STUDY OF *LEUCAENA LEUCOCEPHALA* (Lam.) De Wit. AND NATIVE SPECIES DIVERSITY IN SECONDARY FOREST FRAGMENTS AT SURANAREE UNIVERSITY OF TECHNOLOGY

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A Thesis Submitted in Partial Fulfillment of the Requirements for the

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การศึกษากระถินยักษ์และความหลากหลายของชนิดพืชท้องถิ่น ในหย่อมป่ารุ่นสองในมหาวิทยาลัยเทคโนโลยีสุรนารี

นายจันดานา อะบิซีนา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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ปีการศึกษา 2560

STUDY OF *LEUCAENA LEUCOCEPHALA* (Lam.) De Wit. AND NATIVE SPECIES DIVERSITY IN SECONDARY FOREST FRAGMENTS AT SURANAREE UNIVERSITY OF TECHNOLOGY

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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จันดานา อะบีซีนา : การศึกษากระถินยักษ์และความหลากหลายของชนิดพืชท้องถิ่นในหย่อมป่ารุ่นสองในมหาวิทยาลัยเทคโนโลยีสุรนารี (STUDY OF *LEUCAENA LEUCOCEPHALA* (Lam.) De Wit. AND NATIVE SPECIES DIVERSITY IN SECONDARY FOREST FRAGMENTS AT SURANAREE UNIVERSITY OF TECHNOLOGY) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.หนูเดือน เมืองแสน, 87 หน้า.

กระถินยักษ์ (*Leucaena leucocephala* (Lam.) de Wit.) เป็นพืชรุกรานต่างถิ่นที่อยู่ในวงศ์ถั่ว ที่มักจะพบตามหย่อมป่าทั่วไป การศึกษาครั้งนี้ดำเนินการในพื้นที่มหาวิทยาลัยเทคโนโลยีสุรนารี (มทส.) ในภูมิภาคตะวันออกเฉียงเหนือของประเทศไทย เพื่อประเมินผลกระทบของจำนวนกระถินยักษ์ต่อความหลากหลายและความหนาแน่นของพืชมีเนื้อไม้ท้องถิ่น (ไม้ต้นและไม้เลื้อย) ที่สัมพันธ์กับขนาดและรูปร่างของหย่อมป่า โดยเก็บข้อมูลจากช่วง 80 เมตร แบบสุ่มบนแนวสำรวจแบบเส้นตรงที่ยาวที่สุดในแต่ละหย่อมป่าจำนวน 9 แนว เพื่อเปรียบเทียบความสัมพันธ์ระหว่างความหลากหลายของชนิด และปัจจัยสิ่งแวดล้อม พบว่า พีเอชของดิน และความชื้นในดิน มีผลเชิงบวกต่อความหนาแน่นของต้นกระถินยักษ์ ความหนาแน่นของพืชท้องถิ่นและค่าดัชนีความหลากหลายของซิมสัน มีความสัมพันธ์เชิงลบกับความชื้นในดิน เห็นชัดได้จากกราฟออร์ดิเนชัน ข้อมูลจากผลการศึกษาพบว่า ขนาดและรูปร่างของหย่อมป่าไม่มีผลต่อความหลากหลายของชนิดพืชท้องถิ่น จากกราฟออร์ดิเนชันและผลการวิเคราะห์โมเดลเชิงเส้นโดยนัยทั่วไป ไม่พบว่า จำนวนของกระถินยักษ์มีผลเชิงลบต่อความหลากหลายของพืชท้องถิ่น แม้ว่ากระถินยักษ์มีผลเชิงลบต่อความหนาแน่นและจำนวนของพืชมีเนื้อไม้ท้องถิ่น แต่การเปลี่ยนแปลงเพื่อรักษาความหลากหลายระดับเบต้าในหย่อมป่ายังคงเกิดขึ้นได้ การปรากฏ และจำนวนต้นของกระถินยักษ์ไม่ได้มีส่วนทำให้ความหลากหลายของพืชท้องถิ่นเพิ่มขึ้น แต่ไม่มีผลต่อความหลากหลายของพืชท้องถิ่น และการเปลี่ยนแปลงของพืชมีเนื้อไม้ในหย่อมป่าของมหาวิทยาลัยเทคโนโลยีสุรนารี

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M. A. CHANDANA ABEYSENA : STUDY OF *LEUCAENA LEUCOCEPHALA* (Lam.) De Wit. AND NATIVE SPECIES DIVERSITY IN SECONDARY FOREST FRAGMENTS AT SURANAREE UNIVERSITY OF TECHNOLOGY. THESIS ADVISOR : ASSOC. PROF. NOODUAN MUANGSAN, Ph.D. 87 PP.

EXOTIC INVASIVE /FRAGMENT/ECOLOGY/DIVERSITY

Leucaena (*Leucaena leucocephala* (Lam.) de Wit.), a leguminous invasive exotic plant usually present in fragmented forests. The study was conducted in Suranaree University of Technology (SUT) in Northeastern Thailand to study the effect of *Leucaena* abundance on the native woody species (tree and climber) diversity and density based on size and the shape of fragments. Random 80 m segments of nine line transects were selected to compare species diversity and environmental measurements. *Leucaena* density was positively correlated with soil pH and soil moisture content while, negatively correlated with Simpson's diversity index. Native species density and Simpson's diversity index negatively correlated to soil moisture and this was confirmed by ordinations. According to results, size and shape of the fragments did not affect to the native species diversity and ordinations or generalized linear model outputs did not find any negative affect from *Leucaena* abundance on native species diversity. Even though *Leucaena* was negatively associated with native woody density and abundance but, maintaining healthy beta diversity was evident for succession within fragments. Results did not revealed *Leucaena* occurrence and abundance enhanced native species diversity but neither did

it adversely affect the native diversity and successional dynamic of the native woody species within SUT fragments.

School of Biology

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LIST OF ABBREVIATIONS

AIC	=	Akaike's Information Criterion
AICc	=	(Corrected) Akaike's Information Criterion
cano_c_o	=	Open or close of canopy
CCA	=	Canonical Correspondence Analysis
dAICc	=	(Delta) Akaike's Information Criterion
DBH	=	Diameter at Breast Height
df	=	Degrees of freedom
GLM	=	Generalized Linear Model
GPS	=	Global Positioning System
ha	=	Hectare
J_even	=	Pielou’s evenness Index
leu_stden	=	*Leucaena* stem density
leu_stden	=	*Leucaena* stem density
leu_y_n	=	Presence or absence of *Leucaena*
LL	=	Log-likelihood
LM	=	Linear Model
LWC	=	Leaf Water Content
NMDS	=	Nonmetric Multidimensional Scaling
nonlue_y_n	=	Presence or absence of non *Leucaena* species
osp_stden	=	Other species stem density

LIST OF ABBREVIATIONS (Continued)

PCA	=	Principal Components Analysis
peri	=	Perimeter
prop_pre	=	Propagule pressure
SD	=	Standard Deviation
SE	=	Standard Error
sha_ind	=	Shannon diversity index
SI	=	Shape Index
si_sasd	=	Sorenson similarity index between saplings and seedlings
si_tsa	=	Sorenson similarity index between trees and saplings
sim_ind	=	Simpsons diversity index
smc	=	Soil moisture content %
SUT	=	Suranaree University of Technology
UTM	=	Universal Transverse Mercator
w	=	Weight

CHAPTER I

INTRODUCTION

1.1 Introduction

Ecological factors of global biodiversity depletion have awakened substantial interest with debates in the past few decades (Loreau *et al*., 2001). Landscape modification and habitat fragmentation have become major research themes in conservation biology (Haila, 2002) which are considered severe threats to global biodiversity (Foley *et al*., 2005) and believed to be negatively affected all taxonomic groups including plants (Hansena *et al*., 2010).

Tropical forest edges in small forest fragments or edge affected habitats undergo habitat loss and further fragmentation by occurrence of rapid, drastic and persistent functional changes in plant community (Laurance *et al*., 2006b). Exclusively in disturbed sites in the many areas, vegetation is dominated by exotic plant species (Denslow and Hughes, 2004) while utilize early succession (Kulmatiski, 2006).

Around last few decades, investigation of the success of invasive plant has become one of the major issues (Catford *et al*., 2009). Establishment of invasive exotic species was often promoted by both natural and direct anthropogenic disturbances (Hobbs and Huenneke, 1992) thus, combination of factors may affect the accomplishment of most introduced species while consequent loss of native species (Weiher, 2007).

Further fragmentation of the forested landscapes by roads, leakage of heavy metals, destruction of limestone karsts, Reservoir construction, wetland drainage, fires, pollution, invasive species and diseases are major threaten factors of bio diversity in Southeast Asia (Thompson *et al*., 2013; Wilson *et al*., 2016; Hughes, 2017).

In Thailand, fragmentation has been more prolonged over the last three decades due to population expansion leading to increases in fragmentation (Fox *et al*., 1995) and ultimately reduced biodiversity (Pattanavibool and Dearden, 2002). Trisurat *et al*. (2010) also predicted that the highest deforestation was expected to occur in the lower north and forest cover in 2050 would mainly remain in the west and upper north regions of Thailand because of unreachability and rugged landscape. In contrast, the highest deforestation was expected to occur in the lower north

Leucaena (*Leucaena leucocephala* (Lam.) de Wit.), is a small leguminous tree, native to Central America with great potential of survive in dry areas with poor soil conditions (Kuo, 2003), thus categorized as the one of 100 most harmful invasive species in the world (Lowe *et al*., 2000). It was introduced for reforestation purposes in Thailand due to its tolerance to withstand strong seasonal climate shifts (Yige *et al*., 2012), such as degraded sub-tropical dry forests (Peter *et al*., 2003). Percentage of remaining forest area of the northeast region of Thailand (in 2008) was the lowest in the country, only 16.32% of the total land (Prachaiyo, 2000).

Figure 1.1 Landscape of SUT in early stages (Memorial hall of SUT, unknown photographer).

Suranaree University of Technology (SUT) is located in Nakhon Ratchasima, Thailand since July 27, 1990 and 1,120 hectares of degraded forest area of the Huay Ban Yang Reservoir was allocated to the establishment (http://web.sut.ac.th/) and at present, according to my study using Google Earth Pro images, 34% of the area is covered by 26 secondary forest fragments that could have resulted from the absence of anthropogenic activities for nearly 25 years since establishment of the University (Figure 1.1). The entire area has a total of 383 plant species including one species of cycad, 308 species of dicots and 74 species of monocots (Flora of Suranaree University of Technology Campus, 2001).

All fragments have been invaded by exotic invasive species *L. leucocephala* at varying levels. Such fragments are bounded by network of paved roads and have been often used as dumping sites for building residuals and earth removals. My study aims to investigate the distribution of *L. leucocephala*, spread from edges to interior of the disturbed fragments at SUT and provide a baseline understanding (Because previous work on related area is not found) of species diversity and relationship of *L. leucocephala* to the plant community as well.

1.2 Research hypothesis

In this study I aim to test four hypotheses concerning differences in proportion and abundance of the *L. leucocephala* in SUT forest fragments.

1. Pardini *et al*. (2005) concluded according to their studies in Amazonian tropical that species abundance and alpha diversity is higher in large fragments and continuous forests than small or medium sized fragments while connected comparing to isolated and further supported by Lasky and Keitt (2013) in regards to shape (Saunders *et al*., 1991). Therefore my first hypothesis (H_1) states that species diversity is unequal in each fragment and likely based on fragment size and shape.

2. My second hypothesis (H_2) is expressed as *L. leucocephala* species proportion is variable in different sites.

3. My third hypothesis (H_3) is that native species proportion is variable in different fragments.

4. There were significant differences in tree species diversity as well as abundance of exotic species across and among forest fragments while decline of alpha

diversity was found in remnants. Therefore my fourth hypothesis (H_4) is that the invasive exotic plant species (*L. leucocephala*) affect native species diversity of the forest fragments.

1.3 Research objectives

My study is based on two objectives;

1. To assess the relationship between *L. leucocephala* and native species in terms of abundance and diversity.

2. To determine the influence of size and shape on tree species diversity of disturbed forest fragments within SUT premises.

1.4 Scopes and limitations

My study was concentrated on proportion of invasive plant *L. leucocephala* within the fragment forest landscapes of SUT premises. I have been engaged one year time period since November 2016 to October 2017. Only 9 fragments of the 26 total fragments were selected for sampling. Other conditions that could affect the plant distribution were not considered due to time and monitory constraints.

Forest fragments at SUT have the potential to be a representative as an ideal model for the sub-urban deciduous forest fragments of Northeastern Thailand. Therefore it is important to keep such area as healthy ecosystem acting as a reservoir for biodiversity.

CHAPTER II

LITERATURE REVIEW

2.1 *Leucaena leucocephala*

2.1.1 Classification and morphology

Leucaena (*Leucaena leucocephala* (Lam.) de Wit., Family: Fabaceae, Subfamily: Mimosoideae, Tribe: Mimoseae) is an evergreen tree, native to Mexico and Central America (Kuo, 2003), height in 4–16 m with 10–30 cm basal diameter, long tap rooted, vigorous laterals, and many fine tertiary roots and deeply rooted. The stem is woody, erect, cylindrical, solid, branched rough with shallow, rusty orange-brown vertical fissures and deep red inner bark. Branches are smooth, stout, woody, and dark grey-brown in color. Leaves are pinnately pinnate with 6–9 pairs pinnae; pinnular rachis 5–10.2 cm long, leaflets 9–16 mm long, 2–4.5 mm wide, 13–21 pairs per pinna, slightly asymmetric, linear-oblong to weakly elliptic, apex acute and rounded to obtuse at base, glabrous except on margins. Inflorescence capitated, each 12–21 mm in diameter composing 100–180 flowers per head as 2–6 groups in leaf axils. Calyx is tubular and 2.5 mm long, teeth triangular, acute, pubiculous. Petals are 4.5–5 mm long, spathulate. Stamens with filaments and 8–10 mm long stipulated ovary. White or pale cream-white inflorescences are vigorously mounting on young shoots. Pods are 11–19 cm long, and 15–21 mm wide, 5–25 per flower head, linear-oblong, acute or rounded at apex, flat, 8–18 seeded, mid- to orange-brown, glabrous and slightly lustrous or densely

covered in white velvety hairs, papery, opening along both margins. Flowering and fruiting is occurred through the year. Generally flowers, immature and mature pods all present on the tree at the same time. Seeds are dark brown with a hard, shining testa, 6.7–9.6 mm long, 4–6.3 mm wide, aligned squarely in pod (Hughes, 1998) with hard seed coat dormancy (Tadros *et al*., 2011).

2.1.2 Distribution

According to Kuo (2003), *L. leucocephala* has been distributed worldwide especially in tropical areas and survive in dry areas with poor soils because of its nitrogen fixation ability, thus categorized as the one of 100 most harmful invasive plant species in the world database (Lowe *et al*., 2000). Global invasive species database (2017) indicates aggressive invasion of *L. leucocephala* in disturbed areas of many tropical and sub-tropical regions thus, difficult to eradicate once established while inaccessible and threatens native plants. In early 1980, it was introduced for reforestation purposes in Thailand due to tolerance in a wide range of annual rainfall (500–3,500 mm) and ability to withstand strong seasonal climates up to 7 months of dry season (Nehdi *et al*., 2014), it now often dominated highly degraded sub-tropical dry forests (Peter *et al*., 2003).

2.1.3 Propagule pressure and physiological responses

In the context of species invasions based on anthropogenic interference, potential number of exotic individuals released into a non-native region is defined as propagule pressure (Carlton, 1996) that enables to quantify the establishment success and the rate of geographical range expansion (Lockwood *et al*., 2005) thus, it is considered a null model for studies of biological invasion patterns (Colautti *et al*., 2006). It can be estimated for exotic woody species as the number of introduced

individuals per area where introduction or the duration after introduction (Nunez *et al*., 2011).

Physiological responses of *L. leucocephala* seedlings in leaf water content, displays considerable tolerance to draught stress even in degraded landscapes because seedlings are capable of retaining water that not significantly decreased even after a 12 day drought period (Yige *et al*., 2012).

Several years after the removal of mature trees, seedlings can be germinated from the soil seed bank (Kuo, 2003). Even young *L. leucocephala* are capable of producing large numbers of seeds to form a persistent short-lived seed bank (viability 1–5 years) with viability remaining >80% of the recovered seeds even after two years of in situ storage (Marques *et al*., 2014).

Reducing solar transmission to the forest floor, *L. leucocephala* restrict natural regeneration via establishing high stem density of ca. 1196 ha^{-1} with closed canopy, low light conditions and plays an important role in preventing seed germination and growth of native and pioneer species. Although provides some positive effects on soil nutrient improvement by accumulating large bulk of litter on floor as well (Marod *et al*., 2012).

Yielded seed bulk of *L. leucocephala* is viable for many years. Its cut trunk has an ability to produce nearly 20 sprouts that reach 30cm height within one month, 80cm in two months with >90% of survival rate and potentially growing to greater height than the original. Leaves have strong allopathic potential which inhibits the germination of other trees (Chou and Kuo, 1986; Tewari *et al*., 2004).

2.2 Exotic invasive species impact to plant community

Natural forest ecosystems are negatively and positively affected by exotic invasive species (Stinson *et al*., 2012) across trophic levels to re-structure communities and leads to evolutionary changes (Rodriguez, 2006). Siderhurst and coworkers (2012) found exotic invasive species adversely affect to the native tree species diversity while altering species composition in alpine forests. Furthermore, exotic invasive species are vastly influenced by altering soil chemical properties via bulky biomass accumulation (Kamo *et al*., 2002) and restricting natural forest regeneration by its invasive growing habit which reduces light transmittance to the forest floor (Marod *et al*., 2012).

2.3 Soil properties

Water and nutrient flow in tropical areas with sparse vegetation cover affects surface soil properties (Maestre and Cortina, 2002). Soil properties of pH, texture, soil nutrients (C, N, Ca, P, K, Mg and Na) are identified as the driving forces for seedlings, saplings and mature native woody species spatial distribution (Omoro *et al*., 2011). Alele *et al*. (2014) found that soil pH contributes to conversion of β-diversity to total diversity ensuring biotic homogenization in converted ecosystems.

2.4 Importance of the fragments

In Asia, current land-use practices have triggered the hasty loss and fragmentation of the region's forests (Whitmore, 1997; Thompson *et al*., 2013) but, fewer studies have been carried out in Asian region constrained by socioeconomic factors, including poverty and lack of infrastructure, compared with rest of the world.

Southeast Asia is a mega-biodiversity region but, deforestation rates expressed as fourth fold than elsewhere in the tropics (Laurance, 2004; Sodhi *et al*., 2004; Sodhi *et al*., 2010). In Thailand, fragmentation has been occurring over centuries as a result of traditional agricultural related undertakings though, more prolonged over the last 30 years due to population expansion and ultimately has led to visually obvious increases in fragmentation rates, an observation confirmed by quantitative measurement in one area (Fox *et al*., 1995) thus, high rate of fragmentation often synergistically interrelates with other pressures to reduce biodiversity (Pattanavibool and Dearden, 2002; Hughes, 2017).

At present, global biodiversity is severely affected by landscape fragmentation (Boutin and Hebert, 2002) and rapid habitat fragmentation occurred in Southeast region than that of others and several hundred million hectares of forest have been demolished (Figure 2.1), during the past few decades indicates that the global net rate of change in forest cover for the humid tropics is 23% lower than the generally accepted rate (Achard *et al*., 2002). Removal of forest cover including both natural and human-induced causes estimated as 0.6% out of total per annum (Hansena *et al*., 2010).

One of the adverse threats to biodiversity is habitat fragmentation (Drinnan, 2005) and, drastic increase in the amount of abrupt, artificial forest edge is a one of the most obvious acute consequences of habitat fragmentation. Fundamental land uses, result in irregularly shaped fragments with large amounts of edge typically created by slash and burn farming or other anthropogenic activities related to the forests (Skole and Tucker, 1993).

