree alternative to eucalypt in V3 (Table 5.1). *Dolichandrone spathacea*, *Dipterocarpus alatus*, *Diospyros rhodocalyx*, and *Senna siamea* are all remnant species from the original forest; however, their seedlings were protected and they have been replanted on the paddy levees for multiple purposes (Table 5.1). Trees in paddy field also supply edible shoots and flowers (Table 5.1), which are not only self-consumed but also sold at local markets as cash income for women and children (Moreno-Black and Price, 1993).

Use of the same tree species in paddy field in Northeast Thailand differed with that in Laos, according to the preliminary survey conducted in 2011 (Table 5.1). This might due to the recent prevalence of substituting industrial goods, in addition to the rapid urbanization and economic expansion in Northeast Thailand. Farmers have recognized that the leaf litter of 14 species has fertilized the soil, whereas 9 species have had a negative effect on rice yields due to shading or competition for nutrients and water (Table 5.1). The trees have also provided aesthetic qualities and shade for farmers and livestock (Table 5.1).

Sustainable management was employed in the periodic collection of timber and fuelwood in the paddy fields, including the coppicing of eucalypt in a periodic harvest every 4–6 years and the pollarding of *Mitragyna diversifolia* branches at a height of 2–3 m every 3 years to sustain fuelwood collection (Fig. 2.2e, f, Chapter 2). Farmers recognized both positive and negative effects of trees on the rice yield (Table 5.1). Previous agronomic studies have analyzed the effect of soil fertilization and shading from trees in paddy fields. Vityakon and Dangthaisong (2005) revealed that trees in paddy fields can improve soil fertility through the mineralization of nitrogen in their litter. Rice yield was higher at a site near *Irvingia malayana*, but significantly lower near *Ficus religiosa* due to the shading effect of its large crown (Miyagawa et al., 2013). Pollarding and coppicing (Fig. 2.2e and f, Chapter 2), both skills for sustainable forest resource use, can also assist in reducing excess shade from trees on rice crops. Shading, however, can mitigate drought damage by reducing evapotranspiration in rice crops (Vityakon, 2001). Keeping trees on levees and applying the appropriate management practices—such as periodical timber or fuelwood collection and pruning to reduce shade on the rice crops—is one form of a paddy field-based land sharing system for sustainable agriculture and resource use in the forest-depleted region of Northeast Thailand.

5.3 Species composition of trees in paddy fields

5.3.1 Field survey

Three villages in the Northeast Thailand: Phon Than, Lao Nokchum, and Si Chompu, were subjected to an intensive field survey in March 2015 to collect data on tree species diversity. In each studied villages, there were 6 random target sites and thus 18 target sites in total, with the area of each site varying from 0.7 to 1.6 ha. Three measures, total individual trees (the total number of individual trees), individual tree density (the average number of individual trees per hectare), and species richness (the total number of trees species) with diameter at breast height (DBH) of more than 1 cm and height (H) of more than 1 m at each target site were recorded separately for each microhabitat, both in the floor and on the levee. The nomenclature of the tree species followed Smitinand and Larsen (1970-1996) and Santisuk and Larsen (1997-2013).

5.3.2 Variation in tree species composition

Across all 18 sites, we recorded 334 individual trees and identified 44 tree species representing 20 families, along with two unidentified species (Table 5.2). Twenty species were remnants from forest, seven ruderal species that adapted to the disturbed paddy field environment (Kosaka et al., 2006), seventeen were planted ones, and two species were both planted and ruderals.

Variation among microhabitats

When analyze the species richness data of total 18 sites, there found to be a high correlation between number of tree and number of species, for both microhabitats: in the floor ($r = 0.959$, $p < 0.01$), and on the levee ($r = 0.797$, $p < 0.01$). However, it is notable that the variation is larger for trees on the levee (Fig 5.1).

Among 17 planted species, only one planted species (*Pithecellobium dulce*) was found in a termite mound in the floor, while other sixteen planted species were found on the levees (Table 5.2). Many trees of the same species (*Combretum quadrangulare* or

Eucalyptus spp.) were planted on the levees (field observation). This is the reason why there was a large variation between number of trees on the levees and their species richness. On the other hand, most of trees in the floor are remnants from forest, such as *Shorea obtusa, Streblus asper*, and *Senna siamea* (Table 5.2), which explain for the high correlation between number of trees in the floor and their species richness.

