# NATURAL ESTABLISHMENT OF TREE SEEDLING IN FOREST RESTORATION TRIALS AT BAN MAE SA MAI, CHIANG MAI PROVINCE

**KHWANKHAO SINHASENI**

**MASTER OF SCIENCE
IN BIOLOGY**



**THE GRADUATE SCHOOL
CHIANG MAI UNIVERSITY
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**A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGY**



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## ACKNOWLEDGEMENTS

First and examining, I express my gratitude and respect to my advisor of special project of my thesis committee, Dr. Stephen Elliott. He gave me recommendations and suggestion, without which I could not have completed my research. I am sincerely indebted to supervisor of my thesis, lecturer Dr. Sutthathorn Chairuangsri, for her suggestions and corrections in report, especially Thai part, as well as the best counselor for everything. I also would like to express my thank to lecturer Dr. Prasit Wangpakapattanawong, my examining committee member for his suggestions and corrections with his kindness. And I also thank Dr. Kriangsak Sri-Ngernyuang from Mae Jo University, an external committee in the thesis examination.

Likewise sincere thanks to the staff of the Forest Restoration Research Unit, Mr. Cherdsak, Miss Panitnart, Mrs. Tinglao, Mr. Naeng and all education teams for locating trees samples, suggestions, planting and looking after through all seedling process and myself.

The author is grateful to the Faculty of Science, Chiang Mai University, particularly to Department of Biology and all staff for a lot of assistance for this study can be successful.

The author is especially grateful to Mr. James F. Maxwell, for mental support and kindly help in identifying tree seedlings.

Special thanks are to all my best friends and colleagues, especially Miss Parinyarat Jinto, Miss Nuttira Gawinjun, Mr. Chawapich Wydhayagarn, Miss Patcharawadee Tongcomekun and Miss Kulrapat Yimpak for sharing the precious time and helping hands during the data collection. Moreover, my heartfelt thank to Mr. Rattapol Ampol to support transportation.

Above all these, I am blessed with love, patience and encouragement of my parents, grandmother, aunt Ae and Brother for their understanding and mental support in every times.

I thank the Biodiversity Research and Training Program (BRT) for financial support in my research (Grant BRT T_350004).

Khwankhao Sinhaseni

**Thesis Title** Natural Establishment of Tree Seedling in Forest Restoration Trials at Ban Mae Sa Mai, Chiang Mai Province

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**Degree** Master of Science (Biology)

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## ABSTRACT

The Forest Restoration Research Unit (FORRU) has successfully adapted the framework species method of forest restoration to accelerate natural forest regeneration on deforested sites in northern Thailand. This method involves planting 20-30 indigenous forest tree species, selected for fast growth, resilience to weeds and fire and attractiveness to seed-dispersing animals. Trial plots to test the technique have been established annually in Doi Suthep-Pui National Park, northern Thailand, since 1998. The objectives of the research presented here were i) to determine if forest restoration encourages recruitment of non-planted tree species in the planted areas, increasing tree species diversity ii) to determine the effects of the tree species planted, planting density, plot-age and fire on naturally tree seedling establishment. The study was carried out using two survey techniques. To determine the effects of planting density on natural seedling establishment, rectangular sample units measuring 30x10m were established in the centre of plots planted in 1999 at 3 different densities (2.3, 1.8 and 1.5 m between trees at planting time). To determine the effects of plot age on natural tree seedling establishment, circular sample units 10 m in diameter were laid out across plots planted in 1998 and 2002 and non-planted control plots. In all sample

units, the following measurements were made on all naturally established seedlings observed: height, root collar diameter (using vernier calipers), canopy width, health, weed cover, shade. Furthermore, the species of any tree crowns immediately above the naturally established seedlings were record. This enabled associations between establishing tree species and planted tree species to be determined.

The population density of naturally established tree seedlings and proportion of climax species increased with age of planted plots. Spacing framework tree 1.8 m apart (3,125 trees per hectare) at planting time, resulted in optimal natural seedling establishment. Most seedlings grew from seeds that had been dispersed into the planted plots by animals (rather than by wind). Mortality of seedlings in the control sites was significantly higher than in planted plots, and the highest mortality occurred in the rainy season. Seventy-three tree seedling species in the planted plots were recruit species (non-planted species). Previous fires in the forest restoration areas inhibited seedling establishment and increased mortality rate, resulting lower species diversity of the seedling community. The 57 framework tree species planted fostered considerable seedling recruitment beneath their crowns. The top three framework tree species for fostering natural regeneration were *Ficus glaberrima* Bl. var. *glaberrima*, *Prunus cerasoides* D. Don, and *Erythrina subumbrans* (Hassk.) Merr. Most of the seedling species recorded growing beneath their crowns grew from animal-dispersed seeds. In conclusion, this study shows that the framework species method is effective at enhancing natural forest regeneration.

**ชื่อเรื่องวิทยานิพนธ์** การตั้งตัวตามธรรมชาติของต้นกล้าไม้ยืนต้นในพื้นที่ทดสอบการฟื้นฟูป่า ที่บ้านแม่สาใหม่ จังหวัดเชียงใหม่

**ผู้เขียน** นางสาวขวัญข้าว สิงหเสนี

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อ. ดร. สุทธาธร ไชยเรืองศรี

## บทคัดย่อ

หน่วยวิจัยและฟื้นฟูป่า (FORRU) ประสบความสำเร็จในการใช้วิธีพรรณไม้โครงสร้างฟื้นฟูป่าโดยกระตุ้นการกลับคืนมาของป่าตามธรรมชาติบริเวณพื้นที่ป่าที่ถูกทำลายในภาคเหนือของประเทศไทย โดยปลูกไม้ยืนต้นท้องถิ่น 20-30 ชนิด ที่เจริญเติบโตได้อย่างรวดเร็ว ทนทานต่อไฟและวัชพืช รวมถึงดึงดูดสัตว์ป่าที่ช่วยกระจายเมล็ด พื้นที่ทดลองตั้งอยู่ในเขตอุทยานแห่งชาติดอยสุเทพ-ปุย ภาคเหนือของประเทศไทยและมีการปลูกป่าอย่างต่อเนื่องตั้งแต่ปี พ.ศ. 2541 วัตถุประสงค์ของงานวิจัยในครั้งนี้ คือ I) เพื่อศึกษาว่าการฟื้นฟูช่วยสนับสนุนการเกิดต้นกล้าไม้ยืนต้นที่ไม่ได้ปลูกในแปลงทดลองปลูกป่า และการเพิ่มขึ้นของความหลากหลายของชนิดพันธุ์หรือไม่ และ II) ศึกษาอิทธิพลจากชนิดไม้ยืนต้นที่ปลูก ความหนาแน่นของแปลงปลูก อายุแปลงปลูก และไฟ ต่อการตั้งตัวตามธรรมชาติของกล้าไม้ยืนต้น ในการวิจัยนี้ใช้สองวิธีในการสำรวจต้นกล้า ในการศึกษาอิทธิพลของความหนาแน่นในการปลูกโดยวางพื้นที่หน่วยเก็บตัวอย่างรูปสี่เหลี่ยมผืนผ้าขนาด 10x30 เมตร ในแปลงปลูกปี พ.ศ.2542 ที่มีความหนาแน่นของกล้าไม้ 3 ระดับ (ระยะระหว่างต้นเมื่อปลูก คือ 2.3, 1.8 และ1.5 เมตร) ส่วนการศึกษาอิทธิพลของอายุแปลงปลูกต่อต้นกล้าที่เกิดขึ้นใหม่ในแปลงปลูกป่า ด้วยการใช้หน่วยเก็บตัวอย่างรูปวงกลม ขนาดเส้นผ่าศูนย์กลาง 10 เมตร วางในแปลงปลูกป่าเมื่อปี พ.ศ. 2541, 2545 และแปลงที่ไม่มีการปลูก โดยในทุกหน่วยการเก็บตัวอย่าง จะเก็บข้อมูลของต้นกล้าที่เกิดขึ้นตามธรรมชาติและวัดความสูง เส้นผ่านศูนย์กลางบริเวณโคนต้น (ใช้เวอ

เนียร์คาลิปเปอร์) ความกว้างทรงพุ่ม สุขภาพของต้นกล้า วัชพืชที่อยู่ใกล้เคียง และร่มเงา นอกจากนี้บันทึกชนิดของพรรณไม้โครงสร้างที่พบต้นกล้าอยู่ใต้ทรงพุ่ม ว่ามีความสัมพันธ์ซึ่งกันและกันหรือไม่

ความหนาแน่นของประชากรต้นกล้าที่เกิดขึ้นตามธรรมชาติ และอัตราส่วนของชนิดพืชของป่าอุดมสมบูรณ์เพิ่มขึ้นตามอายุของแปลงปลูก การปลูกด้วยระยะ 1.8 เมตร (3,125 ต้นต่อเฮกแตร์) ให้ผลลัพธ์ที่มีประสิทธิ์ภาพสูงสุดต่อการตั้งตัวของต้นกล้า เมล็ดส่วนใหญ่ที่เข้าสู่แปลงเป็นกลุ่มที่กระจายด้วยสัตว์ (มากกว่าลม) การตายของกล้าไม้ในแปลงควบคุมสูงกว่าในแปลงปลูกป่า และมีการตายสูงที่สุดในช่วงฤดูฝนที่ 2 กล้าไม้ยืนต้น 73 ชนิดที่พบในแปลงปลูกเป็นชนิดใหม่ไม่ใช่พรรณไม้โครงสร้าง ไฟที่เข้ามาในแปลงฟื้นฟูป่าขัดขวางการตั้งตัวของต้นกล้าและเพิ่มอัตราการตายส่งผลให้ค่าดัชนีความหลากหลายทางชีวภาพลดลง พรรณไม้โครงสร้างทั้ง 57 ชนิดที่ปลูกสนับสนุนการตั้งตัวของกล้าไม้ชนิดใหม่ใต้ทรงพุ่ม ซึ่ง 3 อันดับแรกที่มีผลดังกล่าว คือ เดื่อไทร นางพญาเสือโคร่ง และ ทองหลางป่า และต้นกล้าที่พบใต้พุ่มส่วนใหญ่เป็นชนิดที่นำพาเมล็ดด้วยสัตว์ ดังนั้นวิธีการพรรณไม้โครงสร้างจึงเป็นวิธีการที่มีประสิทธิภาพในการกระตุ้นการฟื้นตัวของป่า

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**ABBREVIATIONS**

cm : centimeter

Seedling : The tree and treelet plants since have true leaves until their height not over 1 meter

FORRU : Forest Restoration Research Unit

RGR : relative growth rate

# CHAPTER 1

# INTRODUCTION

## Rationale

Tropical deforestation is one of the most important environmental problems of the modern age. If we continue at the current rate of deforestation and destruction of major ecosystems like rainforests and coral reefs, where most of the biodiversity is concentrated, we will surely lose more than half of all species of plants and animals on the earth by the end of 21st century (Wilson, 1992).

Tropical rain forests cover only 7 percent of total world area but they are habitats for 90 percent of the total world's plant and animal species. In addition, Thailand represents approximately 0.34 percent of Earth's land surface, but the country supports disproportionately high 6-10 percent of the earth's biodiversity.

The forests in northern Thailand are the Kingdom's most important natural resources. They protect headwater resources that support the Chao Phraya River, irrigate rice fields of the central plain, and supply water to Bangkok, the Thai capital city. They are habitat for many wildlife species, including 150 mammal species (Lekagul and McNeely, 1988), birds (Round, 1984) and at least 3,450 vascular plants, of which 1,116 are tree species (Maxwell and Elliott, 2001). Moreover, these forests support fundamental ecological resources for human life, such as water, clean air and soil. They provide many products, such as fuel-wood, medical plants, food, fibers, educational values, etc.



Deforestation is the one of the main causes of biodiversity loss and is the one of the most important environmental problems in Thailand. Data from the Thai Royal Forest Department (RFD) in 1962 showed that the Kingdon's total forest area was 171 million rai. Between 1961-1993, forest cover in Thailand decreased by an average of 2.73 million rai (0.44 million ha) per year. In 1994, the rate of deforestation remained at 1 million rai (0.16 million hectar) per year. There were 80 million rai (12.8 million ha) of total forests in 1999

(RFD, 2004). Over-exploitation of forest resources, such as illegal logging, shifting cultivation, hunting, collection etc, were the main causes of deforestation.

Deforestation reduces the quality of life, since it results in depletion of topsoil, especially on the steep slopes, with sparse vegetation cover. Consequently, carbon, nitrogen and phosphorus cycles are changed (Vitousek, 1983). In addition, the climate has been changed due to forest loss. Global warming is now a serious concern for every country. Data from the Meteorological Department show that annual average temperature in Thailand increased by 0.64 ˚C from 1986 to 1995 (OEPP, 1996), and that total average annual rainfall decreased from 1,542 mm in 1986 to 1,428 mm in 1993. However, annual rainfall increased to 1,692 and 1,686 mm in 1994 and 1995 respectively (OEPP, 1996).

Tree plantations have been used to restore degraded forest land and they have been established by both government and non-government organizations. Initially, forest restoration programs concentrated on establishing monocultures of commercially valuable tree species such as pines, eucalyptus, teaks. Establishment of plantations has not been successful for wildlife conversation and watershed protection. Furthermore, monoculture plantations lack the high biodiversity found in natural forests. A comparison of ground flora diversity among different types of tree plantations and primary forest, showed the highest diversity in natural forest (Karimuna, 1995). If forest restoration areas have high plant species diversity, succession towards natural forest will be accelerated because various types of food and habitat are provided to attract wildlife such as birds, monkeys and deer leading to the establishment of a restored and balanced ecosystem.

After realizing that monoculture plantations are of low value for wildlife conservation and watershed protection, attitudes towards reforestation are changing. Planting indigenous tree is now recommended for restoration projects because they promote biodiversity (Wightman, 1997).

Planting native forest trees is recommended for reforestation projects because they can promote biodiversity (Lamb, 1997; Robison and Handel, 1993). Thought, secondary forest can accrete biodiversity rapidly in tropics, it may not be of direct value in conservation.

It can have other indirect roles, such as providing resources for native animals and buffering and protecting primary forest fragments (Turner et al., 1997). Forest restoration goals are divided in three alternative goals, reclamation, rehabilitation, and restoration. Rehabilitation involves planting mostly native species and some exotic species planted in deforested areas. Reclamation is done only with exotic species, for economic or ecological reasons. Finally, restoration attempts to restore a forest ecosystem to original condition, with the main objective to preserve biological diversity (Lamb et al., 1997).

The Forest Restoration Research Unit (FORRU), a co-operative project between Chiang Mai University and Doi Suthep-Pui National Park, was established in November 1994. FORRU initiated a research program to develop appropriate methods to propagate and plant a wide range of native forest tree species and assess which ones might be useful for forest restoration programs. The approach being developed by FORRU is the "framework species" method of forest restoration which stimulates recovery of tree species richness. The framework species method of forest restoration involves planting 20-30 indigenous tree species, to accelerate natural forest regeneration by attracting seed-dispersing animals from nearby patches of surviving natural forest. When seeds, dropped by the attracted animals, germinate, the tree species composition of the original forest should gradually be restored (FORRU, 2006). During 1999 – 2004, the RFD reported that the total forest area increased from 80 million rai (12.8 million ha) to 105 million rais (16.8 million ha).

Such framework species were planted in a deforestation area near Mae Sa Mai village in Doi Suthep-Pui National Park and have been cared for after planting with weed control, fertilizer application, and fire protection. Monitoring their survival and growth is done at least twice per year in the first 2-3 years after planting. In addition, naturally seedlings establishment in both planted and control sites are also monitored.

## Hypothesis

The first hypothesis tested was that which the framework tree species technique was high potential to accelerate forest regeneration. Therefore, this project surveyed natural tree seedlings establishment in different age stages of forest restoration areas.

The second hypothesis tested was that the density at which the framework trees are planted affects colonization of plots by naturally established trees. If the trees are planted too close together, competition from the planted trees may prevent natural tree establishment. On the other hand, planting the trees too far apart results in weed invasion and the weeds may prevent natural establishment of trees also by competition. This hypothesis was tested by recording natural tree seedling establishment in plots planted with different densities of framework trees.

Final hypothesis tested was that which species of framework trees planted affects the species of trees that naturally establish beneath them, since different framework tree species attract different animals with different diets. In addition, the microclimate beneath different framework tree species with different canopy structures may influence which tree species can germinate and grow. This hypothesis was tested by measuring association between naturally established trees and planted framework species.

## Objectives

1. To determine the species, population density, growth and survival of naturally establishing recruit tree species in forest restoration sites
2. To determine how recruitment is affected by the density of planted trees, incidence of fire and time since plot establishment and the tree species which are planted.

## Usefulness of the Research

1. The study will determine the effects of forest restoration (framework species method) on the natural establishment of native forest tree species.

2. The study will generate advice to increase the effectiveness of forest restoration techniques such as the spacing between planted trees (planted-tree density), fire control and the most effective framework species to accelerate tree species recruitment.

## Future implications of the study

The results of this study will provide basic ecological knowledge on the use of indigenous trees to accelerate forest succession and promote and preserve plant diversity. Furthermore, the research will evaluate the effectiveness of forest restoration techniques with regard to promotion of biodiversity recovery.

# CHAPTER 2

# LITERATURE REVIEW

## Tropical Forest and Biodiversity

Tropical and sub-tropical forest cover only 16.8 percent of the earth area (FAO, 2001), but they are habitat of more than half of terrestrial wildlife species (Wilson, 1988). Deforestation gradually reduces large forest tracts into tiny, isolates fragments, each of which is incapable of supporting viable populations of plant and animal species, especially large birds and mammals. As species start to disappear, the complex web of interrelationships, vital for maintenance of tropical forest biodiversity. The plants lose their pollinators and seed dispersers; herbivore populations, formerly held in check by predators, expand and threaten the survival of their food plants. Keystone species die out, common weedy species that dominant in the landscape. Therefore, devastation of tropical forests is causing the extinction of more species now than at any time during our planet's history (Wilson, 1992).

The biodiversity of tropical forest provides many products to local communities, such as medicinal herbs and foods, wood. If humans can harvest these goods sustainably, they can provide a valuable, long-term contribution towards the livelihoods of local people. Forests also provide vital ecological services that maintain environmental stability. Predators, that live in forest, can control pests in surrounding farmland. The huge quantities of leaf litter, produced by mature forests, create deep organic-matter-rich soils, which store vast amounts of water per unit volume. The soil soaks up water during the rainy season, preventing flooding. On the other hand in the dry season, water slowly drains out of forest soils, maintaining stream flow and thus averting droughts. Furthermore, forests help to reduce global warming, which is recently a critical problem, by absorbing vast quantities of carbon dioxide into their canopies and converting it into wood (FORRU, 2006)

**Thai Forest situation and Forest Plantation**

In Thailand, natural forests covered 9.8 million ha (19.3 per cent of the country's area) in 2000. Although there has been a ban on commercial logging since 1989, the average annual reduction in natural forest cover (1995-2000) remained 0.26 million hectare (2.3 percent of the 1995) (FAO, 2001). Overall since 1961, Thailand has lost nearly two thirds of its forests (Bhumibamon, 1986). Deforestation is an important problem in Thailand. Therefore in 1994 the Thai government embarked a national project to restore forest to deforested or degraded land. To start with monoculture, economics trees, such as pine eucalyptus, were planted.

However, the ground flora of eucalyptus plantations contains less biomass and fewer plant species than in natural forest, despite a high light level beneath the canopy (Del Moral and Muller, 1970). This may be due to an inability of native plants to compete with eucalyptus trees for water and nutrients or because of the production of chemicals by eucalyptus tree which inhibit growth of other plants. De Candolle (1983) suspected that plants release toxic materials into soil and that these last long enough to necessitate the rotation of crops. From the beginning of this century evidence has accumulated that plants may, directly or indirectly, harm each other through release of chemicals to the environment, the phenomenon of allelopathy (Rice, 1979).

In view of its fast growing nature and money producing capacity, the eucalyptus is considered by profit oriented people as the "God-Sent-Plant" or "Green Gold", but the large scale of its plantation has generated much controversial debate by environmentalists, who have called it an "Ecological Monster". Sharma et al. (1989) showed that eucalyptus depletes the water table, degrades soil, provides little shade, is not easily bio-degradable and does not attract microorganisms (due to the exudation of some toxic chemical by roots), which kills all useful bacterial around the plants.



Karimuna (1995) carried out a survey of ground flora in Doi Suthep-Pui National Park. The total number of species recorded in the extensive qualitative survey the number of species recorded in evergreen forest, regenerating gap, eucalyptus, mature and young pine plantation were 174, 105, 86, 102 and 138 respectively. The highest species diversity (Hill's number, N1 and N2) and evenness (Modified Hill's ratio) occurred in the evergreen forest (55.91, 35.69 and 0.63; respectively) and the lowest was in the mature pine plantation (16.46, 6.88 and 0.38; respectively). The highest relative growth rate (RGR) of tree seedlings was 0.234 cm growth/cm of original height/year in the regenerating gap, whilst the lowest was 0.017 cm growth/cm of original height/year in the mature pine plantation. The highest percent mortality of tree seedlings was 15.60 in the mature pine plantation, while the lowest was 3.27 in the forest.

Economic tree plantations are not the solution to forest degradation in Thailand and cannot replace forest ecosystems, which have high complexity of ecological function and structure. Assisted or Accelerated Natural Regeneration (ANR) was suggested by Dalmacio (1986) and is already practiced for accelerated reforestation of degraded uplands and *Imperata* grassland in Philippines (Dalmacio, 1986; Durst, 1990). The basic concept of ANR emphasizes protection and nurturing of tree seedlings and saplings already existing on degraded sites, rather than establishment of entirely new forest. ANR required tree seedlings and saplings on degraded sites be marked and assisted in their survival and growth by one or more of the following activities: I) pressing or cutting of grasses, II) weeding around existing seedlings and saplings, III) fire protection, and IV) enrichment planting. However, in Thailand, ANR has not been successful because knowledge of how to assist the natural regeneration of each species is lacking. Literature on fruit production, seed germination, seed bank, and tree seed dispersal are required. Different plant species need different ANR method. Suitable methods may include planting *Beilschmiedia* sp. (Lauraceae) under the shade of existing herbaceous vegetation, direct sowing of *Prunus cerasoides* (Rosaceae), and for *Eugelhardia spicata* (Juglandaceae), cutting weeds (particularly grasses and ferns) or shading them out with nurse tree (Hardwick *et al*., 1997)

**Alternative technique for Forest Restoration**

One effective approach to forest restoration is the framework species method, first developed in Australia (Goosem and Tucker, 1995). The method has now been used to restore forest to a degraded watershed in the Mae Sa Valley, evergreen forests, in Doi Suthep-Pui National Park, Northern Thailand by Forest Restoration Research Unit: FORRU (FORRU, 1998). Framework species are fast growing with dense spreading canopies, which rapidly shade out weeds. They also provide resources for wildlife (such as fruits, nectar, perching sites) at a young age. Animals (especially birds and bats), attracted by such resources, disperse seeds into the planted sites, thus accelerating the return of biodiversity (Blakesley *et al*., 2002). Saplings of 20-30 framework tree species from FORRU nursery were planted in degradation areas since 1997 until present.

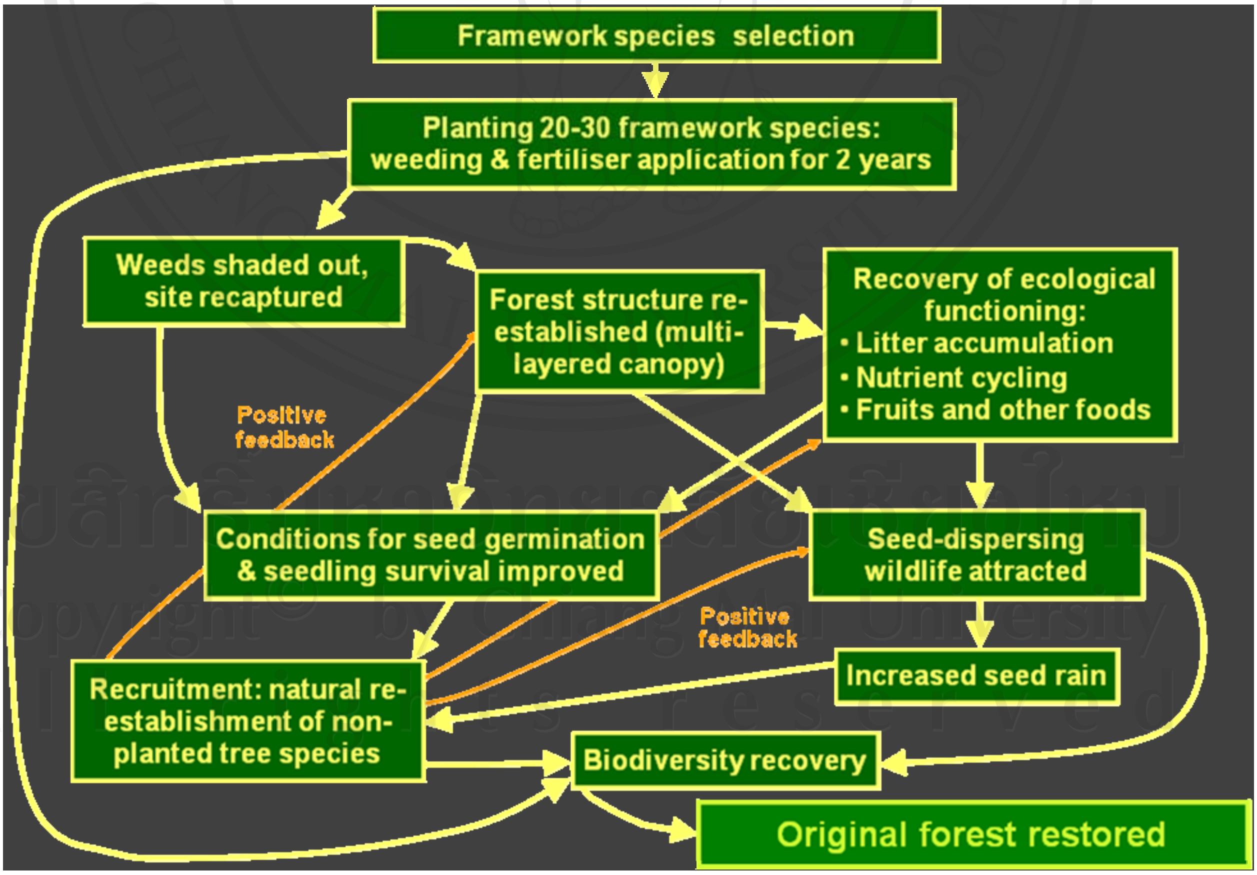


Figure 2.1 How the framework tree species method work (FORRU, 2006)

Vegetation survey of Maxwell and Elliott (2001) in Doi Suthep-Pui National Park, Northern Thailand in 1981, 2,247 vascular plants were recorded and the highest species richness was evergreen forest. At least species of 250 trees, 91 treelets, 22 shrubs and 91 woody climbers have been recorded in evergreen forest. Therefore, vegetation survey was required to determine forest regeneration in forest restoration trials.

**Forest Regeneration**

Ecologists regard forest regeneration as one particular form of “forest succession”: a series of predictable changes in ecosystem structure and composition over time, which if allowed to run its course, eventually results in final, stable ecosystems, called the “climax” ecosystem. The climax ecosystem, for any particular area, depends on soil type and climatic conditions. Disturbance of forest, by tree cutting, fire, and so on, cause it to revert to an earlier, temporary ecosystems in the successional series known as a “serial state”. Once disturbances ceases, sequential changes in species composition occur due to interactions among plants and animal with their surrounding environment. Tree species may be divided into two categories, depending on when they appear in the sequence of forest succession. Pioneer tree species are the first to colonize after deforestation. Over many years, as succession proceeds, they are gradually replaced by tree species characteristic of mature forest: so called climax tree species. The pioneer tree species are eventually shaded out by shade-tolerant climax ones. In the large, open, deforested areas, remain after logging or cultivation, the establishment of forest tree depends on seeds being dispersed into areas. The seed must land where conditions are suitable for their germination and they must escape the attention of seed-eating animals: seed predators. After germination, tree seedlings must win an intense competition with weeds for light, moisture and nutrients. The growing trees must avoid being burnt by wildfire or eaten. The factors that forest regeneration are therefore (FORRU, 2006):

- Lack of a seed source

- Lack of seed disperser
- Seed predation
- Unsuitable soil and microclimatic conditions for germination and early seedling growth
- Dominance by herbaceous weeds
- Fire
- Browsing by domestic animals

Species diversity tends to increase with succession (Sharma *et al*., 1989) Recent studies indicate that the time taken for achieving the climax growth in primary succession is at least nearly 1000 years whereas secondary succession on deforested land or abandoned agricultural land proceeds rapidly, but still needs at least 200 years for the development of mature secondary forests.