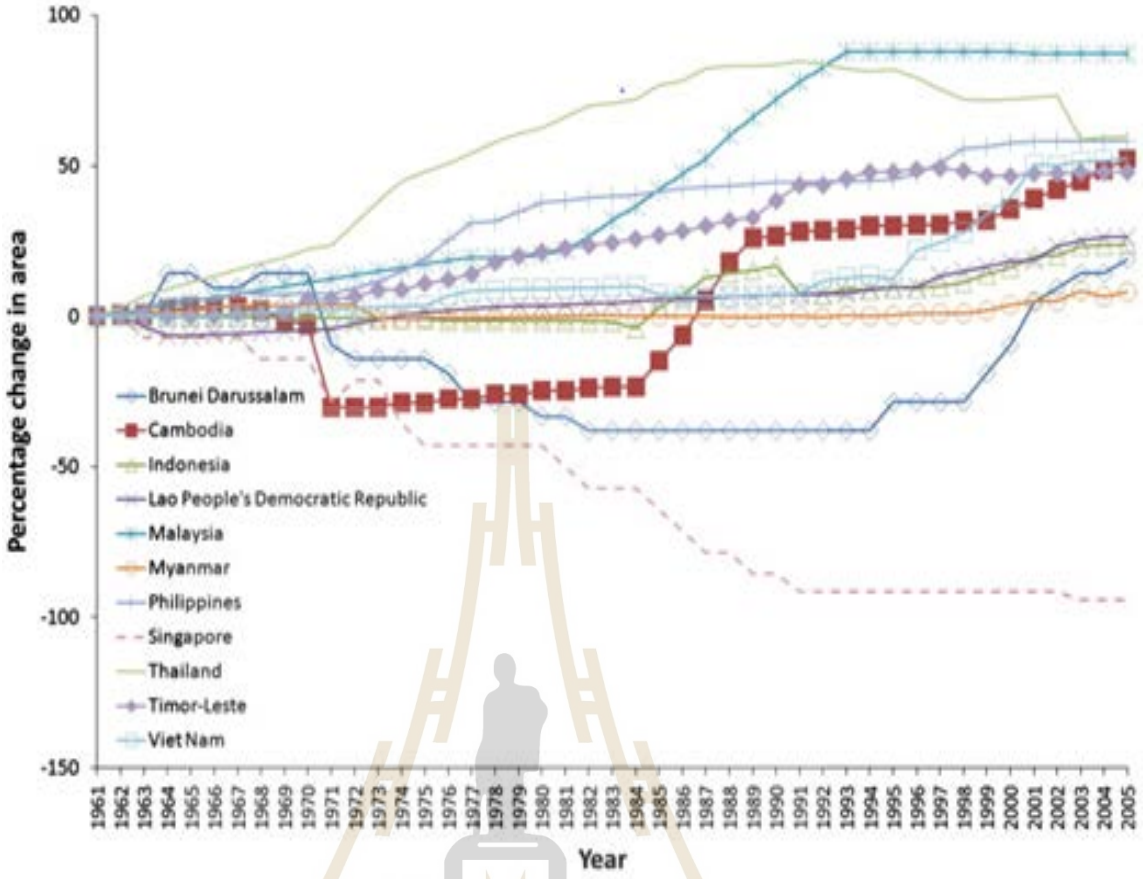

Figure 2.1 Increase in agricultural area in Southeast Asia from 1961 to 2005 (FAO, 2010).

In tropical rain forests, changes in edge size and shape lead to species loss in local scale and reduction of species richness relate with the time after separation from continuous forest area. Fewer species are recorded in small fragments than in larger fragments and indigenous species are intolerant to survive in outside of the tropical rain forests are more susceptible to extinction while in fragments (Turner, 1996).

Castillo (2015) argued that fragment metrics affect colonization thus; the origin of the fragments can be identified as direct fragmentation or reverse fragmentation by generation or increase of vegetated fragments through colonization. Fragment species are altered habitat modifications as the result of autogenic mode and,

antagonized by disturbances and modulated by abiotic inputs as well. In contrast with commonly disturbed landscapes, reverse fragmentation is an ordinary process that neutralizes the habitat and serves as vital strategy for biodiversity.

Wilcove *et al*. (1986) defined fragmentation as an advance separation of forest in relatively homogenous in nature into heterogeneous small patchy areas with some plant and animal habitat loss, decrease in vegetation connectivity while increasing distance between patches in addition to enlarging edge to interior habitat.

Fragmentation also defined as a phenomenon of species survival in their habitat remnants with a modified environment reduced under isolation and altered ecological boundaries. Life history influences the effect of isolation in different species and the impact of the fragmentation is further magnified by the result of synergistic interactions such as climate change, anthropogenic disturbances and species interactions (Ewers and Didham, 2006).

Edge influence on forest structure and composition in boreal, temperate, and tropical forests, abiotic (climate, edge characteristics and stand attributes) and biotic gradients near created forest edges cause a set of primary responses of the edge habitat (Harper *et al*., 2005). In Amazonian human modified landscapes, Uriarte and co-workers (2010) found that abiotic factors may be more vital than biotic factors prior to biodiversity loss in tropical forests

According to Metzger (2000), edge complexity and fragment connectivity is important parameters to link landscapes to the functional group richness and to total diversity. But Laurance *et al*. (1998) identified that edge aspect had no significant effect on forest dynamics in Atlantic forests of Brazil.

Furthermore, fragment age had robust, positive effects on the density and basal area suggesting that successional species could become even more abundant in fragments over time. The multiplying of fast-growing successional trees and correlated decline of old-growth trees have important effects on species composition, forest dynamics, carbon storage, and nutrient cycling in fragmented forests (Laurance *et al*., 2006a)

Structural complexity in ecology is discussed in six dimensions: spatial, temporal, structural, process, behavioral, and geometric (Loehle, 2004) as well as fragments driven by foliage arrangement, canopy cover, diameter, height and spacing of the plant species, stand biomass, understory vegetation and deadwood (McElhinny *et al*., 2005; Nally *et al*., 2001).

But in the urban fragments of deciduous forests, Godefroid and Koedam (2003) found that high conservation value species such as ancient forest and rare species are more signified at the edge than in the forest interior while no forest specialists were found in the interior which disagreed the general hypothesis of true forest plants and species groups of high conservation value would be more recurrent in the interior of the forest than on the edges.

2.4.1 Effect of patch size

Species diversity variation of single large habitat reserve against many small reserves, Lasky and Keitt (2013) found that small reserve systems increased the distance between environments dominated by different species, diminishing the effects of source-sink dynamics. As reserve size decreased, α species richness decreased, and γ richness increased while dispersal occurred across short distances, a large reserves with greater α richness, and lower γ richness than that in small reserve systems.

Species composition, stand structure and anthropogenic disturbances are greatly influenced by patch size. Patch size variation is significantly related to the species abundance and shrubs associated with interior and edge habitats and significant decline of basal area (Echeverría *et al*., 2007). In podocarp-broadleaf forest fragments of North Island, New Zealand, Young and Mitchell (1994) found that forest fragments <9.0 ha in regular shape, dominated by edge patterns and processes but not supported below 1 ha respectively.

Time since isolation, distance and degree of connectivity with other remnants are the major controlling factors of the species composition and further modified by the size, shape and position while less adverse effect on larger remnants (Saunders *et al*., 1991). According to Leigh *et al*. (1993), plant diversity depends on the plant-animal interactions (such as seed dispersal) of the remnant area (Holl, 1999).

Species composition in fragments likely change with mortality of over story trees prior to seedling and sapling diversity (Siderhurst *et al*., 2012), fragment age, random droughts and windstorms (Laurance *et al*., 2007).

Honnay *et al*. (1999) stated that even small forest fragments with high habitat quality, could be very important for maintaining plant species diversity in Northern France and Belgium temperate zone. In hyper-fragmented Atlantic forest landscapes, Lopesa and co-workers (2009) found that slight forest corridors and small fragments gradually dominated by edge-affected habitats.

2.4.2 Edge effect

Edge effects or edge-driven processes differ in proximity of plots to forest edge. Varying matrix vegetation is more important than area effects in seedling

abundance, plant community composition, invading species, and carbon storage (Benitez-Malvido, 1998; Laurance *et al*., 2007; Cumming *et al*., 2012).

2.4.3 Microclimates

Microclimate across forest edges have been the subject of a number of studies. Davies-Colley and co-workers (2000) revealed that climatic variables (light exposure, wind speed, air and soil temperature, and vapor pressure deficit) vary at least 40 m distance from the edge to interior fragments, and with 15 m in temperate forest fragments in Lake Velence, Hungary (Báldi, 1999). In tropical forests of Sri Lanka, forest interior as far as 10 m away from the edge has different micro climate (Haluwana and Madawala, 2013).

Forest-climate interactions in tropical zones are severely affected by habitat fragmentations. Tree mortality in fragment margins sharply increases by elevated desiccation and wind disturbance thus altering canopy-gap dynamics, plant community composition, biomass dynamics and carbon storage. Fragmented forests with periodic droughts or strong dry seasons are also highly vulnerable to edge-related fires while at landscape to regional scales in between 10–1000 km, with important consequences for atmospheric circulation, water cycling and precipitation. Habitat fragmentation may have complex effects on forest–climate interactions respectively (Laurance, 2004).

2.4.4 Importance role of the fragments

Fragments of semi-natural forests sometimes act as refuges for plant diversity in the surrounding landscape matrix (Lomba *et al*., 2011). Small fragments also act as seed source in the restoration of relatively minor rain forest areas while providing sound shelter for species under threat of extinction (Turner and Corlett, 1996).

2.5 Ecological modeling of plant community

Several models have been studied in order to predict or understand the relationship of plants and their environmental factors (Choiu *et al*., 2013).

Choiu *et al*. (2013) analyzed geo-referenced data to identify potential variables of *L. leucocephala* invasion and to predict likelihood of further invasion using boosted regression trees and results indicated probability of invasion correlate with climatic conditions, landscape features and anthropogenic factors. The most influential variables were average annual temperature, altitude, precipitation and slope, thus providing useful information to aid forest managers in the development of long term monitoring and control strategies for *L. leucocephala*, in the early detection and eradication of newly established invasions.

Boosted regression tree (BRT) is one of most influential statistical learning method that attains both of regression and classification analyses, deals with nonlinear ecological data and also many types of response variables (such as numeric, categorical, and censored), loss functions (Gaussian, binomial, Poisson,and robust) as well as predictors (De'Ath, 2007).

Chiou and Chen (2016) also stated that the logistic regression indicated *L. leucocephala* favors warm, dry areas containing a higher percentage of natural landscape and such predictions might be useful to develop proactive management plans for the areas most likely to be invaded.

CHAPTER III

MATERIALS AND METHODS

3.1 Study area

Field research was conducted in 9 forest fragments within the premises of Suranaree University of Technology (SUT) (14° 52′ 22.5″ N, 102° 1′ 25.32″ E, 252–233 m above sea level) located at Mueang District, in Nakhon Ratchasima Province of Northeastern Thailand (Figure 3.1). The area is mostly flat terrain, with seasonal climatic condition (see also Figure 3.2). Each fragment is bounded by paved roads and selected fragments are shown in Table 3.1 (see also Figure 3.1)

According to the records of Nakorn Ratchasrima climate station for past 30 years (1981-2010), average temperature ranged from 18 to 35 ºC, and 225 mm maximum precipitation in September (Figure 3.2), while minimum recorded in December (Source: Climate of Thailand (1981–2010): https://www.tmd.go.th).

3.2 Selection of study sites

Recently updated SUT satellite image (dated: 11.16.2016) of Google Earth pro was used to determine area and perimeter of existing forest fragments. Arc Map (10.3) was field inspections to determine boundaries. As the result, 26 forest fragments covering 34% of the total area (Table 3.1; Figure 3.1) and after inspections for current site conditions prior to *L. leucocephala* distribution (Figure 3.3), most

possible 9 fragments (named as A to I) were used selected based on area, Shape Index (SI) and proximity.

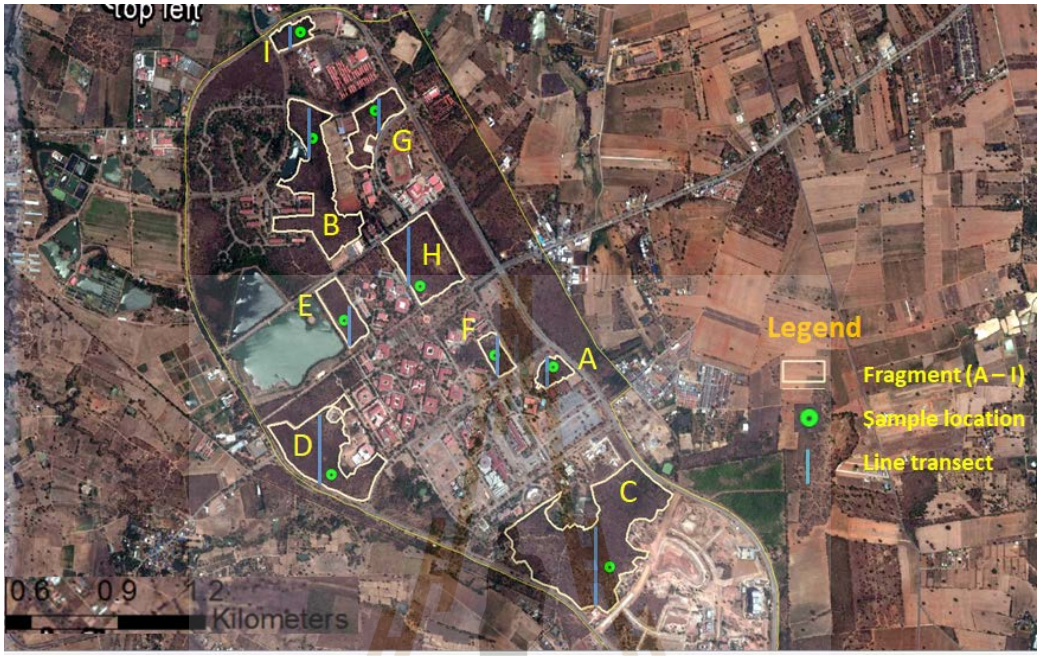

Figure 3.1 Map of SUT and forest fragments within the SUT premises (white outline), select fragments (yellow outline). Random sample plot locations (green circles) and line transects along widest distance (blue line).
(Source: Google maps (2017) and modified from Arc Map by author).

At least 100m distance between selected sites were kept to get rid of special autocorrelation among environmental and community variables because close proximity of selected fragments lead to disrupt statistical testing by violating independence of most standard statistical proceedings (Legendre, 1993).

3.3 Descriptions of selected sites

3.3.1 Fragment A

One of the smallest (2.41ha) located beside the water body. Only fragment with fenced but some areas has still been used as a dumping site for construction. The vegetation is dominated by *Sindora siamensis*, a native plant and less *L. leucocephala* than other sites.

Table 3.1 Study sites of the nine fragment of SUT. Shape Index (SI); ratio between area and perimeter (discussed in chapter 3.6.4).

ID	Location	Area (ha)	Perimeter (m)	Distance to the nearest selected fragment (m)	SI value
A	Close to Surasamanakhan	2.4	691.77	421	1.36
B	Near staff quarters complex	17.91	3155.62	102	2.16
C	Near hospital complex	36.97	3752.18	421	1.74
D	Front of gate 3	15.82	2659.87	268	1.57
E	East to the tank	5.11	1006.25	102	1.31
F	Next to transport hub	2.40	666.00	135	1.21
G	Near tennis court	6.43	1421.58	110	1.59
H	Near classroom building	12.40	1453.79	133	1.13
I	Near seven-eleven, gate 4	2.75	776.99	254	1.48

3.3.2 Fragment B

Second largest (17.91 ha) fragment surrounded by housing apartments while some are located inside. The edges are mostly dominated by *L. leucocephala* while moderately within the core and nearby the water body at the northwest boundary.

3.3.3 Fragment C

The largest fragment within SUT with 36.97 ha in extent. *L. leucocephala* is established within the forest as well as edge. Several small water bodies are presence inside the area lead to maintain water logged areas throughout rainy seasons of the year. Some edges of the north end being used for earth removal of the constructions. Ruins of abandoned paddy fields make an evidence for past land use.

3.3.4 Fragment D

Heavily dominated by L. *Leucocephala*, both in the edge and core. Seasonal stream flows across the land. Area is covered 15.83 ha in extent and north edge and surroundings have often been using as dumping sites for concrete residuals of the constructions.

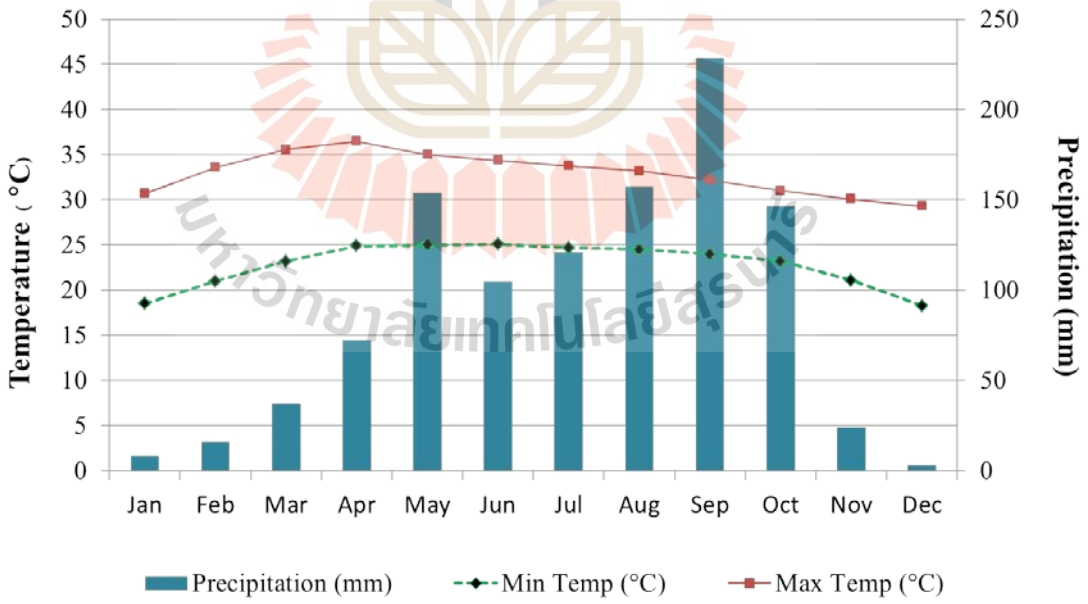

Figure 3.2 Climate of Korat city averaged from 30 years (1981–2010).

(Source: https://www.tmd.go.th/province_weather_stat.php?StationNumber=48431)

Figure 3.3 Fragment characteristics of SUT; fragment forest with native species dominant (left) and with *L. leucocephala* dominant (right).

3.3.5 Fragment E

L. Leucocephala dominated vegetation edge to the large water tank. Relatively moderate in extent (5.11 ha). Less damages from anthropogenic activities such as dumping site.

3.3.6 Fragment F

Small fragment (2.4 ha) surrounded by road network and *L. Leucocephala* is moderately distributed within the area and less damages from anthropogenic activities.

3.3.7 Fragment G

Relatively low frequency of *L. Leucocephala* distribution except edges. Moderate in size (6.43ha) and located at the middle of open areas of ground complex of SUT.

3.3.8 Fragment H

Fragment contains by road network and buildings. Extent in 12.40 ha and abandoned concrete structures and roads given evidence to existence of temporary

camping sites in previous stages of SUT construction and *L. leucocephala* moderately dispersed into the vegetation.