Variation among villages

Nineteen different species were recorded at the sites of Phon Than, while the number was 22 for both Lao Nokchum and Si Chompu. Phon Than also had only 8 species that were remnants from forest, lower than Si Chompu (10 remnant species), and Lao Nokchum (11 remnant species) (Table 5.2). In contrast, Lao Nokchum had 9 species that were planted, Phon Than had 7, and Si Chompu only had 5 planted species (Table 5.2).

The Sorensen similarity indices (Sorensen 1948) were calculated for further comparison of species composition between three selected villages. Si Chompu and Phon Than have similar topography and soil properties (low terrace with moderate to low soil fertility), and both villages have the tree species that characterize the dry dipterocarp forest such as *Shorea obtusa* and *Dipterocarpus obtusifolius* (Table 5.2). Nevertheless, the lowest similarity index was between the sites in Si Chompu and the sites in Phon Than

(0.19). The sites of Lao Nokchum which located in floodplain and the sites in Si Chompu has the similarity of 0.27. The highest similarity index was between the sites in Lao Nokchum and the sites in Phon Than (0.44), with up to 9 similar species (Table 5.2). Each village has several unique ruderal species that other does not have (e.g. *Phyllanthus taxodiifolius* in Phon Than sites; *Diospyros mollis* in Si Chompu sites; and *Diospyros rhodocalyx* in Lao Nokchum sites). Several tree species have specifically adapted to some particular conditions (Prachaiyo 2000), resulted in this general low similarity in species composition between villages.

Table 5.1 Uses and characteristics of trees in paddy fields in Northeast Thailand, and comparison with the uses in Laos.

Scientific name	Family	Thai name (Lao name)	Status	Use (NE)	Use (Laos)[1]	Farmers' perception of effects on rice
Mangifera indica L.	Anacardiaceae	Ma muang (Mouang)	P	Fo*	C, F, Fo, Fu, T	Soil fertilization by leaf litter Yield reduction by shading
Elaeis guineensis Jacq.	Arecaceae	Tan	P	Ol*		
Dolichandrone spathacea (L.f.) Baillon ex Schumann	Bignoniaceae	Khae na	P/W	Fo, T		
Parinari anamensis Hance	Chrysobalanaceae	Phok	W	S, T		
Combretum quadrangulare Kurz	Combretaceae	Sakae na	W	C		
Dipterocarpus alatus Roxb. ex G.Don	Dipterocarpaceae	Yang na (Nyang)	P/W	S, T	C, F, Fu, T	Soil fertilization by leaf litter Yield reduction by shading
Dipterocarpus intricatus Dyer	Dipterocarpaceae	Sabaeng (Sabeng)	W	C, T	C, F, Fu, T	Soil fertilization by leaf litter Yield reduction by shading
Dipterocarpus tuberculatus Roxb.	Dipterocarpaceae	Phluang (Koung)	W	Fu	C, Fu, T	
Shorea obtusa Wall. ex Bl.	Dipterocarpaceae	Teng (Chik)	W	C, Fu, T	C, F, Fu, T	
Shorea siamensis Miq.	Dipterocarpaceae	Rang (Hang)	W	C, Fu, T	C, F, Fu, T	Soil fertilization by leaf litter
Shorea roxburghii G. Don	Dipterocarpaceae	Phayom	W	C, T*		Soil fertilization by leaf litter
Diospyros rhodocalyx Kurz	Ebenaceae	Tako	P/W	S		Soil fertilization by leaf litter Yield reduction by shading

Table 5.1 (continued)

