Natural regeneration and ecological succession in *Pinus kesiya* watershed plantations in northern Thailand: implications for plantation management.

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Tiivistelmä — Referat — Abstract

Establishment of *Pinus kesiya* Roy. ex Gord. plantations in Thailand began in the 1960s by the Royal Forest Department. The aim was to reforest abandoned swidden areas and grasslands in order to reduce erosion and to produce timber and fuel wood. Today there are about 150, 000 ha of *P. kesiya* plantations in northern Thailand. Most of these plantations cannot be harvested due to a national logging ban. Previous studies have suggested that *Pinus kesiya* plantations posses a capability as a foster environment for native broadleaved tree species, but little is known about the extent of regeneration in these plantations.

The general aim of the study was to clarify the extent of forest regeneration and interactions behind it in *Pinus kesiya* plantations of the Ping River basin, northern Thailand. Based on the results of this study and previous literature, forest management proposals were produced for the area studied.

In four different pine plantation areas, a total of seven plantations were assessed using systematic data collection with clustered circular sample plots. Vegetation and environmental data were statistically analysed, so as to recognise the key factors affecting regeneration.

Regeneration had occurred in all plantations studied. Regeneration of broadleaved trees was negatively affected by forest fire and canopy coverage. A high basal area of mature broadleaved trees affected the regeneration process positively. Forest fire disturbance had a strong effect also on plantation structure and species composition.

Because of an unclear future forest management setting as regards forest laws in Thailand, a management system that enables various future utilisation possibilities and emphasises local participation is recommended for *P. kesiya* watershed plantations of northern Thailand.

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Preface

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Contents

1. Introduction

1.1 Forest policy, administration and plantation forestry in Thailand

From 1782 onwards, the commercial value of Thailand's forest resources increased rapidly. Till then the government had focused its control only on people and not on the still plentiful natural resources. King Chulalongkorn hired a British forester H. Slade to evaluate the situation. Based on Slade's recommendations, the Royal Forest Department (RFD) was established in 1896 and the ownership of natural resources was passed to the government. Aims of the RFD were to regulate the harvest of trees, allocate some of the incomes from harvesting to the central government, and consolidation of central government over regional feudal chiefs. Partnership between feudal chiefs and international concessionaires ended, and a new one was born between the latter and the state. In this process the local people were alienated from ownership and decision making over forests and branded as forest destroyers (Pragtong and Thomas 1990). Since then locals have had limited ownership over land. The Land Code of 1954 divides land tenure into three classes that for farmers are often difficult to understand: (1) occupancy grants no right of ownership, as is so often felt by the farmers; (2) utilisation, in which the use right is permanent and inheritable, and finally (3) legal ownership (Northeast Thailand…1987, Hafner 1990).

Although RFD has set up laws to enforce forest use, regeneration and conservation, the abundant forests continued to deteriorate. By 1967 the forest cover had dropped to 48%, from being 60% in 1953. The government's push for economic growth still accelerated deforestation, leaving only 32% of the Kingdom under forest by 1980, despite efforts to reforest and to protect the forests. In 1985 a forest policy was established that which urges all sectors of the Government and society to help the RFD in maintaining the forests. However, the pressure to reallocate some of the forest reserves and to grant villagers the ownership mounted. Newspapers blamed the RFD for loving trees more than the people and for still failing to protect the environment.

In 1988 floods in southern Thailand caused a death of over 200 people, and this disaster was linked to deforestation of watersheds. Illegal logging and concession abuses were revealed, and the public became outraged. In response, the government declared a nation-wide commercial logging ban in 1989. After that the RFDs task was forest conservation only (Luukkanen 2001, Pragtong and Thomas 1990, Thai Forestry…1993).

In October 2003; the RFD was transferred from the Ministry of Agriculture to be under a new ministry, the Ministry of Natural Resources and Environment. The new ministry's mission was conservation and the restoration of natural resources and the environment combined with management and utilisation of them in a sustainable manner. In the same process the Royal Forest Department was split into three departments, (1) the National Park, Wildlife and Plant Protection Department, (2) the Marine and Coastal Resources Department, and (3) the Royal Forest Department. The Department of Mineral Resources also works under the new ministry (Ministry of Natural…2004).

Most of the RFD staff moved to the Department of National Parks and Natural Resources, while the rest stayed at the RFD. New tasks of the RFD consisted of issuing permits for logging transportation and control over natural resources, more specifically covering the general management of the department, legislation and permits, and promotion of community forestry and tree planting outside the reserved forests. The department sets up roadblocks for timber trucks inside the Kingdom in order to inspect the necessary transportation permits. It is also eager to promote community forestry, even though there is still no legal framework for it (Srisooksomwong 2004, pers. comm.).

The future management methods for protected areas are now under planning. New initiative is the Strategic Plan for Integrated Management of Watersheds; it is a ten-year process started in 2004. The aim of this plan is to develop a knowledge base for the preservation, conservation, rehabilitation and utilisation of forests, with participation of all stakeholders (Thammincha 2004, pers. comm.). The new administrative structure is still developing, and because of this, it is still a confusing for officers who are not sure what they are in charge of (Srisooksomwong 2004, pers. comm.).

Thailand has a population of 62.4 million people, with an annual increase of 0.7% (RFD 2001).Thailand's land area is 511,114 km², of which 33.4% (170,712 km²) is reported to be covered by forest (RFD 2001). The national goal is to get the cover up to 40%, of which 15% is bound to be protection forest and 25% production forest. By FAO, the annual forest cover loss is currently estimated as 0.7% (112,000 ha) (FAO 2001).

The Royal Forest Department (2001), reports the annual reforestation in the whole kingdom aas 22,400 ha for the year 2001. Most of the new plantations are located in the North and Northeast. The RFD has been an active agent in the establishment of plantations concentrating, both on industrial plantations reforested with teak (*Tectona grandis* L.f.) and on, denuded and watershed areas, on nonindustrial plantations.

Establishment by the RFD of Khasi pine (*Pinus kesiya* roy. ex Gord.) plantations began in the 1960s. The aim was to reforest abandoned swidden areas and grasslands in order to reduce erosion and to produce timber and fuelwood (Savage 1994). Khasi pine was selected for plantations because being a native species and because of its rapid growth and long fibre length. The species should be ready for felling in 10 years from when used as timber (Banijbatana 1978).

Watershed Development Units took over the plantation establishment in the 1970s, and the plantation establishment was subsequently escalated. Today there are about 150,000 ha of *P. kesiya* plantations in northern Thailand. Most of these plantations areas located within the Protected Area System (RFD 1993). Pine plantations were established on old opium and upland rice fields traditionally cultivated by hill tribes.

This development has had a direct effect on the livelihood of the local villagers. Because of the logging ban and the existence of watershed protection areas, income from timber is not available and, apart from kindlings and resin, there is little more that pines can offer in terms of non-timber forest products (NTFP) (Koskela 1993). Within this framework, native broadleaved trees could offer more income possibilities in the form of NTFPs, which include construction material, food, medicine, fuel, tool material, rope material, glue, pillow stuffing and decoration (Holmberg 1996). This is also clearly evident from studies conducted by Kunarattanapruk *et al.* (1998) and May (1995, www-document), who found out that considerable proportions of the yearly incomes (15%) is collected as NTFPs and 31% of all household food comes from the forests. Most important food groups collected were animals (36%), vegetables (34%), mushrooms (13%), fruits (9%) and bamboo shoots (5%). It was also noted by both authors (May 1995, Kunarattanapruk *et al.* 1998) that the level of forest-based income was higher among poor people. May (1995) considered it to be a positive fact that NTFP collection was mainly practiced by women, since this contributed to better family nutrition and empowered the women by allowing them to regenerate income.

Today, along with traditional monoculture plantation establishment plantations with mixture of native trees are also used (Hardwick *et al.* 1997, Oberhauser 1997). At higher altitudes of northern Thailand these species include *Prunus cerasoides* D. Don, *Docynia indica* (Wall.) Decne, *Betula alnoides* Ham. ex D. Don and *Schima wallichii* (DC.) Korth.. Khasi pine is still the most common species planted with a proportion of about 50%. The current management objective is to create watershed plantations that are diverse, site-adapted, multi-storeyed and sustainably manageable with as little damage to the environment as possible (Oberhauser 1997).

Figure 1. Mae Chon Luang, Mae Chaem catchment, Mae Chaem district.
Original picture taken in 1980 by RFD.

The most serious obstacles of plantation establishment in Thailand have been socio-economic and environmental. Competing needs for land resources and suspicions against monoculture plantations among the rural people and environmentalists alike have restricted the spreading of plantation forestry (Niskanen 1996).

1.2 Aims of the study

The general aim of the present study was to analyse the extent of forest regeneration and interactions behind it in these plantations. New insights might help future land rehabilitation and in the efforts for better management of the *P. kesiya* watershed plantations in northern Thailand.

Specific aims of the study were:

1) To clarify the limiting factors of forest succession in these pine plantations.
2) To examine the effect of forest fire on tree species composition and vegetation structure.
3) To characterise seed dispersion mechanisms as related to environmental condition.
4) Forest type alteration noticed in previous studies was also reviewed, to find out if it was taking place in the plantations studied.
5) Outline future management recommendations based on the preliminary results of the present work and previous studies.

It was hoped that, in the future, the species composition and plantation structure data could be used in the management planning for watershed areas in northern Thailand.

2. General background and framework

2.1 Watershed management

2.1.1 Definition of watersheds

A watershed is a land area that drains through a common river system. An area located at a steeper slope than 8% is considered a watershed area and one at steeper than 30% slope an upper watershed area (Lai and Garrity 1999). Mountainous areas cover 14% (totalling 1.7 billion ha) of the Asia and Pacific region, with 128 million people living in them; most of these people are facing poverty and other constraints (Tangtham 1999). Watersheds have both environmental service function and production functions. Environmental services provided by watersheds include water flow regulation, soil loss prevention, biodiversity conservation and carbon sequestration. Production functions include, the containment of agricultural production and the forest resource availability for local uses. Stakeholders outside watershed areas, i.e. governments, industry, environmentalists etc. are mostly interested in services, and the local people mostly in production functions (Lai and Garrity 1999).

2.1.2 Watershed degradation and cost sharing

Highlands are recognized as fragile ecosystems. They are easily disturbed by unsuitable land use (Tangtham 1999). Because of an increasing population that needs new agricultural land and because of the global markets, there is a demand for more timber, rubber, oil, fruits and tree resins over the now more open national borders. Watersheds are under much pressure as manifested by forest degradation and soil erosion (Lai & Garrity 1999). Because lowlands are generally already fully utilized for agricultural production, the highlands are needed in order to increase the productivity and to meet the market demands (Tangtham 1999).