3.3.9 Fragment I

One of the smallest fragments of the selected sites (2.75ha). Dominated by *L. leucocephala* both in the edge and core. Fragment is surrounded by road network.

3.4 Sampling

3.4.1 Quadrat samples

Selected 9 fragments were plotted as polygons and sample locations randomly generated via "create random point tool" of Arc Map software (ESRI, 2011). Re randomized the process until locations were laid at least 40m away from the fragment edge to minimize edge effects. Universal Transverse Mercator coordinates (UTM) of created random sample locations were loaded into GPS navigator (Garmin GPSmap64s) in WGS 84 Coordinate System and demarcated on the field. Related UTM coordinates were recorded (Table 3.3) to fulfill future revisions or repeat measurements. Samples (20x20 m) were set out as the mid-point of UTM coordinate. Cardinal ends of sample boundary were demarcated using wooden poles and nylon chords for easy identification of margins. Quadrat sample data were only used to express species composition in family, generic and taxa levels to get general idea about the species composition of the study sites but not for statistical analysis due to special autocorrelation among multiple samples in close proximity (Legendre, 1993).

3.4.2 Line transects

Nine line transects, one per each fragment were selected (Kaiser, 1983) at the widest distance along south to north direction (north faced). Distances were inspected

and UTM coordinates of the south end were loaded to GPS navigator (Gramin GPSmap64s) using Arc Map (ESRI, 2011) and demarcated on the edge of each fragment (Table 3.3). Line transects of 9 fragments varied between 80 to 627 m in length and based on the shortest length, 80 m segments for each were selected (Ripley *et al*., 1963) according to the generated random numbers using R statistical software (R- Development Core team, 2017) (Table 3.4).

3.5 Data collection

Every individual woody plant (excluding herbs and palms) within quadrat plot was recorded and measured. Each individual was tagged using calibrated metal tag prior to revisions and repeats and identified to the least taxonomic level as possible. Diameter of every individual woody plant (exclude seedlings in quadrat samples), was measured at breast height (DBH) using calibrated diameter tape and recorded in three distinct categories; 1) trees (DBH greater than or equal to 4.5 cm and total height over or equal to 1.3 m), 2) saplings (DBH between 1–4.4 cm and total height over or equal to 1.3 m), and 3) seedlings (DBH less than 1 cm and height over 15 cm) (Marod *et al*., 2012). At least one herbarium specimen was collected per species per each plot. Species name, DBH and habitat (tree or liana) were also recorded.

3.5.1 Environmental variables

Line transect direction was aligned with GPS navigator (Garmin GPSmap64s) and a measuring tape was laid along the line. Soil samples were collected along every 10 m intervals as described below.

After removal of the living material on the surface and objects larger than 2 cm, approximately 500g of fresh material (not exceeding 15 cm depth) was extracted

to the labeled polythene container and transported to the laboratory. As soon as possible samples were air dried at a temperature of 40 °C for at least 48 hours and filtered by 2mm sieve. Filtered samples were kept under room temperature until analysis (Soil Survey Staff, 2011).

Table 3.2 Total transect lengths with randomly selected segments (random number in bolded) based on smallest length of 80 m in fragment I, Universal Transverse Mercator (UTM) coordinates of the (x and y axis) south end of line transects and quadrat sample centers.

ID	Total length of transect (m)	Randomly selected 80 m transect segment	UTM coordinates of line transects		UTM coordinates of quadrat samples	
			Point X	Point Y	Point X	Point Y
A	160	**100** - 160, 0 - 20	179,877.342	1,646,869.495	179,920.64	1,646,982.40
B	270	**210** - 270, 0 - 10	178,604.530	1,647,573.867	178,511.69	1,648,229.39
C	627	**420** - 500	180,167.741	1,645,692.452	180,254.68	1,645,904.22
D	306	**190** - 270	178,731.193	1,647,101.196	178,624.18	1,646,397.01
E	178	**40** - 120	178,731.618	1,647,101.274	178,692.71	1,647,240.76
F	140	**120** - 140, 0 - 60	179,605.479	1,646,931.282	179,576.68	1,647,051.85
G	180	**120** - 180, 0 - 20	178,885.661	1,648,225.720	178,877.17	1,648,379.14
H	440	**30** - 110	179,146.850	1,647,326.400	179,142.81	1,647,425.58
I	80	80	179,101.915	1,647,394.684	178,438.57	1,648,806.44

From the starting point, canopy cover was estimated by a handmade spherical densitometer along 10 m intervals of the transect. In the contrast of cross hairs of the eye peace in vertical direction covered by the canopy, thus recorded as closed or open (Emlen, 1967).

3.5.2 Diversity variables

A measuring tape (40 m length) was laid along the already aligned transect line. Woody plants (excluding herbs and palms) that only touched the tape were considered (Wheater *et al.*, 2011). Each individual was identified to species level as possible, counted and diameter at breast height (DBH) of every individual was measured using calibrated diameter tape and recorded according to the three distinct categories that explained in chapter 3.4.1. At least one herbarium specimen was collected per species per each transect for validation purposes. Transect line was shifted rectangular direction to avoid disturbances (such as water logged areas). Species name, intercept length, DBH and habitat (tree or liana) was recorded.

Along the line transect, presence or absence of *L. leucocephala* and other plant species (any woody plant other than *L. leucocephala*) was recorded at every 10 m interval.

3.6 Data preparation

Woody plant data collected from 9 fragments (in quadrat samples) was used to express species composition in family and generic level to get general idea about the study sites.

3.6.1 Test for soil moisture content (smc)

Air dried soil samples were taken to the laboratory. Approximately 5–8 g portion was put into the tared moisture tin and weigh using analytical balance with accuracy at 0.01 g (Sartorius BL600) and dried at 105 °C (lid removed) for 24 hour in a drying and heating chamber (Binder FD 115) and re weighted after temperature returned to 40 °C. Moisture content in weight percentage was calculated by using;

Soil moisture content (smc) % = (A–B)*100/ (B–tare tin)

Where, A: weight of tared moisture tin and air-dried soil sample and B: Weight of tared moisture tin and oven-dried soil sample (Soil Survey Staff, 2011).

3.6.2 Test for soil pH

Approximately 5 ml volume of air-dried soil (fraction <2 mm) sample was placed in the sample bottle and add five times its volume of distilled water and mixed the suspension vigorously for 5 minutes using the mechanical shaker and left 2 hours. Values were measured after calibration of electronic pH meter (Mettler-Toledo S220) as per user manual, at pH 4.1 and 7.0 using standard buffers (Soil Survey Staff, 2011).

3.6.3 Canopy closed % measurements

Densitometer readings regarding canopy open or closure that were recorded at every 10 m intervals used to calculate a single value of canopy closed % (C) per transect using following equation (Jennings, 1999):

$$C = Nc / Nt \times 100$$

Where, Nc is no of point locations covered by the canopy and Nt is total no of points sampled.

3.6.4 Shape index (SI) of fragments

Prior to SI values calculations, most reliable area and perimeter measures of each fragment were obtained by Arc Map (ESRI, 2011), based on the shape files of fragments that were developed by recently updated Google pro satellite images (Google Maps, 2017).

Shape index (SI) were calculated for each fragment using the formula in metric units:

$$\text{Shape Index (SI)} = P/200[(\pi A)^{1/2}]$$

Where P is the fragment perimeter (m) and A the area (ha). Fragments with irregular shapes, or higher SI values, tend to show more edge effects than do circular fragments (Laurance and Yensen, 1991; Yates *et al*., 2004).

3.6.5 Diversity variables

Species richness (Total number of species in a specific area), species abundance (Density of individuals species per specific area), and two indices (Simpsons Index (D) and Shannon-Weaver Index (H') were used to evaluate species diversity (Krohne, 2001) of line transects.

$$\text{Simpsons Index (D)} = \Sigma\, n\,(n-1)/\, N\,(N-1)$$

Where n denotes total number of individuals of a particular species while, N for the total number of individuals of all species per specific area.

$$\text{Shannon-Weaver Index (H')} = -\,\Sigma\, pi\, \ln\,(pi)$$

Where pi denotes the relative abundance of the species i.

Species evenness for each community is derived as Pielou's evenness (J′), that Pielou was introduced in 1975 (Patil, 2002; Zhang *et al*., 2012). Shannon index is scaled by the species richness to measure species evenness for each community:

$$J' = H'/\ln(S)$$

Where H' represents the observed value of Shannon index, and S is the numeric number of species richness.

Sorenson similarity index / Dice's coefficient is used to compare the similarity or dissimilarity between two groups based on presence and absence probability by the use of formula given below (Diserud and Odegaard, 2007; Wolda, 1981).

$$\text{Sorenson Index} = 2A/\,(B+C)$$

Where, A denotes no of shared species between group B and C while B and C denotes no of species in group A and B.

Propagule pressure is commonly defined as the level of matured individuals in the introduced population that enables siblings production (Lonsdale, 1999). I observed many flowering and fruit baring *L. leucocephala* individuals above 2.5 cm DBH within fragments and therefore considered as matured individuals.

Stem density of the measured individuals of the line transect was calculated by the below equation (Strong, 1966):

$$\text{Stem density} = (\Sigma\ 1/M \times A) / T$$

Where, Σ 1/M denotes the total number of reciprocal DBH value of the individuals, A for sampled area (considered as 10000 m^2) and T for total transect length.

3.7 Statistical analysis

Based on my hypothesis, Simpsons diversity index (sim_ind) and other species (non- *L. leucocephala*) stem density were considered as a representative of native species composition and species diversity as well as *L. leucocephala* stem density (leu_stden) and propagule pressure (prop_pre) were selected as *L. leucocephala* species abundance and density.

At the initial step, I inspected Pearson's correlation coefficients of all environmental and diversity variables to find most effective correlations to test my hypothesis.

To test *L. leucocephala* effect on natural species diversity and the relationship of environmental variables, I applied linear or generalized linear models (LM, GLM), using *L. leucocephala* stem density (leu_stden) and *L. leucocephala* propagule

pressure (prop_pre) as dependent and soil moisture content (smc), soil pH (soil_ph), canopy closure % (cano_cl), species richness (sp_rich), Pielou's evenness (j_even), propagule pressure (prop_pre), non *Leucaena* species stem density (osp_stden), Shannon diversity index (sha_ind), Simpsons diversity index (sim_ind), Sorenson similarity index between trees and saplings (si_tsa), Sorenson similarity index between saplings and seedlings (si_sasd), area, perimeter (peri) and shape index (si) as predictors to find significant linear correlations between dependent and predictors.

In the contrast of species diversity, I followed the same procedure as explained above to test Simpsons diversity index (sim_ind) as dependent against all other variables (except Shannon diversity index) as predictors.

I tested each variable for normality, homoscedasticity, independence and fitted to the proper family (Gaussian for all dependents) and validated all models by testing residuals and standardized residuals versus fitted as well as predicted values by Crook's distances. Corrected Akaike's Information Criterion used for all samples (AICc; Akaike, 1974) comparison between each other but priority was given to the model with more random and independence distribution of residuals because if any model violates the GLM assumptions (linearity, continuity of outcome variable, covariates are correlated with the error terms, zero conditional mean error, constant variance) resulted to the wrong interpretations (Casson and Farmer, 2014).

To investigate the relationship between paired data, I used Pearson's Chi-Square test among categorical variables (Agresti and Kateri, 2014) of presence or absence of *Leucaena* (leu_y_n), other plant species (nonlue_y_n), open or close of canopy (cano_c_o) and other all continuous variables to investigate the effect of

Leucaena existence on native species diversity according to 4th hypothesis (*L. leucocephala* affects native species composition).

Kruskal-Wallis one-way analysis of variance by ranks test (Chan, and Walmsley, 1997) was used to compare *L. leucocephala* abundance from edge to core area of the fragments, using five 10 m intervals (0–10, 11–20, 21–30, 31–40 and 41–50 m) along the line transect at north and south ends separately because non-normal data distribution of *L. leucocephala* and normal distribution of the residuals are not assumed by the method (Kruskal and Wallis, 1952).

Sorenson similarity indexes between seedlings, saplings and trees were used to compare β diversity among fragments (Jurasinski *et al*., 2009).

To test significant correlations between species abundance data and environmental variables, I also used Nonmetric Multidimensional Scaling (NMDS) in 1000 permutations (p= <0.05) because nonlinear of the data (Oksanen, 2015). Canonical Correspondence Analysis (CCA) bi plots were used to describe the correlations of environmental variables alone species abundance and cluster diagram (Ward's average distance method) was used to find the dissimilarity between fragments (Murtagh and Legendre, 2014).

Rank abundance curves were formulated with and without *L. leucocephala* to compare species evenness and abundance and use species accumulation curves based on pooled individuals (random, 1000 permutations) to determine adequacy of collected data.

I performed all statistical calculations using R statistical software version 3.0.2 (R- Development Core Team, 2013) and significance level was set at α <0.05 (chance of a false positive is only 5%) and all described statistics as means ± standard deviation.

CHAPTER IV

RESULTS AND DISCUSSIONS

4. 1 Results

4.1.1 Plant community of SUT fragments

Woody plants were censured between 2017.05.04 and 2017.06.07 within 9 quadrat samples and 51 taxa of 47 genera under 27 families were identified (Table 4.1 and 4.2). All fragments were dominated by family Fabaceae with 74.88% (Table 4.3; Figure 4.2). The highest species richness and diversity (Simpson's diversity index) was found in fragment G (28 & 0.87) while lowest from I (3 & 0.02). High variation in basal area of *Leucaena* in Fragment I (99.70%) but only 0.18% in fragment A. (Table 4.1; Figure 4.1 and 4.2).

Table 4.1 List of plant species found in SUT fragments from quadrat sample plots (20x20 m).

	Species	Fragments								
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
1	*Albizia lebbek*	+		+		+	+	+	+	
2	*Albizia lebbekoides*		+	+	+	+		+		
3	*Anona squamosa*								+	
4	*Aporosa serrata*							+		
5	*Azadirachta indica*	+	+	+	+	+	+	+	+	
6	*Bauhinia saccocalyx*		+			+			+	
7	*Bombax anceps*	+		+				+		
8	*Breynia retusa*							+		
9	*Bridelia glauca*							+		
10	*Caesalpinia digyna*								+	
11	*Cansiera rheedii*						+			

Table 4.1 (Continued).

	Species	Fragments								
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
12	*Capparis flavicans*				+					
13	*Celastrus paniculatus*		+						+	
14	*Combretum quadrangulare*	+	+		+	+	+	+	+	
15	*Cratoxylum cochinchinense*	+						+		
16	*Dalbergia nigrescens*	+	+					+		
17	*Derris scandens*		+							
18	*Dimocarpus longan*								+	
19	*Diospyros rhodocalyx*		+			+	+	+	+	
20	*Dolichandrone serrulata*					+				
21	*Elaeodendron glaucum*							+		
22	*Erythrophleum succirubrum*							+		
23	*Flacourtia indica*			+				+		
24	*Flueggea virosa*								+	
25	*Hymenopyramis brachiata*							+		
26	*Hymenopyramis pervifolia*								+	
27	*Lannea coromandelica*	+						+	+	
28	*Lantana camara*			+	+		+			
29	*Leucaena leucocephala*	+	+	+	+	+	+	+	+	+
30	*Litsea glutinosa*			+						
31	*Maerua siamensis*					+	+	+	+	+
32	*Mangifera indica*	+								
33	*Memecylon edule*	+						+		
34	*Microcos tomentosa*	+						+	+	
35	*Mitraguna hirsuta*								+	
36	*Morinda elliptica*									+
37	*Morinda tomentosa*							+		
38	*Ochna integerrima*	+								
39	*Olax psittacorum*	+		+	+	+	+	+	+	
40	*Polyalthia cerasoides*	+	+	+				+		
41	*Pterocarpus macrocarpus*	+					+	+	+	
42	*Pterolobium integrum*	+		+						
43	*Shorea siamensis*	+								
44	*Sindora siamensis*	+					+	+	+	
45	*Tamarindus indica*								+	
46	*Terminalia macronata*								+	
47	*Vitex glabrata*			+						
48	*Wrightia arborea*						+	+	+	
49	*Xylia xylocarpa*	+						+	+	
50	*Ziziphus cambodiana*	+								
51	*Ziziphus oenoplia*	+	+	+	+		+	+	+	
	Total	**21**	**11**	**13**	**8**	**10**	**13**	**28**	**24**	**3**

Table 4.2 List of plant species found in SUT fragments from line transects.

	Species	Family	Genera	Abundance
1	*Abrus precatorius*	Fabaceae	Arbus	3
2	*Afzelia xylocarpa*	Fabaceae	Afzelia	1
3	*Albizia lebbeckoides*	Fabaceae	Albizia	2
4	*Albizia lebbek*	Fabaceae	Albizia	3
5	*Anthocephalus chinensis*	Rubiaceae	Anthocephalus	1
6	*Azadirachta indica*	Meliaceae	Azadirachta	33
7	*Bauhinia saccocalyx*	Fabaceae	Bauhinia	60
8	*Bridelia glauca*	Phyllanthaceae	Bridelia	17
9	*Buchanania lanzan*	Anacardiaceae	Buchanania	1
10	*Caesalpinia godefroyana*	Fabaceae	Caesalpinia	7
11	*Cansjera rheedii*	Opeliaceae	Cansjera	1
12	*Carissa spinarum*	Apocynaceae	Carissa	8
13	*Colona auriculata*	Malvaceae	Colona	21
14	*Combretum quadrangulare*	Combretaceae	Combretum	155
15	*Cratoxylum cochinchinense*	Hypericaceae	Cratoxylum	17
16	*Croton roxburghii*	Euphorbiaceae	Croton	4
17	*Dalbergia nigrescens*	Fabaceae	Dalbergia	9
18	*Diospyros rhodocalyx*	Ebenaceae	Diospyros	33
19	*Flacourtia indica*	Salicaceae	Flacourtia	7
20	*Harrisonia perforata*	Rutaceae	Harrisonia	7
21	*Hesperethusa crenulata*	Rutaceae	Hesperethusa	1
22	*Hymenopyramis brachiata*	Lamiaceae	Hymenopyramis	23
23	*Lannea coromandelica*	Anacardiaceae	Lannea	1
24	*Lantana camara*	Verbenaceae	Lantana	18
25	*Leucaena leucocephala*	Fabaceae	Leucaena	708
26	*Litsea glutinosa*	Lauraceae	Litsea	4
27	*Maerua siamensis*	Capparaceae	Maerua	23
28	*Memecylon caeruleum*	Melastomataceae	Memecylon	3
29	*Microcos tomentosa*	Malvaceae	Microcos	5
30	*Millingtonia hortensis*	Bignoniaceae	Millingtonia	1
31	*Morinda tomentosa*	Rubiaceae	morinda	1
32	*Ochna integerrima*	Ochnaceae	Ochna	1
33	*Olax psittacorum*	Olacaceae	Olax	47
34	*Phyllanthus reticulatus*	Phyllanthaceae	Phyllanthus	3
35	*Polyalthia cerasoides*	Annonaceae	Polyalthia	4
36	*Pterocarpus macrocarpus*	Fabaceae	Pterocarpus	5
37	*Pterolobium integrum*	Fabaceae	Pterolobium	1
38	*Salacia chinensis*	Celastraceae	Salacia	1
39	*Senna garrettiana*	Fabaceae	Senna	5
40	*Sindora siamensis*	Fabaceae	Sindora	64
41	*Streblus asper*	Moraceae	Streblus	1
42	*Tamarindus indica*	Fabaceae	Tamarindus	1
43	*Vitex glabrata*	Lamiaceae	Vitex	1
44	*Wrightia arborea*	Apocynaceae	Wrightia	6
45	*Xylia xylocarpa*	Fabaceae	Xylia	1
46	*Ziziphus cambodiana*	Rhamnaceae	Ziziphus	2
47	*Ziziphus oenoplia*	Rhamnaceae	Ziziphus	49
			Total	**1370**

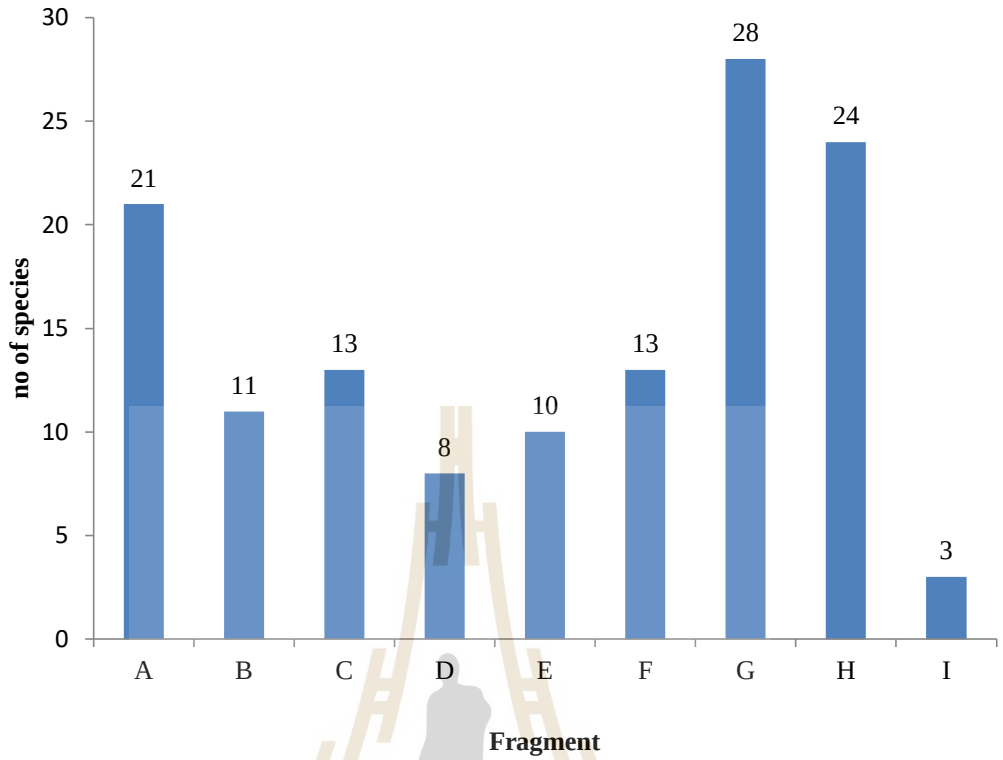

Figure 4.1 Number of plant species found in fragments quadrat samples.