Scientific name	Family	Thai name (Lao name)	Status	Use (NE)	Use (Laos)[1]	Farmers' perception of effects on rice
Afzelia xylocarpa (Kurz) Craib	Fabaceae	Makha mong (Tekha)	W	T	C, F, Fo, Fu, T	
Butea monosperma (Lmk.) Taub.	Fabaceae	Chan (Chan)	W	C	C, Fo, Fu	
Dalbergia sp.	Fabaceae	Pha yung	W	T*		
Pterocarpus macrocarpus Kurz	Fabaceae	Pradu (Dou)	W	Fu, T*	C, F, Fu, M, T	Soil fertilization by leaf litter Yield reduction by shading
Samanea saman (Jacq.) Merr.	Fabaceae	Cham churi (Samsa)	W	S	C, F, Fu, T	
Senna siamea (Lmk.) Irwin & Barn	Fabaceae	Khilek	P/W	Fo		Soil fertilization by leaf litter
Sindora siamensis Teysm. ex Miq. var. *siamensis*	Fabaceae	Makha tae (Tenam)	W	T	C, F, Fu, T	Soil fertilization by leaf litter Yield reduction by shading
Tamarindus indica L.	Fabaceae	Ma kham (Kham)	P	Fo*	C, Fo, Fu, M, T	Soil fertilization by leaf litter
Xylia xylocarpa (Roxb.) Taub. var. *kerrii* (Craib & Hutch.) Niels	Fabaceae	Daeng (Deng)	W	T	C, F, Fo, Fu, M, T	
Irvingia malayana Oliv. ex Benn.	Irvingiaceae	Kra bok (Bok)	W	T	C, Fo, Fu, T	Soil fertilization by leaf litter
Tectona grandis L.f.	Lamiaceae	Sak	P	T*		
Careya arborea Roxb.	Lecythidaceae	Ka don	W	Fo		
Lagerstroemia macrocarpa Kurz var. *macrocarpa*	Lythraceae	Kalao (Kalao)	W	Or	C, F, M, T	
Lagerstroemia sp.	Lythraceae	Puay	W	C, Fu		
Michelia champaca L. var. *champaca*	Magnoliaceae	Champa	W	T		

Table 5.1 (continued)

Scientific name	Family	Thai name (Lao name)	Status	Use (NE)	Use (Laos)[1]	Farmers' perception of effects on rice
Azadirachta indica A. Juss. var. *siamensis* Valeton	Meliaceae	Sadao	W	C, Fo, T		Soil fertilization and pest control by leaf litter
Ficus religiosa L.	Moraceae	Pho (Pho)	W	Or*	C, Fo, Fu, M	
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Yuka (Vik)	P	P*, S, T*	C, F, Fu, M, T	Soil fertilization by leaf litter Competing against rice for nutrition and water Yield reduction by shading and leaf litter
Syzygium cumini (L.) Skeels	Myrtaceae	Waa (Waa)	W	T	C, Fo, Fu, T	Soil fertilization by leaf litter Yield reduction by shading
Bambusa sp.	Poaceae	Phai (Phai)	W	Fo, T	Fo	Competing against rice for nutrition and water
Mitragyna diversifolia (G.Don) Havil.	Rubiaceae	Krathum	W	C, Fu		

Use: C, Charcoal; F, Furniture; Fo, Food; Fu, Fuelwood; M, Medication; Ol, Oil; Or, Ornamental; P, Pulp; S, Shade; T, Timber; *, sale for cash income.

Status: P, Planted; W, Wild.

[1]Field survey and interview were conducted in Vientiane, Laos at December, 2011.

Table 5.2 List of all woody plants species recorded in field surveys

Scientific Name	Family	Classification	Village*	Microhabitat**
Mangifera indica	Anacardiaceae	Planted	LN+PT	L
Spondias pinnata	Anacardiaceae	Remnant	LN+PT	L
Annona squamosa	Annonaceae	Planted	SC	L
Borassus flabellifer	Arecaceae	Planted	PT	L
Dolichandrone spathacea	Bignoniaceae	Remnant	SC	L
Millingtonia hortensis	Bignoniaceae	Ruderal	LN+SC	L
Crateva magna	Capparaceae	Remnant	LN+PT	L
Combretum quadrangulare	Combretaceae	Planted & Ruderal	LN	L
Dipterocarpus intricatus	Dipterocarpaceae	Remnant	SC	F+L
Dipterocarpus obtusifolius	Dipterocarpaceae	Remnant	PT	L
Shorea obtusa	Dipterocarpaceae	Remnant	PT	F
Diospyros mollis	Ebenaceae	Ruderal	SC	F+L
Diospyros rhodocalyx	Ebenaceae	Ruderal	LN	F+L
Albizia lebbeck	Fabaceae	Remnant	LN	F
Albizia lebbekoides	Fabaceae	Remnant	SC	L
Albizia procera	Fabaceae	Remnant	SC	L
Butea monosperma	Fabaceae	Remnant	LN+PT+SC	F+L
Cassia fistula	Fabaceae	Planted	LN	L
Derris sp.	Fabaceae	Remnant	LN	F
Leucaena leucocephala	Fabaceae	Ruderal	LN+PT	F+L
Pithecellobium dulce	Fabaceae	Planted	LN	F
Pterocarpus macrocarpus	Fabaceae	Remnant	PT+SC	F+L
Samanea saman	Fabaceae	Planted	SC	L