When natural forest is cleared to make way for agricultural land or plantations, stream flows increase with higher quantities of sediment and higher concentration of chemical residues and plant nutrients in them. This is caused by a decrease in evapotranpiration and by the decreased soil water infiltration capacity. As a result, in the rainy seasons floods become more frequent and, because water flows faster, it leads to water shortages in the dry season (Tangtham 1999). The dry-season flow decreases if rain water infiltration is weakened by compaction of the topsoil, overgrazing, or creation of impervious grounds, such as roads. Consequently, dry season flows can increase after forest clearance, if topsoil compaction is avoided. The response of stream flows to forest clearing depends also of rainfall conditions, elevation, distance from the coast, catchments steepness, soil depth, disturbance of undergrowth and fertility of the soil (Brooks *et al.* 1991, Bruijnzeel 2004).

As a consequence of watershed degradation there are on-site and off-site economic losses. On-site losses are caused by decrease of land productivity. Off-site losses are indirect effects of the degradation of watershed services (Lai and Garrity 1999). On-site costs can lead to emigration; people are forced to leave their homes and livelihoods. Off-site costs include sedimentation of dams and irrigation channels, and flood hazards (Tangtham 1999).

Watershed management is usually rationalized by off-site losses that affect outside stakeholders more than locals, even though the on-site losses may be much higher than the off-site losses (Lai and Garrity 1999).

Figure 2. Doi Inthanon and Mae Chaem watershed area. Photograph by S. Kiianmaa

2.1.3 Watershed management in Thailand

In Thailand areas are roughly separated into lowlands and uplands. Lowland is situated at elevations from 0 to 200 m above the sea level (a.s.l) and upland from 200 to 700 m; and if an area is at about 300 m a.s.l. it can be considered as highland as well as upland (Chanpaka 1984).

Watershed areas, together with national parks, wildlife sanctuaries, non-hunting areas, forest parks and biosphere reserves, form Thailand's "Protected Area System". Main problems that these areas face include a lack of representativeness of biotopes, unsuitable land-use, conflicts between government agencies, lack of management plans, and a need for local involvement (Tangtham and Chunkao 1989).

In 1964 Thailand launched its first watershed management program to fight siltation problems of the country's largest dam, Bhumibol Dam (Dulyapach 1984). The Integrated Watershed and Forest Land-Use Project was launched in 1972 in the Mae Sa watershed in Chiang Mai province. Economic growth, living conditions and environmental improvement were to be improved by change of agricultural methods from shifting cultivation to market-oriented agriculture. The Mae Chaem project was established in 1981 with additional aims of increasing local planning efficiency and securing continuity after the project officially terminates. All these projects initiated by Royal Thai Government have had a somewhat limited effect (Tangtham 1999).

A watershed classification project to classify the utilization potential of different land areas, based on classification on solid data, was launched by forming a Committee on Watershed Management in 1979. The committee consisted of experts in different fields.

The watershed class for a certain area can be calculated with an equation including the slope, elevation, landform, geologic and soil characteristics. Five different watershed/land-use suitability classes were created and placed on topographic maps. Field verifications were done, so as to guarantee that everybody agrees on the watershed class boundaries (Tangtham and Chunkao 1989; Tangtham, pers. comm.).

Political matters were also taken into account when deciding on the classes. Is it suitable to classify highland for agricultural use, with a pesticide flow to downstream areas as a consequence? Cultural land uses were also recognized; forest lands used, for instance, as cemeteries were classified as agricultural land instead of protection area. The protection area class (I) was divided into two, forest in good condition and forest with swidden cultivation, because there were communities already resident in some forest areas to be classified as protection area (Tangtham, pers. comm.). The watershed classes of Thailand are as follows (Dulyapach 1984, Boonsaner 1985, Tangtham and Chunkao 1989, Tangtham 1999):

- Class I. Protected, forested headwaters supply area at higher elevations with steep slopes.
- Class II. Slightly degraded forest in the highlands, for commercial forestry or mining with specific water and soil protection measures, slope between 50 and 85 %.
- Class III. Upland area with slope between 35 and 50 %, used for commercial forestry, mining or tree crop agriculture with water and soil protection measures.
- Class IV. Degraded lowland with deep soil and slope of 12-35 %, suitable for both lowland and upland agricultural crops with moderate soil and water protection.
- Class V. All land-uses are allowed.

Now that the whole of Thailand has been classified into these five classes it is possible to add more parameters to the equation to make it more detailed or make the land units classified smaller and more precise with the help of GIS. The value of the land use suitability/watershed class of certain watershed areas is not fixed; it can change if there are changes in the values of parameters (Tangtham and Chunkao 1989, Tangtham 1999).

Thailand's Watershed Management Strategy includes an analysis of the watershed area, i.e. precise information about the site and development plans for natural resources and socio-economic factors. First the area is classified, along suitable land-uses, into watershed classes. In order to improve the natural environment, reforestation is done as well as management of natural forest, fire protection, agroforestry and extension work. To improve the living conditions of local people, agricultural land is allocated to them, technical aid is given about cultivation techniques, and communal grazing land is provided as well as woodlots for village use. Education, health services, basic infrastructure and communication between stakeholders are enhanced (Chanpaka 1984). This work has been done under the Forest Village Project since 1975 and the Hill Tribe Development Project since 1977. The objective of these projects has been abandonment of shifting cultivation through resettlement of the communities living in critical watersheds to new permanent villages with improved, stabilized farming techniques. Despite the efforts, forest degradation has continued. The main problems that these projects have countered are lack of budget and local resistance by farmers and populist politicians (Chuntanaparb and Wood 1986).

Problems concerning watersheds that Thailand has faced are flooding in downstream areas during rainy season and lack of water in the dry season (Dulyapach 1984, Giambelluca and Ziegler 1996). There has also been a decrease in agricultural productivity due to soil erosion (Dulyapach 1984). Randhava and Kanchanadul (1996) reported that in North Thailand's highlands, with a population of about 700,000 people, the population increase has forced the farmers to intensify the land-use by shortening fallow times. Soil erosion is very serious, with annual soil losses of 50 –100 tons/ha.

The rapid population increase in Thailand has also been one of the indirect causes for deforestation. During 1960's and 1970's the population increase was 70 % as compared to a 35 % increase in agricultural land allocation during the same period; this resulted in about 60,000 km^2 of illegal settlements in the forests (Dulyapach 1984, Boonsaner 1985).

The Highland Development Project that was implemented for 30 years resulted in a higher income for farmers and abandonment of opium cultivation. After introduction of cash crops, vegetables, fruits and flowers, the vegetable production has increased from an annual 150 tons to 1000 tons (1997) through agricultural land expansion that has caused even more destruction to highland forests. Because of the success in income accumulation by vegetable cultivation, farmers now prefer agricultural land to forests and neglect or destroy government-planted seedlings in reforested areas (Ming-Lii 1999).

Figure 3. Agricultural fields in Mae Sa Noi catchment, Mae Rim. Photograph by S. Kiianmaa

In the highlands of northern Thailand, new farming techniques have been realized. Use of grass and weedy strips to minimize surface erosion and use of leguminous and fruit trees in agroforetry for regaining soil fertility and production of food, fodder and mulch, have yielded better results in both conservation and agricultural production (Randhava & Kanchanadul 1996). A study made in three provinces of which the first is situated in North-East Thailand and the last two are in North Thailand, Nakhon Ratchasima, Lamphun and Chiang Mai, respectively the effectiveness of different natural resource management models in six different community forests, including management by the state, NGOs, public and private co-operation and community based organizations (CBOs). The study concluded that the most successful model for forest protection was the one that gave the local communities opportunities to initiate and participate in decision-making and management of their community resources. The success also depends on strength and feeling of togetherness of the community, and on condition of natural resources and existence of good human resources within the community. When these qualities are combined with outside support by the state, NGOs and international organizations, the potentials for successful forest protection are good (Phimphisut 1997). Records show that there are 71 community forests in Thailand with land areas ranging from 0.8 to 32 ha (Srisooksomwong, pers. comm.).

2.1.4 Forest fire management

Forest fire management can vary from zero tolerance to prescribed fires that are intended and controlled in order to achieve management goals. Stott *et al.* (1990) emphasised that fire management should be case-sensitive, taking the environment, landscape, fire problem and management aim into account. As an example of this, Chandler *et al.* (1983) mention different fire management plans for conservation forests, watershed areas, industrial plantations and multiple use forests. In conservation forests one should mimic the natural fire cycle typical for the area. In watershed protection areas the aim is to protect soil properties which sometimes require use of fire to prevent more damaging fires. In areas with multiple usages, fire management plans should be formulated together by the fire manager and the land manager; one possible way is to divide the land into zones according to management aims and to use fire accordingly to achieve these goals.

Velez (1990) recommended creating a mosaic of species to create discontinuity, thus making it harder for the fire to advance. Prescribed burning of litter in the early dry season is the best alternative to control the risk of severe fire later. If this is not possible, other methods must be used to control the build-up of litter on the ground (Stott *et al.* 1990). More information on forest fire management techniques can be found in Brown and Davis (1973) and De Ronde *et al.* (1990) among others. As London (2003), points out, swidden cultivators *already* know how to practise prescribed burning and thus the solution for a problem might be surprising: maybe they could be asked?

Figure 4. Even small roads can act as effective fire-breaks for surface fires. *P. kesiya* damaged by kindling collectors. Mae Sa Noi, Mae Rim. Photograph by S. Kiianmaa

In Thailand fires have traditionally been used as an agricultural tool for swidden cultivation, but because of permanent settlements, fire is now used widely in forests to stimulate the growth of ground vegetation for cattle grazing (Savage 1994). Fire is also used in hunting and debris control (Chue Chan, pers. comm.). Due to effective fire protection by the Thai Government, the land area affected by fire annually has dropped dramatically between 1992 when 1,900,000 ha was affected, and 2000 when fire occurred only on 27,000 ha (National report…2002). There are six forest fire control centres in Thailand that work under the Department of Forest Protection and Fire Control within the Ministry of Environment; since 2003 there has been a forest fire station in every province. One centre has about 100 km² of forest under its protection (Kaitpraneet, pers. comm.). The fire fighting crews consist of farmers who farm their land for six months and fight fires for the other half of the year (Chue Chan, pers. comm.).

Methods that are used to fight forest fires in northern Thailand are various. Public awareness about fires has been raised with events, visits to schools, radio announcements and posters that, for example, inform about level of current forest fire risk. Participation of villagers has been encouraged. Villagers put up their own preventive fire lines (15-20m in width) and fire guards for early detection of fires in order to put them out more easily.

Participation has been successful especially in villages further away from cities. In Chiang Mai the most effective reason behind the great reduction in forest fires has been prevention through public awareness. Villagers have taken especially seriously the possible water shortage caused by forest fires. As methods to put out fires, beating and water spraying have proved to be the best in difficult terrains, although other methods have also been tried (Chue Chan, pers. comm.).