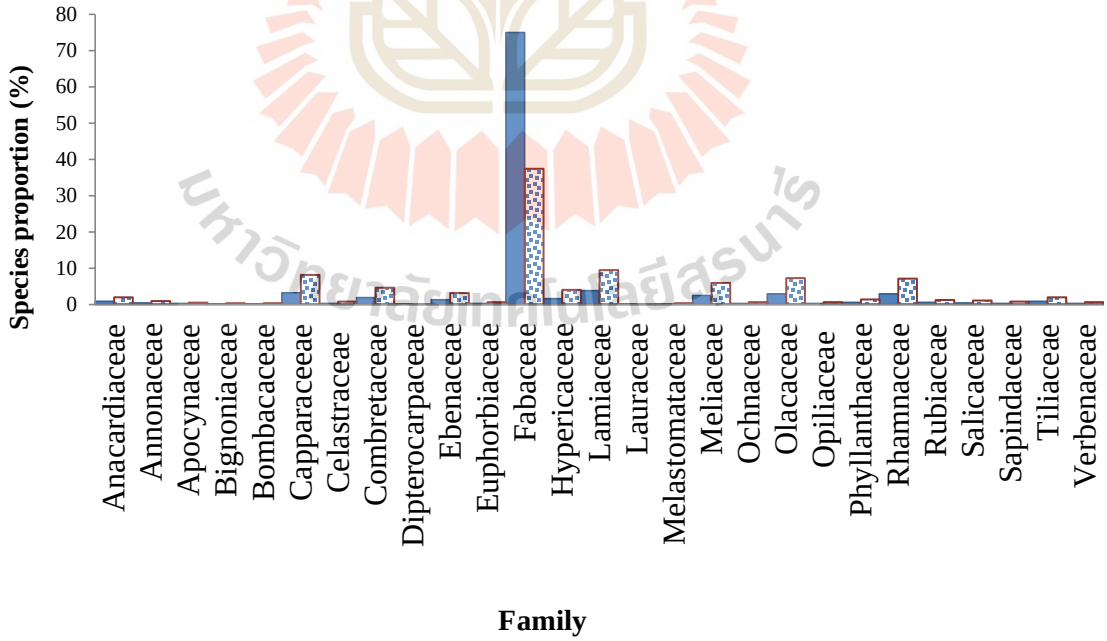

Figure 4.2 Species distribution within families (with *Leucaena* in blue and without in dotted) in fragments quadrat samples.

Total 2.38 km length of transect was measured within 2017.07.04 – 2017.09.06 duration, 1370 individuals including 126 trees, 270 saplings and 974 seedlings within 48 taxa, 46 genera and 28 families were identified (Table 4.2). As per random species accumulation curve at 1000 permutation (Figure 4.3), at least 400 individual data would be required to identify maximum species richness in 80 m line transect segment but I used to collect 467 individuals measurements for data adequacy.

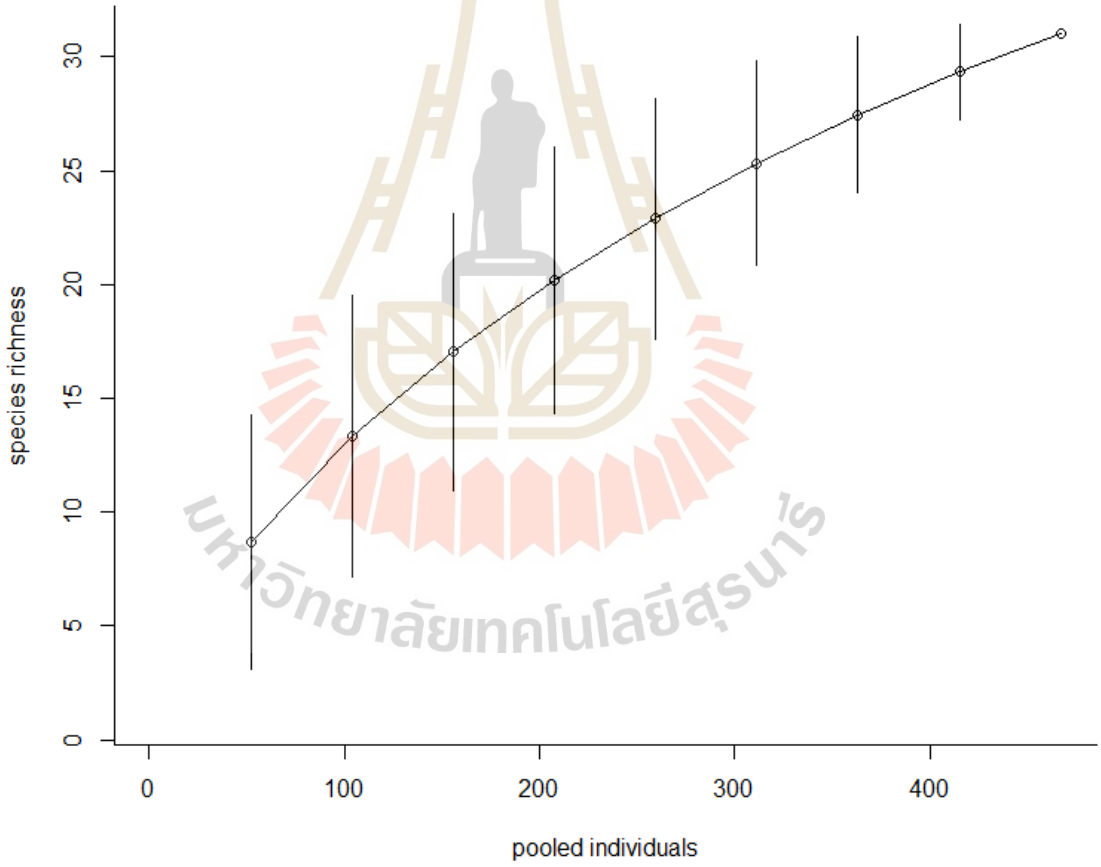

Figure 4.3 Species accumulation curve of the SUT fragments based on pooled individuals (random, 1000 permutations).

4.1.2 Environmental and diversity variables of nine random line transects

Table 4.3 shows the mean values of all environmental and diversity variables in each fragment from the random line transect data. Highest soil moisture content % was recorded from fragment E (10.38±1.64), and the lowest in fragment A (2.27±2.04). Soil pH varied between 6.31–7.72 and exceeded 7 in five locations (fragment D= 7.72±0.12, I= 7.33±0.15, E= 7.29±0.23, B= 7.24±0.27 and C= 7.00±0.44) and was lowest in fragment A (6.31±0.30).

In the perspective of diversity variables, species richness varied from 14 (fragment A) to 4 (fragment I) while, Pielou's J′ evenness Index from 0.68 (fragment B) to 0.24 (fragment G). *Leucaena* propagule pressure was highest at fragment E (20) but zero in fragment A. The largest total stem density was recorded from fragment D (1968.67 m^2ha^{-1}) while smallest at fragment B (316.34 m^2ha^{-1}) but highest *Leucaena* stem density was observed in fragment D (1741.40 m^2ha^{-1}) and zero in fragment A. Shannon and Simpson's diversity indexes were highest at fragment A (1.78 and 0.72) and lowest in fragment E (0.41 and 0.17). Sorenson similarity index between trees and saplings was highest (1.0) in fragment F and lowest in fragment A (0.00) while fragment H (0.77) and G (0.20) for same index between saplings and seedlings.

4.1.3 Pearson's correlation coefficients among environmental and diversity variables

According to Pearson's correlation coefficients (Table 4.4), Simpson's diversity index was strongly negative correlated with *Leucaena* propagule pressure (r= -0.947, t= -26.34, p= <0.0001) followed by soil moisture content % (r= -0.513, t= -5.31, p= <0.0001) and soil pH (r= -0.509, t= -5.26, p= <0.0001), but positively

insignificant with area (*r*= 0.195, *t*= 1.76, *p*= 0.0809), perimeter (*r*= 1.37, *t*= 0.17, *p*= 0.1735) and shape index (*r*= 0.029, *t*= 0.26, *p*= <0.7913). *Leucaena* stem density positively correlated with soil pH (*r*= 0.684, *t*= 8.34, *p*= <0.0001) and *Leucaena* propagule pressure (*r*= 0.627, *t*= 7.16, *p*= <0.0001) while was negatively associated with Pielou's J′ evenness index (*r*= -0.483, *t*= -4.90, *p*= <0.0001). *Leucaena* propagule pressure positively correlated with soil moisture content%, soil pH and canopy closed % (*r*= 0.577, *t*= 6.28, *p*= <0.0001: *r*= 0.491, *t*= 5.01, *p*= <0.0001: *r*= 0.453, *t*= 4.52, *p*= <0.0001) and negatively with species richness and Pielou's J′ evenness index (*r*= -0.521, *t*= -5.43, *p*= <0.0001: *r*= -0.637, *t*= -7.34, *p*= <0.0001). Other species (non- *Leucaena*) stem diversity was positively correlated with area (*r*= 0.428, *t*= 4.218, *p*= <0.0001) and negatively with canopy closed % and *Leucaena* propagule pressure (*r*= -0.778, *t*= 10.99, *p*= <0.0001: *r*= -0.431, *t*= 4.24, *p*= <0.0001).

4.1.4 Results of model selections

I selected soil moisture content and *Leucaena* stem density as predictors of Simpson diversity index (Table 4.5) and soil pH, *Leucaena* propagule pressure and Simpson diversity index as predictors for *Leucaena* stem density (Table 4.6), soil moisture content % and soil pH as predictors for dependents of both *Leucaena* propagule pressure and other species (non- *Leucaena*) stem density (Table 4.7 and 4.8).

4.1.5 Evaluation of selected parsimonious models

According to Table 4.9, *Leucaena* propagule pressure (*n*= 9, 6.78±6.43) was significant positively correlated with soil pH (*t*= 8.477, *p*= <0.00) and soil moisture content % (*t*= 9.542, *p*= <0.00), *Leucaena* stem density (*n*= 9, 665.2±494.34) significant positively correlated with soil pH (*t*= 6.715, *p*= <0.00), Simpson's

diversity index (t= 3.338, p= <0.001) and *Leucaena* propagule pressure (t= 4.885, p= <0.00), other species (non- *Leucaena*) stem diversity (n= 9, 253.8±155.55) was negatively correlated with soil moisture content % (t= -2.399, p= <0.01) and soil pH (t= -2.649, p= <0.001) and Simpson's diversity index (n= 9, 0.5244±0.17) was negatively correlated with soil moisture content % (t= -4.386, p= <0.00) and *Leucaena* stem diversity (t= -4.878, p= <0.00).

4.1.6 Pearson's Chi-squared test results

Presence or absence of *Leucaena* was significantly affected to the presence or absence of native (non- *Leucaena*) species individuals (x^2= 11.648, df= 1, p= <0.000) but not in significance with any other tested variables (Table 4.10).

4.1.7 Comparison of β diversity among fragments

According to the Table 4.11, combinations between fragments (similarity between seedlings, saplings and trees) in value at 1.0 were 37.5% and 87.5% represented > 0.60 similarity as well. Zero similarities within any combination were 9.4% in only three occasions (between fragment I & D, I & F and F & E).

4.1.8 Ordination expressions of species and environmental variables

According to the ordinations of the CCA bi plot (together explained 61% of total variance; Figure 4.4), *Leucaena* stem density (leu_stden) strongly and negatively correlated to Pielou's J′ evenness (j_even) and Shanon diversity index (sha_in) while species richness (sp_rich) was also negatively correlated with soil pH (soil_ph) followed by canopy closed % (can_cl). *Leucaena* stem density, total stem density (st_den), soil moisture content % and canopy closed % were not correlated as well as with species richness, Shanon index and Pielou's J′ evenness.and (Figure 4.5), Principal components analysis (PCA) bi plot was resulted as same. Nonmetric

Multidimensional Scaling (NMDS) output of species abundance against environmental variables at 1000 permutations, only Shannon diversity index (r^2= 0.6553, p= 0.044) and total stem density (r^2= 0.7314, p= 0.0244) were significance and negatively correlated (see Figure 4.6).

Table 4.3 Table shown values of environmental and diversity variables of the random transects. Soil moisture content and soil pH values as Mean±SD. Sørensen index (tree & sap): Sørensen index between trees & saplings, Sørensen index (sap & seed): Sørensen index between saplings & seedlings.

Environmental variables	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Soil moisture content (%)	2.27±2.04	3.10±0.63	3.87±3.99	5.20±1.95	10.38±1.64	3.05±1.54	3.51±2.56	3.57±1.68	3.71±1.10
Soil pH	6.31±0.36	7.24±0.27	7.00±0.44	7.72±0.12	7.29±0.23	6.95±0.40	6.45±0.25	6.63±0.48	7.33±0.15
Canopy closed (%)	55.56	66.67	33.33	44.44	88.89	77.78	55.56	66.67	66.67
Area (ha)	2.41	17.91	36.97	5.11	2.4	6.43	12.4	12.4	2.75
Perimeter (m)	691.77	3155.62	3752.18	2659.87	1006.25	666.00	1421.58	1453.79	776.99
Shape Index	1.36	2.16	1.74	1.57	1.31	1.21	1.59	1.13	1.48
Diversity variables									
Species richness	14	7	6	8	5	7	10	8	4
Pielou's J′ evenness Index	0.67	0.68	0.65	0.49	0.26	0.61	0.24	0.32	0.45
Propagule pressure	0	1	2	10	20	5	9	1	13
Total stem density (m^2ha^{-1})	395.88	316.34	831.81	1968.67	855.14	477.27	1047.46	914.36	1373.98
Leucaena stem density (m^2ha^{-1})	0	123.53	357.76	1741.40	841.70	477.27	738.51	619.30	997.70
Shanon diversity index	1.78	1.32	1.17	1.03	0.41	1.18	0.55	0.66	0.63
Simpsons diversity index	0.72	0.61	0.57	0.44	0.17	0.55	0.56	0.76	0.34
Sørensen index (trees & saplings)	0	0.4	0	0.5	0.67	1.0	0.33	0.75	0.67
Sørensen index (saplings & seedlings)	0.27	0.60	0.57	0.55	0.33	0.25	0.20	0.77	0.67

Table 4.4 Pearson's correlation coefficients (*df*= 79) among environmental and diversity variables of the random transects as Simpsons index (sim_ind), soil moisture content (smc), *Leucaena* stem density (leu_stden), other species (non- *Leuceana*) stem density (osp_stden), soil pH (soil_ph), Shape index (si), perimeter (peri), Pielou's J′ evenness (j_even), *Leucaena* propagule pressure (prop_pre) and canopy closed % (cano_cl).

Variables		Pearson's correlation	*t* value	*p*-value
Sim_ind	smc	-0.513	-5.31	<0.0001
	Leu_stden	-0.544	-5.76	<0.0001
	Soil_ph	-0.509	-5.26	<0.0001
	si	0.029	0.26	0.7913
	peri	0.152	1.37	0.1735
	area	0.195	1.76	0.0809
	J_even	0.387	3.73	<0.0001
	prop_pre	-0.947	-26.34	<0.0001
	Cano_cl	-0.396	-3.83	<0.0001
Leu_stden	Soil_ph	0.684	8.34	<0.0001
	Prop_pre	0.627	7.16	<0.0001
	J_even	-0.483	-4.90	<0.0001
Prop_pre	smc	0.577	6.28	<0.0001
	soil pH	0.491	5.01	<0.0001
	cano_cl	0.453	4.52	<0.0001
	Sp_rich	-0.521	-5.43	<0.0001
	j_even	-0.637	-7.34	<0.0001
osp_stden	si	0.237	2.17	0.0328
	area	0.428	4.218	<0.0001
	peri	0.318	2.98	<0.005
	leu_stden	-0.160	-1.44	0.1528
	prop_pre	-0.431	-4.24	<0.0001
	sim_ind	0.424	4.16	<0.0001
	cano_cl	-0.778	-10.99	<0.0001

Table 4.5 Model selection results of predicting Simpson index (sim_ind) as dependent against soil moisture content (smc), *Leucaena* stem density (leu_stden), soil pH (soil_ph) and Pielou's J′ evenness (j_even) as responsive variables using generalized linear models (Gaussian family). Models are ranked by AICc differences because AICc is an estimator of the relative quality of statistical models for a given collection of models (dAICc). K: number of parameters, W: AICc weight, LL: log-likelihood.