Fire protection and weeding are very important in forest restoration in the most places (FORRU, 2006). Meng (1997) and Kafle (1997) compared an area of deciduous dipterocarp-oak forest, protected from fire for 27-28 years, with an adjacent frequently burnt area, on the lower slopes of Doi Suthep near Wat Palaht (520 m elevation). They found that frequent fires reduce both the density and species richness of the tree seedling community and the accumulation of viable seeds in the soil seed bank. Moreover, fire burns off soil organic matter, leading to a reduction in the soil's moisture holding capacity. The drier the soil, the less favorable it is for germination of tree seeds. Burning also reduces soil nutrients and destroys the vegetation. It kills beneficial soil micro-organisms, especially mycorrhizal fungi and microbes which break down dead organic matter and recycle nutrients.



Weeds prevent forest regeneration by shading out tree seedlings (FORRU, 2006). Herbs rapidly exploit the soil and develop a dense canopy, which absorbs almost all light available for photosynthesis. Furthermore, weeds provide fuel for wildfires in the dry season. Most herbaceous weeds survive fire as seeds, corms or tubers, buried in the soil, or they possess well-protected growing points (*e.g* grasses, cycads, phoenix palms) that resprout after fire. Saidee (1994) reported that weeding around existing seedlings and saplings, and enrichment planting were used for forest restoration in the Ping watershed, Jomthong and Hod district, Chiang Mai province. After six years, the existing trees grew rapidly as a middle layer with planted trees.

Successful regeneration by plants depends upon fruits/seeds being dispersed to locations where they can germination and establish (Fenner, 1985). Each species has its own specific requirements in this respect (e.g. safe site for one species may be unsafe for another). Presumably, the different patterns of dispersal are the result of natural selection for features, which increase the chances of seeds being favorably placed in locations where offspring are successfully recruited and depend on both the number of seeds dispersed to any distance from the parent and the probability of their survival (Janzen, 1970). The few studies of the dispersal of seeds of know parentage all show that seed density declines rapidly with increasing distance from the parent (Janzen et al., 1976). Hoppes (1988) reported that around individual fruiting plants, seed-fall declines with distance from the seed source.

**Seed Dispersal**

The function of any plant is to grow and eventually to reproduce itself. One of the most essential processes in plant reproduction is the production and dispersal of seeds (Elliott, 2000). The definition of seed dispersal is that it is an active (dynamic) process of transportation, differentiating it from the result it leads to: the passive (static) state of distribution (Van der Pijl, 1972).

The two main reasons for dispersal are i) escaping competition from the parent tree and ii) escaping seed or seedling predators. If seeds are dispersed too far away from the parent, however, it is likely that they will be deposited in an unsuitable habitat. Therefore, there is an optimum dispersal distance, not too far but not too near the parent plant (FORRU, 2006).

Seeds can be dispersed by wind, by animals (both on the outside of animals and through ingestion), by gravity, by water and by explosive fruits. Most tree species in the tropics are dispersed by animals rather than the other forms (wind, water, *etc.*) of dispersal (Wunderle, 1997). Also, wind dispersal is effective only for relatively small seeds that are the first to arrive at a newly cleared site (McDonnell and Stiles, 1983). As the vegetation develops, its increasing complexity attracts a range of mammals and birds and which accelerates the rate of input of seeds from the source. Most fruit ingested by a variety of birds have small seeds. Frugivores are the principal dispersal agents for large seeds fruits which make up most their diet (Snow & Snow, 1971). Seed dispersal by vertebrates is a key process in the dynamics of natural vegetation and in forest succession on degraded tropical forestland (Corlett, 1998).

Forster and Janson (1985) compared seed masses of mature tree species in tropical forest with different light gap requirements for establishment in Peru. They reported that the species that become establishment beneath a closed canopy or in small gaps have higher mean seed masses than those that require large gaps. Moreover, the seed masses of mature forest species is significantly large than that of pioneer species.

Sharp (1995) studied seed dispersal and seed predations in Doi Suthep-Pui National Park, Thailand. Small, flat, light-weight, and usually winged fruits/seeds could disperse farther into gaps, while bigger ones could spread only a few meters from parent trees. Furthermore, the species diversity of fruit/seeds declined with distance from forest edges.

In Ban Mae Sa Mai forest restoration areas, Hitchcock and Kuarak (1998) compared the number of bird dispersed seedlings beneath the canopies of remnant trees (14 individual trees, 9 species) and in control plots, away from their crowns. They found that *Schima wallichii* (DC.) Korth. (Theaceae) and *Albizia chinensis* (Obs.) Merr. (Leguminosae, Mimosoideae) were the most important remnant trees that promoted seed dispersal by birds, there were abundant bird-dispersed tree seedling beneath their crowns over in control plots. Furthermore, they observed birds feeding on 17 fruiting trees species in mature forest. They found that only 8 species, *Bischofia javanica* (DC.) Roxb. (Myrtaceae), *Eurya acuminate* DC. var. *wallchiana* Dyer (Theaceae), *Ficus altissima* Bl., *Ficus glaberrima* Bl. var. *glaberrima*, *Ficus microcarpa* L. f. var. *microcarpa* (Moraceae), and *Hovenia dulcis* Thunb. (Rhammaceae) are clearly attractive to birds. Therefore, it is impossible that the mature can attract several frugivore birds, what bring other seeds nearby the forest restoration areas into the sites.

**Natural Seedling Establishment**

Post-dispersal processes, such as seed predation, seed germination, and seedling establishment, are dependent and affect seedling distribution (Verdu and Garcia-Fayos, 1998). For seedling establishment, research has concentrated an various factors, such as competition with herbaceous weeds, seed size, and nutrient availability. The probability of survival varies significantly among species, between habitat, forest type, and fruit types (Osunkoya, 1994). Furthermore, much research has indicated a higher abundance of seedlings, especially of animal-dispersed plants, under tree canopy than in open areas.

Trees can also alter the local environment with respect to the nature of throughfall, soil moisture, soil nutrient availability and a myriad of other factors. Shugart (1987) treats the question of tree/environment interactions by considering the minimal categories of gap competition in trees. The different roles of trees with respect to gap colonization produce essentially different biomass and numbers of individual when mono species plots are simulated at small partial scales ( ca. 0.1 ha).



Competition for occupancy of canopy gaps is important in understanding the dynamics of natural forests. Trees attain sufficient size to alter their own microenvironment and that of subordinate trees. The species, shapes and sizes of trees in a forest can have a direct influence on the local forest environment. The environment, in turn, has a profound influence on the performance of different species, shapes and sizes of tree. Thus, there can be a feedback from the canopy tree to the local micro-environment and subsequently to the seedling and sapling regeneration that may result in a future canopy (Solomon and Shugart, 1993)

Indigenous tree species in Thailand produce seeds at different times throughout the year. Seed germination is divided into three syndromes (Garwood, 1983):

- In the delayed-rainy syndrome (18 percent of all species) seed were dispersed in the rainy season but were dominant until the beginning of the next rainy season, 4-8 months later. Dormancy is the primary mechanism controlling time of germination. In the delayed-rainy syndrome and the intermediate dry syndrome which follows, the length of the dormant period decreased as the interval between seed dispersal and beginning of the rainy season decreased.

- In the intermediate-dry syndrome (42 percent of all spices) seeds were dispersed during the dry season and remain dormant until the beginning of the rainy season. Seeds are primary dispersed 1-2 months before the beginning of the rainy season, which reduces the number of false germination cues encountered and decreased the length of time seed are exposed to post-dispersal predation while dormancy prevents germination during dry season rains.

- In the rapid-rainy syndrome (40 percent of all species) seeds were dispersed in the rainy season and germinated during, but not early in that season. Dormancy has been replaced entirely by timing of dispersal as a mechanism controlling time of germination. Half of these species germinated in more than 2 weeks the rest in 2-16 weeks.



However, seed of tree species in seasonally dry tropical forest in the neo-tropics tend to germinate at the beginning of the rainy season. Thus, vegetation monitoring ought to record all seasons and it is impossible that the species composition, species richness were different.

Debussche and Isenmann (1994) studied the composition and spatial patterns of the seedlings of fleshy-fruits plants in patchy Mediterranean vegetation in France. Their results indicated that establishment of plants is favored when seeds were deposited under pioneer woody plants rather than in open areas.

Leishman and Westoby (1994) found that the role of seed size on seedling establishment on dry soils in Australia. Their results indicated that seed size was positively associated with survival time of seedlings under dry conditions. Large seeds provided an advantage for seedlings establishment when soil moisture is low, such as deforest sites. Moreover, Leishman et al. (1995) suggested that seed size is more important that environmental conditions for seedling establishment.

Adhikari (1996) studied relationship between tree seedling establishment and herbaceous vegetation in degraded areas of Doi Suthep-Pui National Park, Norther Thailand. The result show that tree seedlings of three species, *Castanopsis diversiforia* (Kurz) King ex Hk. f. (Fagaceae), *Leea indica* (Burm. f.) Merr. (Leeaceae), and *Phoebe lanceolata* (Wall. Ex Nees) Nees (Lauraceae) showed significant association with the Eupatorium dominated sites. He suggested that the dominant ground flora does not provide a reliable indication of the tree seedlings community or of soil condition.

Dos Santos and Valio (2002) studied the effect of litter accumulation on seedling recruitment in Southeast Brazilian tropical forest. The monthly accumulation of litter and its relation to climatic factors (such as rainfall, photoperiod and temperature), also the litter effect on the seedling recruitments were observed in 40 sampling sites under the selected trees canopy in the Mata de Santa Genebra forest. The correlation between litter accumulation and climate was very weak. Litter accumulation and seedlings recruitment had large spatial and temporal variations in different sites. High seedlings mortality was observed at all sites, mainly during the dry season. Biotic factors such as predators and disease may also cause seedlings mortality. Under canopy, the removal of the litter layer increased seedlings emergence. Seedling also increased in response to rain.

Lorena et al. (2005) studied canopy and soil effects in the facilitation of tree seedlings by pioneer shrubs, in two successional montane shrublands at the Sierra Nevada Protected Area, Spain. The canopy effect involved the microclimatic amelioration and the possession of canopy structure that protected seedlings from herbivores (e.g. thorns, spines). The soil effect involves the modification that vegetations produce on chemical, physical and biological soil properties. Seedlings of Quercus and Pinus species were planted in four experimental treatments: I) under shrubs, II) in open interspaces without vegetation, III) under shrubs where the canopy were removed, and IV) in open interspaces but covering seedlings with branches, mimicking a shrub canopy. Seedling survival, heights, herbivory damage and the accumulated Relative Growth Rate (RGR) were calculated during the whole study period. Pioneer shrubs facilitated early recruitment of tree seedlings in the Mediterranean mountains. Seedlings survival was higher with shrubs than for any other treatment without shrub in study sites. Both canopy and soil effects benefited seedlings performance. The canopy effect due to canopy shading was the main mechanism enhancing seedling survival and growth. Modification of soil physical and chemical properties by shrubs (soil effects) exerted a lower benefit over seedling survival and growth than the canopy effect.

**Seedlings Survey in Forest Restoration Areas**

Robinson and Handel (1993) investigated forest restoration in New York, USA by planting trees and shrubs of 17 species to attract avain seed dispersal agents. One year after planting the plantation spread and increased in diversity, with 20 additional species. They found a total of 1,097 woody seedlings, of which 95% came from sources outside the plantation. Most seedlings (71%) were fleshy fruits, dispersed by birds from nearby woodland fringes. The density of new recruits of each species is dependent on the distance from the nearest potential seed sources.

Elliott *et al.* (1997) surveyed naturally established seedlings or saplings (>30 cm tall, gbh < 10 cm) in 1,600 cm$^2$ of plots in this deforested area above Ban Mae Sa Mai village. They found 174 natural seedlings of 36 species and density of 0.12 seedlings / m$^2$.

Tucker and Murphy (1998) studied the forest restoration areas (using framework tree species method) in tropical north Queensland, Australia. Seven-year-old rehabilitation plots contiguous with forest had recruited up to seventy-two plant species across all growth forms and successional phases. Recruitment in 5-year-old plots was less abundant and diverse. Control sites by comparison were dominated by disclimax grasses and diversity of recruitment was reduced.

Khopai (2000) carried out vegetation surveys in the Mae Sa Mai forest restoration plots using 10-m diameter sample units and recording the presence of ground flora species and naturally established trees (height >1 m). Her results showed that weeding and fertilizer application accelerated establishment of natural seedlings and further increased the tree density of naturally established trees (wildings) in plots aged 1 and 2 years. Since 1997, the system of experimental plots has been expanded every until now the oldest planted plots are 8 years old.  Her recommendation was the experiment should be monitored continuously to see more indications of results of planted native forest tree species in the forest restoration areas. Therefore the study presented here expands the work of Khopai (2000) by investigating longer term monitoring of older plots and by considering extra factors such as the effects of tree density on recruit tree establishment.

Seedling recruitment of some species due to the presence of the others has been described for a variety of environments (Garwood, 1983). Establishment below forest canopies possibly protect seedlings from high irradiance, temperature, rate of transpiration and predation (Villier *et al*.,2001). Thus, my research was carried out the effect of individual framework tree species on the survival seedling to attract the seed-dispersal agent to planted areas.

Southwood (1992), Ludwig and Reynolds (1998) and Goldsmith *et al.,* (1986), wrote that quadrats are the most commonly used sample unit to survey the ground flora communities. The shape of a quadrat is a simple square or rectangular sample area for detailed examination. Quadrats may be used to select a typical sample or repeated over an area. They may be positioned regularly or randomly (considered to be the ideal method of sampling-each sample by definition has an equal chance of being chosen) (Goldsmith et al., 1986; and McLean and Cook, 1968).

Diversity is a macroscopic property of communities, encompassing both the number of species present and the distribution of individuals between them. Ideally an index of diversity will vary from a minimum, when all the individuals present in a community belong to a single species, to a maximum, when each individual belongs to a different species. The weakness of diversity as an ecological tool lies in its ambiguity, as noted by Odum (1969). Indices of diversity have been proposed by Simpson (1949), but the most commonly used index, the information content, "H", was introduced by Margalef (1958).

Ludwig and Reynolds (1988) explained that species diversity is composed of two components, species richness, the number of species in the community and species evenness or equitability, how the species abundance are distributed among the species. A number of indices have been proposed for characterizing species richness and evenness. Such indices are termed richness indices and evenness indices. Indices that attempt to combine both indices are called diversity indices. The major criticism of all diversity indices is that they attempt to combine and, hence confound a number of variables that characterize community structure: 1)the number of species, 2)relative species abundances (evenness), and 3)the homogeneity and size of the area sampled (James and Rathbun, 1981)

# CHAPTER 3

# STUDY SITE

## General Description of Study Sites

The study site was been FORRU’s restoration plots near Baan Mae Sa Mai, Chiang Mai, Northern Thailand, in a degraded watershed (18° 52’N, 98° 49’E) at 1207-1310 m elevation above sea level within Doi Suthep Pui National Park. The park has exceptionally high biodiversity (Maxwell and Elliott, 2001). There were total 2,247 vascular plants, 21.6% was tree species (Maxwell, 2001). Animal species included 326 bird species (Round, 1984), 61 mammal species, 28 amphibian species, 50 reptile species, more than 500 butterfly species, and more than 300 moth species (Elliott and Maxwell, 1995). The location of the plots was decided in collaboration with FORRU and the villagers of Ban Mae Sa Mai, a Hmong hill tribe community which is located about 2 km below the plots. Every year about 10 rai of plots were planted with candidate framework tree species by FORRU and the villagers of Ban Mae Sa Mai since 1997 until 2006 and monitoring and planting new plots have continued.

Figure 3.1 Ban Mae Sa Mai village, Mae Rim distinct, Chiang Mai Province

**General climatic conditions**

The local climatic data was measured during January 2005 to June 2006 by the Royal Project Center of Ban Mae Sa Mai, at elevation of 880 m; about 4 km. distance from the study sites.

The area has two main seasons: the wet season (March to April and September to October) and dry season (mean monthly rainfall below 100 mm, May to February except September and October). The dry season is subdivided into the cool-dry season (November to January) and the hot-dry season (February to March)

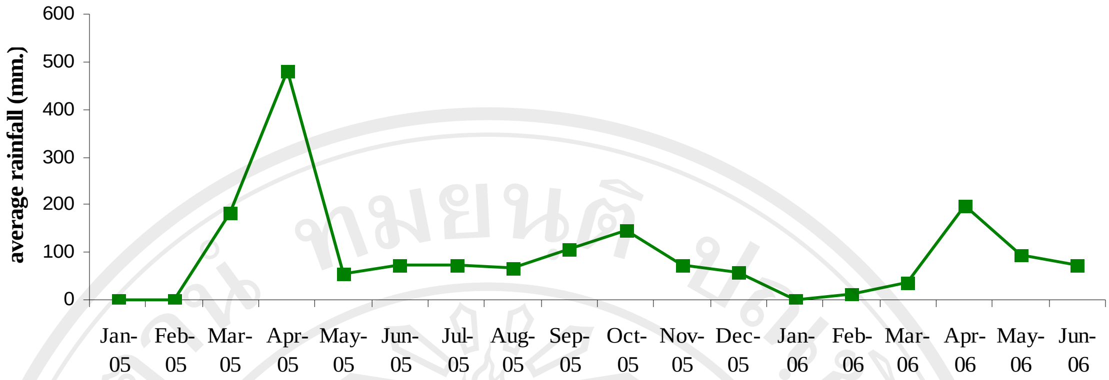


Figure 3.2 the average rainfall (data from Royal Project Centre of Ban Mae Sa Mai)

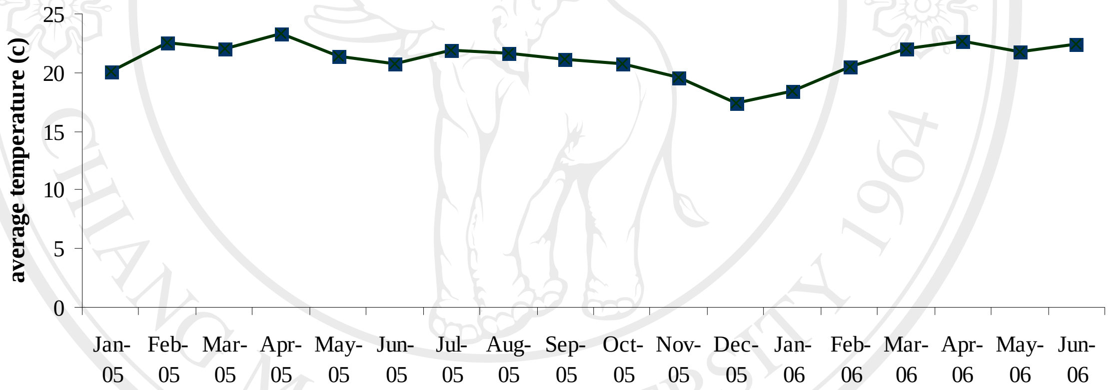


Figure 3.3 the average temperature (data from Royal Project Centre of Ban Mae Sa Mai)

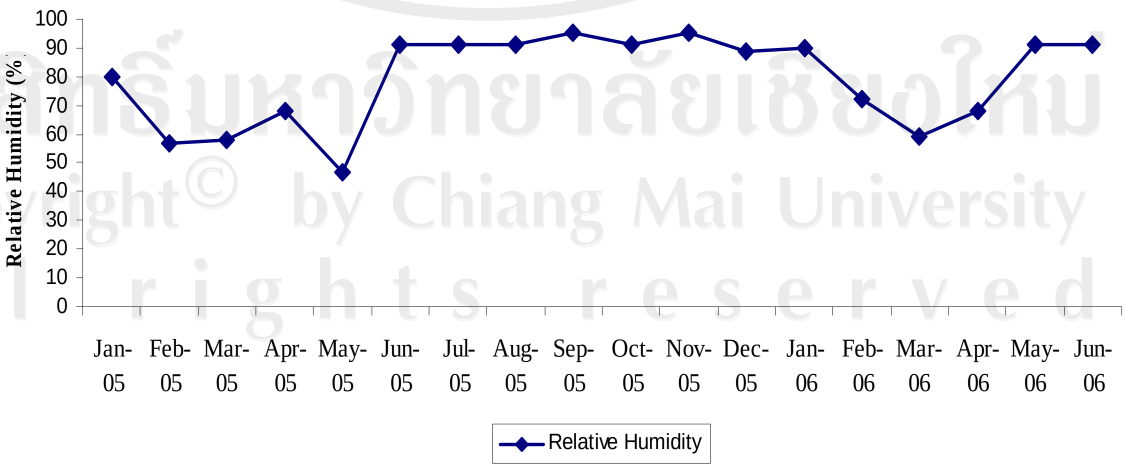


Figure 3.4 the Relative humidity (data from Royal Project Centre of Ban Mae Sa Mai)

**Planted Plots Description**

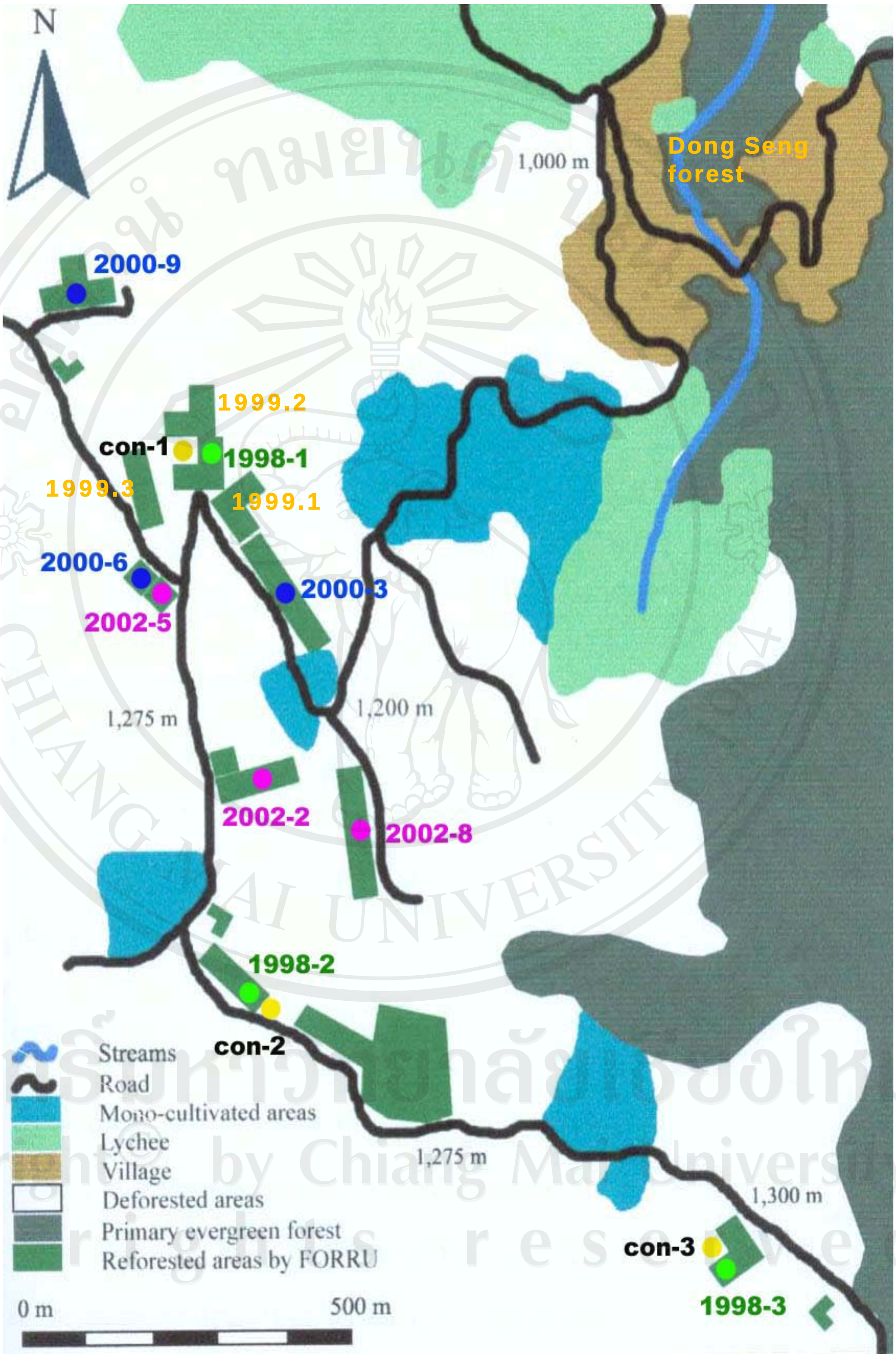


Figure 3.5 the map of studied plots in forest restoration areas at Ban Mae Sa Mai

**Circular sampling units**

Forest restoration areas by the framework tree species technique have been established near Ban Mae Sa Mai since 1997 and continuously planted at least 10 rai/year. In 1998, 2002 and control (unplanted) sites demarcated in 1998 with three replications were surveyed for recruit tree species in this study. This study was made use of permanent circular sample units (circles 10 m in diameter) that had already been established for previous monitoring in the in the 1998, 2002 and control sites. The aluminum poles were put for the center of circular sampling units (Figure 3.8). All the position was in the map of studied sites (Figure 3.5). There were 4 circular sampling units in one replication, are 1600 square meter (1 rai).

In 1998-planted plots, the canopy was closed, so the ground was clear and there were no weeds (figure 3.9) and high leaf litter was accumulation. Light intensity was lower than in the 2002 planted plots and control sites (Figure 3.). A few herbaceous plants on the ground of 2002 planted plots persisted. On the other hand, weeds grew taller than 2 m in control sites and there were a few big trees.

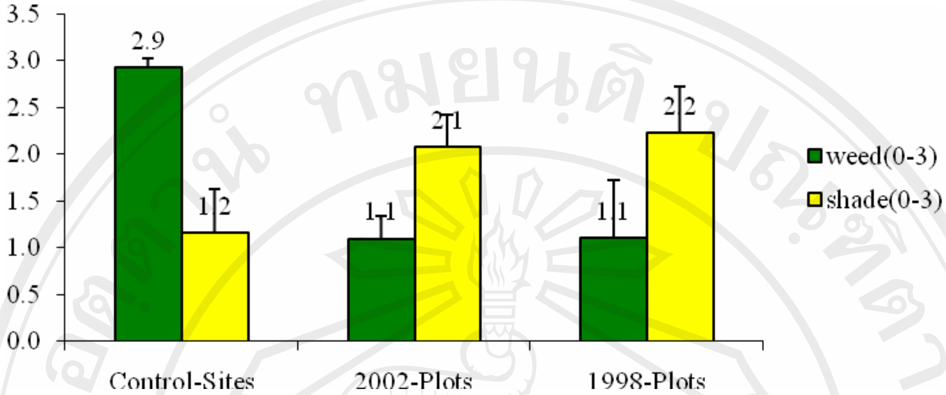


Figure 3.6 Weed and shade scores in 1998, 2002 planted plots and control sites

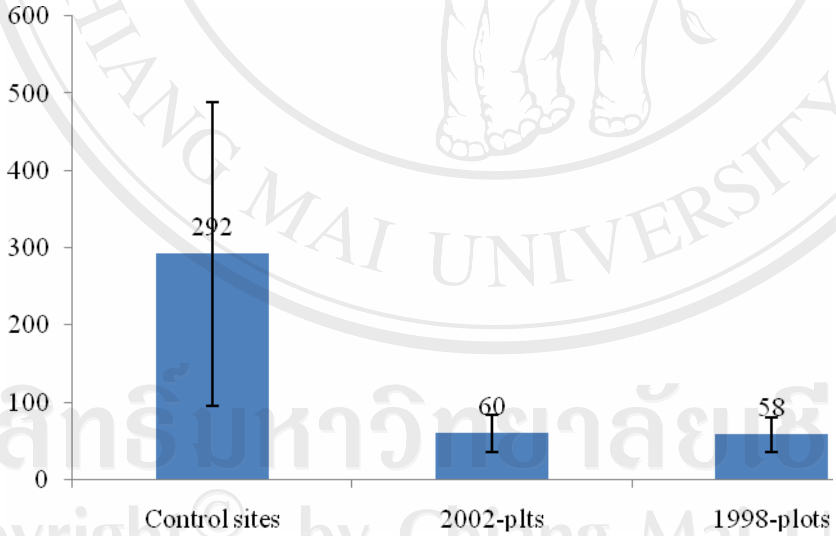


Figure 3.7 Light intensity (x20,000 lux) in 1998, 2002 planted plots and unplanted plots


Figure 3.8 the aluminum pole was set on the center of circular sampling units

Figure 3.9 the canopy of planted tree in 1998 plots, many tree stratum

Figure 3.10 The ground flora was seedling, more shade and leaf litter accumulation

Figure 3.11 The canopy of planted trees in 2002-planted plots

Figure 3.12 Planted trees in 2002 and the ground flora

Figure 3.13 In unplanted site, covered by weed

**Rectangular sampling units**

In 1999, plots were established using three different densities of planted trees (2.3, 1.8 and 1.5 m between trees at planting time) and some of the replicated plots had been affected by fire in some places since 1 year after planting, replication 2 (normal planted and low density planted plots). The 10x30 rectangular sampling units were set in each three planted densities (1 treatment had three replications).