2.1.5 Future of watershed management

When managing watersheds, there are two factors to be considered, the natural resources and the people. The aim of management is to affect both of these factors simultaneously (Chanpaka 1984). In the past 50 years, watershed management has been top-down orientated. Stakeholders from the outside identified a problem and gave a solution, usually a large-scale reforestation project in an area already occupied by local communities. The past interventions did not take watershed productivity functions into account, which lead to conflicts with locals who destroyed or neglected the planted seedlings (Lai and Garrity 1999). Sharma (1999) sees a new approach merging. If watershed management projects are to be successful, the participation of the local people is necessary. A participatory approach in watershed management transfers principles- not solutions- and works only as a facilitator, not as imposer, for the farmers empowerment process. Different known choices and limits are given to the local community which then decides on how to solve their problem. Thus local knowledge is recognized and the local people can take over the development work done in the past by outsiders. This, however, requires farmer empowerment through group formation and secure land tenure. A link is seen between empowerment and the control over resources that is further linked with ownership.

There is also a new understanding in Asia that watersheds should have production and conservation functions simultaneously. New biological means of conservation techniques are being tested, and small watershed units are considered as units of development. Some attempts have been made to encourage farmers to participate and invest in conservation with the help of quick benefits. Needs to reconstruct land-tenure systems are also recognized in many Asian countries. Local knowledge and the role of NGOs has also been noted (Sharma 1996).

Watershed management programs have multiple objectives, which are often in conflict with each other, e.g. production and conservation needs, which makes them hard to be successful. Nevertheless, Sharma (1996) has listed some common characteristics among successful participatory watershed management programs in Asia. These include: correct identification of the problem, i.e. natural resource management for human development, a call for a higher human dimension to introduce watershed management into the dominant culture of the local people, people's ownership of the program (empowerment), allocation of control and ownership of the resources to the people, benefit-generation in short, medium and long timescale, and equity between genders and among other groups. London (2003) noticed, while working with a community-based fire management (CBFiM) project in Lao People's Democratic Republic, that the term "sustainable resources use" gives better results than "conservation".

Figure 5. Non-timber forest products at sale in Lampung province. Photograph by S. Kiianmaa

2.2 Forest succession and factors limiting succession

2.2.1 Forest succession cycle

Tree regeneration can take place on a spatial and a temporal scale. The first one refers to biomass accumulation on a site and the latter one to increase of floristic and structural diversity. On deforested sites the first growth cycle is spatial in nature and usually includes pioneer trees that form a secondary forest. When pioneer species begin to die and make gaps into the forest canopy, the second growth cycle of the forest accelerates as the microclimate becomes more favourable for climax species to develop in these gaps. If no major disturbances occur, this temporal regeneration leads to a climax forest (Whitmore 1991).

Pioneer species can be separated into early secondary and late secondary species. Early secondary species regenerate well in large gaps, whereas late secondary species regenerate well in small gaps. Primary, or climax, species regenerate both under a closed canopy and in gaps (Chandrashekara and Ramakrishnan 1993).

Forest succession has numerous limiting factors or stressors which can be manipulated through management (Lamprecht 1989). These stressors can be divided into five groups: (1) site resources, (2) competition with weeds, (3) human-caused disturbance, (4) occurrence of established woody plants or their propagules, and (5) seed dispersal by animals (Hardwick *et al.* unpublished).

2.2.2 Site resources

Site resources include light, water and nutrients. In seasonal climates the amounts of resources differ according to season. In general forest cover equalizes fluctuations of microclimate i.e. temperature and air humidity. Light availability can be too excessive or too low. Many shade-tolerant species require increase of light at a certain age so that these suppressed seedlings can reach the canopy. These complements to light can be done with gaps in forest canopy and at the same time generate income from timber. Gap creation mimics the natural growth cycle of the forest (Whitmore 1991).

Gap openings favour coppice shoots of the remaining trees and shrubs over new seedling establishment (Stocker 1981). Light conditions in the understory are different in the forest stand and the gap centre, the gap having naturally more light. This increase in light accelerates height growth of seedlings (Otsamo 2000, Yirdaw 2002). During the first year of gap formation the density of ground vegetation increases, more in large gaps or selection-felled ones than in small or naturally formed gaps (Chandrashekara and Ramakrishnan 1993). Otsamo (2000) also considers the shrub vegetation in the gaps to have a positive effect on soil fertility through depressed nutrient leaching and the fact that temperature fluctuations may be reduced when the shrub recruitment is rapid.

Study results of Carnevale and Montagnini (2002) suggest that canopy shading and litter depth in plantations have an influence on seedling density and richness. They also concluded that monocultural plantations with the fastest litter decomposing rates have the smallest density of seedlings in height classes of 0.15-1m and >2m, whereas plantations of tree species with slow decomposing rates had the highest seedling density. This can be explained both by litter's ability to hinder growth of competing herbaceous layer and by slower release of nutrients over time thus reducing leaching. When Lugo (1992) compared *Pinus caribaea* and *Swietenia macrophylla* plantations of different ages to secondary forests, he found that plantations produce and decompose more litter than the secondary forests. Pines produced four times more litter than mahoganies (10.26 and 2.47 Mg/ha/-a) and although the decomposing rate was faster in pines the annual balance was less on the negative side than for that in mahogany (-1.28 and –4.57 Mg/ha/-a).

Pinus patula has also been found to accumulate relatively high amounts of litter especially at high altitudes (Yirdaw 2002). When the undergrowth is well developed, the litterfall composition and behaviour in the forest floor change towards those of secondary forest i.e. fast rate of litterfall turnover (high production, high accumulation, and high decomposition). As an example of this, Lugo (1992) mentions *P. caribeae* plantation over 17 year old. When ten commonly used plantation species were studied in Puerto Rico, *P. caribaea* var. *hondurensis* (Sénécl.) W.H. Barrett et Golfari and *Pinus elliottii* Engelmann stood out as the most efficient users of N and P (Cuevas and Lugo 1998). In fact, *P. caribaea* is adapted to poor soils by producing large amounts of organic matter with little use of nutrients; and therefore also the litter is nutrient poor.

As in pine plantations, the litter accumulation is rapid in natural dry dipterocarp forests as well. According to Turakka *et al.* (1982) and Koskela (1993), the litter covers the mineral soil in these forests almost totally two years after a groundfire. After a recent fire the litter mostly consists of needles and leaves, but the amount of dead grasses soon increases.

Canopy water interception studies made in Thailand, show that the natural hill-evergreen and dry-dipterocarp forest intercept 5-9 and 62 %, respectively, of the annual rainfall, while natural pine forests and especially pine plantations tend to intercept a larger amount of the annual rainfall than any other forest type (Tangtham 1999). Pukjaloon *et al.* (1985) found that the evapotranspiration from *Pinus merkusii* Jungh. & De Vriese forest was also greater than the average values for natural forested watersheds.

2.2.3 Competition with weeds

Weed competition in the ground layer decreases the availability of resources to tree seedlings during early stages of succession. This competition may vary according to season, as Hardwick (1999) found in northern Thailand, where weeds compete with seedlings for light during the rainy season but protect seedlings from damaging excessive light during the hot dry season. On sites with dense and tall herbaceous vegetation, dry season drought is the most limiting factor and the survival is highest in large seeded, drought and shade tolerant species (Hardwick *et al.* 1997). Most of the seedling species that die in the fire-protected dry dipterocarp forest in northern Thailand are light demanders (Montyak 1997). In a study concerning secondary succession in fast-growing forest plantations in Indonesia, Otsamo (2000) found that seedling and sapling densities under plantations could not be explained by ground vegetation coverage or height. Yet, a comparison of seedling and sapling densities among different ground vegetation types (bareland, grass, shrub) revealed clear differences; bare ground and shrub were the most favourable for regeneration of tree species. Under a canopy closure of 70-80% in natural hill evergreen forest the ground vegetation is sparse (Turakka *et al.* 1982).

2.2.4 Human-caused disturbance

Fires are divided into three main classes; (1) ground fires, with slow burning of organic matter on the ground; (2) surface fires, including rapid burning of litter, herbs and shrubs; and (3) crown fires, resulting in the burning of tree crowns in the woody vegetation. Fires can be further categorised by their frequency and intensity and different combinations of these two. Chandler *et al.* (1983) classify surface fires into frequent low-intensity, infrequent low-intensity, and infrequent high-intensity surface fires. Fire has a major effect on forest regeneration in northern Thailand where the frequency of fires has increased because of human activities. Fires have traditionally been used as an agricultural tool for swidden cultivation, but because of permanent settlements fire is now widely used in forests to stimulate growth of the ground vegetation, cattle grazing (Savage 1994). A total of 90 % of the fires occur during the so-called fire season between January and March when the ground vegetation is extremely dry (Kaitpraneet 2004). If fires occur soon after the rainy season they tend to be of low intensity because of a thin and moist litter layer. These low-intensity fires leave a burned forest ground with patches of untouched areas (Monyrak 1997).

Fires can have a severe impact on soil moisture. If organic matter is burned at the soil surface it can reduce the infiltration rate and increase the surface run-off and further increase the erosion. Moisture storage can also be damaged especially on coarser soil, where much of the storage capacity is provided by organic matter. The heat of the fire may also affect water infiltration by forming a water-repellent layer on the soil the phenomenon of hydrophobicity (Kimmins 1987). Costales (1980) made a comparison between a surface burned *P. kesiya* watershed and an unburned one in the Philippines and found that the surface runoff was up to 40% higher in the burned area during the following rainy season, but the difference disappeared after that rainy season; sediment yields behaved similarly. An increasing frequency of fires has caused the humus layer to be almost absent in most parts of northern Thailand (Koskela 1993).

Tree species can be categorized into five fire adaptation groups according to their life-history characteristics (Rowe 1983):

- Intense fires favour ***endurers***, species with vegetative reproduction.
- ***Evaders*** are species which form a soil seed bank,
- ***Invaders*** are pioneer species with rapid growth.
- Low-intensity fires favour ***resisters***, species that can survive fires.
- ***Avoiders*** are species with poor fire adaptation and well off only if fire is excluded.

Some forest types are more sensitive to fires than others. In these forests fire acts as a stabilising factor by inhibiting a change to a more evergreen type. Thus, fire protection on these sites will catalyse this change. Different forest types respond differently to fire that changes the balance between tree species and controls the survival of seedlings. Prescribed burning of the litter in the early dry season is the best way to avoid the risk of severe fire. If this kind of management is not possible, another suitable method must be used (Stott *et al.* 1990).

Munro (1966) specified seven phases in a cycle from hardwood forest to *Pinus caribaea* forest and back to hardwood forest. This cycle is controlled by fire and its occurrence frequency. When fires are annual, the forest can be described as open pine savanna, and when they are less frequent hardwood species will regenerate and slowly take over the area by shading out the pine seedlings.