Model combination	Rank	K	LL	AICc	dAICc	w
Sim_ind~ smc + leu_stden	1	4	49.962	-91.9	0.00	0.511
Sim_ind~ smc + soil_ph + leu_stden	2	5	50.601	-91.2	0.72	0.356
Sim_ind~ smc + soil_ph + j_even + leu_stden	3	6	50.620	-89.2	2.68	0.133

Table 4.6 Model selection results of predicting *Leucaena* stem density (leu_stden) as dependent against soil pH (soil_ph), *Leucaena* propagule pressure (prop_pre), Pielou's J′ evenness (j_even) and Simpsons index (sim_ind) as responsive variables using generalized linear models (Gaussian family). Models are ranked by AICc differences but, the parsimonious model (bolded) was selected by the comparison of 'goodness of fit', according to the assumptions of generalized linear regression. (dAICc). K: number of parameters, W: AICc weight, LL: log-likelihood

Model combination	Rank	K	LL	AICc	dAICc	w
leu_stden~ soil_ph	1	3	-591.276	8	0	0.644
leu_stden ~ soil_ph+ prop_pre	2	4	-581.689	10	2	0.237
leu_stden~ soil_ph+ prop_pre+ sim_ind	**3**	**5**	**-576.214**	**12**	**4**	**0.087**
leu_stden~ soil_ph+ prop_pre+ j_even+ sim_ind	4	6	-573.520	14	6	0.032

Table 4.7 Model selection results of predicting *Leucaena* propagule pressure (prop_pre) as dependent against soil moisture content (smc), soil pH (soil_ph), canopy closed % (cano_cl), species richness (sp_rich), Pielou's J′ evenness (j_even), *Leucaena* stem density (leu_stden) and Simpsons index (sim_ind) as responsive variables using generalized linear models (Gaussian family). Models are ranked by AICc differences but, the parsimonious model (bolded) was selected by the comparison of 'goodness of fit', according to the assumptions of generalized linear regression. (dAICc). K: number of parameters, W: AICc weight, LL: log-likelihood.

Model	**Rank**	**K**	**LL**	**AICc**	**dAICc**	**w**
prop_pre~ smc+ soil_ph+ cano_cl+ sp_rich+ j_even+ leu_stden+ sim_ind	1	8	-149.523	315.0	0.00	0.546
prop_pre~ soil_ph+ cano_cl+ sp_rich+ j_even+ leu_stden+ sim_ind	2	7	-150.730	315.5	0.41	0.444
prop_pre~ cano_cl+ sp_rich+ j_even+ leu_stden+ sim_ind	3	6	-155.573	323.1	8.10	0.010
prop_pre~ soil_ph+ smc+ sim_ind	4	4	-185.053	378.1	63.06	0.000
prop_pre~ soil_ph+ sp_rich+ j_even	5	4	-206.617	421.2	106.19	0.000
prop_pre~ soil_ph+ smc	**6**	**3**	**-278.934**	**563.9**	**248.82**	**0.000**

Table 4.8 Model selection results of predicting other species (non- *Leucaena)* stem density (m^2ha^{-1}) abbreviated as (osp_stden), dependent against soil moisture content(smc), soil pH (soil_ph), Pielou's J′ evenness (j_even), *Leucaena* stem density (leu_stden), area and Simpsons index (sim_ind) as responsive variables using generalized linear models (Gaussian family). Models are ranked by AICc differences (dAICc). K: number of parameters, W: AICc weight, LL: log-likelihood but, the best model (bolded) was selected by the comparison of random distribution of residuals against fitted values.

Model	**Rank**	**K**	**LL**	**AICc**	**dAICc**	**w**
osp_stden~ smc+ soil_ph+ prop_pre+ j_even+ sim_ind+ area	1	8	-498.56	1017.0	0.0	0.529
osp_stden~ smc+ soil_ph+ prop_pre+ sim_ind+ area	2	7	-500.51	1018.0	0.9	0.330
osp_stden~ soil_ph+ prop_pre+ sim_ind+ area	3	6	-503.46	1021.1	4.1	0.069
osp_stden~ soil_ph+ sim_ind+ area	4	5	-505.17	1021.9	4.8	0.047
osp_stden~ soil_ph+ area	5	4	-507.09	1023.2	6.1	0.024
osp_stden~ smc+soil_ph	**6**	**4**	**-513.78**	**1036.5**	**19.5**	**<0.001**
osp_stden~ area	7	3	-515.01	1036.6	19.6	<0.001
osp_stden~ smc+soil_ph+leu_stden	8	5	-512.56	1036.6	19.6	<0.001
osp_stden~ soil_ph	9	3	-516.66	1039.9	22.9	<0.001

Table 4.9 Summary of selected models according to the random line transect data. *Leucaena* propagule pressure (prop_pre), *Luecaena* stem density (leu_stden), other species (non- *Leucaena*) stem density (osp_stden) and Simpsons diversity index (sim_ind) as dependents and smc: soil moisture content %, soil pH: soil_ph. Coefficients and estimates (β) for all final models used to predict these variables. SD: standard deviation, Min: minimal value measured, Max: maximum value measured, n: sample size, SE: standard error.

Dependent	n	mean±SD	Min	Max	Coefficients	Estimate	SE	*t* value	*p*-value
prop_pre (count)	9	6.78±6.4	0	20.00	**(Intercept)**	-5.051	0.769	-6.568	< 0.000
					soil_ph	0.909	0.107	8..477	< 0.000
					smc	0.940	0.009	9.542	< 0.000
Leu_stden (m^2ha^{-1})	9	665.2±494.3	0	1741.40	**(Intercept)**	-4608.09	-729.02	-6.321	< 0.000
					soil_ph	521.35	77.64	6.715	< 0.000
					sim_ind	2062.65	617.87	3.338	< 0.001
					Prop_pre	81.07	16.59	4.885	< 0.000
osp_stden (m^2ha^{-1})	9	253.8±155.5	0	474.1	**(Intercept)**	915.784	224.397	4.081	< 0.000
					smc	-11.292	4.708	-2.399	<0.01
					Soil_ph	-87.803	33.150	-2.649	<0.001
sim_ind (Index)	9	0.5244±0.1	0.17	0.76	**(Intercept)**	0.7091	0.2803	25.297	< 0.000
					smc	-0.0189	0.0043	-4.386	< 0.000
					leu_stden	-0.0015	0.0000	-4.878	< 0.000

Table 4.10 Pearson's Chi-squared test results between categorical and numerical variables of the random transect. *Leucaena* presence or absence: leu_yes_no, non-*Leucaena* species presence or absence: nonleu_yes_no, soil moisture content %: smc, Simpson's diversity index: sim_ind, canopy closed or opened: cano_c_o.

Variable combination	X^2	***df***	***p*-value**
leu_yes_no ~ smc	78.856	71	0.2445
leu_yes_no ~ sim_ind	14.294	8	0.0744
nonleu_yes_no ~ sim_ind	11.571	8	0.1714
leu_yes_no ~ cano_c_o	3.5524	1	0.0594
leu_yes_no ~ nonleu_yes_no	11.648	1	<0.000

4.1.9 Rank abundance curves

High abundance proportion displayed by *Leucaena* (60%) and followed by *Sindora siamensis* (10%), *Combretum quadrangulare* (5%) and other 3 species (*Olax psittacorum, Bridelia glauca* and *Diospyros rhodocalyx*) against other species among fragments, indicated by the steep gradient but in the context of other species exclude *Leucaena*, gradual distribution of richness and evenness expressed in moderate gradient (Figure 4.6).

4.1.10 Cluster diagram of dissimilarity

Relatively highest dissimilarity reported by fragment B and lowest by 4 fragments (C & D and E& I) pair wisely clustered and unable to find any relationship between species abundance and *Leucaena* stem diversity % of each fragment.

Table 4.11 Comparison of *Leucaena* stem density % (brackets) and Sorenson similarity indexes (β diversity) between seedlings, saplings and trees (1st, 2nd and 3rd lines of each raw) of the 9 fragments (A to I) as the equation of (A+B-2*J)/ (A+B), where A, B = no. of species in site A and B and J= no. of shared species. Values > 0.6 are bolded.

	A (0.00)	B (39.05)	C (43.01)	D (88.46)	E (98.43)	F (100.00)	G (70.49)	H (67.73)
B (39.05)	**0.67**							
	1.00							
	1.00							
C (43.01)	**0.87**	**0.78**						
	0.67	0.50						
	1.00	**1.00**						
D (88.46)	**0.60**	0.57	**0.64**					
	0.60	**0.71**	0.43					
	1.00	**1.00**	**1.00**					
E (98.43)	0.53	**0.64**	**0.75**	**0.69**				
	1.00	**0.60**	**0.60**	0.50				
	1.00	**1.00**	**1.00**	0.33				
F (100.00)	**0.68**	**0.69**	**0.60**	**0.60**	**0.67**			
	1.00	**0.60**	**0.60**	0.50	0.00			
	1.00	**1.00**	**1.00**	**0.00**	**0.33**			
G (70.49)	0.56	0.50	**0.78**	0.43	0.45	**0.69**		
	1.00	**0.78**	**0.78**	0.50	**0.67**	**0.67**		
	1.00	**1.00**	**1.00**	0.33	0.50	0.33		
H (67.73)	0.50	0.43	**0.82**	**0.63**	**0.69**	**0.73**	0.57	
	1.00	0.56	0.56	**0.75**	**0.66**	**0.66**	**0.80**	
	1.00	**1.00**	**1.00**	0.50	**0.60**	0.50	**0.60**	
I (72.61)	**0.75**	**0.60**	0.43	0.50	**0.78**	0.45	**0.60**	**0.67**
	1.00	**0.67**	**0.67**	**0.60**	0.33	0.33	**0.71**	**0.71**
	1.00	**1.00**	**1.00**	0.00	0.33	0.00	0.33	0.50

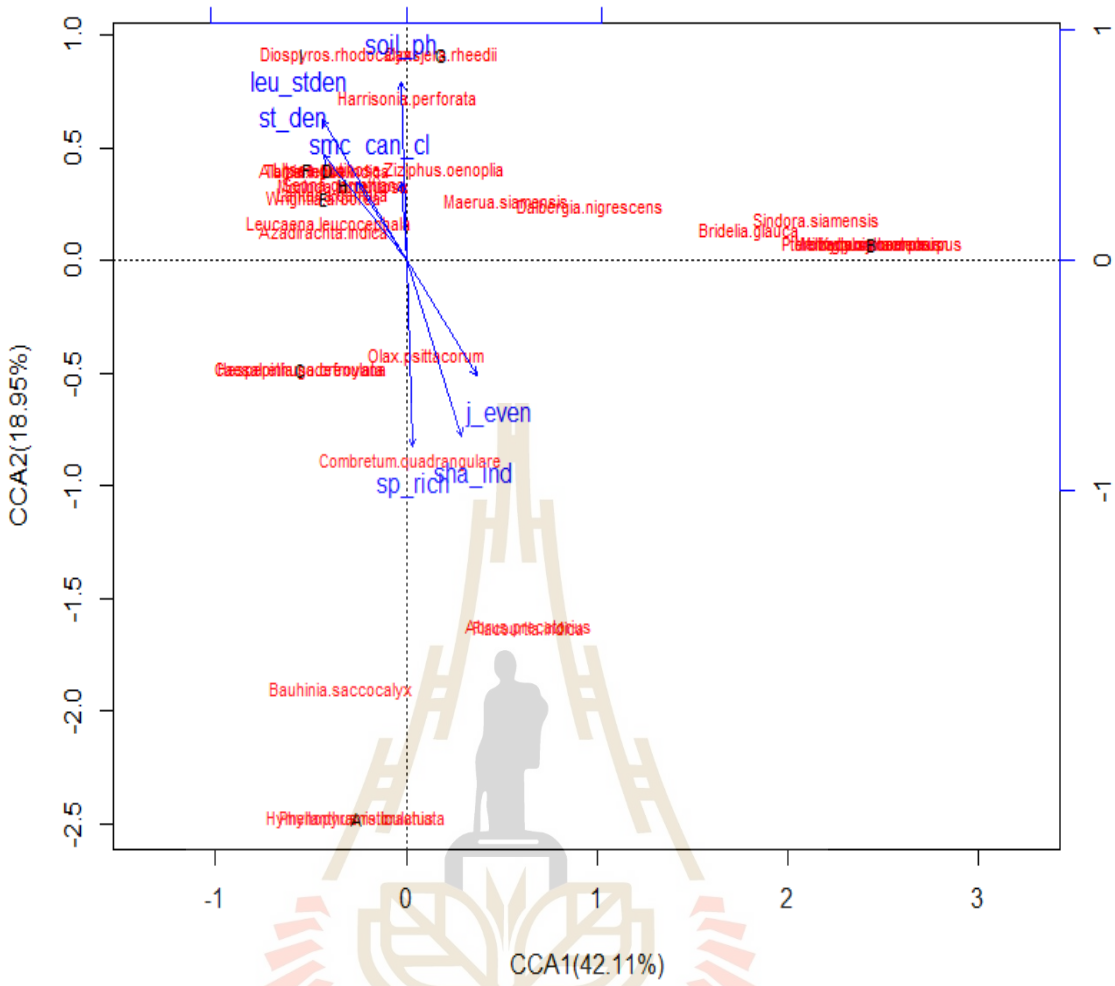

Figure 4.4 CCA biplot showing species distribution along environmental (canopy closed %: can_cl, soil moisture content: smc and soil pH: soil_ph), and biotic (species richness: sp_rich, Pielou's J' evenness: j_even, *Leucaena* stem density: leu_stden, total stem density: st_den and Shanon index: sha_ind) gradients among 9 fragments. The first axis alone explained 42.11% of total unexplained variance. (Taken together, the first and second axes of the data set explained 61% of total variance).

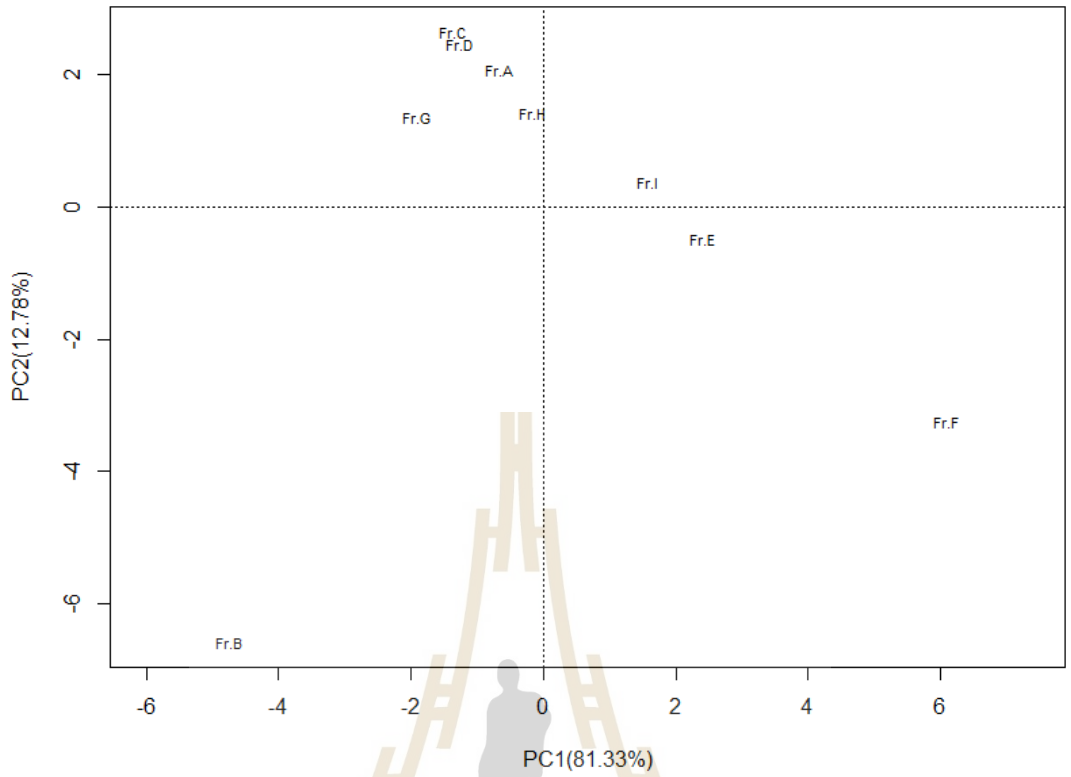

Figure 4.5 Principal components analysis (PCA) bi plot showing relative positions of the fragments (Fra. A to I) related to Euclidian distances of species abundance. First and second axis explained 81.33% and 12.78% of total variance (710.6).

4.1.11 *Leucaena* abundance variability from edge to core area of the Fragments

According to Kruskal-Wallis one-way analysis of variance results, *Leucaena* abundance was not significant from the edge to core, either in north (W= 5.1483, df= 4, p= 0.2724) or south direction (W= 4.0475, df= 4, p= 0.3996) of the line transects (see Figure 4.9 for details).

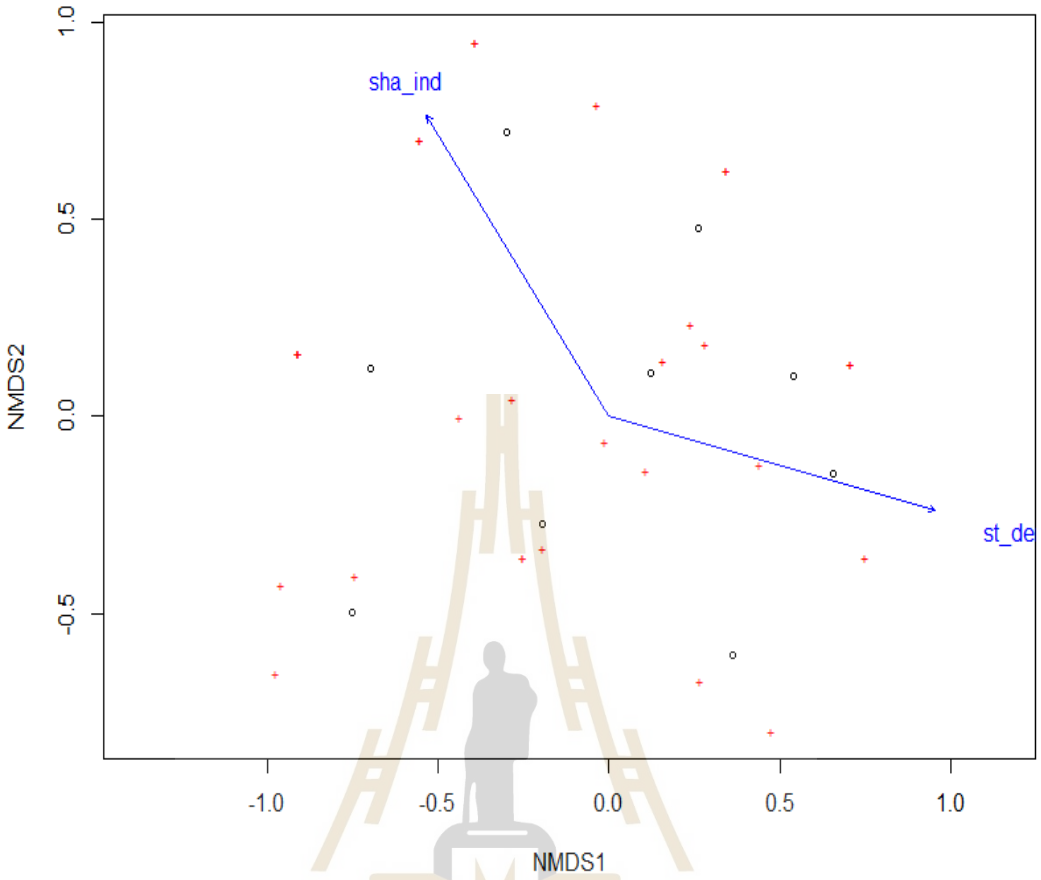

Figure 4.6 Nonmetric Multidimensional Scaling (NMDS) output of species abundance against environmental variables in 1000 permutations (*p*= <0.05)**.** Shannon index (sha_ind) and total stem density (st_den) in blue, species in red crosses and fragments in blue circles.