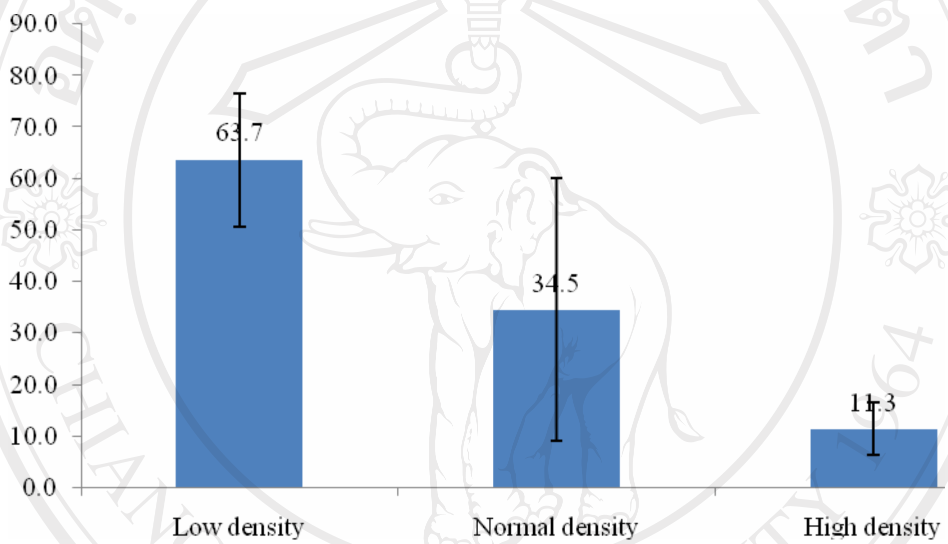


Figure 3.14 Light intensity (x20000 lux) in three planted tree densities in1999-plots

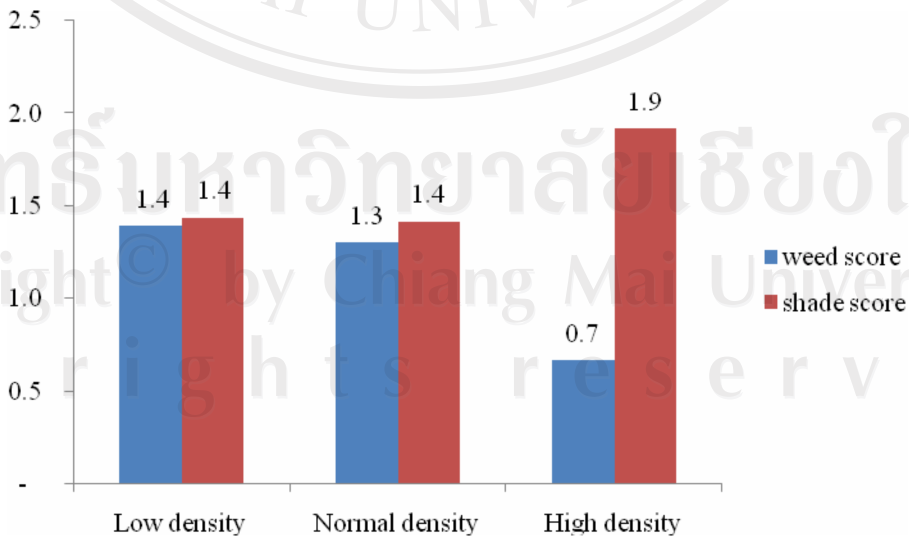


Figure 3.15 Weed and shade score in 1999-plots

Figure 3.16 Low planted density in 1999-plots, more sunlight and more weed

Figure 3.17 Normal planted density plots

Figure 3.18 High planted density plot, many trunk of trees

## CHAPTER 4

## MATERIALS AND METHODS

### 3.1 Material

1. Aluminium poles
2. Ropes
3. Pocketknife
4. Compass
5. Study area map
6. GPS
7. Measuring tapes
9. Recorded forms
10. Clipboard
11. Vernier calipers
12. labeling tags

### 3.2 Data Collection

3.2.1 Effects of plot age on tree recruitment

Circular sample units (diameter 10 m) previously laid out in each of the three replicates of plots planted in 1998 (8 years since planting); 2002 (4 years since planting) and in non-planted control plots demarcated in 1998 (8 years ago) were re-surveyed for naturally established trees. In each replicate, 4 circular sample units were surveyed (totally 12 in the 1998 plots; 12 in the 2000 plots and 12 in the control plots). Samples have already been laid out using a metal pole to mark the centre of each unit and string 5 m long to delineate the unit boundary.

All naturally established, non-planted recruit seedlings, saplings and trees in each circular SU were identified, labeled and measured. Data collected included species (identified by expert in Herbarium, Department of Biology, Chiang Mai University); height, root collar diameter (using vernier calipers) for smaller trees and girth at breast height (using tape measure) for larger ones; canopy width and health (1 for nearly dead to 3 for perfect health) (FORRU, 1998). This survey was repeated three times over 1 year 2006-07 (summer, dry season and 2$^{nd}$ rainy season).

3.2.2 Effects of planted tree density on natural recruitment

The effects of different planting densities and fire were examined by surveying the 1999 plots that included 3 replicates each planted at low, medium and high densities (2.3, 1.8 and 1.5 m between trees at planting time respectively). Furthermore, fire had an additional effect on reducing the current density of planted trees in some subplots. Therefore, rectangular plots in the centre of each replicated 1999 plot (leaving a boundary strip of 10 meters) were laid out in order to record the density and species composition of all naturally establishing recruit trees. Within these sample units, the number (direct counting), size and species of surviving planted framework tree species were measured to determine the current density of planted trees. Each sample unit was then thoroughly surveyed for any naturally establishing trees. Data collected included species, height, tree trunk diameter, canopy width, shading, weed and health of the seedlings and nearest framework tree species and the distance (between each recruit tree and nearest framework tree). This survey was carried out 3 times in the summer, post rainy and dry season.

## 3.3 Data analysis

Species richness (direct counting), evenness, species diversity (Hill's number) and distance coefficients (Chord distance: CRD) were calculated by the basic computer program SPDIVERS. BAS and SUDIST.BAS (Ludwig and Reynolds, 1998). Species-area curve in subplots were created using Coleman's equation. Relative growth rate (RGR), and percentage of survival were analyzed.

**Ecological indices**

**Species Richness**

N0 = total number of seedling

**Species diversity indices**

Species diversity (Hill's number) of seedlings and bird communities in each studied plot were calculated by the following indices (N1, N2)

$N1 = e^{H'}$
$N2 = 1/\lambda$

Where: N1 = number of abundant species in the studied plot
N2 = number of very abundant species in the studied plot



H' = Shannon's index
$\lambda$ = Simpson's index

**Shannon's Index (H')**

$$H' = \Sigma p_i \ln p_i$$

**Simpson's Index (λ)**

$$\lambda = \Sigma p_i^2$$

Where: $p_i$ = proportion of individuals of the i $^{th}$ species

$p_i$ = ni/N

Where: $n_i$ = number of individual of the i $^{th}$ species

N = total number of individual

S = total number of species

**Evenness (Modified Hill's Index)**

$$\mathbf{E5} = \frac{(1/\lambda) - 1}{e^{H'} - 1} = \frac{N2-1}{N1-2}$$

**Distance coefficients**

Distance coefficient are mostly based on calculated the sum of the difference between the abundance scores of each species in each sampling units. Ludwig and Reynold (1998) recommended the use of chord distance: CRD. This measure puts greater importance on the relative proportion of species in sampling units and correspondingly less importance on their absolute quantities. CDR range in value from 0 to the square root of 2.

$CRD_{jk}$ = square of 2(1- *c* $\cos_{jk}$)

Where $CRD_{jk}$ = Chord distance between the $j^{th}$SU and $k^{th}$SU

$$c\cos jk = \frac{(X_{ij}X_{ik})}{\text{Square of } X^2_{ij}.\ X^2_{ik}}$$

Where $X_{ij}$ = Number of individual of the $i^{th}$species in the $j^{th}$ SU

$X_{jk}$ = Number of individual of the $i^{th}$species in the $k^{th}$ SU

**Relative growth rate**

Root collar diameter and height of natural tree seedlings were calculated the relative growth rate of root collar diameter (RRGR) and relative growth rate of height (RHGR) by formulas as follows:

**Relative growth rate of root collar diameter (RRGR)**

$$\text{RRGR (\% increase per year)} = \frac{[\ln(RCD2) - \ln(RCD1)] \times 3600}{T2-T1}$$

Where: RCD2 = root collar diameter of seedling in the last survey

RCD1 = root collar diameter of seedling in the first survey

T2-T2 = number of days between T1 and T2

In = natural log

**Seedling mortality percentage**

Percentage of seedling mortality was calculated as follows:

Mortality percentage = (number mortality /Total numbers of seedlings) x 100

Figure 4.1 Expert plant taxonomist, J.F.Maxwell, who identify tree seedlings

Figure 4.2 Seedling of *Litsea monopetala* (Roxb.) Pers., animal dispersed species

Figure 4.3 *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulate*, wind dispersed species

Figure 4.4 *Phoebe lanceolata* (Wall ex Nees) Nees, animal dispersed species and mother tree in planted sites

# CHAPTER 5

# RESULTS

## 1. Overall Seedling Surveys in Forest Restoration Areas

A "seedling", in this survey, is defined as a tree or treelet from expansion of true leaves up to a height of 1 meter. After three surveys during April 2006 and July 2007 in the 1998, 1999 and 2002 planted plots, 3,650 individual seedlings (some were technically "saplings") were recorded, representing a total of 108 species. In the non-planted control plots, only 345 tree seedlings were found, representing 42 species. The highest diversity index was recorded in the in 1999-plots (N1=23.56, N2=11.75 and E5=0.69) (Table 5.1) and highest numbers of recruited species (62 species), because survey areas (2,700 square meter) was higher for the others. The species area curves by rarefaction (Ludwig and Reynolds, 1998) (Figure 5.1) of the 1999-plots were higher than others and support the highest tree seedling diversity in 1999-plots.

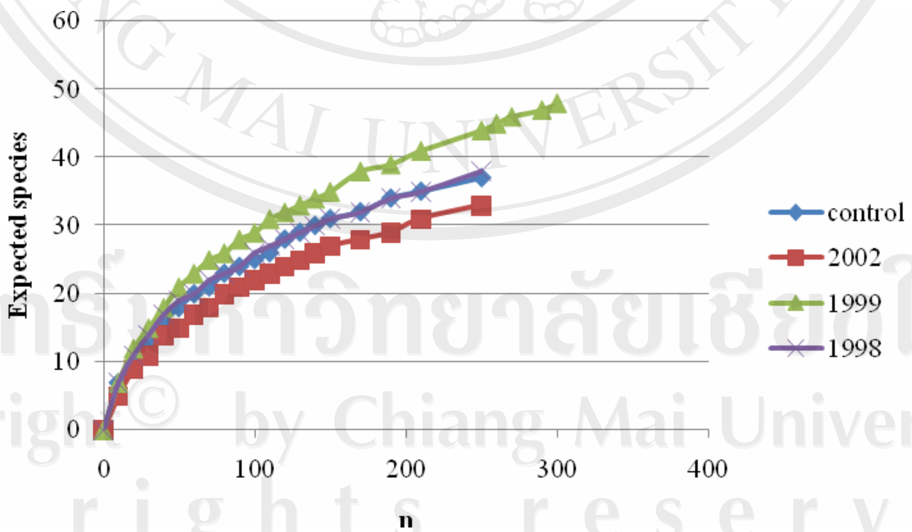


Figure 5.1 Species area curves by rarefaction in 1998, 1999, 2002 and control plots

Table 5.1 Total ecological diversity index of seedlings in forest restoration areas

| Plots | N0 | N1 | N2 | E5 | recruited species | planted species |
|---|---|---|---|---|---|---|
| control sites | 345 | 14.73 | 8.33 | 0.53 | 23.00 | 19.00 |
| 2002 | 553 | 10.48 | 11.75 | 1.13 | 27.00 | 20.00 |
| 1999 | 1883 | 23.56 | 11.75 | 0.70 | 62.00 | 28.00 |
| 1998 | 1009 | 19.10 | 11.17 | 0.56 | 33.00 | 26.00 |
| Total | 3790 | 29.07 | 10.79 | 0.35 | 73.00 | 35.00 |

Except for the 1999-planted plots, the Hill's numbers (N1 and N2), ecological diversity index, were calculated for each age of plots. N1 of 1998 plots (19.1) was the highest while N2 (11.16) was a little lower than in the 2002 plots (11.75) according to evenness value (E5) was above than other plots. Therefore, species diversity also increased with plot age (Table 5.1). The total areas of survey in each age of planted plots was 942 square meter (= 12 circular sampling units). The total of species in 1998, 2002 planted sites and control sites were 59, 47 and 42, respectively.

Average population density of natural seedlings was 0.56 tree per square meter, thus in 1600 square meters (= 1 rai), there were about 894 natural established seedlings. Since the planting density was about 500 trees per rai, natural regeneration more than doubled the tree population density on average. Moreover, most seedling and species, recorded in all plots, were animal dispersed species (Figure 5.2 and 5.3).

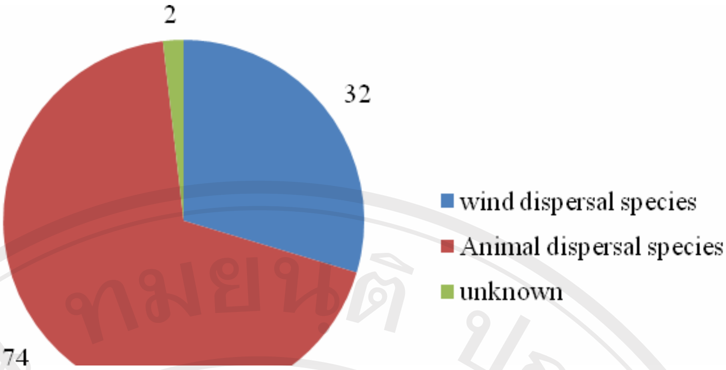


Figure 5.2 Seedling species categorized by dispersal Mechanism all surveys

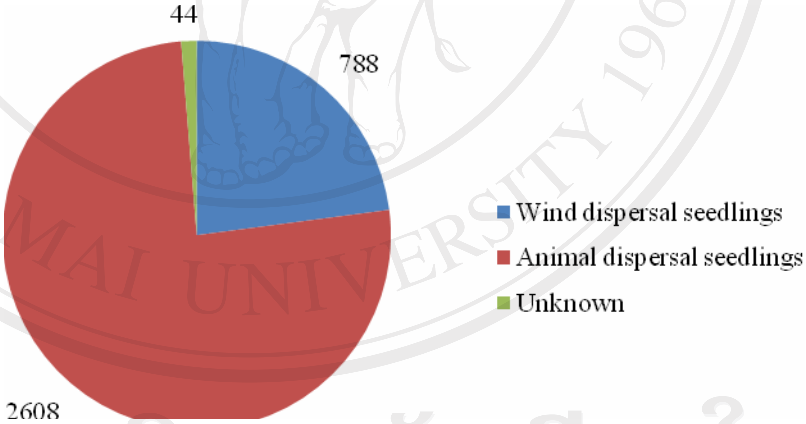




Figure 5.3 Numbers of seedlings individuals categorized by dispersal mechnism all surveys



Seedlings could be divided into 2 groups: i) those of the same species as the planted framework trees in the 1998 plots, considered as "planted species" and ii) those of non-planted species, considered as "recruit species" (Appendix A). The planted group was represented by 35 species (1381 individual seedlings), whilst the recruited group was represented by 73 species (2159 individual seedlings). The numbers of individual seedlings and species found in all sample tree plots are shown in Appendix A. The most abundant animal-dispersed species were *Litsea monopetala* (Roxb.) Pers. (Lauraceae) (908 seedlings), *Phoebe lanceolata* (Wall ex Nees) Nees (Lauraceae) (316 seedlings), *Prunus cerasoides* Ham. ex D. Don (Lauraceae) (258 seedlings), *Antidesma acidum* Retz. (Euphorbaceae) (145 seedlings), *Aporusa octandra* (Buch.-Ham. ex D. Don) (Euphorbaceae) (105 seedlings), *Ficus hirta* Vahl var. *hirta* (Moraceae) (132 seedlings) and *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (Fagaceae) (77 seedlings). The commonest wind-dispersed species were *Erythrina stricta* Roxb. (Leguminosae, Papilionoideae) (121 seedlings), *Erythrina subumbrans* (Hassk.) Merr. (Leguminosae, Papilionoideae) (111 seedlings) and *Schima wallichii* (DC.) Korth. (Theaceae) (131 seedlings).

Seedling and sapling species were classified as pioneer or climax species using the following criteria (FORRU database, 2004):

- Sun or shade treatments of seed germination in the FORRU nursery. Seed species which could germinate in more sunlight were classed as pioneer species, whilst shade-tolerant species were climax species.
- Field seedling performance: Seedlings, with high relative growth rates in plantation areas, were classed as pioneers, whilst low relative growth rate seedling species were classed as climax species.
- Life span and growth-forms: Pioneer species grow fast but have a short life – span, whilst climax species grow slowly but they have long life-spans.
- Field survey habitats of adult tree distribution: Trees located in the opened areas and degradation areas, were classed as pioneer species whilst most climax species are in abundant natural forests.

Some species could be defined clearly as pioneers or climax species, whereas others had various combinations of both pioneer and climax traits. Therefore five categories were used: climax, climax> pioneer, pioneer>climax, pioneer and pioneer=climax. More than half of the recorded seedlings were pioneers (55 species), the number of climax species was a quarter of total species (21 species) (figure 5.4).

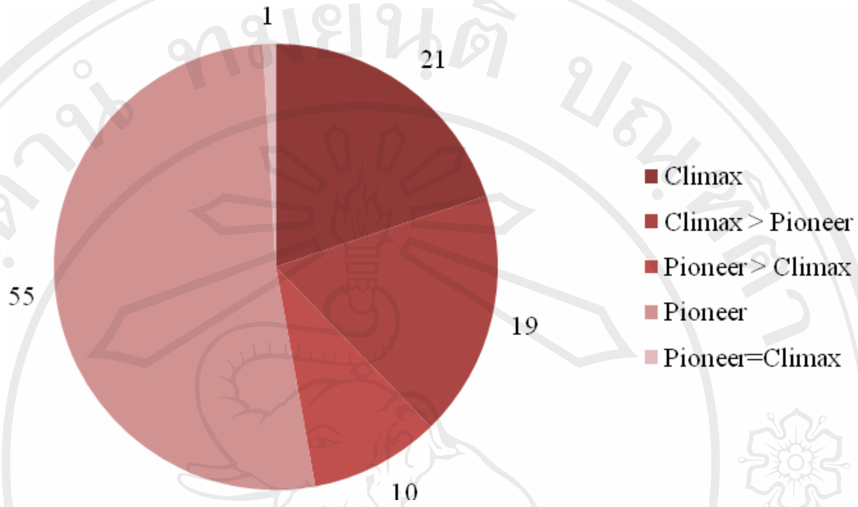


Figure 5.4 The types of seedling species

## 2. Effects of framework tree species on seedling establishment

The planted trees (framework trees), whose crowns covered the seedlings, were also recorded and given "seedling scores" = the number of seedlings occurring beneath each tree crown. The sum of the scores for each framework tree species (species a) were divided by the counted tree numbers of species a, to indicate the effectiveness of each framework tree species in fostering seedling establishment. Sometimes a single seedling occurred beneath the crowns of several planted trees (since tree crowns overlapped), particularly in the 1998 and 1999 planted plots, so the score (1) was divided among the overhead tree crowns. To illustrate, if seedling grew under framework tree A and framework tree B, the framework tree A scored 0.5 and framework tree B scored 0.5, as well.

Beneath 57 planted tree species from all planted plot (1998, 1999, 2002 planted plots), a total score of 456 was recorded and the seedling species list is presented in Appendix A. The top ten planted tree species which fostered the largest numbers of saplings beneath their crowns (highest seedling scores), were *Ficus glaberrima* Bl. var. *glaberrima* (Moraceae) (score=15.5, 6 seedling species), *Prunus cerasoides* D. Don (Rosaceae) (score=10.6, 6 seedling species), *Nyssa javanica* (Bl.) Wang. (Nyssaceae) (score=9.7, 10 seedlings species), *Erythrina subumbrans* (Hassk.) Merr. (Leguminosae, Papilionoideae) (score=11.6, 11 seedling species), *Gmelina arborea* Roxb. (Verbenaceae) (score=14.5, 9 seedling species), *Hovenia dulcis* Thunb. (Rhamnacea) (score=8.5, 4 seedling species), *Spondias axillaris* Roxb. (Anacardiaceae) (score=8.3, 10 seedlings species), *Acrocarpus fraxinifolius* Wight ex Arn. (Leguminosae, Caesalpinioideae) (score=20, 8 seedling species), *Heynea trijuga* Roxb. ex Sims (Meliaceae) (score=15.2, 6 seedling species), and *Michelia baillonii* Pierre (Magnoliaceae) (score=8.5, 6 seedling species). Most of the seedling species recorded were dispered by animals (Table 5.3)

Table 5.3 The species list of framework tree, seedling score and numbers of animal dispersed and recruited species.

| Framework tree species list | Seedling score | Number of animal dispersed and recruited species |
|---|---|---|
| 1. *Acrocarpus fraxinifolius* Wight ex Arn. | 20 | 8 |
| 2. *Acronychia pedunculata* (L.) Miq. | 2.8 | 6 |
| 3. *Albizia chinensis* (Osb.) Merr. | 10.75 | 4 |
| 4.*Antidesma bunius* (L.) Spreng. | 0.75 | 1 |
| 5. *Antidesma ghaesembilla* Gaertn. | 4 | 2 |
| 6. *Aphanamixis polystachya* (Wall.) R. Parker | 4.5 | 1 |
| 7. *Aporusa villosa* (Lindl.) Baill. | 4 | 0 |
| 8. *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | 1 | 0 |
| 9. *Balakata baccata* (Roxb.) Ess. | 6.7 | 7 |
| 10. *Betula alnoides* Ham. ex D. Don | 2 | 1 |
| 11. *Bischofia javanica* Bl. | 13.5 | 1 |
| 12. *Callicarpa arborea* Roxb. var. *arborea* | 10 | 4 |
| 13. Castanopsis acuminatissima (Bl.) A. DC. | 3 | 4 |
| 14. *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | 7.625 | 5 |
| 15. *Castanopsis diversifolia* ( Kurz) King ex Hk. f. | 3 | 0 |
| 16. *Castanopsis tribuloides* (Sm.) A. DC. | 24 | 3 |
| 17. *Catunaregam spathulifolia* Tirv. | 1 | 1 |
| 18. *Cinnamomum caudatum* Nees | 26.5 | 5 |
| 19. *Dalbergia cultrata* Grah. ex Bth. | 12 | 3 |
| 20. *Diospyros glandulosa* Lace | 18.75 | 4 |
| 21. *Elaeocarpus lanceifolius* Roxb. | 7.5 | 2 |
| 22. *Erythrina subumbrans* (Hassk.) Merr. | 11.625 | 11 |
| 23. *Eugenia albiflora* Duth. ex Kurz | 5 | 0 |
| 24. *Eurya acumminata* DC. var. *wallichiana* Dyer | 1 | 0 |
| 25. *Ficus altissima* Bl. | 15.9 | 9 |
| 26. *Ficus benjamina* L. var. *benjamina* | 6.3 | 3 |
| 27. *Ficus capillipes* Gagnep. | 1 | 1 |
| 28. *Ficus fistulosa* Reinw. ex Bl. var. *fistulosa* | 5 | 2 |
| 29. *Ficus glaberrima* Bl. var. glaberrima | 15.5 | 6 |
| 30. *Ficus hispida* L. f. var. *hispida* | 3 | 0 |
| 31. *Ficus subincisa* J.E. Sm. var. *subincisa* | 3.875 | 3 |
| 32. *Ficus racemosa* L. var. *racemosa* | 5.4 | 5 |
| 33. *Garcinia mckeaniana* Craib | 4 | 2 |
| 34. *Glochidion sphaerogynum* (M.-A.) Kurz | 2 | 1 |
| 35. *Gmelina arborea* Roxb. | 14.5 | 9 |
| 36. *Helicia nilagirica* Bedd. | 6.4 | *6* |
| 37. *Heynea trijuga* Roxb. ex Sims | 15.2 | 6 |

| Framework tree species list | Seedling score | Number of animal dispersed and recruited species |
|---|---|---|
| *38. Horsfieldia amygdalina* (Wall.) Warb. var. *amygdalin*a | 6 | 1 |
| *39. Hovenia dulcis* Thunb. | *8.5* | 4 |
| *40. Lithocarpus fenestratus* (Roxb.) Rehd. | 8 | 3 |
| *41. Macaranga denticulata* (Bl.) M.-A. | 8.4 | 5 |
| *42. Machilus bombycina* King ex Hk. f. | 6.7 | 7 |
| *43. Mallotus paniculatus* (Lmk.) M.-A. | 1 | 1 |
| *44. Manglietia garrettii* Craib | 9 | 3 |
| *45. Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* | 10 | 4 |
| *46. Maesa ramentacea* (Roxb.) A.DC. | 1 | 0 |
| *47. Melia toosendan* Sieb. & Zucc. | 4.4 | 5 |
| *48. Michelia baillonii* Pierre | 8.5 | 6 |
| *49. Nyssa javanica* (Bl.) Wang. | 9.7 | 10 |
| *50. Phoebe lanceolata* (Wall. ex Nees) Nees | 9.9 | 2 |
| *51. Prunus cerasoides* D. Don | 10.6 | 6 |
| *52. Pterocarpus macrocarpus* Kurz | 7.7 | 3 |
| *53. Quercus semiserrata* Roxb. | 6 | 3 |
| *54. Rhus rhetsoides* Craib | 4.4 | 3 |
| *55. Sapindus rarak* DC. | 7 | 3 |
| *56. Sarcosperma arboreum* Bth. | 19 | 2 |
| *57. Spondias axillaris* Roxb. | 8.3 | 10 |

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### 3. Age Effect on seedling establishment

Natural seedlings were recorded in 5-metre-radius circular sampling units, three times (Summer, dry season and 2nd rainy season) in 1998-plots (8 year-old), 2002-plots (4 year-old) and unplanted sites (0 year old). The numbers of new saplings found increased with each subsequent survey (Figure 5.5). Furthermore, the number of individual saplings recorded increased with the age of the plots. The seedlings in Figure 5.5 were not the total surviving seedlings from all survey because some seedlings died between surveys. One way ANOVA, however showed no significant differences between plot age and numbers of seedlings recorded for all surveys (first survey, P=0.69) (second survey, P=0.08) (third survey, P=0.18).

The numbers of new seedlings found in planted sites, particularly 1998 plots, tended to tended to increase with each subsequent survey. In the 1998 plot, the seedling numbers of first seedling survey was 341. The seconded survey added 389 and the final survey 403 (Figure 5.5). In contrast in the non-planted sites fewer and fewer seedlings were added to the total found with each subsequent survey.

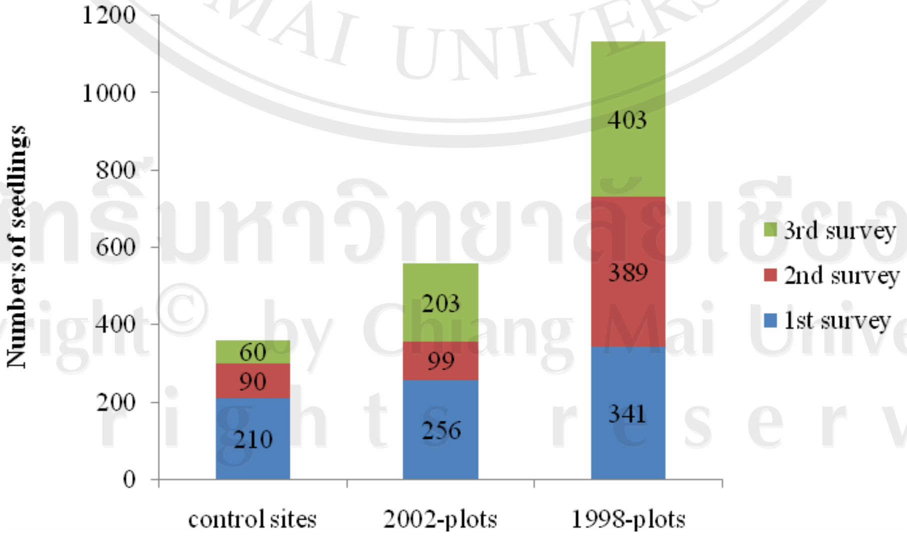


Figure 5.5 All found seedlings in control sites and planted plots (2002 and 1998)

All recorded seedling species were grouped by seed dispersal mechanism (including wind and animal dispersal agent). Most seedlings species were animal-dispersal in all sampling plots. Moreover, the proportion of animal dispersal species increased with increasing plot age (Figure 5.6).