Pinus kesiya is well adapted to fire. It has a thick bark, and deep roots (Stott *et al.* 1990). It even promotes fires and thus excludes other species, by it's abundant , flammable, litter which, is nitrogen poor when decomposed (Singh and Singh 1984). Little and Moore (1953) noted that a severe deeply burned fire can promote pine regeneration by exposing the mineral soil and by eliminating competition with sprouting species. In fact, in total absence of fire, pines could only be found on the very poorest soils (Turakka *et al.* 1982). On the other hand, broadleaved species coppice after fire (Koskela 1993), and if fires are almost annual these species can slowly colonize the understory of a forest stand (Savage 1994).

After a fire the growth of the ground vegetation in dry dipterocarp forests accelerates and develops before the onset of the rains, and deciduous trees shed the leaves and sprout new leaves and flowers (Turakka *et al.* 1982). If a forest stand is often burned and its tree seedlings destroyed, mature trees will not be replaced the result is a sparse, open canopy, an absent understory, and a ground layer consisting of fire-resistant grasses (Maxwell 2001). Fire sensitivity in relation to the successional stage is still poorly known. When tree regeneration proceeds, the risk of fire degreases because of changes in the ground vegetation (Hardwick *et al.,* unpublished).

2.2.5 Occurrence of established woody plants or their propagules and seed dispersal by animals

Because of a lack of seed dormancy in many climax tree genera, soil seed banks are unlikely to impact their regeneration. Pioneer species, on the other hand, have often higher seed longevity, and a soil seed-bank can be an important factor in their regeneration if not damaged by fire (Bazzaz 1991). Frequent fires are common in northern Thailand; therefore, seed dispersion is an important subject within forest regeneration there. Seeds are burned and coppicing plants weakened and, furthermore, an open stand structure enables the spreading of fire-resistant species (De Rouw 1993). In northern Thailand it has been observed that the soil seed bank was larger in a fire-protected dry dipterocarp forest than in a fire-disturbed one but the soil seed bank affected little the seedling establishment due to its small size (Monyrak 1997). When Stocker (1981) studied secondary succession in the rain forest of North Queensland, he found that the time needed for succession back to forest similar to the one before felling depended on the seed dispersal efficiency of absent species and their ability to stand severe competition during early stages of growth while waiting canopy opening created by disturbance to allow rapid height growth.

Seeds can be dispersed by wind or by animals. Wind dispersal proceeds to the down-wind direction, while animal dispersion can be directed towards any direction from the mother tree. Wind-dispersal has also a smaller dispersal area compared to animal dispersal, and trees with wind-dispersed seeds offer less food for animals. In general, animal-generated stands have greater tree species richness than the wind-generated ones and represent a greater proportion of the total population of the area. However, wind-dispersed seeds are more uniformly and densely distributed than the animal dispersed ones (Janzen 1988).

Yirdaw (2002) clarified the importance of seed dispersing animals. Small-seeded zoochorous tree species were well presented in the understory of plantations in the Ethiopian highlands. Equally, climax canopy species with large, recalcitrant seeds were absent. Yirdaw (2002) is in consensus with Wunderle (1997) in recommending plantation establishment primarily next to natural forest. In this way the seed source can be best utilised. Likewise, Tucker and Murphy (1997) concluded that small-seeded pioneers were the most commonly (82%) and large seeded the most sparsely (1%) found species in the undergrowth of a native fleshy-fruited tree plantation in North Queensland. When Monyrak (1997) made a comparative study between fire-disturbed and undisturbed dry dipterocarp forests in Chiang Mai province, he noticed that more animal-dispersed seedlings were found in the undisturbed area. Most of the seeds found in his traps were small. The only larger seeds were found in undisturbed forest.

Thus, if small-seeded animal-dispersed seeds are the main seed matter of tropical plantations what could be done to attract animals into plantations? Wunderle (1997) names the following: trees should have food resources and foraging places, i.e. pests, flowers, fruits, epiphytes and structural diversity. The composition of the plantation is also important; if the dominating tree species is not attractive to animals the undergrowth might be. Most easily these qualities are found in native tree species to which the local fauna is used.

Maxwell (2001) notes that, because of hunting in northern Thailand, populations of seed-dispersing animals, especially large mammals (rhino, elephant and wild cattle) but also birds, bats and civets, have diminished or disappeared. Bird species of the Pycnonotidae family (bulbuls) and possibly fruit bats are the main seed dispersers in northern Thailand (Elliott, pers. comm.). Consequently, wind-dispersed the species become more common. Large mammals used to have an important role in the dispersion of large ($\geq$ 2cm) seeds. If large-seeded species cannot be found among the seedlings, it may be necessary to sow or plant them manually (Tucker and Murphy 1997).

Coppicing stumps and resprouting have a significant role in forest cover emergence (Bazzaz 1991, De Rouw 1993). Therefore, succession back to forest can be seen as a combination of vegetative regrowth and growth from seeds. De Rouw (1993) found that a rapid reforestation of abandoned fields is done by seed-germinated pioneer species and outgrowth of shoots. In fire-prone forests of northern Thailand, coppicing may be an important method of regeneration, as stumps endure fire and browsing better than seedlings and because of rapid early-growth sprouts quickly escape the competition of weeds (Hardwick *et al.*, unpublished). If the fires are severe, they reduce resprouting (Bazzaz 1991). Frequent fires, common in connection with shifting cultivation, are also a disadvantage to coppicing species and to the seed-bank of the site. Uhl *et al.* (1982) found that, if the site is cut, burned and farmed for number of years, the successional process back to forest is even slower. This is due to weeding that decreases future sprouting. Oberhauser (1997) noticed that coppicing in *P. kesiya* plantations from stumps is sparse.

2.3 Ecosystem rehabilitation

Thailand has a large area of degraded lands. Plantation forestry offers a tool to rehabilitate these areas. The idea of ecosystem rehabilitation is to manage succession and in the same process convert degraded land to an area with production potential in environmental services or raw-materials. Rehabilitation management includes all components of the ecosystem: vegetation, soil, animals and microbes (Lugo 1988). Forest management for rehabilitation purposes demands, therefore, a wide understanding of the ecosystem. When a site is degraded it is extremely difficult and a slow process for secondary species to invade it back from grass vegetation. When these limiting environmental factors are known, their effects can be avoided by selecting a site-matching species for plantation establishment, which reshapes the soil and site conditions to become suitable for secondary species (Lugo 1997). For economical reasons one should minimise the human input and try to rehabilitate the land by exploiting natural processes, i.e. limiting or controlling a stressor affecting succession (Lugo 1988). Rehabilitation should not be confused with restoration, in which the aim of management is to restore previous natural forest.

Numerous studies across the globe have proven the ability of plantations to nurse native tree species (Fimbel 1995, Parrotta 1995, Parrotta 1997, Parrotta 1999, Hardwick *et al.* 1997, Oberhauser 1997, Viisteensaari 1999, Otsamo 2000, Yirdaw 2002). Plantations create suitable microclimatic, biotic and soil conditions for native species to regenerate. This occurs through shading out competitors in the herbaceous layer with the canopy, thus creating a more stable climate and restoring the soil nutrient and soil carbon (Fimbel 1995, Parrotta 1995, Parrotta 1997, Hardwick *et al.* 1997). Plantations also create habitats for seed-dispersing animals (Fimbel 1995, Parrotta 1995, Hardwick *et al.* 1997, Yirdaw 2002).

Walters (1997) notes that the impact of a rehabilitation project on local people, who are often economically and politically marginalized and therefore dependent on degraded land, should be included in a planning process. He argues that rehabilitation efforts should avoid negative impact on local people and, if possible, one aim of rehabilitation should be providing alternative economic opportunities as well as reducing pressure on environment. Property rights and use rights of the area should also be clear to minimise the possibility of future conflicts over them. When planning rehabilitation one should consider the time-perspective of the project: what is being produced and is it in consensus with future markets? To make the project work it is important also to know when the first profits are to be collected.

All plantation species do not have equally beneficial effects. Suitable species are fast-growing trees with a rapid canopy closure, open crown structure, and a rapid leaf turn-over with quickly decomposing leaves; in addition, they should provide fruits, nectar or perching sites for animals (Parrotta 1995, Elliott *et al.* 2002). An open canopy structure causes increase in total light, red/far-red light ratio and in temperature, which are factors that enhance seed germination and the growth of seedlings (Yirdaw 2002). On degraded sites, a high nutrient storage and a high organic matter content in litter and in the above-ground biomass may be critical for understory regeneration of native species (Lugo 1997). Otsamo (2000) states that differences between plantation species affect seedling and sapling densities and the species richness, while Yirdaw (2002) emphasises especially the effect on density. Parrotta (1997) recommends the use of broadleaved trees because they appear to give better results than conifers.

Pinus kesiya has a rapid height growth after the first year of establishment, 1-2 m annually, with a canopy closure in three to four years (Armitage and Wood 1980). Although *P. kesiya* does not fit to all of these optimum descriptions, Oberhauser (1997) has stated that *P. kesiya* plantations might indeed speed up the successional process. Studies made on other *Pinus* species (*P. patula* Schiede ex Schltdl. & Cham., *P. caribaea* Morelet, and *P. elliottii* Engelmann) also support this finding (Lugo 1992, Loumeto and

Huttel 1997, Cuevas and Lugo 1998, Yirdaw 2002). The composition of the plantation plays also a key role. When assessing the plantation rehabilitation effectiveness, mixed-in species and multi-storeyed plantations have been found to be especially successful (Wunderle 1997, Carnevale and Montagnini 2002).

Figure 6. 24 year old Pinus kesiya plantation, Mae Chon Luang, Mae Chaem catchment. Photograph by S. Kiianmaa

According to Parrotta (1997), if the woody undergrowth that has developed after plantation establishment is protected, a mixed forest will replace a monocultural plantation. The foster trees may disappear altogether if the species is short-lived and light-demanding. If not the case, planted trees can be removed gradually without damaging the undergrowth, as was done in a *Pinus caribaea* plantation in Puerto Rico that was thinned with consequences of better possibilities for secondary species to reach the canopy (Lugo 1992). The latter alternative is highly presumable in the case of *P. kesiya.* This has to do with the fact that khasi pine is found to be the dominant species in natural dry dipterocarp forests (Turakka *et al.* 1982). On the other hand, in the plot that Oberhauser (1997) made an inventory on, pines had already started to die at the age of 20.

One method to promote rehabilitation is the framework species method. Framework species i.e. tree species that provide a "framework" for re-establishing the biodiversity, are characterised as fleshy-fruited, early successional, and fast growing with a dense canopy (Tucker and Murphy 1997, Elliott *et al.* 2001). Trees are planted to attract seed-dispersing animals that will carry the seeds onwards to other degraded sites.