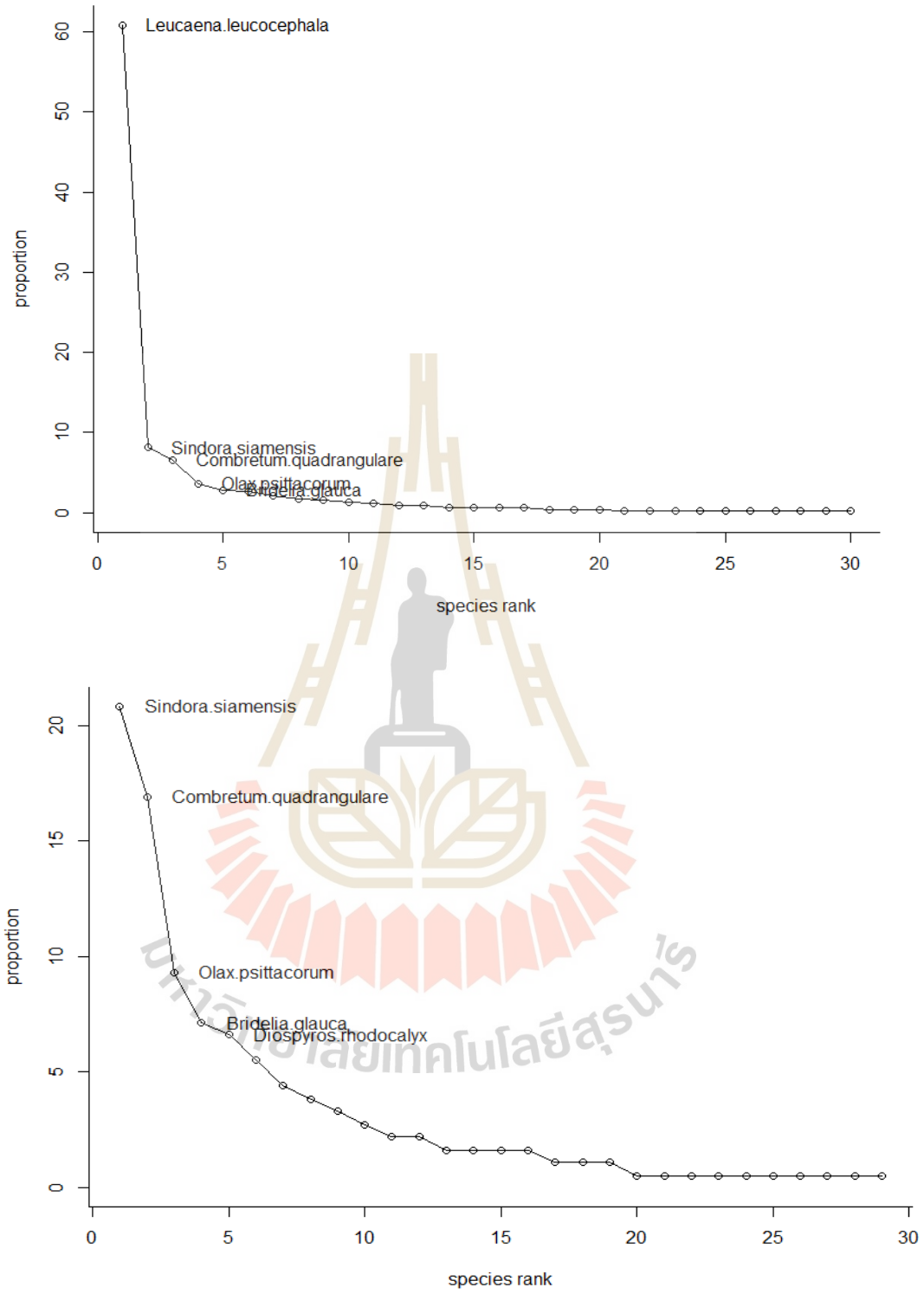

Figure 4.7 Rank abundance curve of the fragments with *Leucaena* (above) and without (below) shown species abundance and evenness, species rank (total no of species) in x and proportion (species abundance / total abundance) in y axis.

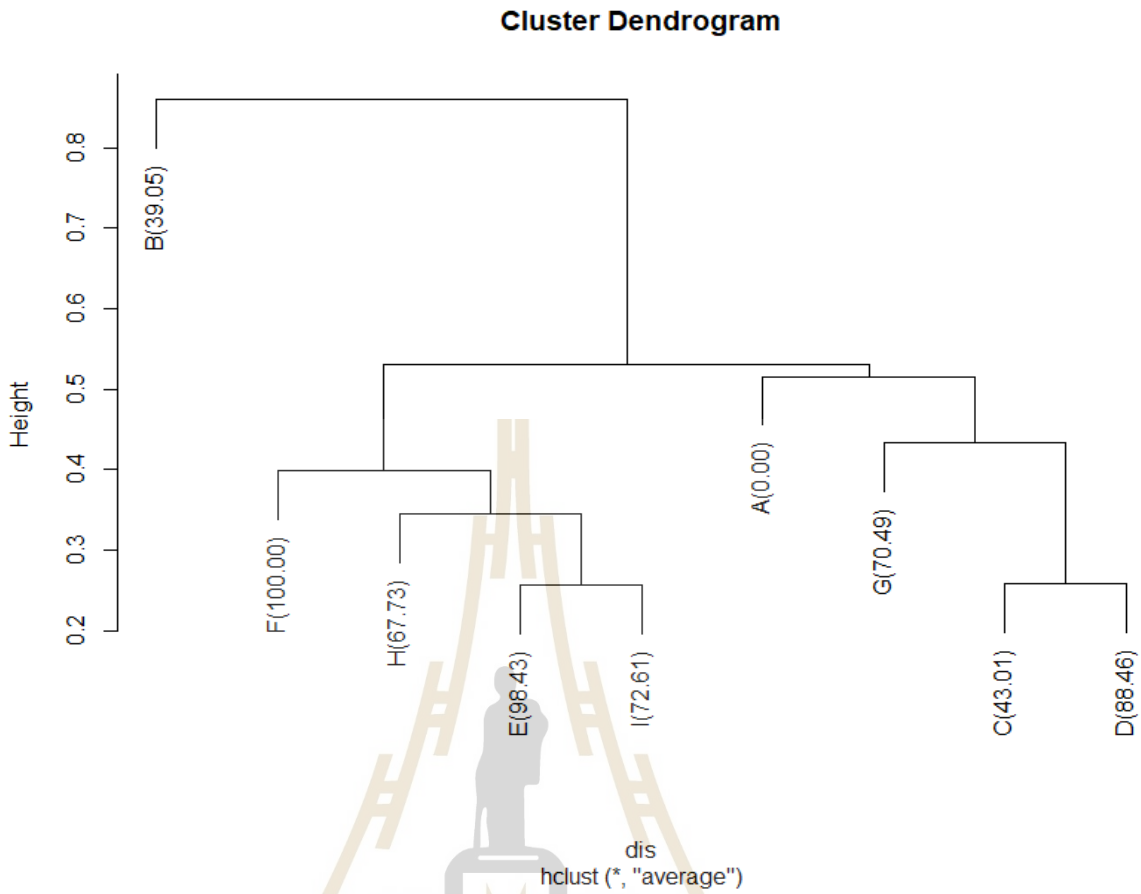

Figure 4.8 Cluster diagram of dissimilarity between species abundance of 9 fragments based on Ward's average distance method (Oksanen, 2015). Correlation between dissimilarities and similarities = 0.92 and, *Leucaena* stem density of each fragment is displayed in brackets.

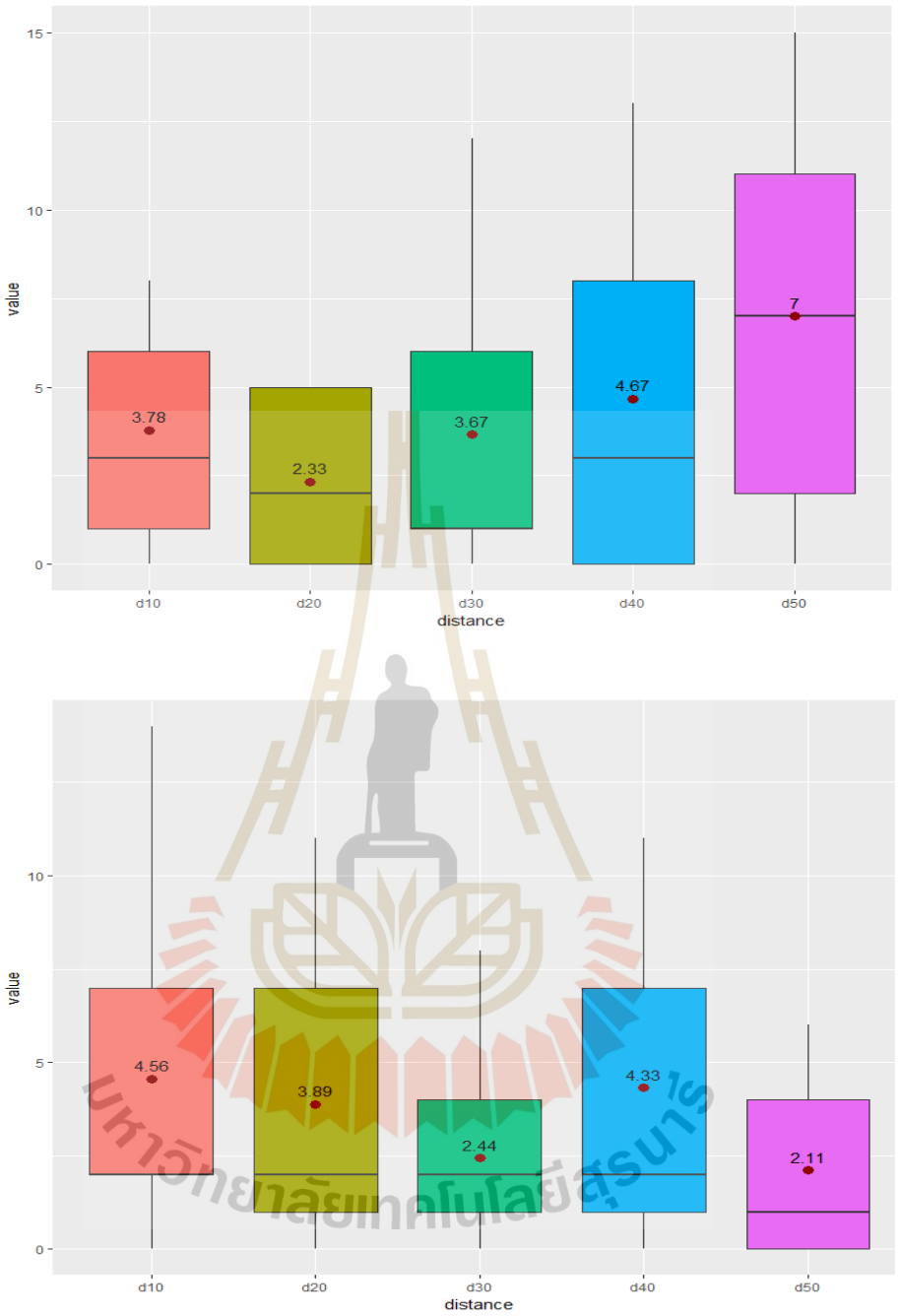

Figure 4.9 Box plots of *Leucaena* distribution from south end (above) and north end (below) to the core area of the line transects at five10 m intervals based on abundance, x axis for distance (10 to 50 m) and y axis for abundance (including trees, saplings and seedlings at p= 0.05) to test the significant of *Leucaena* distribution from edge to core area of the fragments.

4.2 Discussions

Clear evidences for the rational correlation between size and shape (shape index) of the fragments with species diversity was not found due to weak correlation with Simpson's diversity index (Table 4.4) thus, fail to fit any model with diversity related dependent (Simspon's diversity index or other species stem density) or NMDS and CCA ordinations as well. Extent of the fragments are relatively small (varies between 2.4 to 36.97 but 5 of them were under 10 ha) and still being used for anthropogenic activities such as dumping site. Since SUT initiation in 1990, already deforested landscapes due to agricultural activities had been left alone (I observed ruins of paddy field inside the fragment C and abandoned shelters in fragment H) and diversity and dominance measures are unrelated to small (<5 ha) fragment size and perimeter (Tripathi and Reynald, 2010) as well as short-term durations (Munguia-Rosas and Montiel, 2014). In small fragments, the most important driving force of species composition is thought to be light intensity (Wicklein *et al*., 2012).

Modeling results of diversity variables (other species density and Simpson's diversity index) as dependent (see Table 4.9), PCA results of plot positioning (explaining 81.33% of total variance) based on species abundance (Figure 4.5) provided clear evidence to diversity inequity among fragments as per my 1st hypothesis but, diversity cannot be sufficiently explained by using only a single component (Nagendra, 2002) and, Sorenson similarity index between fragments for trees, saplings and seedlings indicates closer relationship among fragments (Tripathi and Reynald, 2010) as 87.5% of combinations of >0.60 similarity (Table 4.10 and chapter 4.1.7) argues nearly equal diversity among fragments.

GLM modeling outputs with *Leucaena* stem density and propagule pressure as dependents (Table 4.8) provide clear evidence of uneven distribution within fragments according to my 2nd hypothesis and model output of native species proportion (defined as other species stem density) as dependent (Table 4.9) in accordance with 3rd hypothesis of unequal distribution but, moderate distribution of richness and evenness of the native species (Figure 4.7; right) in rank abundance curve provided negative argument as well. Lack of seed dispersal (Holl, 1999) and light is considered as the important limiting factors of species composition in small fragments (Wicklein *et al*., 2012) and relatively small sizes and close proximity (maximum distance between fragments is less than 200 m, see Figure 3.1 and Table 3.1)

My results are related to both positive and negative arguments on my 4th hypothesis based on the relationship of *Leucaena* in natural species composition. According to GLM combinations of linear relationship between diversity variables against *Leucaena* stem density and propagule pressure as dependents, *Leucaena* stem density expressed positive linear correlation with Simpson's diversity index as well as with no correlation to propagule pressure (Table 4.9) and also the cluster diagram based on the dissimilarities among species abundance made a clear expression of less correlation of *Leucaena* stem density to the natural species diversity (Figure 4.9). Non metric modeling results between species abundance and diversity variables (Figure 4.6), Shannon index was negatively correlated only with total stem density other than *Leucaena* and, strengthen negative arguments for hypothesis.

Pearson's Chi-squared test results expressed significant effect of presence of *Leucaena* on native species existence (Table 4.10) and rank abundance curve of the

fragments (Graph 4.7; left) shown high proportion and abundance of *Leucaena* alongside native species in accordance to my hypothesis.

Remnants of SUT believed to be a result of reverse fragmentation process (Castillo, 2015). By the comparing 3 fragments satellite images in 8 years gap (Figure 4.10) and early photographs of SUT (Figure 1.1) fair evidence of gradual restoration of bare landscape is visible.

If *Leucaena* was dispersed into the already established forest with succession, significant abundance should be detected at edges instead of interior (Tabarelli *et al*., 2010) but even distribution in SUT fragments (Figure 4.9), suggests otherwise. Legumes have great potential to dominate in severely disturbed soils (Gao *et al*., 2017) and, represented 74.88% of total taxa also agreed with the argument.

As one of the fast growing exotic, *Leucaena* can survive in dry and poor soils (Kuo, 2003), compete with natives but has capability of bulky biomass accumulation (Kamo *et al*., 2002) and nitrogen fixation (Calle *et al*., 2014). Most of the fragments of SUT have been used as dumping sites of construction residuals such as earth removals and concrete related emits (based on my personal field observations) since initial stage of SUT establishment thus native species might lack the potential to properly establish without soil reclamation (Sheoran *et al*., 2010).

Leuceana is also negatively influenced by the growth of vegetation within its stand and is also a light demanding pioneer (Valiente, 2010). Rational reason for zero *Leucaena* stem density of fragment A (Table 4.3) is given by the satellite image from 2007 (Figure 4.10 and 4.11) as it was already dominated by native species (*Sindora siamensis*).

Soil pH values of fragments were between 6.31± 0.36 and 7.33± 0.15, compatible with ambient values (4.8 to 6.0) of tropical forests (Benstead and King, 2001) and positively correlated with *Leucaena* and native species stem density and propagule pressure, meaning that presence of *Leucaena* indirectly enhanced native species diversity as well.

Negative relationship of soil moisture content with both the Simpsons diversity index and non-*Leucaena* stem density could be the result of a lack of aeration, because of the soil compaction due to earth dumping thus native plants unable to compete (Loehwing, 1934; Torbertand and Wood, 1992; Yoshida and Oka, 2006) with relatively higher tolerance of *Leucaena* to degraded dry landscapes (Peter *et al*., 2003) and extreme seasonal climates (Yige *et al*., 2012).

Even though relatively small in extent (total as, 102.2 ha), 50 species were recorded within from SUT fragments (in quadrat samples) and, higher proportions of Sorensen's index meant the healthiness of dynamic succession among fragments (Ricotta, 2017; McKnight *et al*., 2007) therefore, conservation and restoration of small patches is necessary to preserve the plant diversity. Despite the size, enables to confine diverse communities of native plants, including endangered and economically important species (Arroyo *et al*., *2008*) with providing gene flow to the high genetic sapling diversity (Ganzhorn *et al*., 2015).

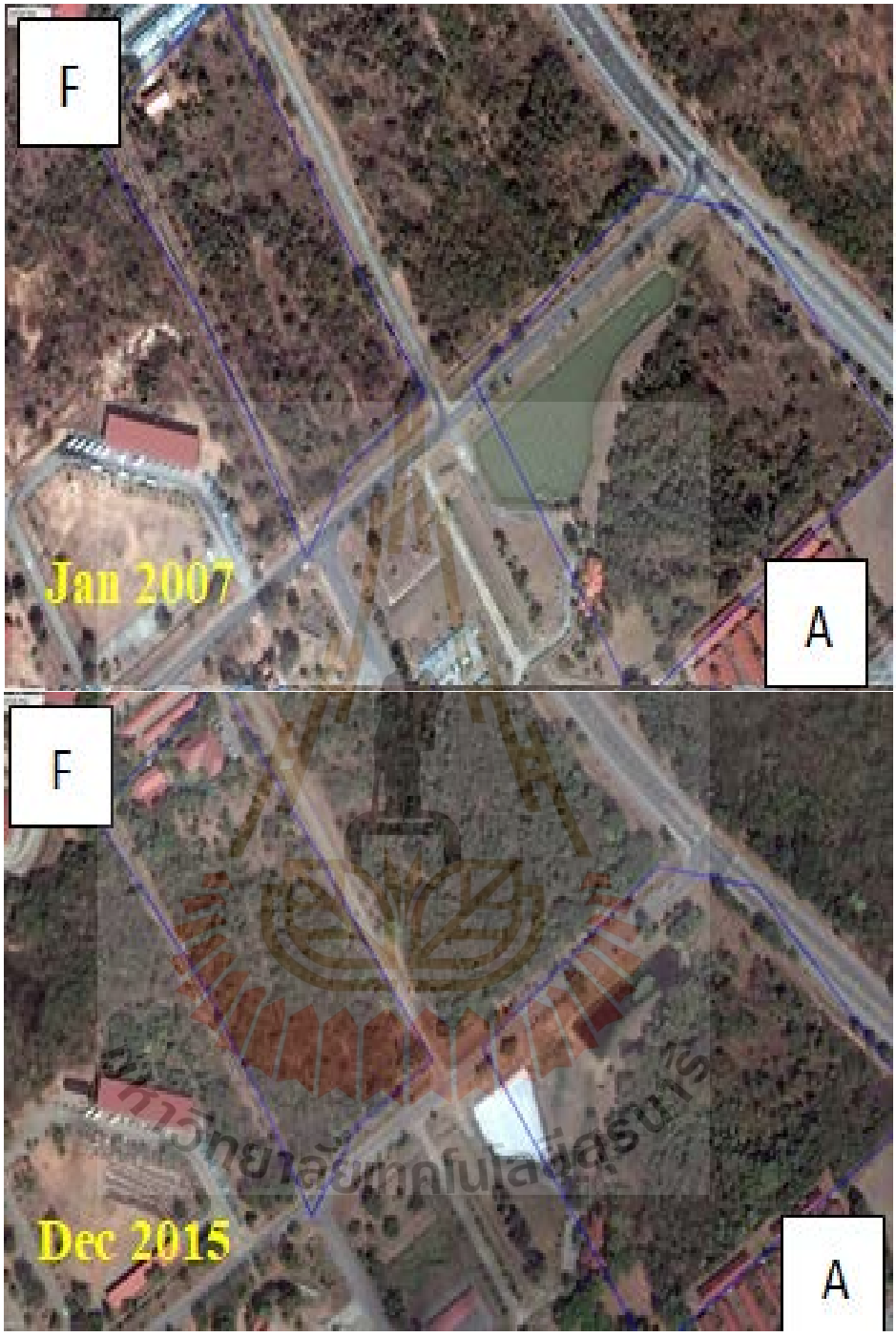

Figure 4.10 Google map imageries of fragment A and F (blue outline) in 1st January 2007 and 30th December 2015 showing vegetation diversity and distribution (Source: Google Earth Pro).