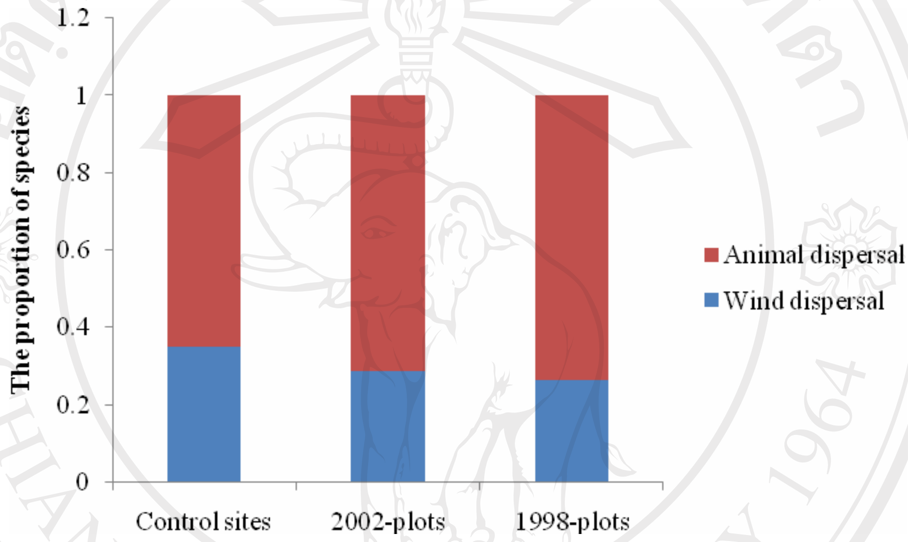


Figure 5.6 The proportion of seedling species (Seed dispersal mechanism)

in control sites and 2002-plots and 1998-plots

Most species were pioneer species in all plots (Figure 5.7). However, in the older plots were, the proportion of climax species tended to increase in proportion. In the 1998 plots, the proportion of climax>pioneer and climax species was greater than 0.5, whilst the proportion of pioneer and pioneer> climax in control sites was 0.7, and the proportions in the 2002 plots were half and half.

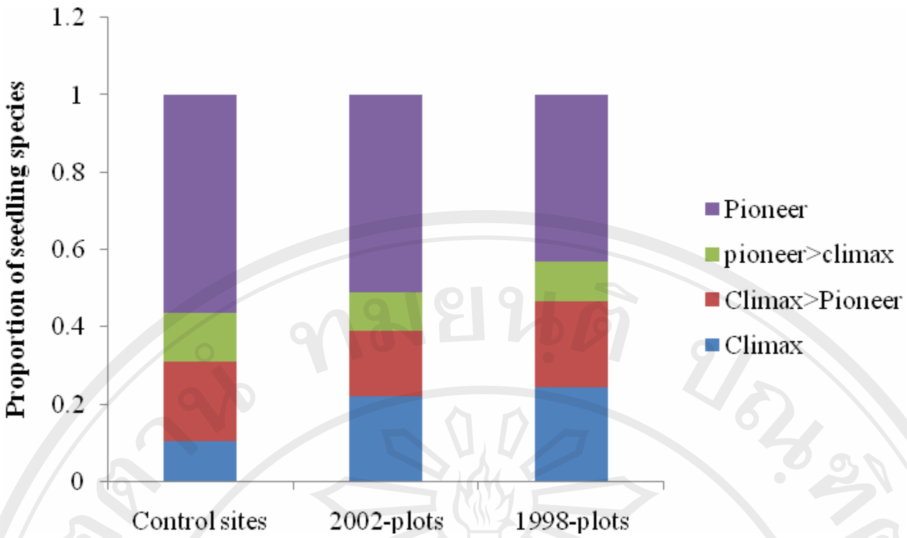


Figure 5.7 The proportion of seedling species, classified by pioneer or climax species

The species diversity index of recruited seedling, Hill's numbers, was calculated. The highest diversity was in 1998 plots (N1= 8.84 and N2=5.83) (Table 5.4). The numbers of individual seedlings and species increased due to plot ages. The most seeds of recruited seedling were dispersed by animals. The numbers of animal-dispersed species grew up following the planted years (Tabled 5.4).

Table 5.4 The diversity index of seedling recruitment in 1998, 2002 plots and control plots

| Plots | species richness | wind-dispersed species | animal-dispersed species | Unknown species | N0 | N1 | N2 | E5 |
|---|---|---|---|---|---|---|---|---|
| 1998 plots | 33 | 9 | 25 | | 435 | 8.84 | 5.83 | 0.62 |
| 2002 plots | 27 | 9 | 18 | 2 | 429 | 5.15 | 2.52 | 0.36 |
| control plots | 23 | 8 | 14 | | 217 | 8.76 | 3.86 | 0.37 |

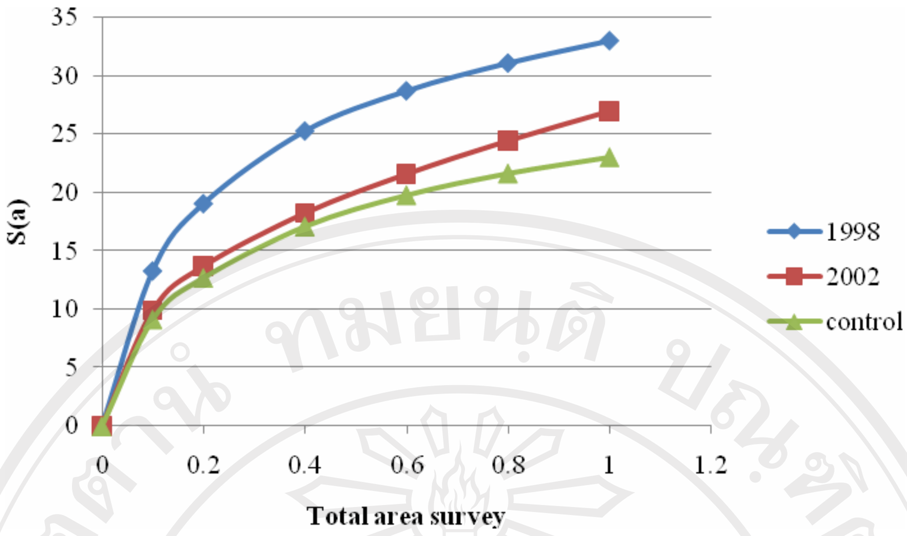


Figure 5.8 Species area curves of recruited species by coleman's equation

in 1998, 2002 planted sites and control sites

Seedling Mortality

After the first 3-month survey, the percentage seedling mortality in the non-planted sites (18.76) was the highest compared with the planted plots, especially the 1998-plots (5.76%) about three times (Figure 5.9). However, when percent seedling mortality was tested by chi square, the results showed that between mortality percentage and survival percentage in the control plots was significant differences. In the last survey (about 9 months), mortality increased in the planted plots about two fold in the 2002-plots (from 17.23% to 28.94%) and six fold (5.67% to 33.87%) in the 1998 plots, whilst the mortality of seedlings in non-planted sites more than doubled from 18.76% to 49.16% (Figure5.12). Consequently, as plot age increased, mortality rate decreased.

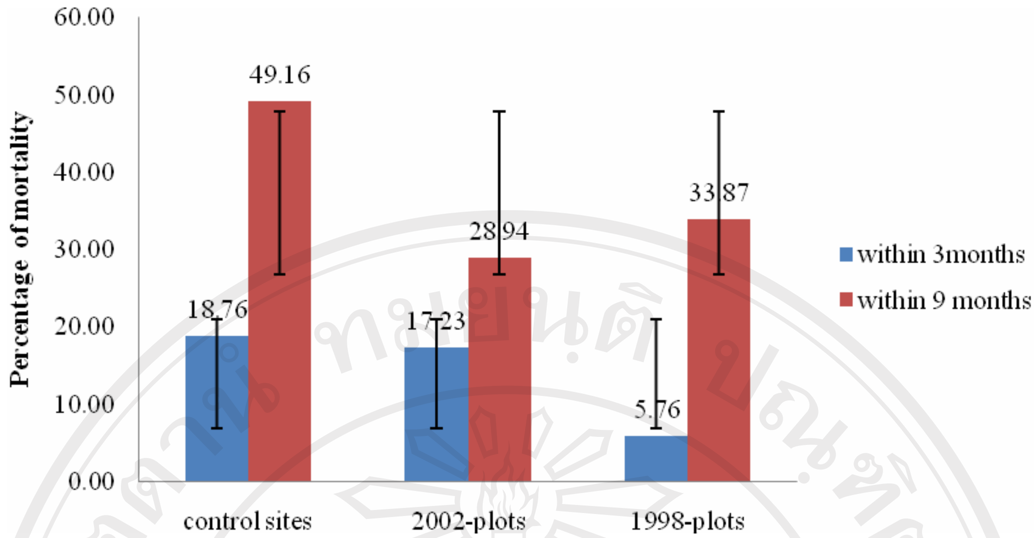


Figure 5.9 Average percentage of seedling mortality within 3 and 9 months

The total population density of recorded seedlings in the control sites was 0.25 (400 seedlings/1600 square meters) whilst it was e 0.37 and 0.67 tree/square meter in 2002 and 1998 plots respectively (587 and 1067 seedlings/1600 square meter) (Figure5.10). Planted plots supported double the numbers of saplings compared with non-planted sites.

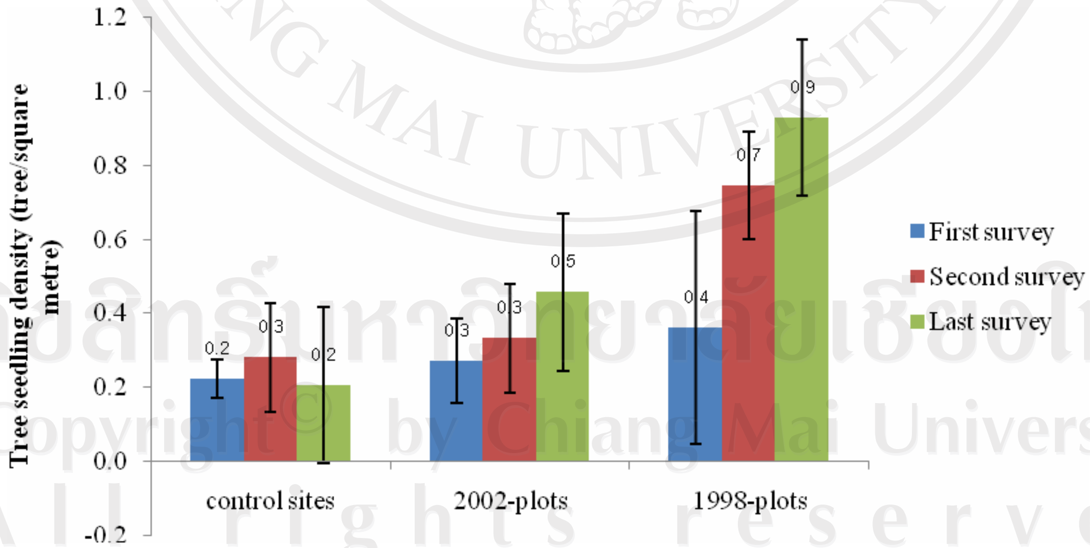


Figure 5.10 The total seedling densities in control sites, 2002 and 1998 planted plots

The community of recorded saplings in the 1998-plots was dominated by those of planted tree species *Castanopsis cerebrina* (76 seedlings), *Erythrina subumbrans* (107 seedlings) and *Heynea trijuga* (44 seedlings). The most common recruit species were *Litsea monopetala* (211 seedlings), and *Aporusa octandra* (44 seedlings). In 2002 plots, *Litsea monopetala* (265 seedlings), *Antidesma ghaesembilla* (44 seedlings), and *Wendlandia scabra* (34 seedlings) were common. A lot of *Litsea monopetala* (81seedlings) and *Aporusa octandra* (58 seedlings) were also recorded in unplanted sites, and *Xantolis burnmanica* was common in the control plots  but were much less common in the in the 1998-plots. The numbers of some species varied with the plot age , such as of the pioneer species , *Litsea cubeba* which declined in numbers with increasing age plots, while *Phoebe lanceolata* increased with plot age (Table 5.5).

Table 5.5 The species composition and numbers in control sites and planted sites (2002 and 1998 plots)

| Species list | Dispersal mechanism | Type | Planted/non-planted | Control sites | 2002-plots | 1998-plots |
|---|---|---|---|---|---|---|
| *Acacia megaladena* Desv. var. *megaladena* | W | P | Recruited | 2 | 4 | 0 |
| *Acrocarpus fraxinifolius* Wight ex Arm. | W | P>C | Planted | 6 | 0 | 0 |
| *Albizia chinensis* (Osb.) Merr. | W | P | Planted | 0 | 0 | 1 |
| *Albizia garrettii* Niels. | W | C | Recruited | 0 | 1 | 5 |
| *Alseodaphine andersonii* (King ex Hk. f.) Kosterm. | A | C | Planted | 0 | 0 | 1 |
| *Anneslea fragrans* Wall. | A | P | Recruited | 1 | 0 | 0 |
| *Antidesma acidum* Retz. | A | P | Recruited | 11 | 14 | 13 |
| *Antidesma bunius* (L.) Spreng. | A | C | Recruited | 0 | 1 | 0 |
| *Antidesma ghaesembilla* Gaertn. | A | P | Planted | 0 | 44 | 4 |
| *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | A | P>C | Recruited | 58 | 5 | 44 |
| *Aporusa villosa* (Lindl.) Baill. | A | P | Planted | 0 | 1 | 24 |
| *Aquilaria crassna* Pierre ex Lec. | A | C | Recruited | 0 | 0 | 3 |
| *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | W | P | Planted | 1 | 0 | 2 |
| *Areca laosensis* Becc. Arenga caudata (lour.) H.E. Moore | A | C | Recruited | 0 | 0 | 1 |
| *Artocarpus lakoocha* Roxb. | A | P | Planted | 2 | 5 | 6 |
| *Bauhinia variegata* L. | W | P | Recruited | 0 | 1 | 0 |
| *Beilschmiedia assamica* | W | P | Recruited | 0 | 1 | 0 |
| *Bombax anceps* Pierre var. *anceps* | W | P | Recruited | 0 | 1 | 4 |
| *Bombax ceiba* L. | W | P | Recruited | 3 | 0 | 0 |
| *Bridelia glauca* Bl. var. *glauca* | A | C>P | Recruited | 0 | 1 | 5 |
| *Broussonetia papyrifera* (L.) Vent. | A | P | Recruited | 0 | 1 | 0 |

| Species list | Dispersal mechanism | Type | Planted/non-planted | Control sites | 2002-plots | 1998-plots |
|---|---|---|---|---|---|---|
| *Canthium parvifolium* Roxb. | A | P | Recruited | 6 | 0 | 3 |
| *Castanopsis acuminatissima* (Bl.) A. DC. | A | C | Recruited | 0 | 2 | 0 |
| *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | A | C | Planted | 1 | 0 | 76 |
| *Castanopsis diversifolia* (Kurz) King ex Hk. f. | A | C>P | Planted | 0 | 3 | 0 |
| *Castanopsis tribuloides* (Sm.) A. DC. | A | C | Planted | 0 | 5 | 5 |
| *Chionanthus ramiflorus* Roxb. | A | C>P | Recruited | 0 | 0 | 1 |
| *Cinnamomum caudatum* Nees | A | C | Planted | 0 | 0 | 5 |
| *Clausena excavata* Burm. f. var. *excavate* | A | C | Recruited | 0 | 0 | 1 |
| *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. | W | P | Recruited | 4 | 0 | 2 |
| *Dalbergia cultrata* Grah. ex Bth. | W | P>C | Planted | 0 | 1 | 1 |
| *Dalbergia stipulacea* Roxb. | W | P | Recruited | 0 | 10 | 22 |
| *Debregeasia longifolia* (Burm. f.) Wedd. | A | P=C | Recruited | 0 | 1 | 0 |
| *Diospyros glandulosa* Lace | A | C>P | Recruited | 0 | 0 | 4 |
| *Ehretia acuminata* R. Br. var. *acuminate* | A | P>C | Recruited | 0 | 0 | 1 |
| *Embelia* sp. | | | | 0 | 11 | 0 |
| *Engelhardia spicata* Lechen. ex Bl. var. *spicata* | W | C | Recruited | 0 | 0 | 3 |
| *Erythrina stricta* Roxb. | W | P>C | Recruited | 2 | 2 | 34 |
| *Erythrina subumbrans* (Hassk.) Merr. | W | P | Planted | 1 | 1 | 107 |
| *Eugenia albiflora* Duth. ex Kurz | A | C | Planted | 6 | 6 | 33 |
| *Eugenia fruticosa* (DC.) Roxb. | A | C | Recruited | 5 | 2 | 8 |
| *Eurya acumminata* DC. var. *wallichiana* Dyer | A | P | Planted | 1 | 0 | 0 |
| *Fagraea fragrans* Roxb. | A | P | Recruited | 1 | 0 | 0 |
| *Ficus fistulosa* Reinw. ex Bl. var. *fistulosa* | A | P | Recruited | 1 | 0 | 0 |
| *Ficus hirta* Vahl var. *hirta* | A | P | Recruited | 8 | 8 | 7 |
| *Ficus hispida* L. f. var. *hispida* | A | P | Planted | 0 | 1 | 2 |

| Species list | Dispersal mechanism | Type | Planted/non-planted | Control sites | 2002-plots | 1998-plots |
|---|---|---|---|---|---|---|
| *Glochidion acuminatum* M.-A. var. *siamense* A.S. | A | P | Recruited | 0 | 0 | 6 |
| *Glochidion eriocarpum* Champ. | A | P | Recruited | 0 | 0 | 3 |
| *Glochidion kerrii* Craib | A | C | Recruited | 0 | 0 | 1 |
| *Gluta obovata* | W | P | Recruited | 6 | 0 | 0 |
| *Heynea trijuga* Roxb. ex Sims | A | P>C | Planted | 1 | 0 | 44 |
| *Ixora cibdela* Craib | A | P | Recruited | 0 | 1 | 1 |
| *Lagerstroemia cochinchinensis* Pierre var. *ovalifolia* Furt. & Mont. | W | C>P | Recruited | 0 | 0 | 0 |
| *Leea indica* (Burm. f.) Merr. | A | P | Recruited | 2 | 16 | 7 |
| *Lithocarpus polystachtus* (A. DC.) Rehd. | A | P | Recruited | 1 | 0 | 0 |
| *Litsea cubeba* (lour.) Pers. var. *cubeba* | A | P | Recruited | 36 | 29 | 4 |
| *Litsea monopetala* (Roxb.) Pers. | A | C>P | Recruited | 81 | 265 | 211 |
| Litsea salicifolia (Roxb. ex Nees) Hk.f. | A | C>P | Recruited | 0 | 0 | 1 |
| *Machilus bombycina* King ex Hk. f. | A | C | Planted | 0 | 0 | 3 |
| *Maesa ramentacea* (Roxb.) A.DC. | A | C>P | Planted | 2 | 1 | 0 |
| *Mallotus philippensis* (Lmk.) M.-A. | A | P | Planted | 0 | 13 | 2 |
| *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulate* | W | P>C | Planted | 3 | 0 | 11 |
| *Michelia baillonii* Pierre | A | C>P | Planted | 4 | 0 | 3 |
| *Michelia floribunda* Fin. & Gagnep. | A | C>P | Recruited | 0 | 0 | 6 |
| *Micromelum hirsutum* Oliv. | A | C | Recruited | 2 | 12 | 0 |
| *Micromelum minutum* (Forst. f.) Wight & Arn. | A | C | Recruited | 0 | 0 | 13 |
| *Millettia macrostachya* Coll. & Hemsl. var. *macrostachya* | W | P | Recruited | 0 | 0 | 1 |
| *Morinda tomentosa* Hey. ex Roth | A | P | Recruited | 0 | 1 | 0 |
| *Oroxylum indicum* (L.) Kurz | W | P | Planted | 0 | 4 | 0 |
| *Phoebe lanceolata* (Wall. ex Nees) Nees | A | C | Planted | 8 | 20 | 124 |

| Species list | Dispersal mechanism | Type | Planted/non-planted | Control sites | 2002-plots | 1998-plots |
|---|---|---|---|---|---|---|
| *Prunus cerasoides* Ham. ex D. Don | A | P | Planted | 5 | 3 | 64 |
| *Pterocarpus macrocarpus* Kurz | A | P | Planted | 1 | 6 | 0 |
| *Rhus chinensis* Mill. | A | P | Recruited | 0 | 0 | 9 |
| *Rhus rhetsoides* Craib | A | P>C | Planted | 3 | 0 | 0 |
| *Sapindus rarak* DC. | A | C>P | Planted | 0 | 0 | 2 |
| *Sarcosperma arboreum* Bth. | A | C | Recruited | 0 | 1 | 0 |
| *Schima wallichii* (DC.) Korth. | W | C>P | Planted | 21 | 7 | 46 |
| *Spondias axillaris* Roxb. | A | P>C | Planted | 8 | 3 | 1 |
| *Sterculia villosa* Roxb. | W | C>P | Recruited | 3 | 3 | 8 |
| *Stereospermum colais* (B.-H. ex Dillw.) Mabb. | W | C>P | Recruited | 1 | 0 | 0 |
| *Trema orientalis* (L.) Bl. | W | P | Recruited | 4 | 0 | 0 |
| *Turpinia pomifera* (Roxb.) Wall. ex DC. | A | C>P | Recruited | 0 | 0 | 1 |
| *Wendlandia scabra* Kurz var. *scabra* | W | P | Recruited | 1 | 34 | 0 |
| *Wendlandia tinctoria* (Roxb.) DC. ssp. *floribunda* (Craib) Cowan | W | C>P | Planted | 0 | 0 | 7 |
| *Xantolis burnmanica* (Coll. & Hemsl.) P. Royen | A | P | Recruited | 32 | 0 | 2 |
| Unknown 1 | | | | 0 | 1 | 0 |
| Total | | | | 452 | 556 | 614 |

Remark

A= animal dispersed species, W= wind dispersed species, P=pioneer species, C=climax species

Differences in the species communities in each treatment were tested by distance coefficient (Chord distance). Between control sites vs. 2002 plots, seedling communities were more similar (0.72) than for control sites vs. 1998 plots (chord distance=1.13) and 2002 and 1998 plots (chord distance= 1.33) (Table 5.6).

Table 5.6 Chord distance values of three planted age plots

| Plots | Control sites | 1998-plots |
|---|---|---|
| 2002-plots | 0.72 | 1.33 |
| 1998-plots | 1.13 | |

The seedling heights were grouped according to size: 0-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, 41-50 cm, 51-60 cm, 61-70 cm, 71-80 cm, and over 80 cm. Histograms of height distributions are shown in Figure 5.10. In all sites, the most height class was 11-20 cm. Fewer seedlings were 21- over 80 cm height in all planted plots, but some presented in planted plots more than control plots.

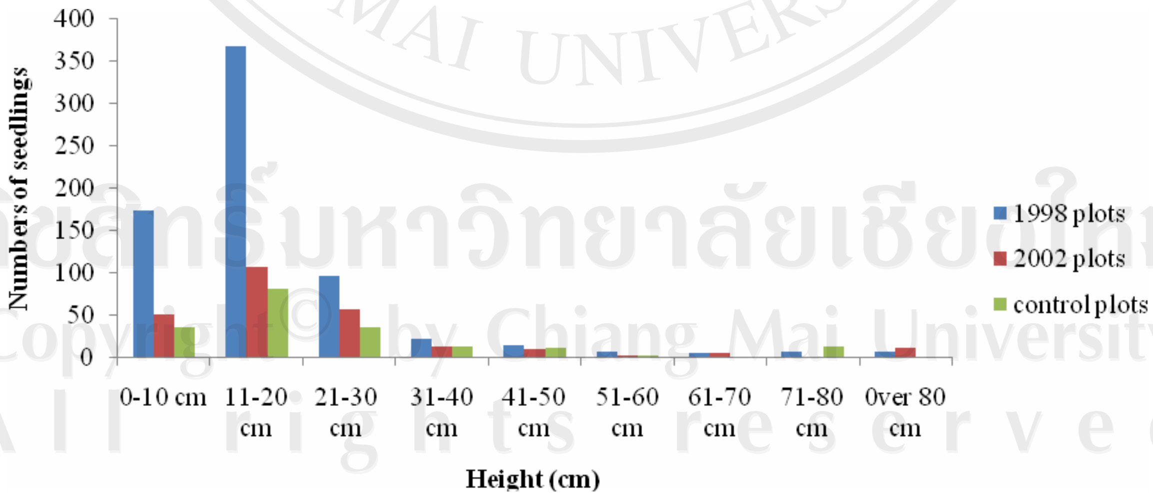


Figure 5.11 The numbers of seedlings in height groups

The relative growth rate: RGR of surviving seedlings by root collar diameter was calculated. *Bridelia glauca* (RGR=33.4633), *Engelhardia spicata* (RGR=27.0734), and *Erythrina stricta* (RGR=23.7777) grew very well in 1998 plots, *Albizia garrettii* (RGR= 68.2963) and *Eugenia fruticosa* (RGR=37.4299) in 2002 had high RGR. In the unplanted sites, *Acacia megaladena* (RGR=27.9108), *Spondias axillaris* (RGR=32.9865) and *Trema orientalis* (RGR=24.9533) had outstanding growth (Table 5.7).

Table 5.7 RGR of root collar diameter of survival seedlings in 2002, 1998 planted plots and control sites

| Species list | Control sites | 2002-plots | 1998-plots |
|---|---|---|---|
| *Acacia megaladena* Desv. var. *megaladena* | 27.9108 | | |
| *Acrocarpus fraxinifolius* Wight ex Arm. | 8.0332 | | |
| *Albizia garrettii* Niels. | | 68.2963 | 0.0000 |
| *Anneslea fragrans* Wall. | 18.3897 | | |
| *Antidesma acidum* Retz. | 5.7992 | | 6.3014 |
| *Antidesma bunius* (L.) Spreng. | | | |
| *Antidesma ghaesembilla* Gaertn. | | 0.7408 | 0.0000 |
| *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | 8.2508 | 0.0000 | 12.0728 |
| *Aporusa villosa* (Lindl.) Baill. | | 1.0000 | 0.0000 |
| *Aquilaria crassna* Pierre ex Lec. | | | 0.0000 |
| *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | | | |
| *Areca laosensis* Becc. Arenga caudata (lour.) H.E. Moore | | | |
| *Artocarpus lakoocha* Roxb. | | 0.0000 | 0.0000 |
| *Bombax anceps* Pierre var. *anceps* | | | 0.0000 |
| *Bridelia glauca* Bl. var. *glauca* | | | 33.4633 |
| *Broussonetia papyrifera* (L.) Vent. | | 12.1130 | |
| *Canthium parvifolium* Roxb. | 2.5253 | | 17.0048 |
| *Castanopsis acuminatissima* (Bl.) A. DC. | | 2.6025 | |
| *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | | | 3.2400 |
| *Castanopsis diversifolia* (Kurz) King ex Hk. f. | | 0.0000 | |
| *Castanopsis tribuloides* (Sm.) A. DC. | | 8.4601 | 2.5758 |
| *Chionanthus ramiflorus* Roxb. | | | 3.4312 |
| *Cinnamomum caudatum* Nees | | | 11.7700 |
| *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. | 12.1130 | | 4.1191 |
| *Dalbergia cultrata* Grah. ex Bth. | | | 14.5967 |
| *Dalbergia stipulacea* Roxb. | | | 7.6939 |
| *Engelhardia spicata* Lechen. ex Bl. var. *spicata* | | | 27.0734 |
| *Erythrina stricta* Roxb. | 2.0000 | 0.0000 | 23.7777 |

| Species list | Control sites | 2002-plots | 1998-plots |
|---|---|---|---|
| *Erythrina subumbrans* (Hassk.) Merr. | 1.0000 | 1.0000 | 10.3791 |
| *Eugenia albiflora* Duth. ex Kurz | 6.0000 | 3.0917 | 3.0004 |
| *Eugenia fruticosa* (DC.) Roxb. | 0.0000 | 37.4299 | 0.0000 |
| *Eurya acumminata* DC. var. *wallichiana* Dyer | 1.0000 | | |
| *Fagraea fragrans* Roxb. | 1.0000 | | |
| *Ficus fistulosa* Reinw. ex Bl. var. *fistulosa* | -8.0332 | | |
| *Ficus hirta* Vahl var. *hirta* | -0.3381 | 12.4766 | 24.9533 |
| *Ficus hispida* L. f. var. *hispida* | | 6.0867 | |
| *Glochidion acuminatum* M.-A. var. *siamense* A.S. | | | 9.0531 |
| *Glochidion eriocarpum* Champ. | | | 1.0141 |
| *Heynea trijuga* Roxb. ex Sims | | | 2.5855 |
| *Ixora cibdela* Craib | | 0.0000 | 0.0000 |
| *Leea indica* (Burm. f.) Merr. | 0.0000 | | 12.1907 |
| *Litsea cubeba* (lour.) Pers. var. *cubeba* | 2.1195 | 14.6646 | 22.6299 |
| *Litsea monopetala* (Roxb.) Pers. | 8.7729 | 8.7821 | 14.5967 |
| Litsea salicifolia (Roxb. ex Nees) Hk.f. | | | 0.0000 |
| *Machilus bombycina* King ex Hk. f. | | | 0.2330 |
| *Maesa ramentacea* (Roxb.) A.DC. | | | |
| *Mallotus philippensis* (Lmk.) M.-A. | | | 2.3010 |
| *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulate* | 0.0000 | 4.0166 | 7.5964 |
| *Michelia baillonii* Pierre | 7.7146 | | 0.0000 |
| *Michelia floribunda* Fin. & Gagnep. | | | 14.5967 |
| *Micromelum hirsutum* Oliv. | 18.6220 | 0.0000 | |
| *Morinda tomentosa* Hey. ex Roth | | 16.2715 | |
| *Oroxylum indicum* (L.) Kurz | | 0.0000 | |
| *Phoebe lanceolata* (Wall. ex Nees) Nees | 15.2817 | 12.1401 | 2.6360 |
| *Prunus cerasoides* Ham. ex D. Don | 7.2241 | 0.0000 | 11.7767 |
| *Pterocarpus macrocarpus* Kurz | 0.0000 | 0.0000 | |
| *Rhus chinensis* Mill. | | | 2.6687 |
| *Rhus rhetsoides* Craib | 8.7134 | | |
| *Sarcosperma arboreum* Bth. | | 12.2734 | |
| *Schima wallichii* (DC.) Korth. | -5.1783 | 2.7747 | 12.8406 |
| *Spondias axillaris* Roxb. | 32.9865 | | 1.0000 |
| *Sterculia villosa* Roxb. | | | 0.0000 |
| *Trema orientalis* (L.) Bl. | 24.9533 | | |
| *Wendlandia scabra* Kurz var. *scabra* | | 0.8675 | |
| *Wendlandia tinctoria* (Roxb.) DC. ssp. *floribunda* (Craib) Cowan | | | 0.0000 |
| *Xantolis burnmanica* (Coll. & Hemsl.) P. Royen | 8.5503 | | 0.0000 |

### 3. Effects of tree planting density on sapling recruitment density

The total numbers of recorded saplings in 1999-plots in three surveys (in the same plots of planted trees) are shown in Figure 5.12. Seedling numbers were highest in the high planting density plots (737), moderate in the normal planting density plots (612), and lowest (568) in the low density sites.