Criteria that are used to define framework species in the seasonally dry tropical forests of northern Thailand include the following: they should be easy to propagate by seed in a nursery and show good sapling survival and growth after planting and they sould have a suitable crown structure attractive to frugivores and resistant to fire (Blakesley *et al.* 2001). Elliott *et al.* (2002) mention ten possible framework tree species for northern Thailand's conservation areas. These species, which all are known to disperse seeds at different times throughout the year, include, *Melia toosendan* Sieb. & Zucc., *Castanopsis acuminatissima* (Bl.) A. DC., *Lithocarpus craibianus* Barn., *Ficus glaberrima* B1. var. *glaberrima*, *Prunus cerasoides* D. Don, *Dalbergia rimosa* Roxb. var *rimosa*, *Quercus semiserrata* Roxb., *Eugenia albiflora* Duth. ex Kurz, *Spondias axillaris* Roxb. and *Diospyros glandulosa* Lace.

Successfully rehabilitated areas can offer different kinds of products, such as environmental services including improvement in biodiversity and hydrology, or products that are harvestable, such as timber, food and fodder, etc.

2.4 Natural forests of northern Thailand

2.4.1 Forest types of Thailand

Northern Thailand's forest types can be divided into two major categories, evergreen and deciduous, and further into subtypes. Natural forests of northern Thailand are belong to the mixed deciduous, dry dipterocarp and hill evergreen subtypes. Because of deforestation, there are no more original lowland deciduous forests and almost all natural upland pines are cut. These degraded sites are invaded by weeds. If the site is left untouched, a slow succession will start. First woody secondary growth will appear, and after a decade primary species will develop (Maxwell and Elliott 2001).

2.4.2 Dry dipterocarp forest

Tree species that characterize dry dipterocarp forests are *Dipterocarpus tuberculatus* Roxb., *D. obtusifolius* Teijsm. ex Miq., *Pentacme suavis* A. DC., *Shorea obtuse* Wall. ex Bl. and *Pinus merkusii* Jungh. & De Vriese. Stands are relatively open with ground vegetation dominated by grasses (*Arundinella setosa* Trin. var. *setosa*, *Imperata cylindrical* (L.) Palisot and sedges (Turakka *et al.* 1982). Maxwell (2001) describes this deciduous dipterocarp-oak seasonal forest, as he calls the type, as frequently burned, which hinders the development of oaks (Fagaceae). Major proportions of tree species are deciduous and relatively short (≤ 20m), with open or irregular canopy. In addition to the above-mentioned species, Maxwell also includes *Quercus kerrii* Craib, *Q. aliena* Bl., *Castanopsis argynophylla* King ex Hk.f. and *Phoenix loureiri* Kunth among the typical species for this forest type. In dry dipterocarp forests that Khamyong *et al.* (1999) studied, the total density of trees h > 1.5m was 1337-1469 ha^{-1} at altitudes between 625 and 880 m a.s.l.. Dominant species were *Shorea* sp. and *Dipterocarpus tuberculatus*. Seedling density was sparse. In the pine-dry dipterocarp forest the seedling density was 29 900 seedlings ha^{-1}.

2.4.3 Hill evergreen forest

Hill evergreen forests are characterised by *Castanopsis indica* (Roxb.) A. DC*., Quercus sp., Shima wallichii* (DC.) Korth*., Dahlbergia cultrata* Roxb*., Phyllanthus emblica* L. and *Pinus kesiya*. Stands are denser than those of dry dicterocarp forests. Mesophytic herbs are the most common ones in the ground layer (Turakka *et al.* 1982). Maxwell (2001) finds the canopy to be open in this forest type ("primary evergreen seasonal forest with pine") with low soil pH. Only about 30% of the tree species are deciduous. Common species include *Viburnum inopinatum* Craib*, Helicia nilagirica* Bedd*., Myrica esculenta* B.–H. ex D. Don*, Castanopsis argyrophylla* and *Quercus* sp. If fires are frequent, the dry dipterocarp forest spreads up into pine forests, resulting in an increased number of the Fagaceae species (Smitinand *et al.* 1978). Khamyong *et al.* (1999) found the tree density of hill evergreen forests to be 869 trees ha^{-1}, with *Phyllanthus emblica, Wendlandia tinctoria* (Roxb.) DC. ssp. *tinctoria* and *Dalbergia oliveri* Gamb. ex Prain having the highest densities. They found the seedling density to be 26,000 seedlings ha^{-1}.

2.4.4 Natural *Pinus kesiya* forest

In the Philippines Kowal (1966) found that *P. kesiya* stands occupy ground from broadleaved trees that are killed by forest fires; when fires are less frequent the area is reoccupied by broadleaved trees. The survival of broadleaved trees seemed to be better on moister spots. On the other hand, Goldammer (1985) observed that where fires are frequent there is scarcely any pine seedling establishment. This has also been noticed in Thailand, where *P. kesiya* seedlings can mostly be found on disturbed, bare ground i.e. where fires can not reach them (Turnbull *et al.* 1980).

Savage (1994) made a study on *P. kesiya* forest in the Doi Inthanon mountain region in northern Thailand, where she found that the forest structure was undergoing a change. This was because of poor regeneration caused by annual fires and kindling collection that damaged mature trees. The stand structure was sparse. Pine seedlings and saplings over one year old were almost absent. This was due to canopy shade, and for the most part also to annual fires that kill the once numerous first-year seedlings. Non-pine species formed a sparse understory below the pines. The higher stem number of broadleaved trees compared to that of pines could not be explained by better fire resistance but rather by coppicing of broadleaved species. Non-pine species included *Dalbergia fusca* Pierre, *Anneslea fragrans* Wall., *Dipterocarpus tuberculatus* Roxb. var. tuberculatus, *Buchanania latifolia* Roxb., *Quercus kerrii* Craib. var. kerrii, *Lithocarpus elegans* (B1.) Hatus ex Soep. and *Castanopsis tribuloides* (Sm.) A. DC., which are typical lower-elevation species that follow the fires. Khamyong *et al.* (1999) point out the forest types where khasi pine can be found to be dry, including pine-dry dipterocarp and pine-hill evergreen forests. Densities of these forests studied were 2012 and 1365 trees ha^{-1}, with basal areas 22 (4) and 26 (9), respectively (*P.kesiya* basal area in the brackets).

2.5 *Pinus kesiya* plantations of northern Thailand

Oberhauser (1997) surveyed the vascular plants of four *P. kesiya* plantations in the province of Chiang Mai. The age of these plantations varied between 7 and 28 years. Plantation structure changed in relation to age. In the 7-year-old stand *P.kesiya* was the dominant species and the ground was densely covered with grasses and herbs and mainly constituting of *Eupatorium adenophorum* Spreng. The twelve-year-old plantation canopy was dense with pines and numerous other species. There were different canopy layers and tree sizes among the non-pine species. The ground cover was light with no pine regeneration. Other species had regenerated and were regularly distributed in the sample plot. Pine mortality could be observed in a 21-year-old plantation, and tree seedlings were found in the ground layer of this stand. A 28-year-old site was diverse in tree species although dominated by *P. kesiya*. In this case, the ground cover was light. Oberhauser (1997) noticed that density of *P. kesiya* declines and density of other trees increases with time. After the age of 21, an increasing basal area of other trees will substitute for the decrease of basal area of *P. kesiya*. He also speculated a possibility of gaps created by dying pines and of thinning operations to enhance natural regeneration. Many of the tree species recorded were just seedlings or small saplings, which may not even survive; furthermore, few of the seedlings were pines.

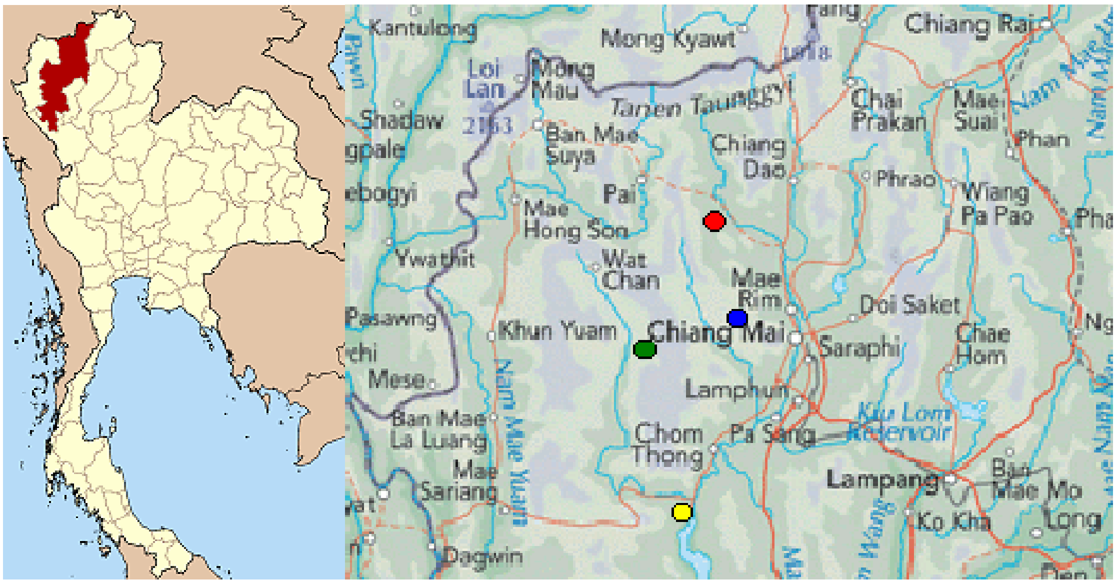
3. Materials and methods

3.1 Chiang Mai province and its climatic conditions

Northern Thailand covers 17.1 million hectares. Half of the area is highland, 35% upland and 15% lowland (Randhava and Kanchanadul 1996). The study sites were located in the Ping river basin, Chiang Mai Province, northern Thailand, with 1,600,850 registered inhabitants in 2001. A total of 74 % of the land area (22,117 km^2) is under forest cover. Most of the forest is mixed deciduous forest (8,986 km^2) and tropical evergreen forest (4973 km^2) with 1131 km^2 of plantations and 55 km^2 of secondary forest (RFD 2001). This mountainous area is the water source of Thailand's longest river, the Chao Phraya which gets its water from the Ping, Wang and Yom rivers and further feeds rice fields of the central plains. The catchment area of the Ping river is 26,396 km^2 (Rajani 1984).

In Chiang Mai province the forestland area decreased from 74,555 km^2 to 73,057 km^2, while the farmland has decreased, respectively, from 46,470 km^2 to 45,240 km^2, during the period 1994-1998. At the same time farm sizes have been expanding (in 1998 an average, 3.7 ha) and the number of farms has also decreased. The traditionally most common agricultural practices, paddy rice and field crop cultivation have lost ground to intensive vegetable and fruit tree production (RFD 2001).