Table 5.2 (continued)

Scientific Name	Family	Classification	Village*	Microhabitat**
Senna siamea	Fabaceae	Remnant	SC	F+L
Sesbania grandiflora	Fabaceae	Planted	SC	L
Tamarindus indica	Fabaceae	Planted & Ruderal	PT	F+L
Tectona grandis	Lamiaceae	Planted	SC	L
Lagerstromeia sp.	Lythraceae	Remnant	LN+SC	F+L
Azadirachta indica	Meliaceae	Ruderal	LN+PT+SC	F+L
Artocarpus heterophyllus	Moraceae	Planted	LN	L
Streblus asper	Moraceae	Remnant	LN+SC	F
Moringa oleifera	Moringaceae	Planted	LN	L
Eucalyptus spp.	Myrtaceae	Planted	SC	L
Psidium guajava	Myrtaceae	Planted	LN+PT	L
Syzygium cumini	Myrtaceae	Remnant	PT	F
Syzygium sp.	Myrtaceae	Remnant	LN+PT+SC	L
Phyllanthus taxodiifolius	Phyllanthaceae	Ruderal	PT	L
Bambusa arundiana var. *spinosa*	Poaceae	Planted	PT	L
Bambusa sp.	Poaceae	Planted	PT	L
Dendrocalamus brandisii	Poaceae	Planted	PT	L
Mitragyna diversifolia	Rubiaceae	Remnant	LN	L
Morinda citrifolia	Rubiaceae	Planted	LN	L
Zanthoxylum sp.	Rutaceae	Planted	LN	L
Sapindaceae sp.	Sapindaceae	Remnant	SC	F+L
Unidentified sp.1		Remnant	LN+SC	F
Unidentified sp.2		Ruderal	SC	F

*Village: LN, Lao Nokchum; PT, Phon Than; SC, Si Chompu.

**Microhabitat: F, Floor; L, Levee.

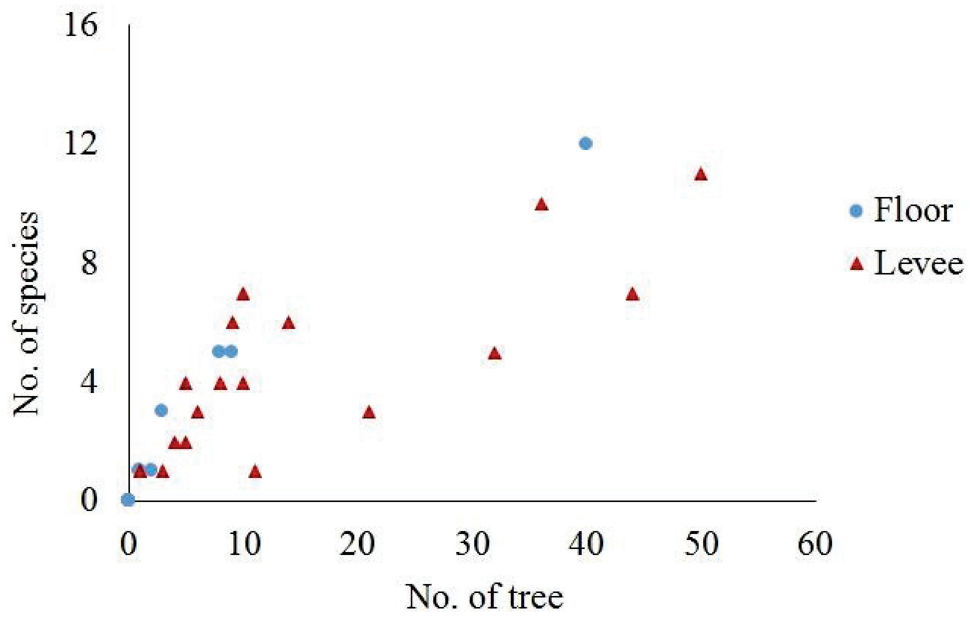

Fig. 5.1 Relationship between number of tree and number of species for each microhabitat in Phon Than, Lao Nokchum, and Si Chompu villages of Northeast Thailand.