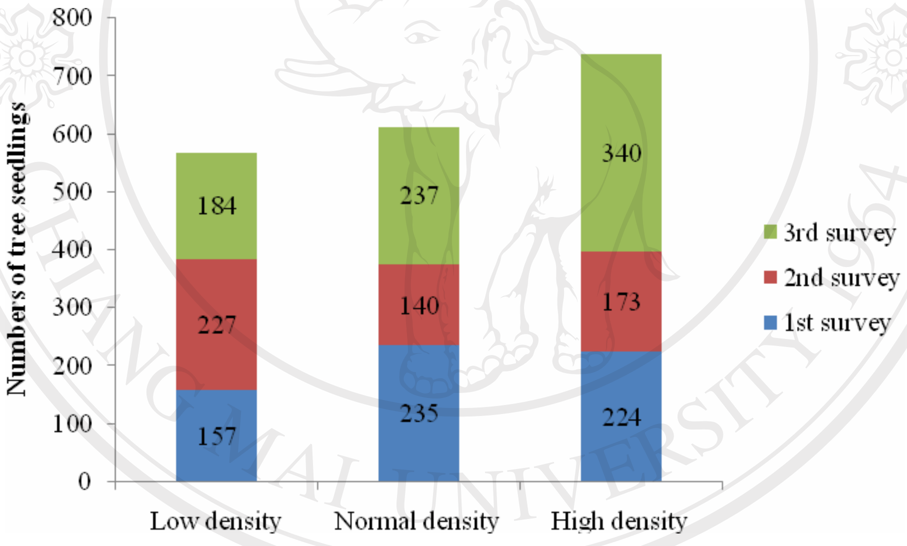


Figure 5.12 The total recorded numbers of tree seedlings in 1999-plots

(low, normal and high planted densities)

However, numbers of planted trees since 1999 in the high planted density plots reduced, so the planted tree densities were nearly similar with normal planted density plots (Figure 5.13). There were not different significantly seedling numbers between the high, normal and low planted density plots because the effect of fire on the seedling numbers in normal and low planted density in the replication 2 were lower than other sampling plots (Figure 5.13) (more information in PART 4: Effect by fire).

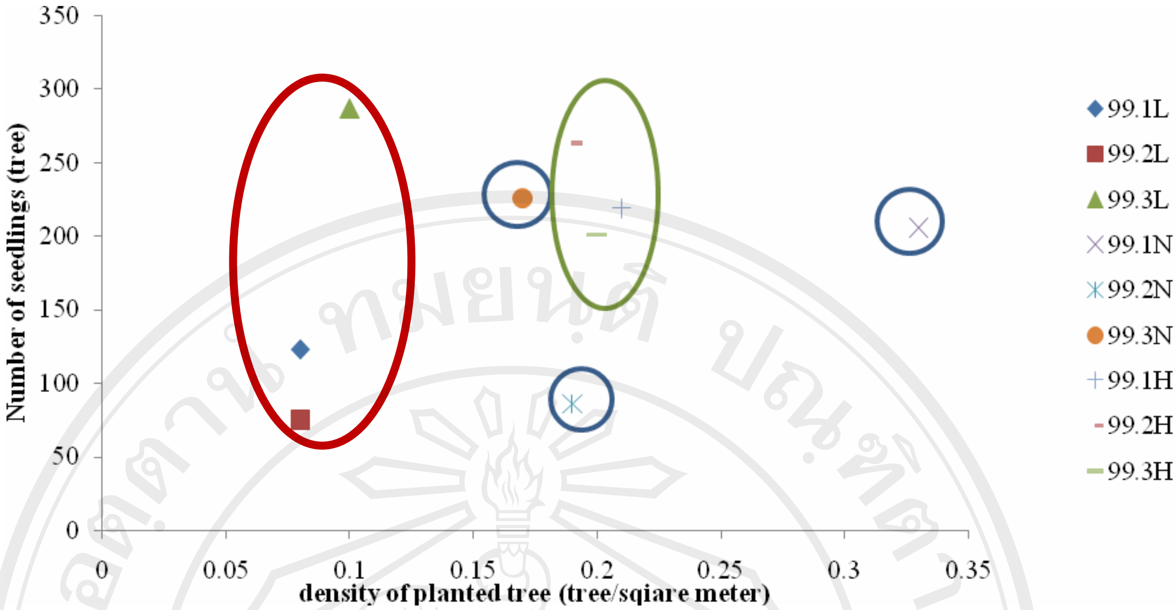


Figure 5.13 The relationship between numbers of natural seedlings and currently planted density in each plots (the red circle = low planted density, the blue circle= normal planted density, and the green circle=high planted density)

In the second survey (3 months after the first survey), some seedlings had died. In the low density plot was 7.3% 2.5 times higher than (than in the normal and high density plots) (Figure 5.14). However, after 9 months, seedling mortality dramatically increased, particularly in normal density (32.3%) and low density (20.8%) plots.

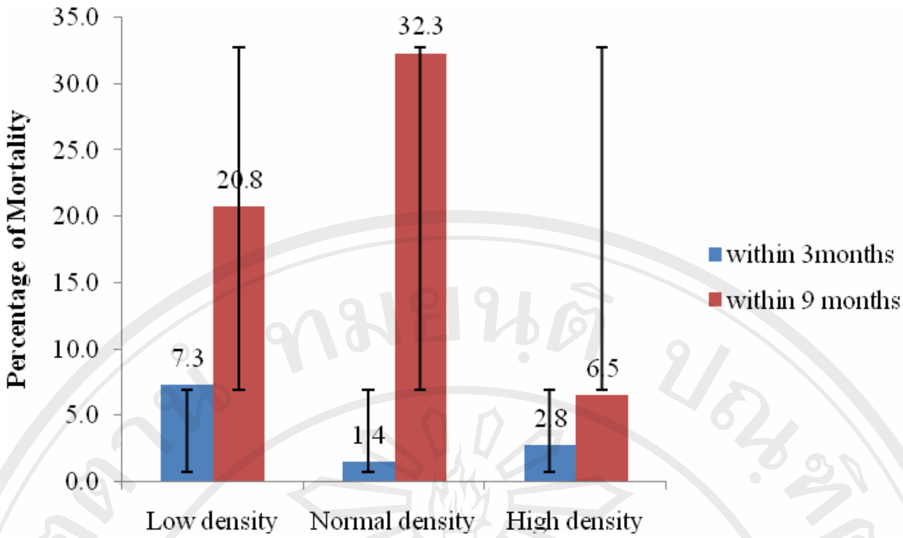


Figure 5.14 Percentage of seedling mortality within 3 and 9 months in 1999 plots

The replicate 2 of normal density had been burnt (more information in PART 4: Effect by fire), so the forest structure of this site was similar that of open areas, covered with grasses, more sunlight, was not suitable for seedling survival (Figure 5.15).

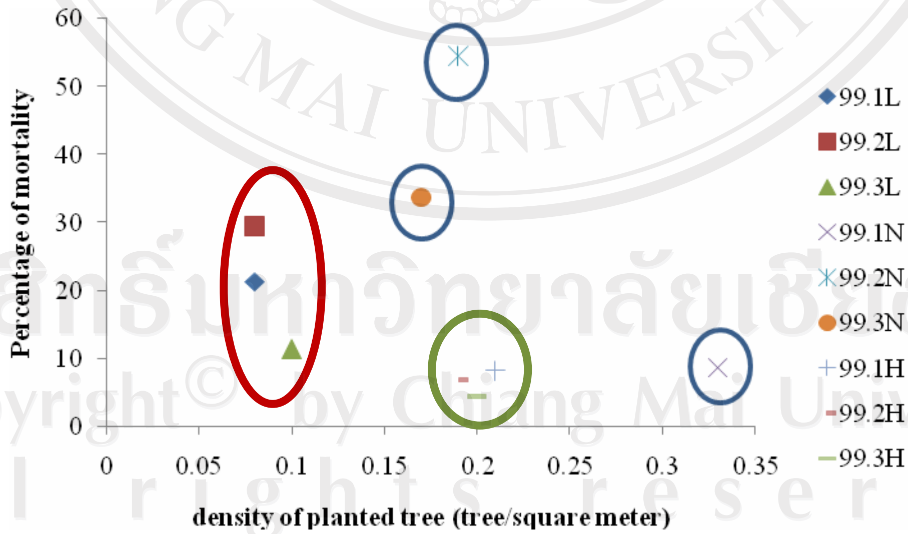


Figure 5.15 The relationship between seedlings mortality and currently planted density in each plots (the red circle = low planted density, the blue circle= normal planted density, and the green circle=high planted density)

Over three surveys, the numbers of seedlings increased overall, although some seedlings died. Consequently, most of the seedlings survived, in particular in the high planted density plots (total 695 seedlings) (Figure 5.16).

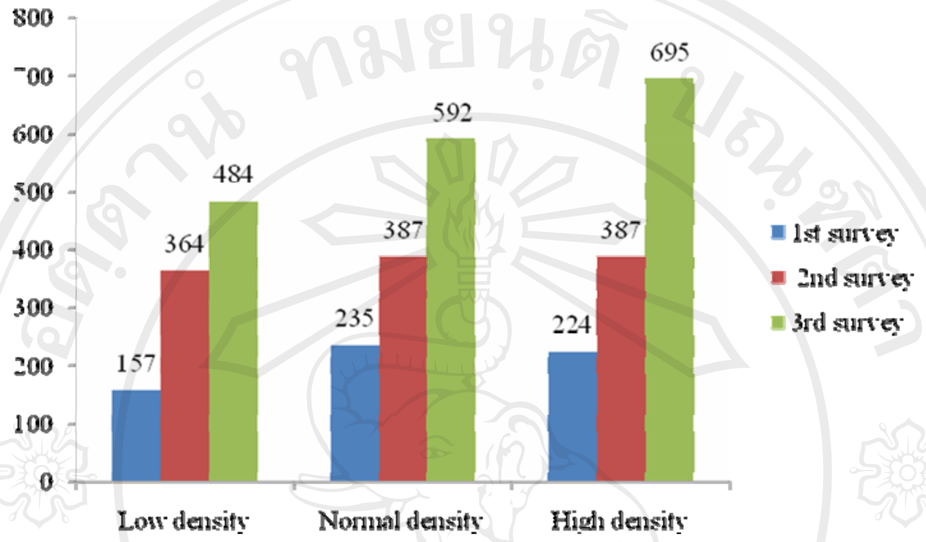


Figure 5.16 The total survival seedlings in 1999-plots each survey

Next, average population density of followed natural seedlings was calculated. This was the same trend as total survival seedlings. From these values, the estimation was occurred in the last survey, there were 863 seedlings in the low density plots, not so very different from normal density plots (921 seedlings), whilst in high density there were 1,214 saplings

Total community species composition is shown in table 5.8. Most species, were recorded all sampling units, including *Litsea monopetala*, *Antidesma acidum*, *Aporusa octandra*, *Phoebe lanceolata*, *Prunus cerasoides*, *Ficus hirta*, all of which are animal dispersed (Figure 5.20). Seedlings of *Erythrina stricta*, *Markhamia stipulata* and *Schima wallichii*, all wind seed dispersed species, were also found in all sampling units.

Table 5.8 Species list and individual numbers of 1999 planted plots with three densities

| Species List | Dispersal mechanism | Framework species | Numbers of seedlings Low density | Normal density | High density |
|---|---|---|---|---|---|
| *Acacia megaladena* Desv. var. *megaladena* | W | Recruited | 1 | 1 | 47 |
| *Alangium kurzii* Craib | A | Recruited | 0 | 1 | 0 |
| *Albizia chinensis* (Osb.) Merr. | W | Planted | 4 | 5 | 18 |
| *Albizia garrettii* Niels. | W | Recruited | 3 | 0 | 3 |
| *Albizia odoratissima* (L. f.) Bth. | W | Recruited | 1 | 1 | 0 |
| *Alstonia scholaris* var. *scholaris* | W | Recruited | 2 | 0 | 0 |
| *Antidesma acidum* Retz. | A | Recruited | 4 | 62 | 33 |
| *Antidesma bunius* (L.) Spreng. | A | Planted | | | 1 |
| *Antidesma ghaesembilla* Gaertn | A | Planted | 4 | 0 | 0 |
| *Aporusa octandra* (B.-H. ex D. Don) Vick. var. octandra | A | Recruited | 19 | 16 | 21 |
| *Aporusa villosa* (Lindl.) Baill. | A | Planted | 6 | 6 | 3 |
| *Archidendron clypearia* (Jack) Niels. ssp. Clypearia var. clypearia | W | Planted | | | 30 |
| *Artocarpus lakoocha* Roxb. | A | Planted | 2 | 2 | 0 |
| *Bauhinia racemosa* Lmk. | W | Recruited | 0 | 7 | 0 |
| *Bauhinia variegata* L. | W | Recruited | 0 | 2 | 0 |
| *Bombax anceps* Pierre var. *anceps* | W | Recruited | 2 | 1 | 2 |
| *Bridelia glauca* Bl. var. *glauca* | A | Recruited | 2 | 0 | 0 |
| *Bridelia stipularis* (L.) Bl. | A | Recruited | 4 | 0 | 0 |
| *Canarium subulatum* Guill. | A | Recruited | | | 1 |
| *Canthium parvifolium* Roxb. | A | Recruited | 0 | 5 | 0 |
| *Castanopsis acuminatissima* (Bl.) A. DC. | A | Planted | 0 | 1 | 1 |
| *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | A | Planted | 0 | 1 | 0 |
| *Castanopsis diversifolia* (Kurz) King ex Hk. f. | A | Planted | 2 | 0 | 0 |

| Species List | Dispersal mechanism | Framework species | Numbers of seedlings | | |
|---|---|---|---|---|---|
| | | | Low density | Normal density | High density |
| *Cinnamomum caudatum* Nees | A | Recruited | 5 | 3 | 4 |
| *Clausena excavata* Burm. f. | A | Recruited | 1 | 0 | 0 |
| *Cratoxylum formosum* (Jack) Dyer ssp. *pruniflorum* (Kurz) Gog. | W | Recruited | 1 | 0 | 0 |
| *Dalbergia rimosa* Roxb. var. *rimosa* | W | Planted | 0 | 2 | 2 |
| *Dalbergia stipulacea* Roxb. | W | Recruited | 2 | 8 | 32 |
| *Dalbergia cultrata* Grah. ex Bth. | W | Recruited | 0 | 2 | 43 |
| *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* | W | Recruited | 9 | 0 | 2 |
| *Embelia* sp. | | Recruited | 8 | 0 | 3 |
| *Engelhardia spicata* Lechen. ex Bl. var. *spicata* | W | Recruited | 1 | 4 | 1 |
| *Erythrina stricta* Roxb. | W | Recruited | 61 | 17 | 7 |
| *Erythrina subumbrans* (Hassk.) Merr. | W | Planted | 3 | 0 | 0 |
| *Eugenia albiflora* Duth. ex Kurz | A | Planted | 2 | 4 | 0 |
| *Eugenia fruticosa* (DC.) Roxb. | A | Recruited | 4 | 3 | 1 |
| *Eurya acumminata* DC. var. wallichiana Dyer | A | Planted | 4 | 1 | 1 |
| *Fernandoa adenophylla* (Wall. ex G. Don) Steen. | W | Recruited | | | 1 |
| *Ficus fistulosa* Reinw. ex Bl. var. fistulosa | A | Recruited | 0 | 1 | 2 |
| *Ficus hirta* Vahl var. hirta | A | Recruited | 54 | 45 | 18 |
| *Ficus hispida* L. f. var. hispida | A | Planted | | | 1 |
| *Ficus obtusifolia* Roxb. | A | Recruited | 2 | 0 | 0 |
| *Ficus subincisa* J.E. Sm. var. *subincisa* | A | Planted | 3 | 0 | 1 |
| *Glochidion acuminatum* M.-A. var. siamense A.S. | A | Recruited | 0 | 1 | 0 |
| *Glochidion eriocarpum* Champ. | A | Recruited | 1 | 1 | 0 |
| *Glochidion kerrii* Craib | A | Recruited | 1 | 0 | 1 |
| *Glochidion sphaerogynum* (M.-A.) Kurz | A | Planted | 0 | 1 | 0 |
| *Gmelina arborea* Roxb. | A | Planted | | | 1 |

| Species List | Dispersal mechanism | Framework species | Numbers of seedlings | | |
|---|---|---|---|---|---|
| | | | Low density | Normal density | High density |
| *Heynea trijuga* Roxb. ex Sims | A | Planted | 1 | 0 | 0 |
| *Hymenodictyon orixense* (Roxb.) Mabb. | A | Recruited | 0 | 1 | 0 |
| *Ixora cibdela* Craib | A | Recruited | 2 | 2 | 0 |
| *Lagerstroemia cochinchinensis* Pierre var. *ovalifolia* Furt. & Mont. | W | Recruited | | | 2 |
| *Leea indica* (Burm. f.) Merr. | A | Recruited | 3 | 7 | 5 |
| *Lithocarpus polystachtus* (A. DC.) Rehd. | A | Recruited | 0 | 2 | 2 |
| *Litsea cubeba* (lour.) Pers. var. *cubeba* | A | Recruited | 6 | 9 | 2 |
| *Litsea monopetala* (Roxb.) Pers. | A | Recruited | 127 | 178 | 127 |
| *Machilus bombycina* King ex Hk. f. | A | Planted | 1 | 1 | 0 |
| *Maesa ramentacea* (Roxb.) A.DC. | A | Planted | 1 | 1 | 0 |
| *Mallotus philippensis* (Lmk.) M.-A. | A | Planted | 2 | 0 | 0 |
| *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* | W | Planted | 6 | 24 | 32 |
| *Melia toosendan* Sieb. & Zucc. | A | Planted | | | 1 |
| *Melientha suavis* Pierre ssp. *suavis* | A | Recruited | 1 | 0 | 0 |
| *Michelia baillonii* Pierre | A | Planted | 1 | 0 | 0 |
| *Michelia floribunda* Fin. & Gagnep. | A | Recruited | 0 | 1 | 1 |
| *Micromelum hirsutum* Oliv. | A | Recruited | 0 | 12 | 0 |
| *Millettia pubinervis* Kurz | A | Recruited | | | 3 |
| *Oroxylum indicum* (L.) Kurz | W | Planted | 0 | 1 | 0 |
| *Pavetta tomentosa* Roxb. ex Sm. var. tomentosa | A | Recruited | 1 | 0 | 0 |
| *Phoebe cathia* (D. Don) Kosterm. | A | Recruited | 0 | 1 | 0 |
| *Phoebe lanceolata* (Wall. ex Nees) Nees | A | Planted | 44 | 40 | 87 |
| *Phyllanthus emblica* L. | A | Planted | 3 | 1 | 2 |
| *Prismatomeris tetrandra* (Roxb.) K. Sch. ssp. *tetrandra* | A | Recruited | 3 | 0 | 1 |
| *Prunus cerasoides* Ham. ex D. Don | A | Planted | 65 | 28 | 96 |

| Species List | Dispersal mechanism | Framework species | Numbers of seedlings | | |
|---|---|---|---|---|---|
| | | | Low density | Normal density | High density |
| *Rhus rhetsoides* Craib | A | Planted | 5 | 1 | 0 |
| *Schima wallichii* (DC.) Korth. | W | Planted | 30 | 35 | 13 |
| *Spondias axillaris* Roxb. | A | Planted | 7 | 2 | 8 |
| *Sterculia lanceolata* Cav. var.lanceolata | W | Recruited | 1 | 0 | 0 |
| *Sterculia villosa* Roxb. | W | Recruited | 1 | 0 | 2 |
| *Stereospermum colais* (B.-H. ex Dillw.) Mabb. | W | Recruited | 0 | 1 | 0 |
| *Styrax benzoides* Craib | A | Recruited | 0 | 4 | 41 |
| *Tarennoidea wallichii* (Hk. f.) Triv. & Sastre | A | Recruited | 0 | 1 | 0 |
| *Turpinia pomifera* (Roxb.) Wall. ex DC. | A | Planted | 1 | 22 | 0 |
| *Vernonia volkameriifolia* DC. var. volkameriifolia | W | Recruited | 5 | 0 | 0 |
| *Wendlandia scabra* Kurz var. scabra | W | Recruited | 5 | 1 | 4 |
| *Wendlandia tinctoria* (Roxb.) DC. ssp. *floribunda* (Craib) Cowan | W | Planted | 1 | 2 | 5 |
| Unknown 1 | | Recruited | 0 | 10 | 0 |
| Unknown 2 | | Recruited | 1 | 0 | 1 |
| total no. | | | **493** | **612** | **724** |

Remark:

A=animal dispersed species, W=wind dispersed species

Diversity index, Hill's number, was used. N1 is number of abundant species in the sample, and N2 is number of very abundant species in the sample. The highest value for N1was in the low density plots (N1=18.17) (Table 5.9), while in high density plots had the highest values of N2, 11.84. However, the high density plots supported only 50 species, 724 individual seedlings. On the other hand, the low planted density plots supported 59 species and there were only 547 seedlings.

Table 5.9 Ecological diversity index (Hill's numbers) of all recorded seedlings in 1999-plots

| Sites | N0 | N1 | N2 | E5 | species richness |
|---|---|---|---|---|---|
| Low density | 547 | 18.16 | 9.71 | 0.51 | 59 |
| Normal density | 612 | 10.48 | 8.57 | 0.89 | 56 |
| High density | 724 | 17.98 | 11.84 | 0.63 | 50 |

The recruited seedling species were the lowest in the high planted density, while contained the most individual numbers (Table 5.10). Moreover, the most species dispersed by animals in all plots. The diversity index, Hill's numbers, of recruited seedling was also calculated, consequently seedlings in the normal planted density was the high ecological diversity (Table 5.9). The species area curves by coleman's equation showed that the highest diversity was in the normal planted density plots (Figure 5.l7).



Table 5.10 Ecological index of recruited species in 1999-plots

| | N0 | N1 | N2 | E5 | species richness | wind dispersed species | animal dispersed species |
|---|---|---|---|---|---|---|---|
| Low density | 165 | 7.46 | 4.25 | 0.50 | 20 | 4 | 16 |
| Normal density | 164 | 9.87 | 7.17 | 0.70 | 20 | 5 | 15 |
| High density | 335 | 7.10 | 5.34 | 0.71 | 17 | 5 | 12 |

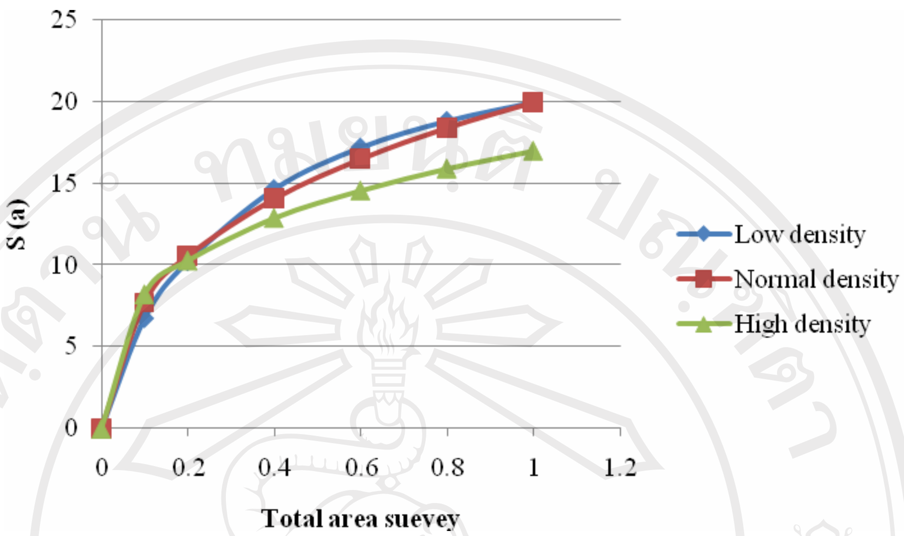


Figure 5.17 Species area curves of seedling recruited species by coleman's equation

The similarity values of all seedling species in each plot were calculated by chord distance (CRD). The most difference of species composition was normal and high planted densities (1.03), whilst between high vs. low density (0.83) and high vs. normal density (0.86) were more similarity (Table 5.11).

Table 5.11 Chord distance values in different planted densities in 1999-plots

| Plots | Normal density | High density |
|---|---|---|
| Low density | 1.03 | 0.83 |
| Normal density | | 0.86 |

The seedling heights were classified: 0-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, 41-50 cm, 51-60 cm, 61-70 cm, 71-80 cm, and over 80 cm, so the numbers of seedlings in each class were created on the Figure 5.18. The most seedlings in all plots were 11-20 cm height. In addition, the seedlings decreased in higher classes. Over 80 cm-height seedlings in the normal planting density presented, while there was no in high density plots

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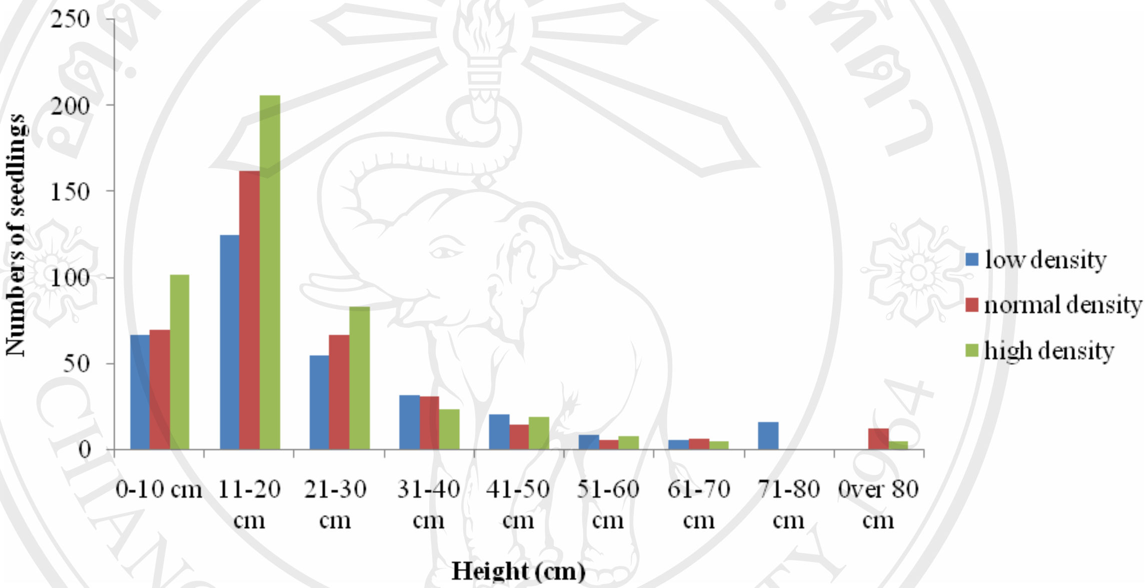


Figure 5.18 The numbers of seedlings in each height classes

**4. Effects of fire (1999 and 2002)**

2002 planted plots

There were three planted replications in 2002-plots, of which the first replication was invaded by fire 1 year after planting. Therefore, some planted seedlings died, whilst resilient species coppiced and grew up again. Fire is the main factor leading to failure of forest restoration projects. Therefore, the vegetation of burnt areas showed some similarities with non-planted control sites: high weed cover and small size of planted trees.

The seedling survey for three times by using circular sampling units with 5 m diameter (Figure 5.19). The numbers of seedlings for first time all replications was higher than other survey and for the third survey (in 2nd rainy season) was higher than second survey (dry season). The total recorded seedlings in the second replication were the highest, 320 seedlings, while the first replication (effect by fire) was 134 and the third replication was 104.