Monsoon climate prevails in the North. The rainy season lasts from May to November, the dry cool season from December to January and dry hot season from February to April. The annual mean temperature of the province is 25.5 C°, with extreme lows around 10 C° and extreme highs about 40 C°. The annual average rainfall is 1220 mm with 106 rainy days and an average relative humidity of 72% (RFD 2001).



a) b)

Figure 7. (a) Map of Thailand, with Chiang Mai province highlighted (Wikipedia www-document). (b) Inventory sites: Mae Rim (blue), Hod (yellow), Mae Chaem (green), Khun Khong (red), Scale of the map: 1:4,000,000 (multimap.com revised www-document).

3.2 Description of plantations

The inventory was carried out in seven *Pinus kesiya* plantations located in four different areas within the Ping river basin in Chiang Mai province, northern Thailand. Three of the plantations were in dry dipterocarp forest and four at higher elevation originally covered by hill evergreen forests. The plantations were of different successional stages from 20 to 38 years of age and at different elevations between 800 and 1500 m a.s.l. In the following each plantation is described.

Plantation 1. Doi Mon Khom Long, Mae Sa Noi catchment, Mae Rim

The small plantation of Doi Mon Khom Long is situated on a ridge north of Mae Sa valley 100 m away from natural hill evergreen forest. Farmland borders the plantation. Two sample plot clusters were measured.

Plantation 2. Khun Huai Huek Pum, Mae Sa Noi catchment, Mae Rim

Khun Huai Huek Pum is on an upper slope south of Queen Sirikit Botanical Garden facilities, with dry dipterocarp forest bordering it downhill. Two sample plot clusters were measured.

Plantation 3. Huai Bong subcatchment, Mae Chaem catchment, Hod

This pine plantation still has clear rows of pines, a sparse understorey and trunks both fallen and cut, on termite-hill-dotted ground. There is dry dipterocarp forest next to the plantation. Prescribed surface burning a few months earlier had cleared the ground vegetation. Seven sample plot clusters were measured.

Plantation 4. Huai Mao Phak An subcatchment, Mae Chaem catchment, Hod

This plantation is next to the road from Hod to Mae Sariang. Pines have small crowns. There are a few of termite hills. A small creek borders the plantation in the east and in the north. The broadleaved tree density clearly rises closer to the creek. There are some remnant pines. The plantation had suffered a surface fire two days before the inventory. Seven sample plot clusters were measured.

Plantation 5. Mae Chon Luang, Mae Chaem catchment, Mae Chaem

This large plantation, close to Ban Khun Mae Wak village, had, in part, the longest history without fire of all plantations surveyed. Half of the ten sample plot clusters had been untouched by fire for 24 years and the other half for six years. The fire that occurred six years ago had in some parts destroyed all trees, leaving gaps as wide as a couple of hectares, with only a grass cover and scattered saplings.

Plantation 6. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong, Chiang Dao

This plantation had dense undergrowth, especially close to its road-lined borders. Some large remnant trees could be found. Five sample plots were measured.

Plantation 7. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong, Chiang Dao

This is the second-youngest pure Khasi pine plantation established in Khun Khong. The youngest plantation was destroyed by forest fire some years back and is now growing secondary forest. Several remnant trees, consisting of *Ternstroemia gymmanthera* (Wight & Arn.) Bedd., *Elaeocarpus lanceaefolius* Roxb. and Fagaceae spp., with ages ranging from about 30 to 100 years, could be observed. Inventory lines went downhill on the northeast- southwest ridges. Fire had destroyed large areas of the plantation in the valley downhill, which was now impenetratable grass and climber thicket. Five sample plots were measured.

3.3 Data collection and Inventory design

The fieldwork, which yielded information on vegetation and both utilisation and disturbance history, was done in the spring of 2004. Local people, who also worked as inventory assistants, identified the tree species by their Thai names, which a local scribe then wrote down using Thai language. The Thai names where later converted to scientific names at the Queen Sirikit Botanical Garden, in Mae Rim, Chiang Mai province by the resident botanist Mr. Prachaya Srisanga and Mr. Methee Wong. Unidentified and untranslatable species were grouped with corresponding numbers. Additional information on the sites was gathered from the responsible officer at each respective watershed management unit, as well as from the local people involved in the inventory. Information on tree species, i.e. on dispersal mechanisms and growth sites, was collected from literature, Maxwell and Elliott 2001, Gardner *et al.* 2000 and Oberhauser 1997.

Trees were placed in classes based on their size: seedlings, h <130 cm, saplings h ≥130, dbh <10cm and mature trees, dbh ≥10 cm. Seedlings were further divided into classes of <30 cm, 30-50 cm and 51-129cm. In total, 38 sapling and mature tree sample plots and 152 seedling sample plots were measured.

The inventory was carried out as a systematic plot survey with clustered sample plots. Distances were 100 m between lines and 50 m between sample plot clusters. From the centre of a sample plot cluster four circular plots with a radius of 0.56 m (1 m²) were located at 2 m distance along the inventory line and perpendicularly to it. The centre point acted also as the centre for larger plots with a radius of 5.6 m (100 m²) and 20 m (1256.6 m²) (Figure 8). Relascope readings to determine the basal area were done from the same centre point.

In the regeneration plots (1 m²) all woody plant seedlings were identified and the total number by species was recorded for height classes of 30-50 cm and 51-129 cm. Seedlings shorter than 30 cm were not considered established but were also counted. The ground vegetation was described by type (bare, grass, shrub, herb) and coverage and its height and main species determined. Average litter depth and litter quality were also determined. In sprouts, the species, number of stems and the height class of the tallest stem were recorded.

The plot with a 5.6 m radius (100 m²) was assessed for information on pines and other trees over 1.3 m in height. The data collected included the following: aspect, slope, damages, special characteristics (with a map, if necessary), fire history, distance from natural forest or old remnant trees, canopy coverage percentage, and size of possible gap. All sample trees were identified by species, and the total number of each species on the plot was counted. In addition, the diameter on breast height (dbh) and the height was also determined from the broadleaved trees.

In the largest plot (1256.6 m²) potential seed producing broadleaved trees, dbh ≥ 10 cm were specified and measured for dbh and height.

A relascope plot was placed in the centre, and the basal area counted separately for pines and non-pines; in addition in the relascope plot the diameter at breast height (dbh) and the height of the mean dbh pine were determined.

Five soil samples were collected from 30 cm depth in each plantation. The soil structure and pH were later determined at Kasetsart University, Faculty of Agriculture, Department of Soil Science, in Bangkok.

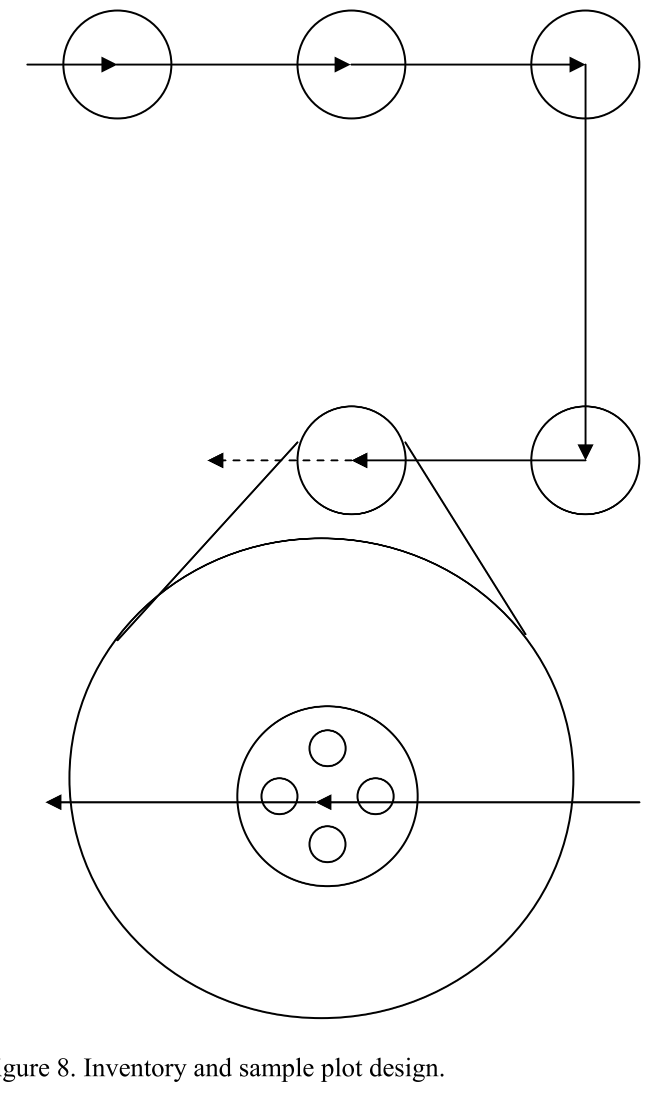


Figure 8. Inventory and sample plot design.

3.4 Statistical analysis

The statistical analysis was made using SPSS 12.0.1 statistical software and Microsoft Excel. The data were first aggregated to depict the sample plot averages, which were then used in subsequent calculations. The four seedling sample plots in each sample plot cluster were aggregated into one with an average value for the four. Plantation averages (cf. Tables 1. and 2.) were calculated using the complete data, i.e. 38 sample plots. Nine sample plots that were not considered representative were eliminated from later analysis. Justification for this decision included position in a canopy gap, presence of remnant tree(s) too close-by, and recent cutting of trees.

Other, corrected plantation averages were also used in a few calculations. Relationships between vegetation and environmental data were tested using Pearsson correlation and further with linear regression analysis. The regression analysis was applied due to the ratio scale of the variables studied.

With data from Plantation 5, Mae Chon Luang, vegetation characteristics of two different areas with fire histories, fire 6 years ago and 24 years ago, could be compared. Species were categorised based on their known seed dispersal mechanism (Maxwell and Elliott 2001, Gardner *et al.* 2000 and Oberhauser 1997) into animal-dispersed and wind-dispersed groups. To find out possible similarities between species in mature tree, sapling and seedling populations within one plantation, the Sorenson and Jaccard similarity indices were calculated. A P-value of 0.050 was the highest one accepted as showing statistically significant differences.

4. Results

4.1 Composition of species

In total, 141 tree and shrub species were found that could be identified at least by family; of these, 31 species were found in the seedling class, 103 species in saplings and 92 species in the mature tree category. Species in Facaceae could not be precisely determined, since all species of the family had the same local name. Ten species were unidentified. On average, the number of species found in the seedling, sapling and mature tree categories, respectively, was 6.3, 18.3 and 19.9 in the whole material.