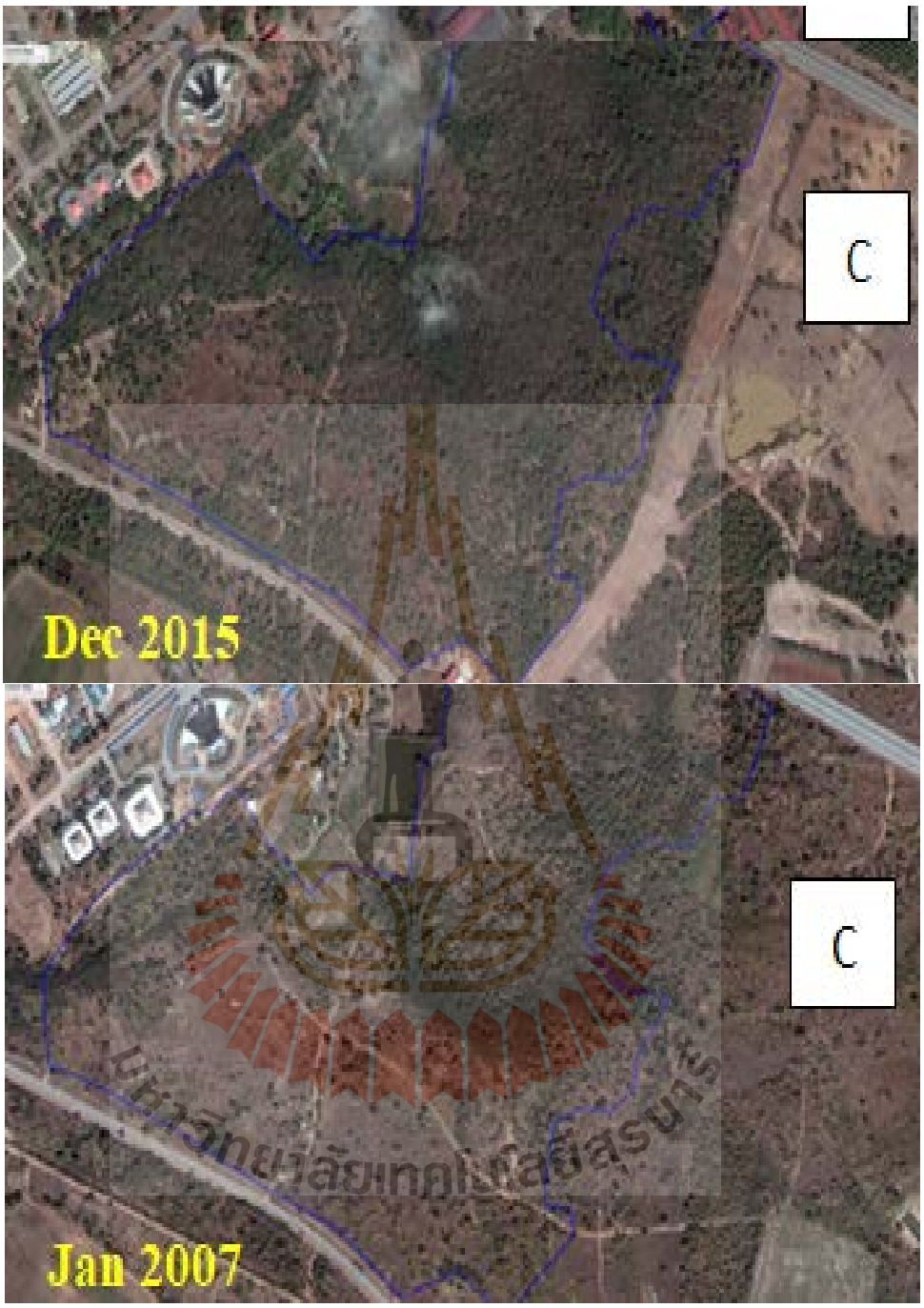

Figure 4.11 Google map imageries of fragment C (blue outline) in 1st January 2007 and 30th December 2015 showing vegetation diversity and distribution (Source: Google Earth Pro).

CHAPTER VI

CONCLUSIONS

In this research study, I found that fragment size or shape did not significantly affect to the species diversity. According to previous studies, proximity of the fragment (Ramos and Santos, 2006), light intensity (Wicklein *et al*., 2012), area (Pinto *et al*., 2010) and malfunction of seed dispersal (Holl, 1999) are the major factors of species diversity regulation. Fragments are relatively small in size and located as a matrix with close to each other thus with minimum effort.

Leucaena and native species proportion was variably distributed between SUT fragments. Local species composition was determined by the top soil morphology, pH value and gravimetric water content (Paluch and Gruba, 2012). Soil properties of each fragment were related to the type and amount of dumping material and fragments distance to the water bodies regulated gravimetric water content.

Native species composition was affected by *Leucaena*. Most of the fragments were dominated by *Leucaena* populations because in highly disturbed bare soils, natives unable to compete but, allowed to secondary succession of natural species providing higher rates of nitrogen, phosphorus and soil carbon (Kuo, 2003).

Forested landscapes of SUT can be identified as urban forest fragments (Alvey, 2006) and total 69 woody species were identified via my study. Comparison with Sakaerat dry evergreen forest (total of 114 including herbs; Kamo *et al*., 2002), ecological importance prior to conservation perceptions is emphasized. In

management point of view, minimizing anthropogenic activities (such as waste dumping, timber removals etc.) would be adequate because secondary succession of the native plant communities passively in progress. To quantify the level of *Leucaena* effect with the time, necessary to repeat my study in at least 10 years and might be helpful to making more reliable decisions in biodiversity conservation of highly modified urban landscapes from an academic perspective, SUT fragments could be used as ideal location for conservation biology related studies.

REFERENCES

REFERENCES

Achard, F., Eva, H. D., Stibig, H. J., Mayaux, P., Gallego, J., Richards, T. and Malingreau, J. P. (2002). Determination of deforestation rates of the world's humid tropical forests. **Science**. 297: 999–1002.

Agresti, A. and Kateri, M. (2014). Categorical Data Analysis. **International Encyclopedia of Statistical Science**: 206–208.

Aizen, M. A. and Feinsinger, P. (1994). Forest fragmentation, pollination, and plant reproduction in a Chaco dry forest Argentina. **Ecology**. 75(2): 330–351.

Akaike, H. (1974). A new look at the statistical model identification. **IEEE Trans. Automat**. **Contr**. 19: 716–723.

Alele, P. O., Sheil, D., Surget-Groba, Y., Lingling, S. and Cannon, C. H. (2014). How does conversion of natural tropical rainforest ecosystems affect soil bacterial and fungal communities in the Nile river watershed of Uganda. **PLoS ONE**. 9(8): e104818. doi:10.1371/journal.pone.0104818.

Alvey, A. A. (2006). Promoting and preserving biodiversity in the urban forest. **Urban Forestry & Urban Greening**. 5: 195–201.

Ande, O. T. and Senjobi, B. A. (2014). Comparison of soil quality improvement under different fallow types on dystric nitosols derived from sand stone in south western Nigeria. **Agricultural Sciences**. 5: 1061–1068.

Anselin, L. (2002). Under the hood: issues in the specification and interpretation of spatial regression models. **Agricultural Economy**. 17: 247–267.

Arroyo, V., Pineda, E., Escobar, F. and Malvido, J. B. (2008). Value of Small Patches in the Conservation of Plant-Species Diversity in Highly Fragmented Rainforest. **Conservation Biology**. 23(3): 729–739.

Atkinson, E. E. and Marín-Spiotta, E. (2015). Land use legacy effects on structure and composition of subtropical dry forests in St. Croix, U.S. Virgin Islands. **Forest Ecology and Management**. 335: 270–280.

Bach, C. E. and Kelly, D. (2004). Effects of forest edges on herbivory in a New Zealand mistletoe, Alepis flavida. **New Zealand Journal of Ecology**. 28(2): 195–205.

Báldi, A. (1999). Microclimate and vegetation edge effects in a reedbed in Hungary. **Biodiversity and Conservation**. 8: 1697–1706.

Benitez-Malvido, J. (1998). Impact of forest fragmentation on seedling abundance in tropical rain forest. **Conservation Biology**. 12(2): 380–389.

Benstead, J. and King, G. M. (2001). The effect of soil acidification on atmospheric methane uptake by a maine forest soil. **FEMS Microbiology Ecology**. 34: 207–212.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. M. and White, J. S. S. (2009). Generalized linear mixed models: A practical guide for ecology and evolution. (Revision). **Trends in Ecology and Evolution**. 24(3): 127–135.

Boutin, S. and Hebert, D. (2002). Landscape ecology and forest management: developing of an effective partnership. **Ecological Applications**. 12: 390–397.

Braak, C. J. F and Verdonschot, P. E. M. (1995). Canonical correspondence analysis and related multivariate methods in aquatic ecology. **Aquatic Sciences**. 57(3): 255–289.

Braak, C. J. F. T. (1986). Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. **Ecology**. 67(5): 1167–1179.

Burkey, T. V. (1994). Tropical tree species diversity: A test of the Janzen-Connell model. **Oecologia**. 97: 533–540.

Calle, A., Calle, Z., Garen, E., and A. Del Cid-Liccardi, eds. (2014). **Symposium on Ecological Restoration and Sustainable Agricultural Landscapes**. Environmental Leadership and Training Initiative. New Haven, CT: Yale University; Panama City: Smithsonian Tropical Research Institute: 28–35.

Carlton, J. T. (1996). Pattern, process, and prediction in marine invasion ecology. **Biological Conservation**. 78: 97–106.

Casson, R. J. and Farmer, L. D. M. (2014). Understanding and checking the assumptions of linear regression: a primer for medical researchers. **Clinical and Experimental Ophthalmology**. 42: 590–596.

Castillo, R. F. D. (2015). A conceptual framework to describe the ecology of fragmented landscapes and implications for conservation and management. **Ecological Applications**. 25(6): 1447–1455.

Catford, J., Jansson, R. and Nilsson, C. (2009). Reducing redundancy in invasion ecology by integrating hypotheses into a single theoretical framework. **Diversity and Distributions**. 15(1): 22–40.

Chan, Y. and Walmsley, R. P. (1997). Learning and understanding the Kruskal Wallis one-way analysis-of-variance-by-ranks test for differences among three or more independent groups. **Physical Therapy**. 77: 1755–1762.

Chiou, C. R. and Chen, Y. J. (2016). Predicted range expansion of the invasive plant *Leucaena leucocephala* in the Hengchun peninsula, Taiwan. **Biological Invasions**. 18: 381–394.

Chiou, C. R., Wang, H. H., Chen, Y. J., Grant, W. E. and Lu, M. L. (2013). Modeling potential range expansion of the invasive shrub *Leucaena leucocephala* in the Hengchun peninsula, Taiwan. **Invasive Plant Science and Management**. 6(4): 492–501.

Chou, C. H. and Kuo, Y. L. (1986). Allelopathic research of subtropical vegetation in Taiwan III. Allelopathic exclusion of understorey by *Leucaena leucocephala* (Lam.) de Wit. **Journal of Chemical Ecology**. 12: 1431–1448.

Climate of Thailand (1981-2010). [Online]. Available: https://www.tmd.go.th. Accessed date: August 15, 2017.

Cobbina, J., Kang, B. T. and Atta-krah, A. N. (1989). Effect of soil fertility on early growth of Leucaena and Gliricidia in alley farms. **Agroforestry Systems**.8: 157–164.

Colautti, R. I., Grigorovich, I. A. and Macisaac, H. J. (2006). Propagule pressure: a null model for biological invasions. **Biological Invasions**. 8: 1023–1037.

Cronk, Q. C. B. and Fuller, J. L. (2001). **Plant Invaders: The Threat to Natural Ecosystems**. Island Press. Washington DC. 241: 1431–1448.

Cuke, M. and Srivastava, D. S. (2016). Divergent effects of tropical forest fragmentation and conversion on leaf litter decomposition. **Landscape Ecology**. 31: 1037–1050.

Cumming, G. S., Southworth, J., Rondon, X. J. and Marsik, M. (2012). Spatial complexity in fragmenting Amazonian rainforests: Do feedbacks from edge effects push forests towards an ecological threshold? **Ecological Complexity**. 11: 67–74.

Davies-Colley, R. J., Paynel, G. W. and van Elswijk, M. (2000). Microclimate gradients across a forest edge. **New Zealand Journal of Ecology**. 24(2): 111–121.

De'Ath, G. (2007). Boosted trees for ecological modeling and prediction. **Ecology**. 88(1): 243–251.

Denslow, J. S. and Hughes, R. F. (2004). Exotic plants as ecosystem dominants. **Weed Technology**. 18: 1283–1287.

Didham, R. (1998) Altered leaf-litter decomposition rates in tropical forest fragments. **Oecologia**. 116: 397–406.

Diserud, O. H. and Odegaard, F. (2007). A multiple-site similarity measure. **Biology Letters**. 3: 20–22.

Drinnan, I. N. (2005). The search for fragmentation thresholds in a southern Sydney suburb. **Biological Conservation**. 124: 339–349.

Echeverría, C., Newton, A. C., Lara, A., María, J., Benayas, R. and Coomes, D. A. (2007). Impacts of forest fragmentation on species composition and forest structure in the temperate landscape of southern Chile. **Global Ecology and Biogeography**. 16: 426–439.

Elledge, A. and Barlow, B. (2012). Basal area: A measure made for management. **Alabama Cooperative Extension System**. 1371: 1–5.

Emlen, J. T. (1967). A rapid method for estimating arboreal canopy cover. **Ecology**. 48(1): 158–160.

ESRI. (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Ewers, R. M. and Didham, R. K. (2006). Confounding factors in the detection of species responses to habitat fragmentation. **Biological Revision**. 81: 117–142.

FAO, (Food and Agriculture Organization of the United Nations). (2010). FAOSTAT.Statistical database of FAO, Rome. [Online]. Available: http://faostat.fao.org/default.aspx. Accessed date: May 26, 2016.

Flora of Suranaree University of Technology Campus. (2001). [Online]. Available: http://flora.sut.ac.th/. Accessed date: January 19, 2016.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N. and Snyder, P. K. (2005) Global consequences of land use. **Science**. 309: 570–574.

Fox, J., Krummel, J., Yarnasarn, S., Ekasingh, M. and Podger, N. (1995). Land use and landscape dynamics in northern Thailand: assessing change in three upland watersheds. **Ambio**. 24: 328–334.

Fox, V. L., Charlotte P., Buehler, C. P., Byers, C. M. and Drake, S. E. (2010). Forest composition, leaf litter, and songbird communities in oak vs. maple dominated forests in the eastern United States. **Forest Ecology and Management**. 259(12): 2426–2432.

Ganzhorn, S. M., Sweeney, B. P., Thomas, W. W., Gaiotto, F. A. and Lewis, J. D. (2015). Effects of fragmentation on density and population genetics of a threatened tree species in a biodiversity hotspot. **Endangered Species Research**. 26: 189–199.

Gao, D., Wang, X., Fu, S. and Zhao, J. (2017). Legume plants enhance the resistance of soil to ecosystem disturbance. **Frontiers in Plant Science**. 8: 1295. doi: 10.3389/fpls.2017.01295.

Garcia-Guzman, G. and Benitez-Malvidot, J. (2003). Effect of litter on the incidence of leaf-fungal pathogens and herbivory in seedlings of the tropical tree Nectandra ambigens. **Journal of Tropical Ecology**. 19: 171–177.

Global Invasive Species Database (2017) Species profile: *Leucaena leucocephala*. [Online]. Available: http://www.iucngisd.org/gisd/species.php?sc=23. Accessed date: December 5, 2016.

Godefroid, S. and Koedam, N. (2003). Distribution pattern of the flora in a peri-urban forest: an effect of the city-forest ecotone. **Landscape and Urban Planning**. 65: 169–185.

Google Maps. (2017). [Online]. Available: http:// www.google.com/maps/@14.8713385. Accessed date: December 5, 2016.

Green, S. B. (1991): How many subjects does it take to do a regression analysis? **Multivariate Behavioral Research**. 26(3): 499–510.

Haila, Y. (2002). A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. **Ecological Applications**. 12: 321–334.

Haluwana, N. and Madawala, H. M. P. S. (2013). Changes in plant diversity and composition across forest edges bordered by *Austroeupatorium inulifolium*

invaded grasslands in the Knuckles Conservation Area, Sri Lanka. **Ceylon Journal of Science**. 42(2): 29–43.

Hansena, M. C., Stehmanb, S. V. and Potapova, P. V. (2010). Quantification of global gross forest cover loss. **Proceedings of the National Academy of Sciences**. 107(19): 8650–8655.

Harper, K. A., Macdonald, K. S. E., Burton, P. J., Chen, J., Brosofske, K. D., Saunders, S. C., Euskirchen, E. E. S., Roberts, D., Jaiteh, M. S. and Esseen, P. A. (2005). Edge influence on forest structure and composition in fragmented landscapes. **Conservation Biology**. 19: 768–782.

Hejda, M., Pysek, P. and Jarosík, V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. **Journal of Ecology**. 97: 393–403.

Hobbs, R. and Huenneke, L. F. (1992). Disturbance, diversity and invasion: implications for conservation. **Conservation Biology**. 6: 324–337.

Holl, K. D. (1999). Factors limiting tropical rain forest regeneration in abandoned pasture: seed rain, seed germination, microclimate, and soil. **Biotropica**. 31(2): 229–242.

Honnay, O., Hermy, M. and Coppin, P. (1999). Effects of area, age and diversity of forest patches in Belgium on plant species richness, and implications for conservation and reforestation. **Biological Conservation**. 87(1): 73–84.

Hughes, A. C. (2017). Understanding the drivers of Southeast Asian biodiversity loss. **Ecosphere**. 8(1):e01624. 10. 1002/ecs2.1624.

Hughes, C. E. (1998). Monograph of *Leucaena* (Leguminosae: Mimosoideae). **Monographs in Systematic Botany**. 55: 1–244.

Jennings, S. B., Brown, N. D. and Sheil, D. (1999). Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. **Forestry**. 72(1): 59–74.

Jurasinski, G., Retzer, V. and Beierkuhnlein, C. (2009). Inventory, differentiation, and proportional diversity: a consistent terminology for quantifying species diversity. **Oecologia**. 159: 15–26.

Kamo, K., Vacharangkura, T., Tiyanon, S., Viriyabuncha, C., Nimpila, S. and Doangsrisen, B. (2002). Plant species diversity in tropical planted forests and implication for restoration of forest ecosystem in Sakaerat, Northeastern Thailand. **Japan Agricultural Research Quarterly**. 36(2): 111–118.