CHAPTER 6

General discussion and conclusion

6.1 General discussion

6.1.1 Ecosystem services of trees in paddy fields

Previous studies have identified several roles of trees in paddy fields, including improving soil quality (Vityakon, 2001, Sae-Lee et al., 1992), providing for the physical needs of humans (e.g., food, timber, and fuel), also for their spiritual ones (Grandstaff et al., 1986; Watanabe et al., 1990; Prachaiyo, 2000), or ecological functions against the trend toward increasing deforestation (Kosaka et al., 2006; Pham et al., 2015). Nevertheless, their role in biodiversity conservation has often been neglected due to the low local diversity. However, several studies (Piessens et al., 2005; Cousins, 2006) have shown that quite ordinary small habitats may harbor many valuable species, and can be important for maintaining species richness in a landscape context due to their high regional diversity (chapter 4).

Unlike the case in semi-natural habitats, humans play a leading role in managing agricultural landscapes. The lack of relationship between tree density and species richness in any of the past landscapes suggested that diversity in managed landscape might not be directly influenced by the historical changes of land use as often be seen in studies of other semi-natural landscapes (Lindborg and Eriksson, 2004; Hanksi, 2005; Helm et al., 2006; Cousins et al., 2007).

6.1.2 Effective utilization of paddy field levees

Private farm forestry has been promoted to meet the demand of wood resources in Thailand (Niskanen, 1998; Prachaiyo, 2000). Commercial tree seedlings for study sites were provided by a government project and the Agricultural Development Bank, and were planted on paddy levees. The majority of plantation trees were eucalypt, teak, and *Pterocarpus* spp. (Niskanen, 1998; Wester and Yongvanit, 2005). Paddy fields in this region are mostly rain-fed (Fukui, 1993) with large levees of 60 cm width or more (Pham, field observation), which provide a suitable place for tree planting. Paddy levees are fragile in many areas of Northeast Thailand where soil has a low clay content; however, the tree roots stabilize them from erosion (Grandstaff et al., 1986).

Rural households that collected their own biomass energy obtained 85% of their biomass fuel from trees in their paddy fields (Nansaior et al., 2013). The annual fuelwood consumption of a rural household could be sustainably met by 68 eucalypt trees (Nansaior et al., 2013). Planting 68 eucalypt trees 3 m apart requires 200 m of paddy levee, which is within the average levee length per paddy area (475.25m/ha; chapter 2) and the average of paddy land holding in Northeast Thailand (2.63 ha/household; Fukui, 1993; 2.4 ha; National Statistical Office, 2013). A mature eucalypt tree has an average annual growth increment of 35 kg (Nansaior et al., 2013) with a price of 26 baht (750 baht/ton of stumpage price; Niskanen, 1998), which is equivalent to 2 kg of unhulled rice (10–15 baht/kg of farm-gate price). The average rice yields were 1.9 ton/ha and 1.4 ton/ha for good and poor harvests, respectively, but are highly variable with frequent crop failure due to unstable precipitation in this region (Miyagawa et al., 2006). Although tree stands in the floor increase the opportunity of costs from crop losses due to the sacrifice of field area and disturbance of agricultural activities, the levees provide suitable habitat and useful trees, which enhance the system productivity of paddy field landscapes.

6.1.3 Possibility of the paddy field-based agroforestry

We assumed that tree density and species richness have a linear relationship, which we called the ideal line (Fig. 6.1). However, the number of species only increases with increasing density to a certain level. Thus, the relationship in reality would be within the range from the bottom threshold (monoculture plantation) to the ideal line (Fig. 6.1). Improving the quality of tree species that are planted on the levee helps offset the cost to biodiversity during the development of intensive agriculture.