The litter layer of the plantations, if present, consisted mainly of pine needles. Grasses and herbaceous climbers dominated the ground vegetation in the plantations.

An independent samples T-test was done to compare sample plots in dry dipterocarp forest with those in hill evergreen forest. The results showed that differences in these group means existed in relation to fire history, canopy coverage, litter coverage, litter depth, seedling density, sapling density, mature broadleaved tree density, pine density and pH. The mean value for all these factors was lower in the dry dipterocarp forest, except in the pine density and pH values in which the dry dipterocarp forest showed a higher value.

In the following, the species composition in each plantation studied is separately described (see also Tables 1-2, Figures 9-10). Species lists with respective are given in Appendix 1 (Tables 12-18), and a list of coppicing species in Appendix 2 (Table 19).

Plantation 1. Doi Mon Khom Long, Mae Sa Noi catchment, Mae Rim

The *P. kesiya* density was 250 trees/ha and broadleaved tree (h> 1.3 m) density 414 trees/ha. The main mature tree species included *P. kesiya*, *Castanopsis armata* (Roxb.) Spach Prodr., *Callicarpa arborea* Roxb. and *Schima wallichii* (DC.) Korth. *Berrya mollis* Wall ex Kurtz was the most common sapling species. *Dalbergia floribunda* Roxb. and seedlings smaller than 30 cm in height formed most of the seedling layer. In the ground layer vegetation there were grasses and climbers 60 to 70 cm high including *Themeda arundinacea* (Roxb.) Ridl. G and *Thysanolaena maxima* Kuntze. Soil texture was sandy clay loam (SCL), and the pH 4.8.

Plantation 2. Khun Huai Huek Pum, Mae Sa Noi catchment, Mae Rim

The *P. kesiya* density was 250 trees/ha and the broadleaved tree (h> 1.3m) density 1338 trees/ha. Main mature tree species included *P. kesiya* and *Castanopsis armata*. Almost half of the sapling category consisted of *Castanopsis armata, Dalbergia cultrata* Grah. ex Bht. var. *cultrat* and *Wendlandia tinctoria* (Roxb.) DC. ssp. *tinctoria.* Seedlings smaller than 30 cm in height formed most of the seedling layer. In ground vegetation there were such species as *Pueraria thansonii* Benth., *Thelytheris* sp. ferns and *Helicteres viscida* Blume and *Eulalia* spp. grass species. Here and there were bamboo clumps. Soil texture was sandy clay loam (SCL) and the pH was 4.6.

Plantation 3. Huai Bong subcatchment, Mae Chaem catchment, Hod

The *P. kesiya* density was 486 trees/ha and the broadleaved tree (h> 1.3m) density 1766 trees/ha. the main mature tree species included *P. kesiya* and *Dipterocarpus obtusifolius* Teijsm. ex Miq., *Dipterocarpus obtusifolius, Gluta usitata* (Wall.) Hou and *Shorea obtusa* Wall ex Bl. were the most common sapling species. Seedlings smaller than 30 cm in height and *Dipterocarpus obtusifolius* formed most of the seedling layer. Soil texture was sandy loam (SL) and the pH was 4.6.

Plantation 4. Huai Mao Phak An subcatchment, Mae Chaem catchment, Hod

The *P. kesiya* density was 557 trees/ha and the broadleaved tree (h> 1.3m) density 1332 trees/ha. The main mature tree species was *P. kesiya*. *Dipterocarpus obtusifolius* and *Dipterocarpus tuberculatus* Roxb. were the most common sapling species. Seedlings smaller than 30 cm in height and *Gluta usitata* formed most of the seedling layer. Soil texture was sandy loam (SL) and the pH was 4.9.

Plantation 5. Mae Chon Luang, Mae Chaem catchment, Mae Chaem

The *P. kesiya* density was 386 trees/ha and the broadleaved tree (h> 1.3m) density 2517 trees/ha. The main mature tree species was *P. kesiya*. *Carpinus viminea* Wall. ex Lindl. and Fagaceae ssp. were the most common sapling species. Seedlings smaller than 30 cm in height and *P. kesiya,* formed most of the seedling layer. *Thunbergia laurifolia*, *Rubus* sp., *Thysanolaena maxima*, *Mucuna* sp., *Capillipedium* sp., *Imperata cylindrica*, *Alpinia* sp. and *Cammelina* sp., were dominant ground vegetation species on the sample plots that had existed 24 years without fire. *Alpinia* sp., *Thysanolaena maxima*, *Imperata cylindrica* and an untranslatable fern species dominated the plots that had had a forest fire six years ago. In the first five sample plots (fire 24 years ago), the soil texture was sandy loam (SL) with a pH value of 4.0, and in plots 6-10 (fire 6 years ago), the soil texture was sandy clay loam (SCL) with a pH value of 4.3.

Plantation 6. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong

The *P. kesiya* density was 240 trees/ha and the broadleaved tree (h> 1.3m) density 4967 trees/ha. The main mature tree species was *P. kesiya*. *Ternstroemia gymnanthera* (Wight & Arn.) Bedd., *Flacourtia indica* (Burm. f.) Merr. and Fagaceae ssp. were the most common sapling species. Seedlings smaller than 30 cm in height and Fagaceae ssp. formed most of the seedling layer. *Thysanolaena maxima*, small palms, *Alpinia* sp., climbers and *Pueraria* sp. formed the dominant ground vegetation. Soil texture or pH could not be determined.

Plantation 7. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong

The *P. kesiya* density was 300 trees/ha and the broadleaved tree (h> 1.3m) density 2847 trees/ha. The main mature tree species was *P. kesiya*. *Dichroa febrifuga* Lour. and *Archidendron clyperia* (Jack) Niels. ssp. *clyperia* var. *clyperia* were the most common sapling species. Seedlings smaller than 30 cm in height formed most of the seedling layer. Soil texture was sandy loam (SL) with a pH value of 4.2.

Table 1. Plantation descriptions indicating the fire disturbance and structure of the *P. kesiya* stands.

Plantation location	Forest type	Elevation a.s.l.	Age (a)	Area (ha)	Aspect	Slope (%)	Last occurence of fire (years)	Establishment density, pines (n ha? ¹)	Pines (n ha? ¹)	Pine h (m)	Pine dbh (cm)	Basal area of pines (m²/ha)
Plantation 1. Doi Mon Khom Long,Mae Sa Noi catchment, Mae Rim	Hill Evergreen	1300	27	2.5	S, SW	26	1,0	625	250	18	36	21
Plantation 2. Khun Huai Huek Pum, Mae Sa Noi catchment, Mae Rim	Dry Dipterocarp	1171	30	5	N, W	39	1,7	625	250	23	25	15
Plantation 3. Huai Bong subcatchment, Mae Chaem catchment, Hod	Dry Dipterocarp	855	24	9	N, NW	13	0,5	1111	486	15	20	21
Plantation 4. Huai Mao Phak An subcatchment, Mae Chaem catchment, Hod	Dry Dipterocarp	1027	20	2.5	NW, NE	23	0,0	1667	557	16	18	22
Plantation 5. Mae Chon Luang, Mae Chaem catchment, Mae Chaem	Hill Evergreen	1300	24	65	NW, S, E	24	14,6	625	386	20	31	23
Plantation 6. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong	Hill Evergreen	1300	38	80	E, SE, W, NW	28	2,7	625	240	29	40	15
Plantation 7. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong	Hill Evergreen	1500	23	184	NE, NW	38	0,5	625	300	20	26	15

Table 2. Plantation descriptions indicating the structure of broadleaved stands and their coppice regeneration proportions.

Plantation location	Mature broad-leaved density (n ha^{-1}) (dbh ≥10 cm)	Mature broadleaved h (m), (dbh ≥10 cm)	Mature broadleaved dbh (cm), (dbh ≥10 cm)	Sapling density (n ha^{-1}) (dbh <10 cm)	Sapling h (m), (dbh <10 cm)	Sapling dbh (cm), (dbh <10 cm)	Basal area of broadleaved trees (m^2/ha)	Seedling density (n ha^{-1}) (h<1.3m)	Broadleaved density (n ha^{-1}) (h ≥1.3m)	Coppice percentage of seedling density (%)	Coppice percentage of sapling density (%)
Plantation 1. Doi Mon Khom Long,Mae Sa Noi catchment, Mae Rim	64	12,4	24,0	350	1,8	1,5	4,3	33750	414	4	0
Plantation 2. Khun Huai Huek Pum, Mae Sa Noi catchment, Mae Rim	88	13,9	24,0	1250	2,6	2,4	5,5	18750	1338	0	0
Plantation 3. Huai Bong subcatchment, Mae Chaem catchment, Hod	138	9,9	13,4	1629	5,5	6,0	8,6	13571	1766	4	14
Plantation 4. Huai Mao Phak An subcatchment, Mae Chaem catchment, Hod	75	9,4	11,7	1257	5,0	5,8	4,7	5714	1332	75	24
Plantation 5. Mae Chon Luang, Mae Chaem catchment, Mae Chaem	77	18,2	35,8	2440	2,9	2,1	4,6	29500	2517	2	31
Plantation 6. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong	347	12,9	18,7	4620	2,8	2,1	11,2	12500	4967	8	40
Plantation 7. Nam Mae Khong subcatchment, Mae Taeng catchment, Khun Khong	247	13,4	20,1	2600	4,4	3,7	6,8	5000	2847	0	75

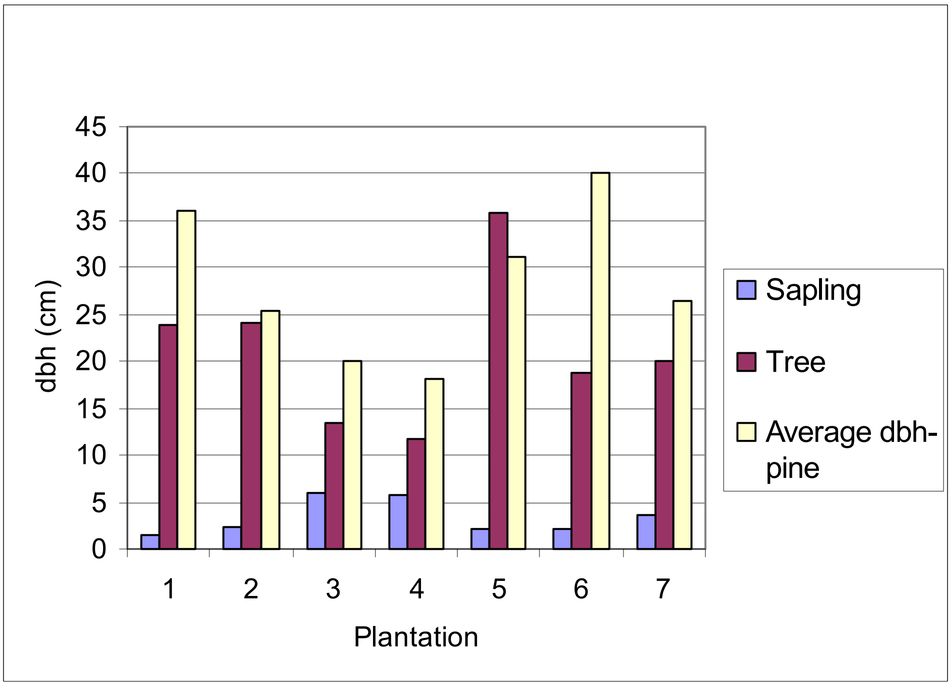


Figure 9. Diameters at breast height of saplings, mature trees and average-dbh pines in each plantation. For plantation identification, cf. Table 1.