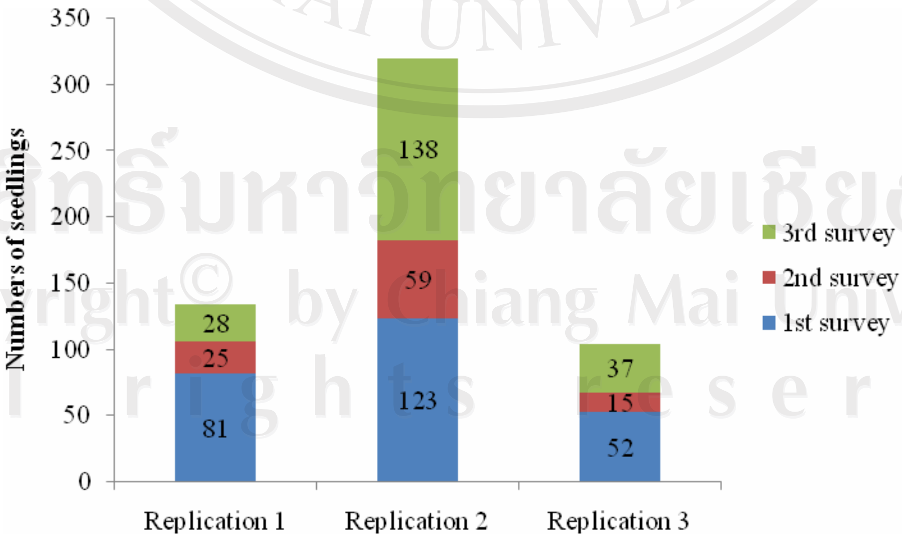


Figure 5.19 The total found seedlings for three times (in replication 1, fire invader).

After three and nine months since the first survey, some seedlings died. The first replication had the highest percentage mortality. Moreover, after 9 months (in rainy season) the mortality percent was higher than 3 months except in the first replication (Figure 5.20).

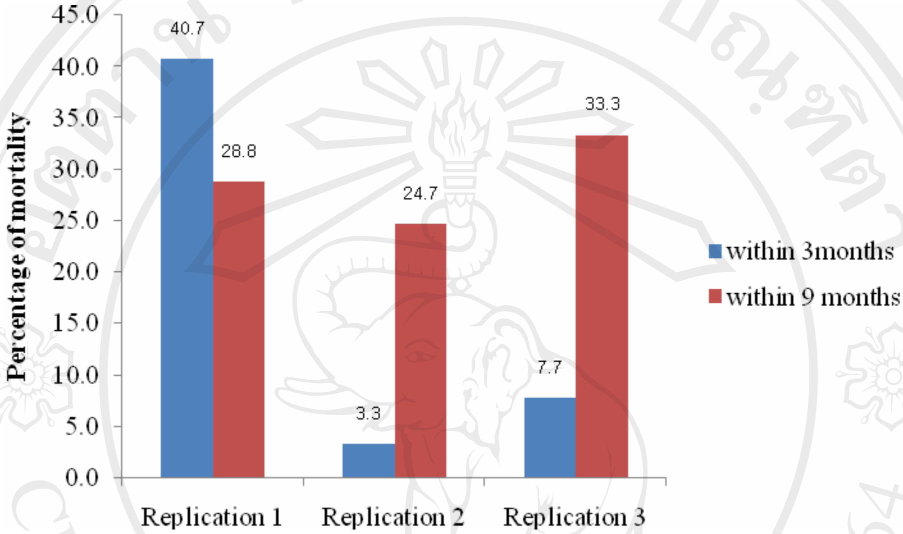


Figure 5.20 The percentage of seedlings mortality in 2002-plots

(in replication 1, fire invader).

Finally, results from the third survey showed that the second replication contained 272 natural survival seedlings, the highest number. On the other hand, seedlings numbers at the first (80) and third replication (79) were lower than second replication about three times (Figure 5.21).

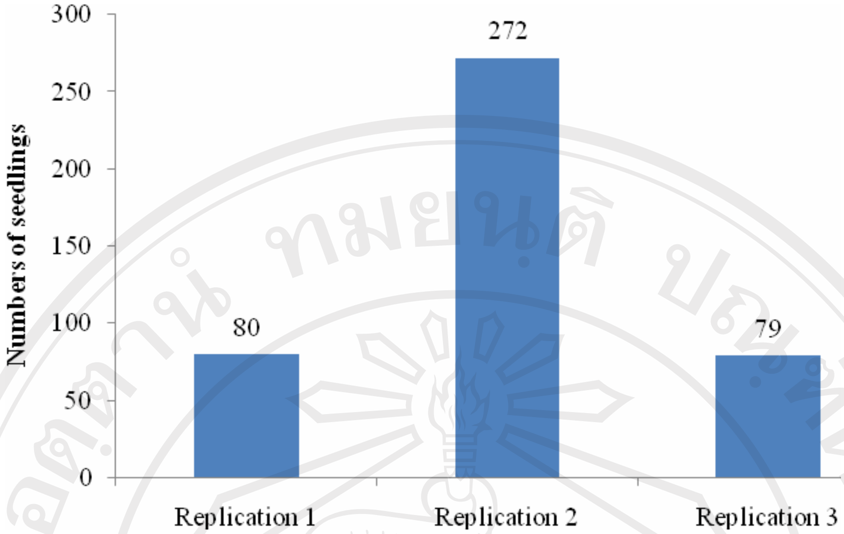


Figure 5.21 Total numbers of seedlings in the second and third survey in 2002-plots (in replication 1, fire invader).

The diversity index and evenness index were the highest in replication 2 (Table5.12), which supported more species and numbers of individual seedlings. The lowest diversity was in replication three. The species area curve of replication 2 was higher than for the others (Figure 5.22). The most common species in all plots was the pioneer *Litsea monopetala* (Table 5.14). The Chord distance was calculated in between replications. It was obvious that the replication 1and replication 3 were the most similar (lower distance value: 0.32) and the replication2 was less like between others (0.51 and 0.53) (Table 5.15).



Table 5.12 Diversity index, evenness and species richness in 2002 plots

| 2002 plots | N0 | N1 | N2 | E5 | Species Richness |
|---|---|---|---|---|---|
| Replication 1 | 132 | 4.66 | 2.593629 | 0.435418 | 18 |
| Replication 2 | 320 | 13.46 | 7.097311 | 0.489351 | 33 |
| Replication 3 | 104 | 2.59 | 1.52338 | 0.32917 | 14 |

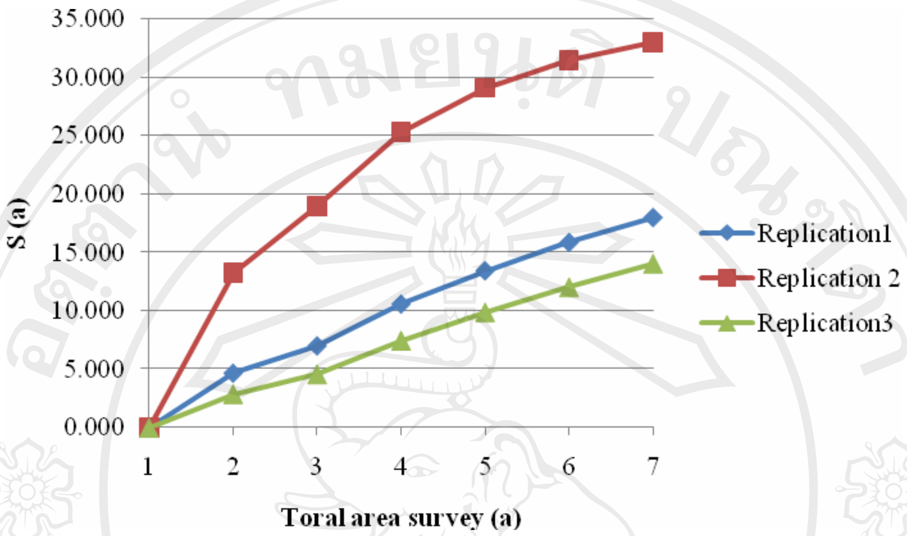


Figure 5.22 Species area curves by Coleman's equation in 2002 plots

The ecological index of recruited species was calculated (Table 5.13), so the similar trend was the diversity index of all species in 2002 planted plots.

Table 5.13 The ecological index of seedling recruitment

| Plots | N0 | N1 | N2 | E5 | species richness | wind-dispersed species | animal-dispersed species |
|---|---|---|---|---|---|---|---|
| replication 1 (Fire) | 113 | 2.80 | 1.92 | 0.51 | 10 | 3 | 7 |
| replication 2 | 222 | 7.24 | 3.96 | 0.47 | 20 | 6 | 14 |
| replication 3 | 95 | 1.86 | 1.28 | 0.32 | 10 | 4 | 6 |

Table 5.14 Species list of seedlings in 2002-plots (replication 1, fire invader)

| Species list | Replication 1 | Replication 2 | Replication 3 |
|---|---|---|---|
| *Acacia megaladena* Desv. var. *megaladena* | 2 | 2 | 0 |
| *Albizia garrettii* Niels. | 0 | 0 | 1 |
| *Antidesma acidum* Retz. | 3 | 11 | 0 |
| *Antidesma bunius* (L.) Spreng. | 1 | 0 | 0 |
| *Antidesma ghaesembilla* Gaertn. | 7 | 37 | 0 |
| *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | 2 | 2 | 1 |
| *Aporusa villosa* (Lindl.) Baill. | 1 | 0 | 0 |
| *Artocarpus lakoocha* Roxb. | 1 | 4 | 0 |
| *Bauhinia variegata* L. | 0 | 0 | 1 |
| *Beilschmiedia assamica* | 1 | 0 | 0 |
| *Bombax anceps* Pierre var. *anceps* | 0 | 0 | 1 |
| *Bridelia glauca* Bl. var. *glauca* | 0 | 1 | 0 |
| *Broussonetia papyrifera* (L.) Vent. | 1 | 0 | 0 |
| *Castanopsis acuminatissima* (Bl.) A. DC. | 0 | 2 | 0 |
| *Castanopsis diversifolia* (Kurz) King ex Hk. f. | 0 | 3 | 0 |
| *Castanopsis tribuloides* (Sm.) A. DC. | 1 | 4 | 0 |
| *Dalbergia cultrata* Grah. ex Bth. | 0 | 1 | 0 |
| *Dalbergia stipulacea* Roxb. | 0 | 10 | 0 |
| *Debregeasia longifolia* (Burm. f.) Wedd. | 0 | 0 | 1 |
| *Embelia* sp. | 0 | 11 | 0 |
| *Erythrina stricta* Roxb. | 0 | 2 | 0 |
| *Erythrina subumbrans* (Hassk.) Merr. | 1 | 0 | 0 |
| *Eugenia albiflora* Duth. ex Kurz | 2 | 6 | 0 |
| *Eugenia fruticosa* (DC.) Roxb. | 0 | 2 | 0 |
| *Ficus hirta* Vahl var. hirta | 0 | 5 | 1 |
| *Ficus hispida* L. f. var. hispida | 0 | 1 | 0 |
| *Ficus subincisa* J.E. Sm. var. *subincisa* | 0 | 3 | 0 |
| *Ixora cibdela* Craib | 0 | 1 | 0 |

| Species list | Replication 1 | Replication 2 | Replication 3 |
|---|---|---|---|
| *Leea indica* (Burm. f.) Merr. | 0 | 15 | 1 |
| *Litsea cubeba* (lour.) Pers. var. *cubeba* | 23 | 6 | 0 |
| *Litsea monopetala* (Roxb.) Pers. | 78 | 103 | 84 |
| *Maesa ramentacea* (Roxb.) A.DC. | 0 | 0 | 1 |
| *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulate* | 12 | 0 | |
| *Micromelum hirsutum* Oliv. | | 1 | 9 |
| *Morinda tomentosa* Hey. ex Roth | 0 | 1 | 0 |
| *Oroxylum indicum* (L.) Kurz | 0 | 0 | 4 |
| *Phoebe lanceolata* (Wall. ex Nees) Nees | 0 | 19 | 0 |
| *Prunus cerasoides* Ham. ex D. Don | 1 | 3 | 0 |
| *Pterocarpus macrocarpus* Kurz | 0 | 3 | 3 |
| *Sarcosperma arboreum* Bth. | 0 | 1 | 0 |
| *Schima wallichii* (DC.) Korth. | 0 | 2 | 0 |
| *Spondias axillaris* Roxb. | 5 | 2 | 1 |
| *Sterculia villosa* Roxb. | 0 | 3 | 0 |
| *Wendlandia scabra* Kurz var. *scabra* | 1 | 33 | 0 |
| unknown 1 | 0 | 0 | 1 |
| Total numbers | 132 | 320 | 104 |

Figure 5.15 The Chord distance (CRD) between three experiment plots in plots x plots matrix form

| Plots | Replication1 | Replication2 | Replication3 |
|---|---|---|---|
| Replication1 | | 0.51 | 0.32 |
| Replication2 | | | 0.53 |

<u>1999 planted plots</u>

The 1999 planted plots had three replications representing three planting densities In the second replication, especially in normal and low planted density, fire occurred 1 year after planting and in 2005 fire invaded again in the normal planted density plot. Therefore weed covered and there were some surviving planted trees. The 3 sampling units 30x10 m were laid out in each replication. For the first survey, the numbers of seedlings in replication 1 (107) was about 3 time higher than in replication 2 (37) In case of second and third survey, recorded seedling numbers (78, 128 respectively) in replication3 was more than others (Figure 5.23).

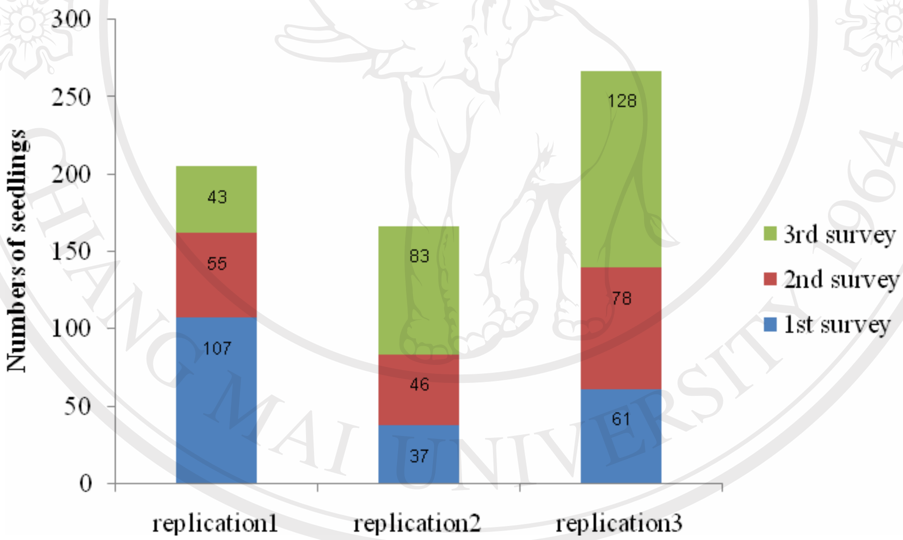


Figure 5.23 The total found seedlings in all 1999-plots

More seedlings died in the previous burnt replication than in the non-burnt replication. In second and third survey, some natural seedlings died. The percentage of seedling mortality in replication 2 (7.9%) within 3 months (second survey) was more than three times when compare with other replications. After 9 months (in third survey), the mortality rate of all replications increased; the replication 2 reach to 30.3%, was higher than replication 1 (12.7%) and replication 3 (16.6%) (Figure 5.24).

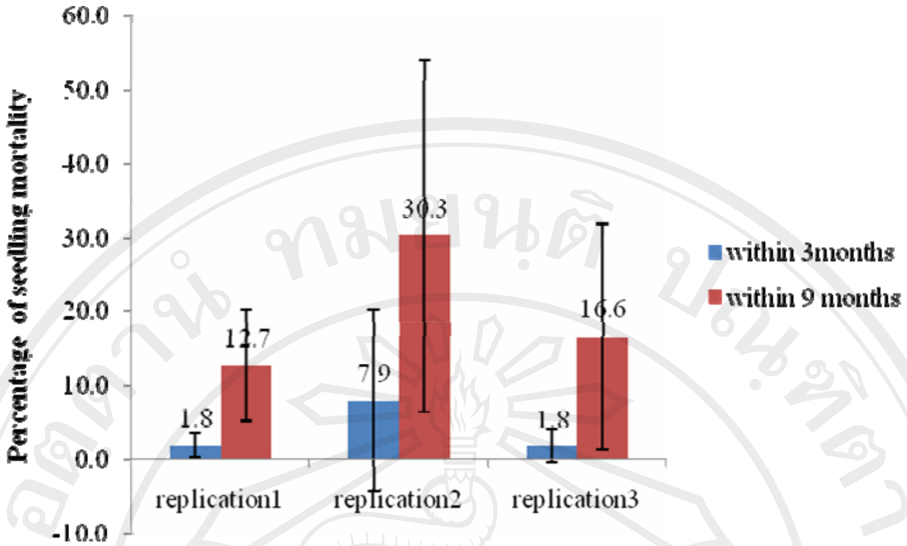


Figure 5.24 The mortality percentage of seedling in 1999-plots

The numbers of seedlings increased continuously with subsequent surveys over time, even though some seedlings from previous survey died. Non-fire invaded sampling units (183 and 238 seedlings) contained higher seedlings than fire invaded sampling units (141) (Figure 5.25).

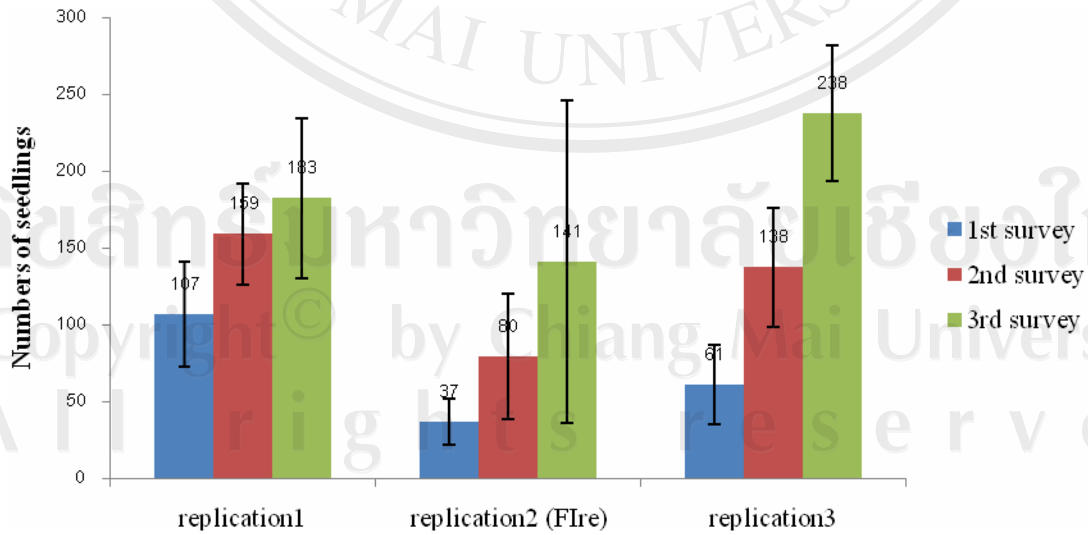


Figure 5.25 The total seedling numbers for each survey

Burning reduced the species richness of the seedling communities. Species richness in second replication (48) was lowest, while there are 53 and 55 in replication 1 and 3 (Figure 5.26). Nevertheless, the Hill's numbers were calculated, N1 and N2 of replication 1 and 3 were lower than replication 2 because evenness (E5) in replication 2 was higher, meant numbers of individual of each species were more than others (Table 5.16).

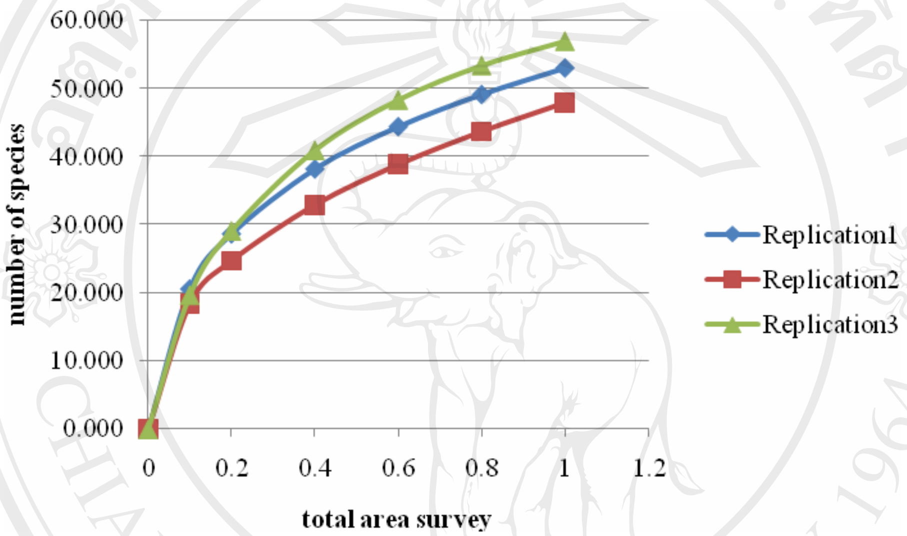


Figure 5.26 Species area curves by coleman's equation in 1999-plots (replication2, burnt sites)

Table 5.16 Ecological diversity index in 1999-plots (replication 2, burnt sites)

| 1999-plots | N0 | N1 | N2 | E5 | species richness |
|---|---|---|---|---|---|
| Replication 1 | 614 | 17.80895 | 9.932448 | 0.53141 | 53 |
| Replication 2 | 503 | 19.68173 | 14.07247 | 0.699746 | 48 |
| Replication 3 | 802 | 11.5854 | 5.565685 | 0.431319 | 55 |

Not only, did the non-burnt plots support a higher diversity index and seedling numbers, but the species compositions of two areas were different (Table 5.18). To illustrate, *Cratoxylum formosum*, *Vernonia volkameriifolia* were found only in replication 2. Chord distance value (Table 5.19) between replication 1 vs. 3 (0.95) was lower than replication 1 vs. replication 2 (1.00), and replication 2 vs. replication 3 (1.03).

The diversity index of seedling recruitment was calculated, so the fire-invaded plot was lowest diversity. However, the numbers of animal-dispersed species was equal in all replication (Figure 5.17).

Table 5.17 The ecological index of recruited species in 1999 plots

| | N0 | N1 | N2 | E5 | species richness | wind-dispersed species | animal-dispersed species |
|---|---|---|---|---|---|---|---|
| replication 1 | 325 | 12.06 | 6.58 | 0.50 | 34 | 12 | 22 |
| replication 2(fire) | 408 | 13.87 | 10.59 | 0.75 | 32 | 10 | 22 |
| replication 3 | 572 | 7.54 | 3.62 | 0.40 | 34 | 12 | 22 |

Table 5.18 The species composition in 1999-plots (the replication 2 was effected by fire)

| Species list | replication 1 | replication 2 | replication 3 |
|---|---|---|---|
| *Acacia megaladena* Desv. var. *megaladena* | 0 | 47 | 2 |
| *Alangium kurzii* Craib | 0 | 0 | 1 |
| *Albizia chinensis* (Osb.) Merr. | 10 | 11 | 5 |
| *Albizia garrettii* Niels. | 4 | 0 | 2 |
| *Albizia odoratissima* (L. f.) Bth. | 2 | 0 | 0 |
| *Alstonia scholaris* var. *scholaris* | 0 | 2 | 0 |
| *Antidesma acidum* Retz. | 30 | 23 | 65 |
| *Antidesma bunius* (L.) Spreng. | 1 | 0 | 0 |
| *Antidesma ghaesembilla* Gaertn. | 0 | 1 | 3 |
| *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | 20 | 21 | 15 |
| *Aporusa villosa* (Lindl.) Baill. | 9 | 3 | 3 |
| *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | 29 | 1 | 0 |
| *Artocarpus lakoocha* Roxb. | 0 | 1 | 3 |
| *Bauhinia racemosa* Lmk. | 0 | 0 | 7 |
| *Bauhinia variegata* L. | 0 | 0 | 2 |
| *Bombax anceps* Pierre var. *anceps* | 2 | 1 | 2 |
| *Bridelia glauca* Bl. var. *glauca* | 0 | 1 | 1 |
| *Bridelia stipularis* (L.) Bl. | 0 | 0 | 4 |
| *Canarium subulatum* Guill. | 0 | 1 | 0 |
| *Canthium parvifolium* Roxb. | 5 | 0 | 0 |
| *Castanopsis acuminatissima* (Bl.) A. DC. | 1 | 0 | 1 |
| *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | 1 | 0 | 0 |
| *Castanopsis diversifolia* (Kurz) King ex Hk. f. | 1 | 1 | 0 |
| *Castanopsis tribuloides* (Sm.) A. DC. | 10 | 4 | 3 |
| *Cinnamomum caudatum* Nees | 3 | 1 | 8 |
| *Clausena excavata* Burm. f. var. *excavate* | 1 | 0 | 0 |

| Species list | replication 1 | replication 2 | replication 3 |
|---|---|---|---|
| *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. | 0 | 1 | 0 |
| *Dalbergia cultrata* Grah. ex Bth. | 0 | 43 | 1 |
| *Dalbergia rimosa* Roxb. var. *rimosa* | 0 | 0 | 4 |
| *Dalbergia stipulacea* Roxb. | 3 | 34 | 6 |
| *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* | 11 | 0 | 0 |
| *Embelia* sp. | 0 | 1 | 10 |
| *Engelhardia spicata* Lechen. ex Bl. var. *spicata* | 2 | 0 | 4 |
| *Erythrina stricta* Roxb. | 0 | 19 | 66 |
| *Erythrina subumbrans* (Hassk.) Merr. | 1 | 1 | 1 |
| *Eugenia albiflora* Duth. ex Kurz | 3 | 2 | 1 |
| *Eugenia fruticosa* (DC.) Roxb. | 2 | 6 | 2 |
| *Eurya acumminata* DC. var. *wallichiana* Dyer | 0 | 3 | 3 |
| *Fernandoa adenophylla* (Wall. ex G. Don) Steen. | 0 | 1 | 0 |
| *Ficus fistulosa* Reinw. ex Bl. var. *fistulosa* | 0 | 2 | 1 |
| *Ficus hirta* Vahl var. *hirta* | 42 | 62 | 13 |
| *Ficus hispida* L. f. var. *hispida* | 1 | 1 | 0 |
| *Ficus obtusifolia* Roxb. | 1 | 1 | 0 |
| *Ficus subincisa* J.E. Sm. var. *subincisa* | 0 | 1 | 2 |
| *Glochidion acuminatum* M.-A. var. *siamense* A.S. | 1 | 0 | 0 |
| *Glochidion eriocarpum* Champ. | 1 | 0 | 1 |
| *Glochidion kerrii* Craib | 0 | 0 | 2 |
| *Glochidion sphaerogynum* (M.-A.) Kurz | 1 | 0 | 0 |
| *Gmelina arborea* Roxb. | 0 | 0 | 1 |
| *Harrisonia perforata* (Blanco) Merr. | 0 | 4 | 0 |
| *Heynea trijuga* Roxb. ex Sims | 1 | 0 | 0 |
| *Hymenodictyon orixense* (Roxb.) Mabb. | 0 | 0 | 1 |
| *Ixora cibdela* Craib | 4 | 0 | 0 |

| Species list | replication 1 | replication 2 | replication 3 |
|---|---|---|---|
| *Leea indica* (Burm. f.) Merr. | 8 | 0 | 7 |
| *Lithocarpus polystachtus* (A. DC.) Rehd. | 2 | 0 | 2 |
| *Litsea cubeba* (lour.) Pers. var. *cubeba* | 0 | 7 | 10 |
| *Litsea monopetala* (Roxb.) Pers. | 108 | 57 | 267 |
| *Machilus bombycina* King ex Hk. f. | 0 | 0 | 2 |
| *Maesa ramentacea* (Roxb.) A.DC. | 0 | 0 | 2 |
| *Mallotus philippensis* (Lmk.) M.-A. | 2 | 0 | 0 |
| *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulate* | 58 | 4 | 0 |
| *Melia toosendan* Sieb. & Zucc. | 0 | 0 | 1 |
| *Melientha suavis* Pierre ssp. *suavis* | 1 | 0 | 0 |
| *Michelia baillonii* Pierre | 0 | 0 | 1 |
| *Michelia floribunda* Fin. & Gagnep. | 0 | 1 | 4 |
| *Micromelum hirsutum* Oliv. | 0 | 9 | 3 |
| *Millettia pubinervis* Kurz | 0 | 3 | 0 |
| *Oroxylum indicum* (L.) Kurz | 1 | 0 | 0 |
| *Pavetta tomentosa* Roxb. ex Sm. var. *tomentosa* | 1 | 0 | 0 |
| *Phoebe cathia* (D. Don) Kosterm. | 1 | 0 | 0 |
| *Phoebe lanceolata* (Wall. ex Nees) Nees | 131 | 15 | 26 |
| *Phyllanthus emblica* L. | 5 | 0 | 1 |
| *Prismatomeris tetrandra* (Roxb.) K. Sch. ssp. *Tetrandra* | 3 | 1 | 0 |
| *Prunus cerasoides* Ham. ex D. Don | 4 | 2 | 183 |
| *Pterocarpus macrocarpus* Kurz | 5 | 1 | 8 |
| *Rhus rhetsoides* Craib | 0 | 0 | 6 |
| *Schima wallichii* (DC.) Korth. | 18 | 40 | 20 |
| *Spondias axillaris* Roxb. | 12 | 0 | 5 |
| *Sterculia lanceolata* Cav. var.*lanceolata* | 1 | 0 | 0 |
| *Sterculia villosa* Roxb. | 3 | 0 | 0 |

| | | | |
|---|---|---|---|
| *Stereospermum colais* (B.-H. ex Dillw.) Mabb. | 1 | 0 | 0 |

| Species list | replication 1 | replication 2 | replication 3 |
|---|---|---|---|
| *Styrax benzoides* Craib | 0 | 45 | 0 |
| *Tarennoidea wallichii* (Hk. f.) Triv. & Sastre | 0 | 0 | 1 |
| *Turpinia pomifera* (Roxb.) Wall. ex DC. | 23 | 0 | 0 |
| *Vernonia volkameriifolia* DC. var. *volkameriifolia* | 0 | 5 | 0 |
| *Wendlandia scabra* Kurz var. *scabra* | 8 | 0 | 2 |
| *Wendlandia tinctoria* (Roxb.) DC. ssp. *floribunda* (Craib) Cowan | 5 | 1 | 2 |
| Unknown 1 | 0 | 8 | 3 |
| Unknown 2 | 10 | | |
| Total | 614 | 503 | 802 |

Table 5.19 Chord distance of 1999-plots

| Plots | Replication1 | Replication2 | Replication3 |
|---|---|---|---|
| Replication1 | | 1 | 0.95 |
| Replication2 | | | 1.03 |

## CHAPTER 6

## DISCUSSION

**Overview of seedling survey in forest restoration areas**

Surveys of saplings were carried out in 1998, 1999, 2002 planted plots and unplanted sites (control sites) three times from April 2006 until July 2007. More than 3000 individual seedling (108 species) were recorded, with an average population density of 0.56 tree per square meter, thus for 1600 square meter (= 1 rai), there were about 894 natural established seedlings.