Besides, in a study case in Canada, Fahrig et al. (2015) found that smaller crop fields have higher within-field biodiversity due to increase of landscape heterogeneity, thus suggested that reducing plot sizes should be considered to enhance biodiversity in farmlands. However, differ with the case of large plot sizes in Canada (varies from 1.2 to 20 ha; Fahrig et al., 2015), reducing plot sizes neither seem effective nor applicable to a rice growing region where the plot sizes were already relatively small (varies from 0.05 to 1.48 ha; Chapter 4) compare to other regions (Thepent and Chamsing, 2009), and most farmers are planning on introducing agricultural machines. Thus, incorporating a wide selection of different tree species into the private farm forestry model, together with protecting seedlings of valuable remnants species would be effective in increasing the diversity of trees in paddy fields in this case. Considering the topography and soil properties is important in selection of species as the suitable species can grow fast on the site, while the unsuitable ones die out in the establishment stage (Prachaiyo, 2000). According to field observation, ruderal trees such as *Combretum quadrangulare* and *Mitragyna diversifolia* are often found at flood plain villages while *Streblus asper* and *Shorea obtusa* are popular at low terrace ones. Common planted species that can be easily growth at any conditions are *Eucalyptus* spp., *Mangifera indica*, *Tamarindus indica*, *Samanea saman*, and *Leucaena leucocephala* (Pham, unpublished data). High fertile soil is suitable for trees with big trunks and canopies such as *Pterocarpus macrocarpus*, *Tamarindus indica*, while moderate and poor soil is suited for *Dipterocarpus* or *Shorea* species (Prachaiyo, 2000). The trees species mentioned above were also found to have various important cultural utilities such as timber, food, fuelwood, etc. (Prachaiyo, 2000; Pham et al., 2015). Besides, *Senna siamea* and *Syzygium* sp. are also two remnants species that applicable as they were considered to have good effect to rice growth (Pham et al., 2015).

The most difficult time to apply the model would be the first several years, when tree planting often fails due to disturbances by flooding or agricultural activities. Guidelines and policies need to be developed to determine which combination of species to use, and subsidies for farmers at the initial stage of planting would also be necessary to ensure success. In a review that analyzed factors influencing adoption of agroforestry from 32 studies in the tropics, almost twice as many studies reported a positive correlation between plot size and tree planting than a negative one (Pattanayak et al., 2003). This common pattern may reflect the fact that farmers with larger plots simply have more space available for trees which do not have to sacrifice other crop growing lands thus diminish the risks associated with growing trees (Sood and Mitchell, 2009). However, smaller farms in central India had much higher densities of *Acacia nilotica* trees than larger farms, due to a large number of labor requiring to prune the tree canopies and roots, making it difficult for farmers with larger farms to maintain high densities (Viswanath et al., 2000). The latter case is more advisable to fit the private farm forestry model in Northeast Thailand, as the average of paddy land holding in the region is relatively small (2.4 ha according to National Statistical Office, 2013) and the fact that farmers prefer to spend little time or effort in managing trees in their paddies due to on-farm labor shortage (Thepent and Chamsing, 2009).

6.2 Trees in paddy fields landscapes at the regional context

Implications from this study do not only contribute in preserving the sustainability of the case study landscape, but also can act as a management model for other similar landscapes that harmonize the needs of human and those of nature around the globe. Still, seeking generalities beyond regional contexts is essential in landscape studies.

Seven villages in Laos were subjected to analyze the distribution patterns of trees using Quantum GIS (similar methods with 20 villages in Northeast Thailand, described in Chapter 2). While there were only significant relationship between tree density on the levee with total tree density (r = 0.983, $p < 0.01$) in 20 villages in Northeast Thailand; total tree density was found to significantly correlate with both density of tree in the floor (r = 0.918, p <0.01), and of tree on the levee (r = 0.957, p <0.01), in 7 studied villages in Laos (Fig 6.2). This result suggests that the distribution patterns of trees in Laos differ with in Northeast Thailand; trees in both microhabitat (either in the floor or on the levee) plays equally important part in variation of trees among villages. Uses of trees were also greatly differed between two regions (Table 5.1 in chapter 5). Thus, a comprehensive comparison between species composition, tree management practices, and effect of landscape transformation to distribution of trees at different regional contexts is needed, to increase the potential of implementing the agroforestry land sharing system for sustainable agriculture at similar paddy field landscapes.