Kamo, K., Vacharangkura, T., Tiyanon, S., Viriyabuncha, C., Nimpila, S., Duangsrisen, B., Thaingam, R. and Sakai, M. (2002). Biomass and dry matter production in planted forests and an adjacent secondary forest in the grassland area of Sakaerat, northeastern Thailand. **Tropics**. 17(3): 209–224.

Kindt, R. and Coe, R. (2005). Tree diversity analysis. **A manual and software for common statistical methods for ecological and biodiversity studies**. Nairobi World Agroforestry Centre (ICRAF).

Kindt, R. and Coe, R. (2005). Tree diversity analysis. A manual and software for common statistical methods for ecological and biodiversity studies. Nairobi World Agroforestry Centre (ICRAF).

Kostel-Hughes, F., Young, T. P. and Carreiro, M. M. (1998). Forest leaf litter quantity and seedling occurrence along an urban-rural gradient. **Urban Ecosystems**. 2: 263–271.

Krohne, D. T. (2001). **General Ecology, 2nd Edition**. CA 93950 USA: Brooks/Cole, Thomson Learning inc.

Kruskal, W. H. and Wallis, W. A. (1952). Use of ranks in one-criterion variance analysis. **Journal of the American Statistical Association**. 47(260): 583–621.

Kulmatiski, A. (2006). Exotic plants establish persistent communities. **Plant Ecology**. 187: 261–275.

Kuo, Y. L. (2003). Ecological characteristics of three invasive plants (*Leucaena leucocephala*, *Mikania Micrantha*, and *Stachytarpheta Urticaefolia*) in Southern Taiwan. [Online]. Available: http://wwwagnetorg/library/eb/541. Accessed date: December 5, 2016.

Laikre, L., Schwartz, M. K., Waples, R. S. and Ryman, N. (2010). Compromising genetic diversity in the wild: unmonitored large-scale release of plants and animals. (Review). **Trends in Ecology & Evolution**. 2(9): 520–529.

Lasky, J. R. and Keitt, T. H. (2013). Reserve size and fragmentation alter community assembly, diversity, and dynamics. **American Naturalist**. 182: 142– 160.

Laurance, W. F. (2004). Forest–climate interactions in fragmented tropical landscapes. **Philosophical transactions of the Royal Society of London**. 359: 345–352.

Laurance, W. F. and Yensen, E. (1991). Predicting the impact of edge effects in fragmented habitats. **Biological Conservation.** 55: 77–92.

Laurance, W. F., Ferreira, L. V., Merona, J. M. R. And Laurance, S. J. (1998). Rain forest fragmentation and the dynamics of Amazonian tree communities. **Ecology**. 79(6): 2032–2040.

Laurance, W. F., Nascimento, H. E. M., Laurance, S. G., Andrade, A. and Ewers, R. M. (2007). Habitat fragmentation, variable edge effects, and the landscape-divergence hypothesis. **PloS ONE**. 2(10): https://doi.org/10.1371/journal.pone.0001017.

Laurance, W. F., Nascimento, H. E. M., Laurance, S. G., Andrade, A., Ribeiro, J., Giraldo, J. P., Lovejoy, T. E., Condit, R., Chave, J., Harms, K. E. and D'Angelo, S. (2006a). Rapid decay of tree-community composition in Amazonian forest fragments. **Proceedings of the National Academy of Sciences of the United States of America**. 103: 19010–19014.

Laurance, W. F., Nascimento, H. E. M., Laurance, S. G., Andrade, A. C., Fearnside, P. M., Ribeiro, J. E. L. and Capretz, R. (2006b). Rain forest fragmentation and the proliferation of successional trees. **Ecology**. 87(2): 469–482.

Legendre, P. (1993). Spatial autocorrelation: Trouble or new paradigm? Ecology. **Agricultural & Environmental Science Database**. 74(6): 1659–1673.

Legendre, P. and Fortin, M. J. (1989). Spatial pattern and ecological analysis. **Vegetation**. 80: 107–138.

Leigh, E. G., Wright, S. J., Herre, E. A. and Putz, F. E. (1993). The decline of tree diversity on newly isolated tropical islands: a test of a null hypothesis and some implications. **Evolutionary Ecology**. 7: 76–102.

Lennon, J. J. (2000). Red-shifts and red herrings in geographical ecology. **Ecography**. 23: 101–113.

Lockwood, J. L., Cassey, P. and Blackburn, T. (2005). The role of propagule pressure in explaining species invasions. **Trends in Ecology and Evolution**. 20: 223–228.

Loehle, C. (2004). Challenges of ecological complexity. **Ecological Complexity**. 1: 3–6.

Loehwing, W. F. (1934). Physiological aspects of the effect of continuous soil aeration on plant growth. **Plant Physiology**. 9(3): 567–583.

Lomba, A., Vicente, J., Moreir, F. and Honrado, J. (2011). Effects of multiple factors on plant diversity of forest fragments in intensive farmland of Northern Portugal. **Forest Ecology and Management**. 262(12): 2219–2228.

Lonsdale, W. M. (1999). Global patterns of plant invasions and the concept of invisibility. **Ecology**. 80(5): 1522–1536.

Lopesa, A. V. L., Girãob, L. C., Santosb, B. A., Peresc, C. A. and Tabarellia, M. (2009). Long term erosion of tree reproductive trait diversity in edge-dominated Atlantic forest fragments. **Biological Conservation**. 142(6): 1154–1165.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper, D., Huston, M., Raffaelli, D., Schmid, B., Tilman, D. and Wardle, D. (2001). Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges. **Science** (New York, N.Y.). 294: 804–8.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M. (2000). 100 of the world's worst invasive alien species. A selection from the global invasive species database. published by the invasive species specialist group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN): 12.

Lugo, A. E. and Erickson, H. E. (2017). Novelty and its ecological implications to dry forest functioning and conservation. **Forests.** 8(5): 161.doi:10.3390/f8050161.

Maestre, F. T. and and Cortina, J. (2002). Spatial patterns of surface soil properties and vegetation in a Mediterranean semi-arid steppe. **Plant and Soil**. 241: 279–291.

Marler, T. E., Dongol, N. and Cruz, G. N. (2016). *Leucaena leucocephala* and adjacent native limestone forest habitats contrast in soil properties on Tinian Island. **Communicative & integrative biology**. 9(5): e1212792 (6 pages). http://dx.doi.org/10.1080/19420889.2016.1212792

Marod, D., Duengkae P., Kutintara, U., Sungkaew, S., Wachrinrat, C., Asanok, L. and Klomwattanakul, N. (2012). The influences of an invasive plant species (*Leucaena leucocephala*) on tree regeneration in Khao Phuluang forest, Northeastern Thailand. **Kasetsart Journal**. (Nat. Sci.). 46: 39–50.

Marques A. R., Costa C. F., Atman A. P. F. and Garcia Q. S. (2014). Germination characteristics and seed bank of the alien species *Leucaena leucocephala* (Fabaceae) in Brazilian forest: Ecological Implications **Weed Research**. 54: 576–583.

McElhinny, C., Gibbons, P., Brack, C. and Bauhus, J. (2005). Forest and woodland stand structural complexity: Its definition and measurement. **Forest Ecology and Management**. 218: 1–24.

McKnight, M. W., White, P. S., McDonald, R. I., Lamoreux, J. F. and Sechrest, W. (2007). Putting beta-diversity on the map: Broad-scale congruence and coincidence in the extremes. **PLoS Biol**. 5(10): e272.doi:10.1371/journal.pbio.0050272.

Metzger, J. P. (2000). Tree functional group richness and landscape structure in a Brazilian tropical fragmented landscape. **Ecological Applications**. 10(4): 1147–1161.

Moroizumi, T., Hamada, H., Sukchan, S. and Ikemoto, M. (2009). Soil water content and water balance in rainfed fields in Northeast Thailand. **Agricultural Water Management**. 96(1): 160–166.

Munguia-Rosas, M. A., Montiel, S. (2014). Patch size and isolation predict plant species density in a naturally fragmented forest. **PLoS ONE**. 9(10): e111742. doi:10.1371/journal.pone.0111742.

Murtagh, F. and Legendre, P. (2014).Ward's hierarchical agglomerative clustering method: Which algorithms implement Ward's criterion? **Journal of Classification**. 31: 274–295.

Nagendra, H. (2002). Opposite trends in response for the Shannon and Simpson indices of landscape diversity. **Applied Geography**. 22: 175–186.

Nally, R. M., Parkinson, A., Horrocks, G., Conole, L. and Tzaros, C. (2001). Relationships between terrestrial vertebrate diversity, abundance and availability of coarse woody debris on south-eastern Australian floodplains. **Biological Conservation**. 99(2): 191–205.

Nehdi, I. A., Sbihi, H., Tan, C. P. and Al-Resayes, S. I. (2014). *Leucaena leucocephala* (Lam.) de Wit seed oil: Characterization and uses. **Industrial Crops and Products**. 52: 582–587.

Nunez, M. A., Moretti, A. and Simberloff, D. (2011). Propagule pressure hypothesis not supported by an 80-year experiment on woody species invasion. **Oikos**. 000: 001–006.

Oksanen, J. (2015). Multivariate Analysis of Ecological Communities in R:VeganTutorial. [Online.]. Available: http://cc.oulu.fi/~jarioksa/opetus/metodi/vegantutor.pdf99. Accessed date: September 5, 2017.

Omoro, L. M. A., Laiho, Starr, R. L. M. and Pellikka, P. K. E. (2011). Relationships between native tree species and soil properties in the indigenous forest fragments of the Eastern Arc Mountains of the Taita Hills, Kenya. **Forestry Studies in China**. 13(3): 198–210.

Pardini, R., de Souza, S. M., Braga-Neto, R. and Metzger, J. P. (2005). The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. **Biological Conservation**. 124(2): 253–266.

Patil, G. P. (2002). Diversity profiles. **Encyclopedia of Environmentrics**, A. El-Shaarawi and W. W. Piegorsch (eds). John Wiley & Sons, UK: 555–561.

Paluch, J. G. and Gruba, P. (2012). Effect of local species composition on top soil properties in mixed stands with silver fir (*Abies alba* Mill). **Forestry**, doi: 10.1093/forestry/cps040.

Pattanavibool, A., and Dearden, P. (2002). Fragmentation and wildlife in montane evergreen forests, northern Thailand. **Biological Conservation**. 107: 155–164.

Peter, L., Weaver, P. L. and Chinea, J. D. (2003). Secondary subtropical dry forest at the La Tinaja tract of the cartagena lagoon national wildlife refuge, Puerto Rico. **Caribbean Journal of Science**. 39(3): 273–285.

Pinto, S. R. R., Mendes, G., Santos, A. M. M., Dantas, M., Tabarelli, M., and Melo, F. (2010). Landscape attributes drive complex spatial microclimate configuration of Brazilian Atlantic forest fragments. **Tropical Conservation Science**. 3(4): 399–402.

Prachaiyo, B. (2000). Farmers and forests: a changing phase in northeast Thailand.Southeast. **Asian Study**. (38): 273–446.

R Core Team. (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [Online.] Available: https://www.R-project.org/. Accessed date: March 2, 2017.

Rainfall/ Precipitation in Korat/ Nakhon Ratcha, Thailand. (2016). [Online.] Available: http://www.korat.climatemps.com/precipitation.php. Accessed date: March 10, 2017.

Ramos, F. N. and Santos, F. A. M. (2006). Microclimate of atlantic forest fragments: regional and local scale heterogeneity. **Brazilian Archives of Biology and Technology**. 49(6): 935–944.

Rautiainen, M., Stenberg, P. and Nilson, T. (2005). Estimating canopy cover in Scots pine stands. **Silva Fennica**. 39: 137–142.

Restrepo, C., Gomez, N. and Heredia, S. (1999). Anthropogenic edges, tree fall gaps, and fruit frugivore interactions in a neotropical montane forest. **Ecology**. 80: 668–685.

Ricotta, C. (2017). Of beta diversity, variance, evenness, and dissimilarity. **Ecology and Evolution**. 7: 4835–4843.

Rodriguez, L. F. (2006). Can invasive species facilitate native species? Evidence of how, when, and why these impacts occur. **Biological Invasions**. 8: 927–939.

Saunders, D. A., Hobbs, R. J. and Margules, C. R. (1991). Biological Consequences of Eco system Fragmentation: Review. **Conservation Biology**. 5(1): 18–32.

Sheoran, V., Sheoran, A. S. and Poonia, P. (2010). Soil reclamation of abandoned mine land by re vegetation: (A Review). **International Journal of Soil, Sediment and Water**. 3(2): Article 13. [Online]. Available: http://scholar works.umass.edu/intljssw/vol3/iss2/13. Accessed date: May 23, 2017.

Siderhurst, L. A., Griscom, H. P., Kyger, C., Stutzman, J. and Trumbo, B. (2012). Tree species composition and diversity and the abundance of exotics in forest fragments of the Shenandoah Valley; Virginia. **Castanea**. 77(4): 348–363.

Skole, D. and Tucker, C. J. (1993). Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. **Science**. 260: 1905–1910.

Smale, M. C., Ross, C. W. and Arnold, G. C. (2005). Vegetation recovery in rural kahikatea (*Dacrycarpus dacrydioides*) forest fragments in the Waikato

region, New Zealand, following retirement from grazing. **New Zealand Journal of Ecology**. 29(2): 261–269.

Sodhi, N. S., Koh, L. P., Brook, B. W. and Ng, P. K. L. (2004). Southeast Asian biodiversity: an impending disaster. **Trends in Ecology and Evolution**. 19: 654–660.

Sodhi, N. S., Koh, L. P., Clements, R., Wanger, T. C., Hille, J.K., Hamer, K. C., Clough, Y., Tscharntke, T., Posa, M. R. C., and Leeh, I. M. L. (2010). Conserving Southeast Asian forest biodiversity in human-modified landscapes. **Biological Conservation**. 143(10): 2375–2384.

Soil Survey Staff. (2011). Soil Survey Laboratory Information Manual. **Soil Survey Investigations Report**. 45, Version 2.0. R. Burt (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service.

Stinson, K. A., Campbell, S. A., Powell, J. R., Wolfe, B. E. and Callaway, R. M. (2006). Invasive plant suppresses the growth of native tree seedlings by disrupting belowground mutualisms. **PLoS Biol** 4(5): e140. doi:10.1371/ journal. pbio.0040140.

Strong, C. W. (1966). An improved method of obtaining density from line-transect data. **Ecology**. 47(2): 311–313.

Tabarelli, M., Aguiar, A. V., Girao, L. G., Peres, C. A. And Lopes, A. V. (2010). Effects of Pioneer Tree Species Hyper abundance on Forest Fragments in Northeastern Brazil. **Conservation Biology**. 24(6): 1654–1663.

Tadros, M. J., Samarah, N. H. and Alqudah, A. M. (2011). Effect of different pre-sowing seed treatments on the germination of *Leucaena leucocephala* (Lam.) and *Acacia farnesiana* (L.). **New Forests**. 42: 397–407.

Tewari, S. K., Katiyar, R. S., Ram, B. and Misra, P. N. (2004). Effect of age and season of harvesting on the growth, coppicing characteristics and biomass productivity of *Leucaena leucocephala* and *Vitex negundo*. **Biomass and Bioenergy**. 26(3): 229–234.

Thompson, I. D., Guariguata, M. R., Okabe, K., Bahamondez, C., Nasi, R., Heymell, V. and Sabogal, C. (2013). An operational framework for defining and monitoring forest degradation. **Ecology and Society**. 18(2): 20.

Tobler, W. R. (1970). A computer movie simulating urban growth in the Detroit region. **Economic Geography**. 46: 234–240.

Torbert, H. A. and Wood, C. W. (1992). Effects of soil compaction and water-filled pore space on soil microbial activity and n losses. **Communications in Soil Science and Plant Analysis**. 23(11&12): 1321–1331.

Tripathi, O. P. and Reynald, K. R. (2010). Effect of forest fragment size on tree diversity and population structure of humid subtropical forest of Meghalaya, India. **Biodiversity Science**.18(2): 208–214.

Trisurat, Y., Alkemade, R. and Verburg, P. H. (2010). Projecting land-use change and its consequences for biodiversity in Northern Thailand. **Environmental Management**. 45: 626–639.

Turner, I. M. (1996). Species loss in fragments of tropical rain forest: a review of the evidence. **Journal of Applied Ecology**. 33: 200–209.

Turner, I. M. and Corlett, T. T. (1996). The conservation value of small, isolated fragments of lowland tropical rain forest. **Tree**. 11: 330–333.

Uriarte, M. A., Bruna, E., Rubim, M., Anciaes, P. M. and Jonckheere, I. (2010). Effects of forest fragmentation on the seedling recruitment of a tropical herb: assessing seed vs. safe-site limitation. **Ecology**. 91(5): 1317–1328.

Valiente, C. A. (2010). The invasion ecology of *Leucaena leucocephala* on Moorea, French Polynesia. **Biology and Geomorphology of Tropical Islands**. 19: 65–72.

Weiher, E. (2007). On the status of restoration science: Obstacles and opportunities. **Restoration Ecology**. 15: 340–343.

Wheater, C. P., Bell, J. R. and Cook, P. A. (2011). **Practical field ecology**: A project guide. London, UK: Wiley Blackwell.

Whitmore, T. C. (1997). Rainforest disturbance, disappearance, and species loss. Laurance, W.F. and Bierregaard, R.O (eds.), **Tropical Forest Remnants:Ecology, Management, and Conservation of Fragmented Communities**. University of Chicago Press, Chicago: 3–12.

Wicklein, H. F., Christopher, D., Carter, M. E. and Smith, B. H. (2012). Edge effects on sapling characteristics and microclimate in a small temperate deciduous forest fragment. **Natural Areas Journal**. 32(1): 110–116.

Wilcove, D. S., McLellan, C. H. and Dobson, A. P. (1986). Habitat fragmentation in temperate zone. **Conservation biology**, (eds), M.C. Soule, Sinauer Associates, Sunderland, M.A: 237–56.

Wilcox, B. A. and Murphy, D. D. (1985). Conservation strategy: effects of fragmentation on extinction. **The American Naturalist**. 125: 879–887.

Wilson, M. C., Chen, X. Y., Corlett, R. T., Didham, R. K., Ding, P., Holt, R. D., Holyoak, M., Hu, G., Hughes, A. C., Jiang, L., Laurance, W. F., Liu, J., Pimm, S. L., Robinson, S. K., Russo, S. E., Si, X., Wilcove, D. S., Wu, J. and Yu, M. (2016). Habitat fragmentation and biodiversity conservation: key findings and future challenges. **Landscape Ecology**. 31: 219–227.

Wolda, H. (1981). Similarity indices, sample size and diversity. **OecoIogia** (Berl). 50: 296–302.

Yates, E. D., Levia, D. F. and Williams, C. L. (2004). Recruitment of three non-native invasive plants into a fragmented forest in Southern Illinois. **Forest Ecology and Management**. 190: 119–130.

Yige, C., Fangqing, C., Lei, L. and Shunbo, S. (2012). Physiological responses of *Leucaena leucocephala* seedlings to drought stress. **Procedia Engineering**. 28: 110–116.

Yoshida, K. and Oka, S. (2006). Invasion of Leucaena leucocephala and its effects on the native plant community in the Ogasawara (Bonin) Islands. **Weed Technology**. 18(1): 1371–1375.

Young, A. and Mitchell, N. (1994). Microclimate and vegetation edge effects in a fragmented podocarp-broadleaf forest in New Zealand. **Biological Conservation**. 67(1): 63–72.

Zhang, H., John, R., Peng, Z., Yuan, J. and Chu, C. (2012). The relationship between species richness and evenness in plant communities along a successional gradient: A study from sub-alpine meadows of the eastern Qinghai-Tibetan plateau, china. **PLoS ONE**. 7(11): e49024. doi:10.1371/ journal.pone.0049 024.

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