The framework tree species method starts with the planting of about 500 trees per rai. The present average total density in the plots, including planted trees and natural seedlings is, therefore, 1394 per 1600 square meter.

The highest diversity and numbers of saplings were recorded in the 1999-planted plots than other plots, because the area sampled (10x30 rectangular square meter sample units) was larger than in the other plots (using 10 meter diameter circular sampling units).When planted and non-planted sites were compared, the diversity index of planted sites was higher than that of non-planted sites, except that N1 (numbers of abundant species in the sampling plots) for the 2002–plots was lower than that calculated for the control sites. However, the numbers of recruited species in 2002 planted plots was higher than control plots.

There were 35 species of 2$^{nd}$ generation seedlings from planted trees (1381 individual seedlings) whilst the number of recruited species was 73 (2159 individual). Anusarnsunthorn and Elliott (2004) monitored natural tree establishment in 1998, 1999, 2000 and 2002 planted plots by using 10 m diameter circular plots in July-August 2004. They reported that 61 tree species recruited species. Therefore the number of sapling species increased by at least 12 new recruit species over the past 3 years.

Moreover, about 74 of the total seedling species (68%), 2608 individual seedlings in restoration areas were dispersed by animals. The result suggests that animal seed dispersal agents such as birds, fruit bats and small mammals play an important role in natural forest regeneration (Corlett, 1998). Attractiveness to seed-dispersing wildlife is one of the most important characteristics of framework tree species, enabling them to accelerate biodiversity recovery (FORRU, 2006).

Half species of surveyed seedlings were pioneers and one forth of the species was climax tree species, because almost all the studied sites were in young planted plots. Whitmore (1990) classified the main distinctions between pioneer and climax trees species as follows: the seeds of pioneers can germinate only in full sunlight and their seedlings cannot grow, whereas climax tree seeds can germinate in shade and their seedling are shade tolerant. Pioneer tree species grow rapidly and usually produce large numbers of small fruit sand seeds dispersed by wind or small birds, at a young age. Their seeds are easily dispersed over long distances and can lie dormant in the soil, before germinating when a gap is formed and light intensity increases. However, once the forest canopy closed, no more seedlings of pioneer species can grow to maturity. Climax tree species grow for many years. They tend to produce large, animal-dispersed, non-dormant seeds, containing large food reserves, which sustain seedlings, whist they grow slowly in shaded conditions. Therefore, climax tree species can regenerate beneath their own shade.



**<u>Effect of framework tree species on Saplings</u>**

Seedling recruitment of some species due to the presence of the others has been described for a variety of environments (Garwood, 1983). Establishment below forest canopies possibly protect seedlings from high irradiance, temperature, rate of transpiration and predation (Villier *et al*.,2001). Therefore, there were plenty of saplings under all 57 framework tree species that were tested in all plots (tree species in 1998, 1999 and 2002 planted plots).

The highest score was for *Ficus glaberrima* Bl. var. *glaberrima* (Moraceae). Twenty-one sapling species grew under the tree crowns of this species. FORRU (2006) recommended *Ficus* species as superior framework tree species because figs are an essential food for a wide range of seed-dispersed animals, including many species of birds and bats, as well as primates, civets, squirrels, bears, deer, and wild pigs. *Ficus* species are well-known as keystone species; their figs sustain populations of fruigivores, when other foods are scarce. Kuarak and Hitchcock (1998) compared the numbers of bird dispersed seedlings beneath the crowns of remnant trees (14 individual trees, 9 species) and in control plots, away from their crowns. They observed birds feeding on 17 fruiting trees species in mature forest. They also reported that *F. glaberima* is attractive to birds as well as 7 other species: *Bischofia javanica* Bl., *Macaranga denticulate* (Bl.) M.-A. (both Euphobiaceae), *Eugenia fruiticosa* (DC.) Roxb. (Myrtaceae), *Eurya acuminate* DC. var. *wallichiana* Dyer (Theaceae), *Ficus altissima* Bl., *Ficus microcarpa* L.f. var. *microcarpa forma microcarpa* (Moraceae), and *Hovenia dulcis* Thunb. (Rhamnaceae) as clearly attractive to birds.



The second most attractive framework tree according to recruit sapling score seedling was *Prunus cerasoides* D. Don involved the most abundant of birds Wydhayagarn (2007). High amount of branches, flowers and fruits of the tree provide a lot of bird perching sites and food resources. This species could support the highest population density and species richness of seedlings both wind-dispersed and animal-dispersed seedling community.

Under crowns of *Erythrina subumbrans* (Hassk.) Merr., 27 seedling species were recorded (animal dispersal species= 22 and wind dispersal species = 5), the highest species number recorded for any framework tree. Wydhayagarn (2007) reported that Bird surveys of *Erythrina subumbrans* (Hassk.) Merr.of the frugivorous birds were recorded. This framework tree species produces bright red color flower when they are leafless, which provide high quantities of nectar as a food sources for many birds species. Moreover, *Erythrina subumbrans* (Hassk.) Merr. had large crown width, determines shade and influences soil moisture content under the trees (Verdu and Garcia-Fayos, 1996). Such factors may then influence the density and distribution of tree seedlings (Maguire and Forman, 1983). Navakitbumrung (2003) studied another *Erythrina* tree species, *Erythrina stricta* Roxb.. The result show that the low shade and long leafless period of tree might support germination and recruitment of wind-dispersed species

*Hovenia dulcis* Thunb. (Rhamnacea) achieved a high score of seedlings under their crowns (score=85) and 17 seedling species, including 12 animal-dispersed and 5 wind-dispersed species. Toktang (2005) suggested that *Hovenia dulcis* Thunb. was highly attractive to birds in forest restoration plots and Wydhayagarn (2007) recorded 8 species and 20 individual numbers that seedling under their crowns, . This framework tree species develop broad crowns, which effectively shade out weed and attract nesting birds by the 4$^{th}$ year (Anusarnsunthorn and Elliott, 2004)). The fruits and the infructescense are very attractive to birds



Seedling score for *Spondias axillaris* Roxb. was 83 of 24 seedlings species (animal-dispersed species=20, wind-dispersed species =4) under their canopies. FORRU (2006) suggested this species grow very fast, flowering and fruiting occur from the 4$^{th}$ year after planting. The tree support bird nesting from 5$^{th}$ year after planting. The fruits are eaten by deer, wild pig and bears. Wydhayagarn (2007) showed this species supported a bird community of highest diversity (28 bird species and 62 individual birds). This may have been the reason why *Spondias axillaris* Roxb. fostered relatively high numbers of recruit seedling species.

In the conclusion, one characteristic of the framework tree species was attractive wildlife, seed dispersal agent, therefore most of the framework tree that planted in forest restoration sites were succeeded to recovery biodiversity.

**<u>Effect of age plots on Seedling establishment</u>**

The numbers of individual saplings and species numbers increased with increased plot age. The highest diversity index was recorded for the in 1998-plots. Most seedlings were of animal dispersed species in all sampling plots. Moreover, the proportion of animal dispersal species increased with plot age. However, N1 of Hill's number in 2002–plots was lower than in control sites because the proportion of seedlings and species was lower. There was some evidence in the control sites for the presence of wildlife, including rabbit, wild pig. Corlett (1998) reported that the role of wild pig (*Susus* spp.) in seed dispersal is less clear. They probably destroy the seeds of most species they consume or feed only on the fleshy fruits, including *Ficus*, *Manilkara* and *Ziziphus*, are found in pig's faeces. The fruit consumed by pigs are already lost to arboreal fruigovres, so any additional dispersal is a bonus to the parent plants.

In addition, most of the sapling species recorded was pioneer species in all sampling plots. However, when the plots were older, the proportion of climax species increased. In the 1998 plots, the climax>pioneer and climax species was 50%, and in 2002 plots it was half and half, while the pioneer and pioneer> climax in control sites accounted for 70%. The average of light intensity in unplanted sites was 292x20000 lux, while it was 60x20000 lux and 58x20000 lux in 2002 and 1998 planted plots respectively. Weeds declined whilst shade increased when as the plots grew older. The canopy of framework tree was closer, and shade out the weed. In addition, the areas of planted sites were more suitable for climax tree species.

The permanent circular sampling units in 1998 planted plots had been established since planting for ground flora monitoring. The species composition in the 1998-planted plots had changed over time. Khopai (2000) surveyed tree species diversity of ground flora in 1998 planted plots (2 year old) since 2000. She found only 29 species of tree saplings and about 75 species of ground flora and in control sites 27 tree seedling species and 71 ground flora species. The most common tree seedlings in 1998-plots included *Acacia megaladena* Desv. var. *megaladena*, *Albizia chinensis* (Osb.) Merr. , both are wind dispersal species and *Litsea cubeba* (lour.) Pers. var. *cubeba.*

Six years later, the 1998-planted plots were 8 years old, with a total of 59 tree seedling species recorded, an increase of 30 species over 6 years. The unplanted sites (control sites) support 42 tree species, an increase of 15 species over 6 years). The sapling communities in the 1998-plots was dominated by *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (76 seedlings) (Planted species), *Erythrina subumbrans* (Hassk.) Merr. (107 seedlings) (Planted species), *Heynea trijuga* Roxb. ex Sims (44 seedlings) (Palnted species), *Litsea monopetala* (Roxb.) Pers. (211 seedlings) (Recruited species), and *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (44 seedlings) (Recruited species). The species was developed more animal-dispersed species and created more numbers of species and individual numbers.



The dominance of *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. because their planted mother trees had been planted in the plots (planting since 1998). They was produced an abundant seed rain and most of the seeds germinated within a few meters of the mother tree.

Lambers and Clark (2003) found that seed size is generally negatively correlated with seed dispersal distances but positively correlated with seedling survival. Moles and Westoby (2004) suggested that large-seed species have higher seedling emergence rate through early seedling establishment than small-seed species. In replication 2 and 3 of 1998-plots, the clumped seedlings of *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. shaded out many smaller seedlings (small-seed species). Therefore, this species might be regarded as a weedy tree species and may have a negative effect on diversity of the recruit sapling community.

My observation effect of framework tree on seedling establishment, under their crowns were dominant with their seedlings and some other species seedlings died. On the other hand, *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. was one of animal dispersed species and food supply for some animals.

*Aquilaria crassna* Pierre ex Lec. (Thymeleaceae), is a rare tree species because of its very high economic value. Its oil is very expensive. It has large seeds size so small birds cannot disperse. Seedlings this species were found in the 1998-plot replication 2 under the crowns of *Diospyros glandulosa* Lace, *Helicia nilagirica* Bedd. and *Spondias axillaris* Roxb. The nearest mother trees of *Aquilaria crassna* Pierre ex Lec. are located about 8 km away. Large animals, probably civets or barking deer dispersed the seeds of this species into the planted plots.



*Litsea cubeba* (lour.) Pers. var. *cubeba* declined in abundance with increasing plot age, while *Phoebe lanceolata* (Wall. ex Nees) Nees increased. Both species were found in all plots. *Litsea cubeba* is a pioneer tree species, requiring high sunlight (although relative growth rate was lower in the control sites), while *Phoebe lanceolata* is a climax tree species, which can grow well in shade (even though relative growth rate was higher in the control sites). Howe (1989) suggested seeds and seedlings survival are influenced by a virtually infinite array of eco-variables. Relevant here are escape from insects, pathogens, intraspecific competition, and mammalian seed predation or seedling herbivory that might cause mortality near parent plants.

Nuttira (2005) studied plant litter dynamics and soil fertility in forest restoration areas and unplanted sites at Ban Mae Sa Mai (The same studied sites) in 1997, 1999, and 2001 planted sites. Organic matter, phosphorus, potassium and cation exchange capacity were not significantly different among the plots but upper layer of soil (0-10 cm depth) from the oldest plots had significantly higher nitrogen levels than the others. Hence, increasing age of forest restoration plots effect on improving soil quality, for suitable seed germination and seedling emergence.

Replicate 2 of the 1998 planted plots supported a lower number of saplings compared with the other replicates, so when testing by One-way ANOVA was not significant with other planted plots even the total number of seedling and species are lowest. This may have been due to distance from nearby seed sources. Robinson and Handel (1993) investigated forest restoration in New York, USA by planting trees and shrubs of 17 species to attract avian seed dispersal agents. One year after planting the plantation spread and increased in diversity, with 20 additional species, of which 95% came from sources outside the plantation. Most seedlings (71%) were of fleshy fruited species, dispersed by birds from nearby woodland fringes. The density of new recruits of each species is dependent on the distance from the nearest potential seed sources. In the control sites numbers of seedling was abundant because the planted tree in 1998-plots have been flowering and fruiting such as *Spondias axillaris* Roxb. and seed dropped into unplanted sites. Therefore a lot of found seedlings, same species with framework in replication 1 of control sites. The framework tree species was not only creating diversity in plantation areas, but they are also the good seed source for degradation areas.



In second survey in dry season, seedling mortality in non-planted sites and 2002-planted plots was lower than in the 1998-planted about three times. In the subsequent survey in 2nd rainy season, seedling mortality increased in all sampling plots, especially in unplanted sites it doubled. Litter accumulation in the tree plots might affect seedling communities. Dalling *et al.* (2002) suggested that In Natural forest, small-seeded pioneer tree species are inhibited by leaf litter on the soil, while large-seeded pioneer tree species can germinate and regenerate under a litter surface. Based on the seedling surveys, leafless or damaged seedlings were found beneath or surrounded by litter layer presented in some tree plots.

The relative growth rate values of many seedlings were regulative in control sites because the seedling was damaged and broken. And RGR in planted areas were increasing particular pioneer tree species and climax tree species in planted sites have slightly grew. All of these related with the research of Veenendaal *et al.*1996 said that the pioneer tree have a much higher growth response to light intensity than shade-tolerant species.

Gale *et al.* (2002) studied about role of bird in forest regeneration of forest in Ban Mae Sa Mai, Northern Thailand. They set up the artificial bird perching to create seeds and seedling in control sites and planted sites. The results demonstrated showed significantly higher survival of seedlings under perches compared with control sites.

**Effect of planted density on seedling establishment**



In the 1999-planted plots, the highest numbers of seedlings was found in the normal density plots. However in second survey, the mortality of seedling in low density was highest about 8%, just 2% in normal density and 3% in high density. Finally, for the total survey, the result show that the numbers was the highest in high planted density plots, while the highest species richness was in low planted density plots. Yamamota (1992) commented that gaps play an important role in the maintenance of tree species richness. The normal planted density plots had moderate value of diversity index. Mortality increased in all plots, particularly in low density plots at 21%; 30% in normal density; while in high density plots it was just 7%. In low density planted plots, there was evidence, fallen framework tree, *Erythrina subumbrans* (Hassk.) Merr. in replication1. In normal density fire invaded replication 2. Thus, there was high mortality and low species lists in the replication. In fire-invaded planted plots, the weed was covered all areas, so natural seedling competed with them and more light intensity in this sites. The research of Maguire and Forman (1983) recommended that herbaceous ground vegetation to compete with the tree seedlings and then affected tree seedling growth and distribution.

The numbers of planted trees in high density plots was reduced from the started plantation in 1999, so the planted tree density in the present was nearly similar with normal density plots. The self-thinning was occur in high planed density, thus the high efficiency of forest restoration on biodiversity recovery and suitable budget was 1.8 meters distance between planted trees, that was recommended by FORRU (2006).

**Effect of fire on seedlings**

Fire in 1999 replication 2. significantly reduced species richness and sapling density and increased sapling mortality compared with the other replications. Two species, *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. and *Vernonia volkameriifolia* DC. var. *volkameriifolia* that live in n open areas (Guardner, 2006), were recorded only in the fire-invaded plots of 1999 planting year. However, the mortality of second survey in replication2 was 9%, while replication1 and replication3 were about 2%. In the last survey, the mortality of seedlings after 9 months, in fire-invaded plots was 30% of mortality percentage, and others were lower than two times.

In 2002 planted plots in replication1, one year after planting fire occurred, weeds colonized the site and some framework trees still survived. Seedling monitoring was done all three replication of 2002-planted plots for three surveys. The highest numbers and species of seedling were in replication 2 (diversity index as well), while in the replication1 was higher than in replication 3. One reason might have been that replication 3 was nearby a cabbage field where herbicide and insecticide were frequently applied, so it is possible that these activities disturbed the seed dispersal agents into this area. Since the site had been used for agriculture for a long time The quality of soil might have been reduced. However, 3 month after the first survey, the percentage of mortality in replication1 reached to 40%, while in other replications it was lower than 10%. However, the mortality percent of all plots after 9 months increased to 30%. Monyrak (1997) studied effects of forest fire protection on seed dispersal, seed bank, and tree seedling establishment in a deciduous dipterocarp-oak forest in Doi Suthep-Pui national park. The mean mortality (4.99%) and recruitment rate (4.67%) of seedlings in the protected areas was much higher compared to 2.17% and 1.49%, respectively, in the burned areas. There were significantly greater species and individual of seedlings in protected areas.

In the conclusion fire protection is essential technique in forest restoration to encourage biodiversity. Seedling regeneration and species richness seem to be facilitated by protection from fire, whilst fire prevents seedling growth. The heterogeneity of the protected forest enhances germination and recruitment (Monyrak, 1997).

**<u>Experimental design</u>**

In addition to the fact that 10 diameter sampling units was not big enough to present the whole plots (for the tree seedlings), which can be seen from all species areas curves, which increased slightly. However, this technique is good for rapid and long term monitoring. The 10x30 square meter rectangular plots was most efficient for seedling monitoring to get more tree seedlings and species. In the conclusion techniques should be used.

# CHAPTER 7

## CONCLUSIONS AND RECOMMENDATIONS

1. Framework tree species method for forest restoration, to start planting 20-30 indigenous forest tree species, is efficient technique to accelerate forest regeneration, natural seedling establishment due to attract animals, such as birds, small mammals, that play role as seed dispersal agents into planted areas. Moreover, the physical condition, light, moisture, litter from leaf planted trees, in forest restoration areas is suitable for seed germination and seedling survival. Therefore, biodiversity increases. Most surveyed seedling species were animal dispersal rather than wind dispersed. Moreover, the proportion of animal dispersed trees and climax tree species are tended to increase with age plots. The total numbers of seedlings was triple that of planted trees.

2. My recommendation, apart planted framework tree seedlings distance should be planted 1.8 meter between seedlings (the normal density= 500 planted trees/rai) for high potential of tree seedling diversity and high survival rate.

3. Fire protection in the forest restoration trails is required for the framework tree species technique, to support forest succession. Fire impact on forest structure, kills some trees and depressed tree growing rate.

4. Not only forests, but grassland, are wildlife habitat (in control sites). They provide a refuge for some wild pigs, rats, rabbits, and other dispersal agents. Thus, in more diversity landscapes, including grassland, forest can conserve more biodiversity, flora and fauna.

5. The top three potential framework tree species, *Ficus glaberrima* Bl. var. glaberrima, *Prunus cerasoides* D. Don, and *Erythrina subumbrans* (Hassk.) Merr.,

there are a lot of seedlings under their canopies and most of them are carried by animal disperser.

6. Future research should be monitor mammal in the forest restoration trails, who are seed dispersers. Moreover, mother tree, who related to found seedling recruitment, ought to be surveyed and estimate the distances from mother tree to plantation areas.

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Appendix A Total species lists of all plots and some information

| Species list | Family | Dispersal mechanism | Habit | Type | Framework species | Control sites | 2002-plots | 1999-plots | 1998-plots | Total number |
|---|---|---|---|---|---|---|---|---|---|---|
| *Acacia megaladena* Desv. var. *megaladena* | Leguminosae, Mimosoideae | W | wc | P | Recruited | 2 | 4 | 49 | 0 | 55 |
| *Acrocarpus fraxinifolius* Wight ex Arm. | Leguminosae, Caesalpinioideae | W | t | P>C | Planted | 6 | 0 | 0 | 0 | 6 |
| *Alangium kurzii* Craib | Alangiaceae | A | t | P | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Albizia chinensis* (Osb.) Merr. | Leguminosae, Mimosoideae | W | t | P | Planted | 0 | 0 | 27 | 1 | 28 |
| *Albizia garrettii* Niels. | Leguminosae, Mimosoideae | W | t | P | Recruited | 0 | 1 | 6 | 5 | 12 2 |
| *Albizia odoratissima* (L. f.) Bth. | Leguminosae, Mimosoideae | W | t | P | Recruited | 0 | 0 | 2 | 0 | |
| *Alseodaphine andersonii* (King ex Hk. f.) Kosterm. | Lauraceae | A | t | C | Recruited | 0 | 0 | 0 | 1 | 1 |
| *Alstonia scholaris* var. *scholaris* | Apocynaceae | W | t | P | Recruited | 0 | 0 | 2 | 0 | 2 |
| *Anneslea fragrans* Wall. | Theaceae | A | t | P | Recruited | 1 | 0 | 0 | 0 | 1 |
| *Antidesma acidum* Retz. | Euphorbiaceae | A | l | P | Recruited | 11 | 14 | 99 | 13 | 137 |
| *Antidesma bunius* (L.) Spreng. | Euphorbiaceae | A | t | C | Planted | 0 | 1 | 1 | 0 | 2 |
| *Antidesma ghaesembilla* Gaertn. | Euphorbiaceae | A | t (l) | P | Planted | 0 | 44 | 4 | 4 | 52 |
| *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | Euphorbiaceae | A | t | P | Recruited | 58 | 5 | 56 | 44 | 163 |
| *Aporusa villosa* (Lindl.) Baill. | Euphorbiaceae | A | t (l) | P | Planted | 0 | 1 | 15 | 24 | 40 |
| *Aquilaria crassna* Pierre ex Lec. | | A | t | C | Recruited | 0 | 0 | 0 | 3 | 3 |
| *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | Leguminosae, Mimosoideae | W | t | P | Planted | 1 | 0 | 30 | 2 | 33 |
| Areca laosensis Becc. Arenga caudata (lour.) H.E. Moore | Palmae | A | l | C | Recruited | 0 | 0 | 0 | 1 | 1 |
| *Artocarpus lakoocha* Roxb. | Moraceae | A | T | P | Planted | 2 | 5 | 4 | 6 | 17 |

| Species list | Family | Dispersal mechanism | Habit | Type | Framework species | Control sites | 2002-plots | 1999-plots | 1998-plots | Total number |
|---|---|---|---|---|---|---|---|---|---|---|
| *Bauhinia racemosa* Lmk. | Leguminosae, Caesalpinioideae | W | t (l) | P | Recruited | 0 | 0 | 7 | 0 | 7 |
| *Bauhinia variegata* L. | Leguminosae, Caesalpinioideae | W | t | P | Recruited | 0 | 1 | 2 | 0 | 3 |
| *Beilschmiedia assamica* | Lauraceae | A | t | C | Recruited | 0 | 1 | 0 | 0 | 1 |
| *Bombax anceps* Pierre var. anceps | Bombacaceae | W | t | P | Recruited | 3 | 1 | 5 | 4 | 13 |
| *Bridelia glauca* Bl. var. glauca | Euphorbiaceae | A | t | C>P | Recruited | 0 | 1 | 2 | 5 | 8 |
| *Bridelia stipularis* (L.) Bl. | Euphorbiaceae | A | t (l, s wc) | C>P | Recruited | 0 | 0 | 4 | 0 | 4 |
| *Broussonetia papyrifera* (L.) Vent. | Moraceae | A | t (l) | P | Recruited | 0 | 1 | 0 | 0 | 1 |
| *Canarium subulatum* Guill. | Burseraceae | A | t | P | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Canthium parvifolium* Roxb. | Rubiaceae | A | l,s (t) | P | Recruited | 6 | 0 | 5 | 3 | 14 |
| *Castanopsis acuminatissima* (Bl.) A. DC. | Fagaceae | A | t | C | Planted | 0 | 2 | 2 | 0 | 4 |
| *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | Fagaceae | A | t | C | Planted | 1 | 0 | 1 | 76 | 78 |
| *Castanopsis diversifolia* (Kurz) King ex Hk. f. | Fagaceae | A | t | C>P | Planted | 0 | 3 | 2 | 0 | 5 |
| *Castanopsis tribuloides* (Sm.) A. DC. | Fagaceae | A | t | C | Planted | 0 | 5 | 15 | 5 | 25 |
| *Chionanthus ramiflorus* Roxb. | Oleaceae | A | t | C>P | Recruited | 0 | 0 | 0 | 1 | 1 |
| *Cinnamomum caudatum* Nees | Lauraceae | A | t | C | Recruited | 0 | 0 | 12 | 5 | 17 |
| *Clausena excavata* Burm. f. var. *excavate* | Rutaceae | A | l (t) | C | Recruited | 0 | 0 | 1 | 1 | 2 |
| *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. | Guttiferae, Hypericaceae | W | t (l) | P | Recruited | 4 | 0 | 1 | 2 | 7 |
| *Dalbergia cultrata* Grah. ex Bth. | Leguminosae, Papilionoideae | W | t | P>C | Planted | 0 | 0 | 45 | 0 | 45 |
| *Dalbergia oliveri* | Leguminosae, Papilionoideae | W | t | P | Recruited | 0 | 0 | 0 | 0 | 0 |

| Species list | Family | Dispersal mechanism | Habit | Type | Framework species | Control sites | 2002-plots | 1999-plots | 1998-plots | Total number |
|---|---|---|---|---|---|---|---|---|---|---|
| *Dalbergia rimosa* Roxb. var. rimosa | Leguminosae, Papilionoideae | W | wc | P>C | Recruited | 0 | 1 | 4 | 1 | 6 |
| *Dalbergia stipulacea* Roxb. | Leguminosae, Papilionoideae | W | l | P | Recruited | 0 | 10 | 42 | 22 | 74 |
| *Debregeasia longifolia* (Burm. f.) Wedd. | Urticaceae | A | t (l,s) | P=C | Recruited | 0 | 0 | 0 | 0 | 0 |
| *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* | Leguminosae, Papilionoideae | W | s (l) (h) | P | Recruited | 0 | 1 | 11 | 0 | 12 |
| *Diospyros glandulosa* Lace | Ebenaceae | A | t | C>P | Planted | 0 | 0 | 0 | 4 | 4 |
| *Ehretia acuminata* R. Br. var. *acuminate* | Boraginaceae | A | t | P>C | Recruited | 0 | 0 | 0 | 1 | 1 |
| *Embelia* sp. | Myrsinaceae | | wc | C | Recruited | 0 | 11 | 11 | 0 | 22 |
| *Engelhardia spicata* Lechen. ex Bl. var. *spicata* | Juglandaceae | W | t | P>C | Recruited | 0 | 0 | 6 | 3 | 9 |
| *Erythrina stricta* Roxb. | Leguminosae, Papilionoideae | W | t | P | Recruited | 2 | 2 | 85 | 34 | 123 |
| *Erythrina subumbrans* (Hassk.) Merr. | Leguminosae, Papilionoideae | W | t | C | Planted | 1 | 1 | 3 | 107 | 112 |
| *Eugenia albiflora* Duth. ex Kurz | Myrtaceae | A | t | C | Planted | 6 | 6 | 6 | 33 | 51 |
| *Eugenia fruticosa* (DC.) Roxb. | Myrtaceae | A | t | P | Recruited | 5 | 2 | 8 | 8 | 23 |
| *Eurya acumminata* DC. var. wallichiana Dyer | Theaceae | A | t (l) | P | Planted | 1 | 0 | 6 | 0 | 7 |
| *Fagraea fragrans* Roxb. | Loganiaceae | A | s (t) | P | Recruited | 0 | 0 | 0 | 0 | 0 |
| *Fernandoa adenophylla* (Wall. ex G. Don) Steen. | Bignoniaceae | W | T | P | Recruited | 1 | 0 | 1 | 0 | 2 |
| *Ficus fistulosa* Reinw. ex Bl. var. fistulosa | Moraceae | A | t (l) | P | Recruited | 1 | 0 | 3 | 0 | 4 |
| *Ficus hirta* Vahl var. hirta | Moraceae | A | L | P | Recruited | 8 | 8 | 117 | 7 | 140 |
| *Ficus hispida* L. f. var. hispida | Moraceae | A | t (l) | P | Planted | 0 | 0 | 1 | 0 | 1 |