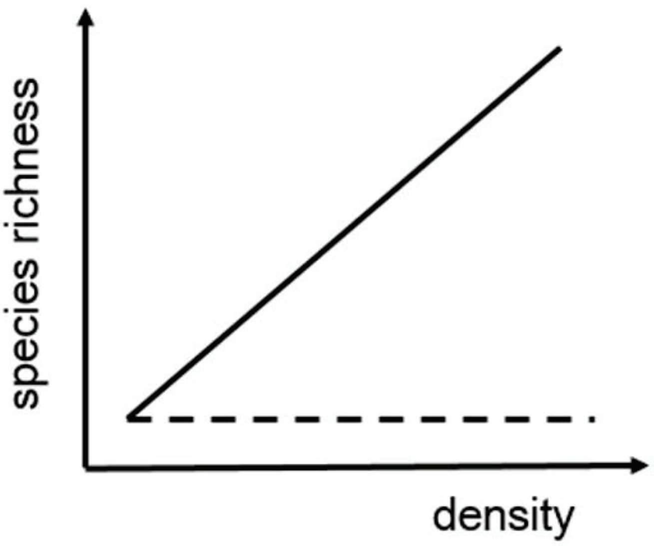

Fig. 6.1 A conceptual model of the relationship between tree density and species richness. The solid line represents an ideal relationship between density and species richness. The dotted line represents the lower threshold for a monoculture plantation. The real relationship is likely to be within the range between the dotted line and the solid line.

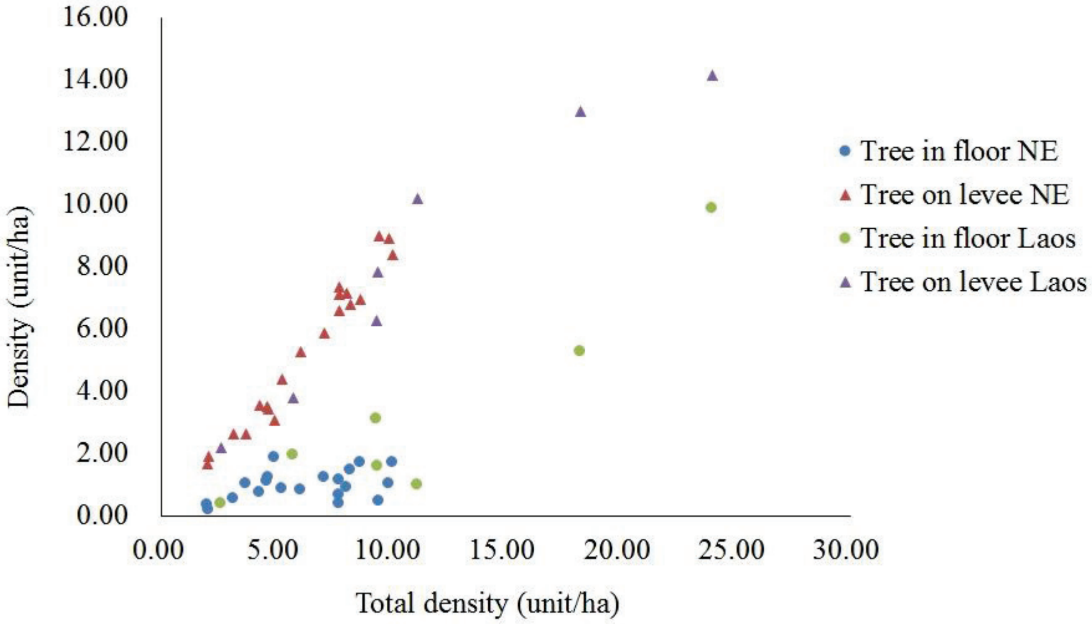

Fig. 6.2 Inter-regional variation of distribution of tree-units at different microhabitats, in Northeast Thailand (NE) (*n* = 20) and Laos (*n* = 7).

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