| Species list | Family | Dispersal mechanism | Habit | Type | Framework species | Control sites | 2002-plots | 1999-plots | 1998-plots | Total number |
|---|---|---|---|---|---|---|---|---|---|---|
| *Ficus obtusifolia* Roxb. | Moraceae | A | t | P | Recruited | 0 | 0 | 2 | 0 | 2 |
| *Ficus subincisa* J.E. Sm. var. *subincisa* | Moraceae | A | l (s) | P | Planted | 0 | 1 | 4 | 2 | 7 |
| *Glochidion acuminatum* M.-A. var. siamense A.S. | Euphorbiaceae | A | t | P | Recruited | 0 | 0 | 1 | 6 | 7 |
| *Glochidion eriocarpum* Champ. | Euphorbiaceae | A | t | P | Recruited | 0 | 0 | 2 | 3 | 5 |
| *Glochidion kerrii* Craib | Euphorbiaceae | A | l | C | Recruited | 0 | 0 | 2 | 1 | 3 |
| *Glochidion sphaerogynum* (M.-A.) Kurz | Euphorbiaceae | A | t | P | Planted | 0 | 0 | 1 | 0 | 1 |
| *Gluta obovata* Craib | Anacardiaceae | W | t | P | Recruited | 6 | 0 | 0 | 0 | 6 |
| *Gmelina arborea* Roxb. | Verbenaceae | A | t | P | Planted | 0 | 0 | 1 | 0 | 1 |
| *Harrisonia perforata* (Blanco) Merr. | Simaroubaceae | A | wc | P | Recruited | 0 | 0 | 4 | 0 | 4 |
| *Heynea trijuga* Roxb. ex Sims | Meliaceae | A | t (l) | P>C | Planted | 1 | 0 | 1 | 44 | 46 |
| *Hymenodictyon orixense* (Roxb.) Mabb. | Rubiaceae | W | t | P | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Ixora cibdela* Craib | Rubiaceae | A | l (s) | P | Recruited | 0 | 1 | 4 | 1 | 6 |
| *Lagerstroemia cochinchinensis* Pierre var. *ovalifolia* Furt. & Mont. | Lythraceae | W | t | C>P | Recruited | 0 | 0 | 2 | 0 | 2 |
| *Leea indica* (Burm. f.) Merr. | Leeaceae | A | l (s,h) | P | Recruited | 2 | 16 | 15 | 7 | 40 |
| *Lithocarpus polystachtus* (A. DC.) Rehd. | Fagaceae | A | t | P | Recruited | 1 | 0 | 4 | 0 | 5 |
| *Litsea cubeba* (lour.) Pers. var. *cubeba* | Lauraceae | A | t | P | Recruited | 36 | 29 | 17 | 4 | 86 |
| *Litsea monopetala* (Roxb.) Pers. | Lauraceae | A | t | C>P | Recruited | 81 | 265 | 432 | 211 | 989 |
| Litsea salicifolia (Roxb. ex Nees) Hk.f. | Lauraceae | A | t | C>P | Recruited | 0 | 0 | 0 | 1 | 1 |
| *Machilus bombycina* King ex Hk. f. | Lauraceae | A | t | C | Planted | 0 | 0 | 2 | 3 | 5 |
| *Maesa ramentacea* (Roxb.) A.DC. | Myrsinaceae | A | t (l) | C>P | Planted | 2 | 1 | 2 | 0 | 5 |
| *Mallotus philippensis* (Lmk.) M.-A. | Euphorbiaceae | A | t | P | Planted | 0 | 13 | 2 | 2 | 17 |
| *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* | Bignoniaceae | W | t | P>C | Planted | 3 | 0 | 62 | 11 | 76 |

| Species list | Family | Dispersal mechanism | Habit | Type | Framework species | Control sites | 2002-plots | 1999-plots | 1998-plots | Total number |
|---|---|---|---|---|---|---|---|---|---|---|
| *Melia toosendan* Sieb. & Zucc. | Meliaceae | A | t | P | Planted | 0 | 0 | 1 | 0 | 1 |
| *Melientha suavis* Pierre ssp. *suavis* | Opiliaceae | W | t (l) | P | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Michelia baillonii* Pierre | Magnoliaceae | A | t | C>P | Planted | 4 | 0 | 1 | 3 | 8 |
| *Michelia floribunda* Fin. & Gagnep. | Magnoliaceae | A | t | C>P | Recruited | 0 | 0 | 2 | 6 | 8 |
| *Micromelum hirsutum* Oliv. | Rutaceae | A | t (l) | C | Recruited | 2 | 12 | 12 | 0 | 26 |
| *Micromelum minutum* (Forst. f.) Wight & Arn. | Rutaceae | A | t (l) | C | Recruited | 0 | 0 | 0 | 13 | 13 |
| *Millettia macrostachya* Coll. & Hemsl. var. *macrostachya* | Leguminosae, Papilionoideae | W | t | P | Recruited | 0 | 0 | 0 | 1 | 1 |
| *Millettia pubinervis* Kurz | Leguminosae, Papilionoideae | A | t | P>C | Recruited | 0 | 0 | 3 | 0 | 3 |
| *Morinda tomentosa* Hey. ex Roth | Rubiaceae | A | t | P | Recruited | 0 | 1 | 0 | 0 | 1 |
| *Oroxylum indicum* (L.) Kurz | Bignoniaceae | W | t (l) | P | Planted | 0 | 4 | 1 | 0 | 5 |
| *Pavetta tomentosa* Roxb. ex Sm. var. tomentosa | Rubiaceae | A | l (s) | P | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Phoebe cathia* (D. Don) Kosterm. | Lauraceae | A | t | C | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Phoebe lanceolata* (Wall. ex Nees) Nees | Lauraceae | A | t (l) | C>P | Planted | 8 | 20 | 171 | 124 | 323 |
| *Phyllanthus emblica* L. | Euphorbiaceae | A | t (l) | P | Planted | 0 | 0 | 6 | 0 | 6 |
| *Prismatomeris tetrandra* (Roxb.) K. Sch. ssp. *tetrandra* | Rubiaceae | A | l | C | Recruited | 0 | 0 | 4 | 0 | 4 |
| *Prunus cerasoides* Ham. ex D. Don | Rosaceae | A | t | P | Planted | 5 | 3 | 189 | 64 | 261 |
| *Pterocarpus macrocarpus* Kurz | Leguminosae, Papilionoideae | A | t | P | Planted | 1 | 6 | 14 | 0 | 21 |
| *Rhus chinensis* Mill. | Anacardiaceae | A | t (l) | P | Recruited | 0 | 0 | 0 | 9 | 9 |
| *Rhus rhetsoides* Craib | Anacardiaceae | A | t | P>C | Planted | 3 | 0 | 6 | 0 | 9 |
| *Sapindus rarak* DC. | Sapindaceae | A | t | C>P | Planted | 0 | 0 | 0 | 2 | 2 |

| Species list | Family | Dispersal mechanism | Habit | Type | Framework species | Control sites | 2002-plots | 1999-plots | 1998-plots | Total number |
|---|---|---|---|---|---|---|---|---|---|---|
| *Sarcosperma arboreum* Bth. | Sapotaceae | A | t | C | Recruited | 0 | 1 | 0 | 0 | 1 |
| *Schima wallichii* (DC.) Korth. | Theaceae | W | t | C>P | Planted | 21 | 7 | 78 | 46 | 152 |
| *Spondias axillaris* Roxb. | Anacardiaceae | A | t | P>C | Planted | 8 | 3 | 17 | 1 | 29 |
| *Sterculia lanceolata* Cav. var.lanceolata | Sterculiaceae | W | t | C>P | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Sterculia villosa* Roxb. | Sterculiaceae | W | t | C>P | Recruited | 3 | 3 | 3 | 8 | 17 |
| *Stereospermum colais* (B.-H. ex Dillw.) Mabb. | Bignoniaceae | W | t | C>P | Recruited | 1 | 0 | 1 | 0 | 2 |
| *Styrax benzoides* Craib | Styracaceae | A | t | P>C | Recruited | 0 | 0 | 45 | 0 | 45 |
| *Tarennoidea wallichii* (Hk. f.) Triv. & Sastre | Rubiaceae | A | t | C | Recruited | 0 | 0 | 1 | 0 | 1 |
| *Trema orientalis* (L.) Bl. | Ulmaceae | W | t (l) | P | Recruited | 4 | 0 | 0 | 0 | 4 |
| *Turpinia pomifera* (Roxb.) Wall. ex DC. | Staphyleaceae | A | t | C>P | Planted | 0 | 0 | 23 | 1 | 24 |
| *Vernonia volkameriifolia* DC. var. volkameriifolia | Compositae | W | l (s) | P | Recruited | 0 | 0 | 5 | 0 | 5 |
| *Wendlandia scabra* Kurz var. *scabra* | Rubiaceae | W | t (l) | P | Recruited | 1 | 34 | 10 | 0 | 45 |
| *Wendlandia tinctoria* (Roxb.) DC. ssp. *floribunda* (Craib) Cowan | Rubiaceae | W | t (l) | C>P | Planted | 0 | 0 | 8 | 7 | 15 |
| *Xantolis burnmanica* (Coll. & Hemsl.) P. Royen | Sapotaceae | A | t | P | Recruited | 32 | 0 | 0 | 2 | 34 |
| Unknown 1 | | | | | Recruited | 0 | 1 | 2 | 0 | 3 |
| Unknown 2 | | | | | Recruited | 0 | 0 | 10 | 0 | 10 |
| Total | | | | | | 345 | 553 | 1883 | 1009 | 3790 |

Remark: A= animal dispersed species, W=wind dispersed species, t=tree, l=treelet, s=shrub, wc= woody climber, P=pioneer species, C=climax species

Appendix B Lists of framework tree species, seedlings under their canopy and seedling scores

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| *1. Acrocarpus fraxinifolius* Wight ex Arn. | 20 | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Pterocarpus macrocarpus* Kurz (W) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Sterculia villosa* Roxb. (W) | Recruited |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Recruited |
| *2. Acronychia pedunculata* (L.) Miq. | 2.8 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Cinnamomum caudatum* Nees (A) | Planted |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr.(W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz (A) | Planted |
| | | *Ficus hirta Vahl var. hirta* (A) | Recruited |
| | | *Heynea trijuga* Roxb. ex Sims (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| 3. *Albizia chinensis* (Osb.) Merr. | 10.75 | *Albizia chinensis* (Osb.) Merr. (W) | Planted |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr.(W) | Planted |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| 4.*Antidesma bunius* (L.) Spreng. | 0.75 | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Dalbergia stipulacea* Roxb. (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |
| 5. *Antidesma ghaesembilla* Gaertn. | 4 | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| 6. *Aphanamixis polystachya* (Wall.) R. Parker | 4.5 | *Heynea trijuga* Roxb. ex Sims (A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Prunus cerasoides Ham. ex D. Don* (A) | Planted |
| | | *Sapindus rarak* DC. (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| 8. *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | 1 | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| ***9. Balakata baccata* (Roxb.) Ess.** | **6.7** | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* | Planted |
| | | *Bombax anceps* Pierre var. anceps (W) | Recruited |
| | | *Bauhinia variegata* L. (W) | Recruited |
| | | *Castanopsis acuminatissima* (Bl.) A. DC. (A) | Planted |
| | | *Dalbergia cultrata* Grah. ex Bth. (W) | Planted |
| | | *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* (W) | Recruited |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Pavetta tomentosa* Roxb. ex Sm. var. tomentosa (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prismatomeris tetrandra* (Roxb.) K. Sch. ssp. *Tetrandra* (A) | Recruited |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Styrax benzoides* Craib (A) | Planted |
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Wendlandia scabra* Kurz var. *scabra (W)* | Planted |
| *10. Betula alnoides* Ham. ex D. Don | 2 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| *11. Bischofia javanica* Bl. | 13.5 | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Erythrina subumbrans* (Hassk.) Merr.(W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Heynea trijuga* Roxb. ex Sims (A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| *12. Callicarpa arborea* Roxb. var. *arborea* | 10 | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Bridelia glauca* Bl. var. *glauca* (A) | Recruited |
| | | *Castanopsis diversifolia* (Kurz) King ex Hk. f. (A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Glochidion sphaerogynum* (M.-A.) Kurz (A) | Planted |
| | | *Michelia baillonii* Pierre (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |
| 13. Castanopsis acuminatissima (Bl.) A. DC. | 3 | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Styrax benzoides* Craib (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| *14. Castanopsis cerebrina* (Hickel & A. Camus) Barnett. | 7.625 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Canthium parvifolium* Roxb. (A) | Recruited |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. © | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Mallotus philippensis* (Lmk.) M.-A. (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| *15. Castanopsis diversifolia* ( Kurz) King ex Hk. f. | 3 | *Pterocarpus macrocarpus* Kurz (A) | Planted |
| | | *Glochidion sphaerogynum* (M.-A.) Kurz (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| *16. Castanopsis tribuloides* (Sm.) A. DC. | 24 | *Albizia chinensis* (Osb.) Merr. (W) | Planted |
| | | *Antidesma acidum* Retz. (A) | Planted |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Eurya acumminata* DC. var. wallichiana Dyer (A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| *17. Catunaregam spathulifolia* Tirv. | 1 | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| *18. Cinnamomum caudatum* Nees | 26.5 | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr.(W) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Glochidion acuminatum* M.-A. var. siamense A.S. (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Styrax benzoides* Craib (A) | Recruited |
| | | *Wendlandia tinctoria* (Roxb.) DC. ssp. *Floribunda* (Craib) Cowan (W) | Recruited |
| *19. Dalbergia cultrata* Grah. ex Bth. | 12 | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Glochidion eriocarpum* Champ. (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Millettia macrostachya* Coll. & Hemsl. var. *macrostachya* | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Styrax benzoides* Craib (A) | Recruited |
| *20. Diospyros glandulosa* Lace | 18.75 | *Albizia chinensis* (Osb.) Merr. (W) | Planted |
| | | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aquilaria crassna* Pierre ex Lec. (A) | Recruited |
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* (A) | Planted |
| | | *Diospyros glandulosa* Lace (A) | Planted |
| | | *Erythrina subumbrans* (Hassk.) Merr.(W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| *21. Elaeocarpus lanceifolius* Roxb. | 7.5 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| ***22. Erythrina subumbrans* (Hassk.) Merr.** | **11.625** | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Antidesma bunius* (L.) Spreng. (A) | Planted |
| | | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Cinnamomum caudatum* Nees (A) | Planted |
| | | *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. (W) | Recruited |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Ficus fistulosa* Reinw. ex Bl. var. *fistulosa* (A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Glochidion eriocarpum* Champ. (A) | Recruited |
| | | *Glochidion kerrii* Craib (A) | Recruited |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Michelia baillonii* Pierre (A) | Planted |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |
| | | *Rhus chinensis* Mill. (A) | Recruited |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| | | *Sterculia villosa* Roxb. (W) | Recruited |
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |
| 23. *Eugenia albiflora* Duth. ex Kurz | 5 | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |
| | | *Wendlandia tinctoria* (Roxb.) DC. ssp. *Floribunda* (Craib) Cowan (W) | Recruited |
| *24. Eurya acumminata* DC. var. *wallichiana* Dyer | 1 | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| ***25. Ficus altissima* Bl.** | **15.9** | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Bridelia glauca* Bl. var. *glauca (A)* | Recruited |
| | | *Canthium parvifolium* Roxb. (A) | Recruited |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Chionanthus ramiflorus* Roxb. (A) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| *26. Ficus benjamina* L. var. *benjamina* | 6.3 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* (A) | Planted |
| | | *Cinnamomum caudatum* Nees (A) | Planted |
| | | *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* (W) | Recruited |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Rhus chinensis* Mill. (A) | Recruited |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Planted |
| | | *Wendlandia tinctoria* (Roxb.) DC. ssp. *Floribunda* (Craib) Cowan (W) | Recruited |
| *27. Ficus capillipes* Gagnep. | 1 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| *28. Ficus fistulosa* Reinw. ex Bl. var. *fistulosa* | 5 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| ***29. Ficus glaberrima* Bl. var. glaberrima** | **15.5** | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Albizia odoratissima* (L. f.) Bth. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* (A) | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba (A)* | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Melia toosendan* Sieb. & Zucc. (A) | Planted |
| | | *Michelia baillonii* Pierre (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Phyllanthus emblica* L. (W) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| | | *Sterculia villosa* Roxb. (W) | Planted |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Planted |
| *30. Ficus hispida* L. f. var. *hispida* | 3 | *Acacia megaladena* Desv. var. *megaladena* | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| *31. Ficus subincisa* J.E. Sm. var. *subincisa* | 3.875 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Bombax anceps* Pierre var. anceps (W) | Recruited |
| | | *Bridelia glauca* Bl. var. glauca (A) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Machilus bombycina* King ex Hk. f. (A) | Planted |
| | | *Michelia baillonii* Pierre (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Spondias axillaris* Roxb. (A) | Planted |
| 32. *Ficus racemosa* L. var. *racemosa* | 5.4 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* (W) | Recruited |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe cathia* (D. Don) Kosterm. (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don (A)* | Planted |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| 33. *Garcinia mckeaniana* Craib | 4 | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| *34. Glochidion sphaerogynum* (M.-A.) Kurz | 2 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |
| ***35. Gmelina arborea* Roxb.** | **14.5** | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Beilschmiedia assamica* (A) | Recruited |
| | | *Bridelia glauca* Bl. var. glauca (A) | Recruited |
| | | *Canthium parvifolium* Roxb. (A) | Recruited |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Cratoxylum formosum* (Jack) Dyer ssp. pruniflorum (Kurz) Gog. (W) | Recruited |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Heynea trijuga* Roxb. ex Sims (A) | Planted |
| | | *Lithocarpus polystachtus* (A. DC.) Rehd. (A) | Planted |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Mallotus philippensis* (Lmk.) M.-A. (A) | Planted |
| | | *Michelia floribunda* Fin. & Gagnep. (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Styrax benzoides* Craib (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |
| *36. Helicia nilagirica* Bedd. | 6.4 | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aquilaria crassna* Pierre ex Lec. (A) | Recruited |
| | | *Bombax anceps* Pierre var. anceps (W) | Recruited |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. © | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Glochidion acuminatum* M.-A. var. siamense A.S.(A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| ***37. Heynea trijuga* Roxb. ex Sims** | **15.2** | *Alstonia scholaris* var. *scholaris* (W) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* (A) | Planted |
| | | *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Glochidion acuminatum* M.-A. var. siamense A.S.(A) | Planted |
| | | *Glochidion eriocarpum* Champ. (A) | Recruited |
| | | *Heynea trijuga* Roxb. ex Sims (A) | Planted |
| | | *Ixora cibdela* Craib (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Sterculia villosa* Roxb. (W) | Recruited |
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |
| *38. Horsfieldia amygdalina* (Wall.) Warb. var. *amygdalina* | 6 | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Heynea trijuga* Roxb. ex Sims (A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| ***39. Hovenia dulcis* Thunb.** | ***8.5*** | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Bombax anceps* Pierre var. anceps (W) | Recruited |
| | | *Castanopsis diversifolia* (Kurz) King ex Hk. f. | Planted |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Eurya acumminata* DC. var. wallichiana Dyer (A) | Planted |
| | | *Ficus hirta* Vahl var. hirta (A) | Recruited |
| | | *Glochidion kerrii* Craib (A) | Recruited |
| | | *Gmelina arborea* Roxb. (A) | Planted |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Rhus rhetsoides* Craib (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Planted |
| *40. Lithocarpus fenestratus* (Roxb.) Rehd. | 8 | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Maesa ramentacea* (Roxb.) A.DC. (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Wendlandia scabra* Kurz var. *scabra (W)* | Planted |
| *41. Macaranga denticulata* (Bl.) M.-A. | 8.4 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* (A) | Planted |
| | | *Castanopsis diversifolia* (Kurz) King ex Hk. f. | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Dalbergia stipulacea* Roxb. (W) | Planted |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| ***42. Machilus bombycina* King ex Hk. f.** | **6.7** | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Dalbergia stipulacea* Roxb. (W) | Planted |
| | | *Debregeasia longifolia* (Burm. f.) Wedd. (A) | Recruited |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Lithocarpus polystachtus* (A. DC.) Rehd. (A) | planted |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| | | *Styrax benzoides* Craib (A) | Recruited |
| | | *Vernonia volkameriifolia* DC. var. volkameriifolia (W) | Recruited |
| *43. Mallotus paniculatus* (Lmk.) M.-A. | 1 | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| *44. Manglietia garrettii* Craib | 9 | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. © | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Ixora cibdela* Craib (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Michelia baillonii* Pierre (A) | Planted |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Sterculia villosa* Roxb. (W) | Planted |
| *45. Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* | 10 | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Glochidion acuminatum* M.-A.var. *siamense* A.S. (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Michelia floribunda* Fin. & Gagnep.(A) | Recruited |
| | | *Morinda tomentosa* Hey. ex Roth (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Sterculia villosa* Roxb. (W) | Recruited |
| *46. Maesa ramentacea* (Roxb.) A.DC. | 1 | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Wendlandia tinctoria* (Roxb.) DC. ssp. *Floribunda* (Craib) Cowan (W) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| *47. Melia toosendan* Sieb. & Zucc. | 4.4 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Clausena excavata* Burm. f. var. *excavata* (A) | Recruited |
| | | *Dalbergia oliveri* (W) | Recruited |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Machilus bombycina* King ex Hk. f. (A) | planted |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| | | *Turpinia pomifera* (Roxb.) Wall. ex DC. (A) | Planted |
| ***48. Michelia baillonii* Pierre** | **8.5** | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Canthium parvifolium* Roxb. (A) | Recruited |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Cinnamomum caudatum* Nees | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Dalbergia stipulacea* Roxb. | Planted |
| | | *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eurya acumminata* DC. var. wallichiana Dyer (A) | Planted |
| | | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Pterocarpus macrocarpus* Kurz (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Sterculia lanceolata* Cav. var.lanceolata (W) | Recruited |
| | | *Styrax benzoides* Craib (A) | Recruited |
| ***49. Nyssa javanica*** **(Bl.) Wang.** | **9.7** | *Alangium kurzii* Craib (A) | Recruited |
| | | *Alseodaphine andersonii* (King ex Hk. f.) Kosterm. (A) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Archidendron clypearia* (Jack) Niels. ssp. clypearia var. *clypearia* (A) | Planted |
| | | *Bauhinia variegata* L. (W) | Recruited |
| | | *Dalbergia stipulacea* Roxb. (W) | Planted |
| | | *Engelhardia spicata* Lechen. ex Bl. var. *spicata* (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Eugenia albiflora* Duth. ex Kurz(A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Heynea trijuga* Roxb. ex Sims (A) | Planted |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Maesa ramentacea* (Roxb.) A.DC. (A) | Planted |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Micromelum hirsutum* Oliv. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prismatomeris tetrandra* (Roxb.) K. Sch. ssp. *Tetrandra* (A) | Recruited |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Planted |
| | | Unknown | |
| ***50. Phoebe lanceolata* (Wall. ex Nees) Nees** | **9.9** | *Bridelia glauca* Bl. var. glauca (A) | Recruited |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Castanopsis diversifolia* (Kurz) King ex Hk. f. (A) | Planted |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Planted |
| ***51. Prunus cerasoides* D. Don** | **10.6** | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Bridelia glauca* Bl. var. glauca (A) | Recruited |
| | | *Cinnamomum caudatum* Nees | Planted |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Recruited |
| | | *Eugenia albiflora* Duth. ex Kurz (A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Rhus rhetsoides* Craib (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| 52. *Pterocarpus macrocarpus* Kurz | 7.7 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Dalbergia stipulacea* Roxb. (W) | Planted |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| | | *Sterculia lanceolata* Cav. var.lanceolata (W) | Recruited |
| | | *Styrax benzoides* Craib (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Wendlandia tinctoria* (Roxb.) DC. ssp. *Floribunda* (Craib) Cowan (W) | Recruited |
| 53. *Quercus semiserrata* Roxb. | 6 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Spondias axillaris* Roxb. (A) | Planted |
| 54. *Rhus rhetsoides* Craib | 4.4 | *Albizia garrettii* Niels. (W) | Recruited |
| | | *Albizia odoratissima* (L. f.) Bth. (W) | Recruited |
| | | *Antidesma acidum* Retz. (A) | Recruited |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Castanopsis diversifolia* (Kurz) King ex Hk. f. (A) | Planted |
| | | *Cinnamomum caudatum* Nees | Planted |
| | | *Eugenia albiflora* Duth. ex Kurz (A) | Planted |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Phyllanthus emblica* L. (A) | Planted |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Prunus cerasoides* Ham. ex D. Don (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Stereospermum colais* (B.-H. ex Dillw.) Mabb. (W) | Recruited |
| | | *Wendlandia tinctoria* (Roxb.) DC. ssp. *Floribunda* (Craib) Cowan (W) | Recruited |
| 55. *Sapindus rarak* DC. | 7 | *Antidesma ghaesembilla* Gaertn (A) | Planted |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Eurya acumminata* DC. var. wallichiana Dyer (A) | Planted |
| | | *Ficus hirta* Vahl var. *hirta* (A) | Recruited |
| | | *Machilus bombycina* King ex Hk. f. (A) | Planted |
| | | *Phoebe lanceolata* (Wall. ex Nees) Nees (A) | Planted |
| | | *Schima wallichii* (DC.) Korth. (W) | Recruited |
| | | *Wendlandia scabra* Kurz var. *scabra* (W) | Planted |
| 56. *Sarcosperma arboreum* Bth. | 19 | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Litsea cubeba* (lour.) Pers. var. *cubeba* (A) | Recruited |
| | | *Litsea monopetala* (Roxb.) Pers. (A) | Recruited |
| | | *Markhamia stipulata* (Wall.) Seem. ex K. Sch. var. *stipulata* (W) | Planted |
| | | *Ficus hispida* L. f. var. hispida (A) | Planted |
| ***57. Spondias axillaris* Roxb.** | **8.3** | *Antidesma ghaesembilla* Gaertn. (A) | Planted |
| | | *Aporusa octandra* (B.-H. ex D. Don) Vick. var. *octandra* (A) | Recruited |
| | | *Aporusa villosa* (Lindl.) Baill. (A) | Planted |
| | | *Aquilaria crassna* Pierre ex Lec. (A) | Recruited |
| | | *Artocarpus lakoocha* Roxb. (A) | Planted |
| | | *Bridelia glauca* Bl. var. *glauca* (A) | Recruited |

| Framework tree species | Seedling score | Seedling species beneath canopy | Planted/recruited |
|---|---|---|---|
| | | *Castanopsis cerebrina* (Hickel & A. Camus) Barnett. (A) | Planted |
| | | *Castanopsis diversifolia* (Kurz) King ex Hk. f. (A) | Planted |
| | | *Castanopsis tribuloides* (Sm.) A. DC. (A) | Planted |
| | | *Cinnamomum caudatum* Nees (A) | Planted |
| | | *Desmodium velutinum* (Willd.) DC. ssp. velutinum var. *velutinum* (W) | Recruited |
| | | *Erythrina stricta* Roxb. (W) | Recruited |
| | | *Erythrina subumbrans* (Hassk.) Merr. (W) | Planted |
| | | *Eugenia albiflora Duth. ex Kurz* (A) | Planted |
| | | *Eugenia fruticosa* (DC.) Roxb. (A) | Recruited |
| | | *Ficus hirta Vahl var. hirta* (A) | Recruited |
| | | *Ixora cibdela* Craib (A) | Recruited |
| | | *Leea indica* (Burm. f.) Merr.(A) | Recruited |
| | | *Litsea monopetala (Roxb.) Pers.*(A) | Recruited |
| | | *Micromelum hirsutum* Oliv.(A) | Recruited |
| | | *Micromelum minutum* (Forst. f.) Wight & Arn.(A) | Recruited |
| | | *Phoebe lanceolata (Wall. ex Nees) Nees* (A) | Planted |
| | | *Prunus cerasoides Ham. ex D. Don* (A) | Planted |
| | | *Schima wallichii (DC.) Korth.* (W) | Recruited |

CIRCULUM VITAE

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