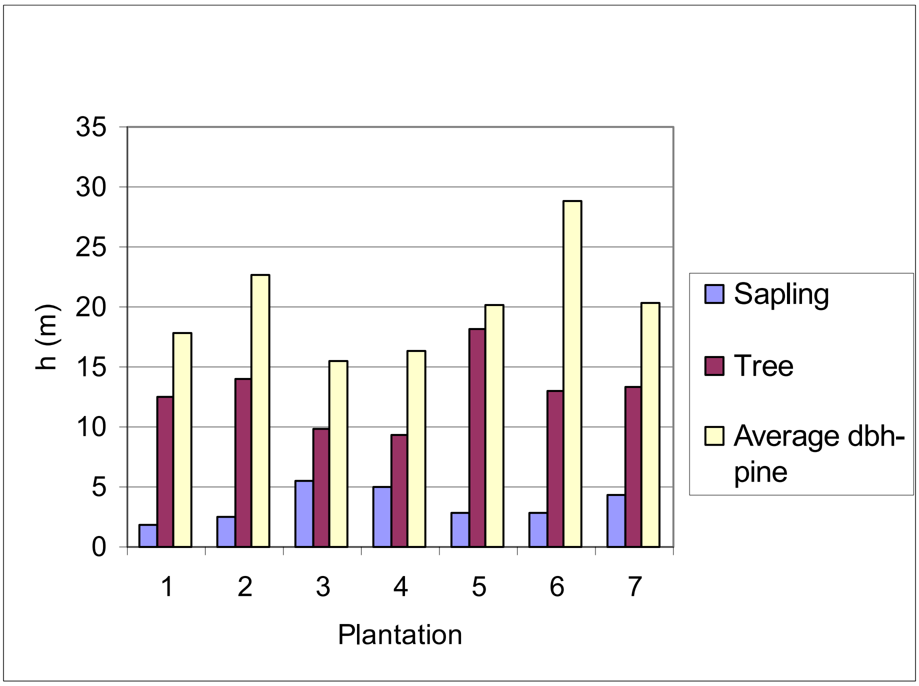


Figure 10. Heights of saplings, trees and average-dbh pines in each plantation. For plantation identification, cf. Table 1.

4.2 Factors affecting tree regeneration

To get a view of possible relationships between different variables, the Pearson correlation was calculated between the sample plot averages. Variables affecting regeneration were of special interest. A positive correlation was found between seedling density (n ha^{-1}) and litter cover percentage (%), (R^2= .694, P= .000). Other variables that correlated positively with seedling density were, fire history (years since last fire), litter depth (cm) and sapling density (n ha^{-1}). The sapling density (n ha^{-1}) correlated positively with litter depth and litter coverage, (R^2= .584, P= .001, R^2= .430, P= .022).

Using linear regression analysis, the seedling density was predicted with litter coverage (%) (R^2= .371, P= .001); (Figure 11.), sapling density (n ha^{-1}); (R^2= .208, P= .013), fire history (years since last fire) (R^2= .175, P= .024), and litter depth (cm); (R^2= .146, P= .041). These were all factors favourable for seedling recruitment. The litter coverage could also to some extent be predicted with the fire history (R^2= .186, P= .022), and sapling density (n ha^{-1}), (R^2= .185, P= .022).

As seedlings were during the field inventory divided into three groups based on their height, the median height for each sample plot was predicted with canopy coverage (%), mature broadleaved tree and sapling densities (n ha^{-1}) and litter coverage (%), (R^2= .472, P= .004). The result showed that canopy cover was the only factor hindering height growth of the seedlings.

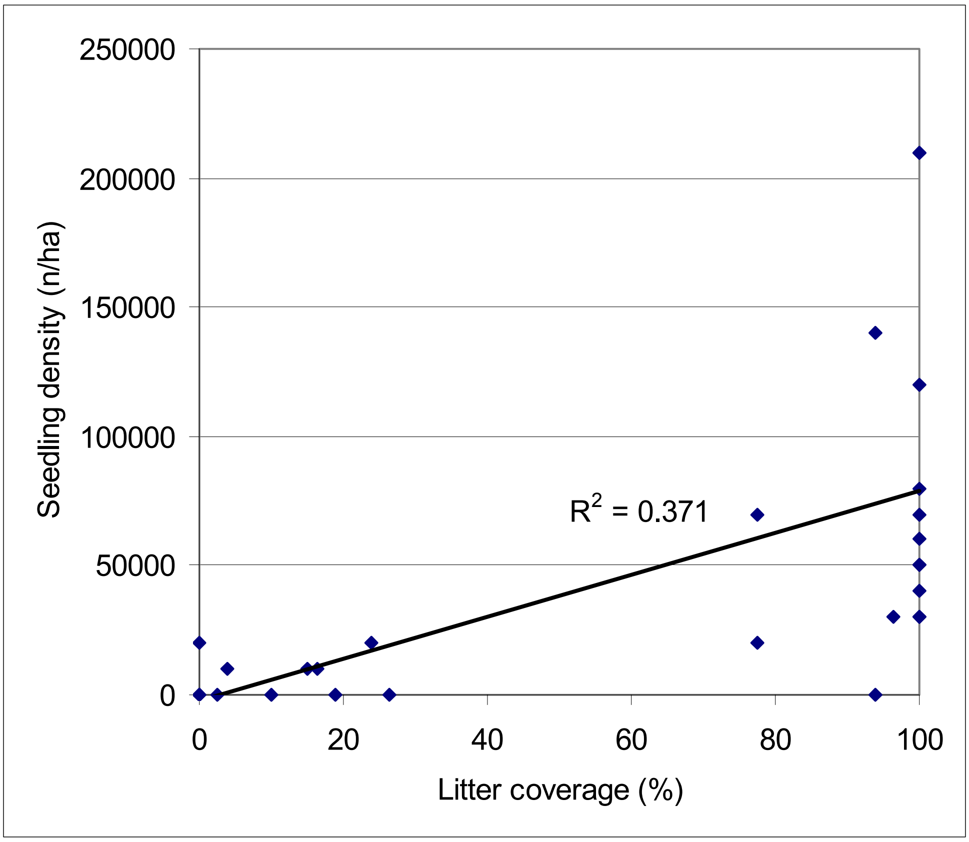


Figure 11. Relationship between litter coverage and seedling density sample based on plot averages.

In the same manner, the sapling density was predicted using litter depth (cm); (R^2= .341, P= .001); (Figure 12), litter cover (%); (R^2= .185, P= .022), and the broadleaved tree basal area (m^2); (R^2= .142, P= .044) as predictors. Results were statistically significant. The litter depth was successively higher when more time had passed since the last fire (R^2= .501, P= .000); (Figure 13), and when the ground vegetation grew successively higher (R^2= .229, P= .009). The pine basal area had a negative relationship with the broadleaved basal area (R^2= .392, P= .000), which in turn had a positive relationship with the density of mature broadleaved trees (n ha^{-1}); (R^2= .764, P= .010).

The average sapling height on the sample plots was successfully predicted with litter coverage (%); (R^2= .342, P= .001). Fire history seemed to mostly affect the sapling dbh (cm); (R^2= .564, P= .000). In both cases the effect of more recent fire was negative. The thinnest tree found to have survived a forest fire in the inventory year was 3.1 cm in dbh.

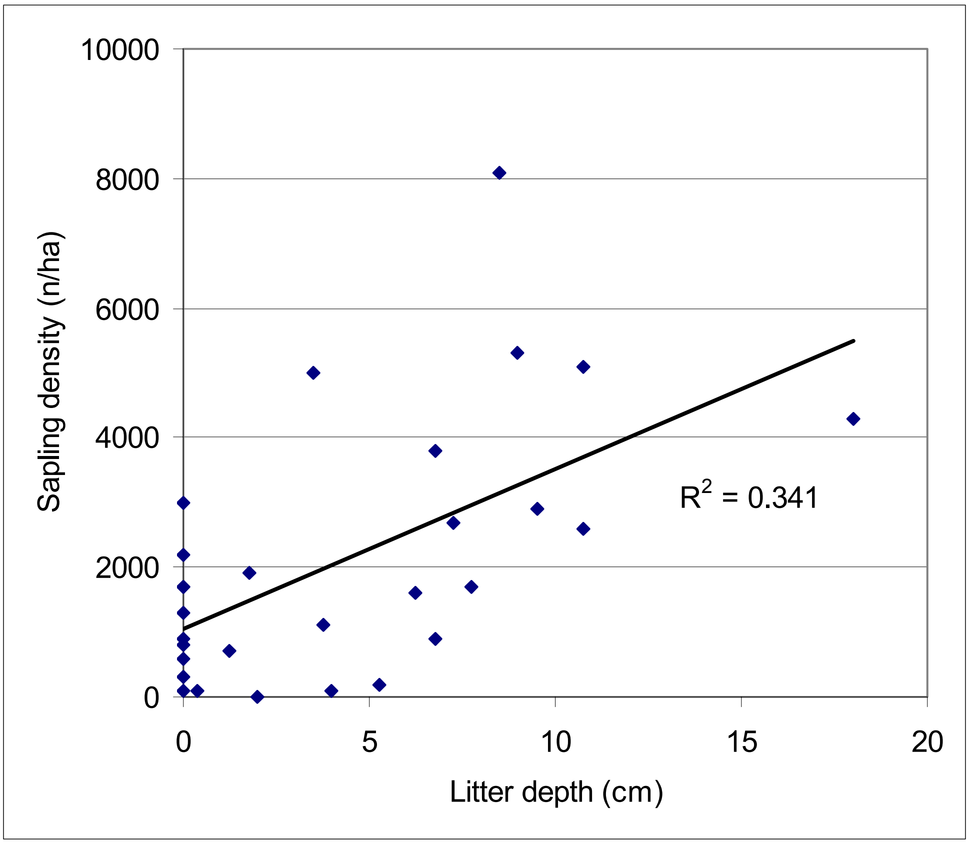


Figure 12. Relationship between litter depth and sapling density, based on sample plot averages.

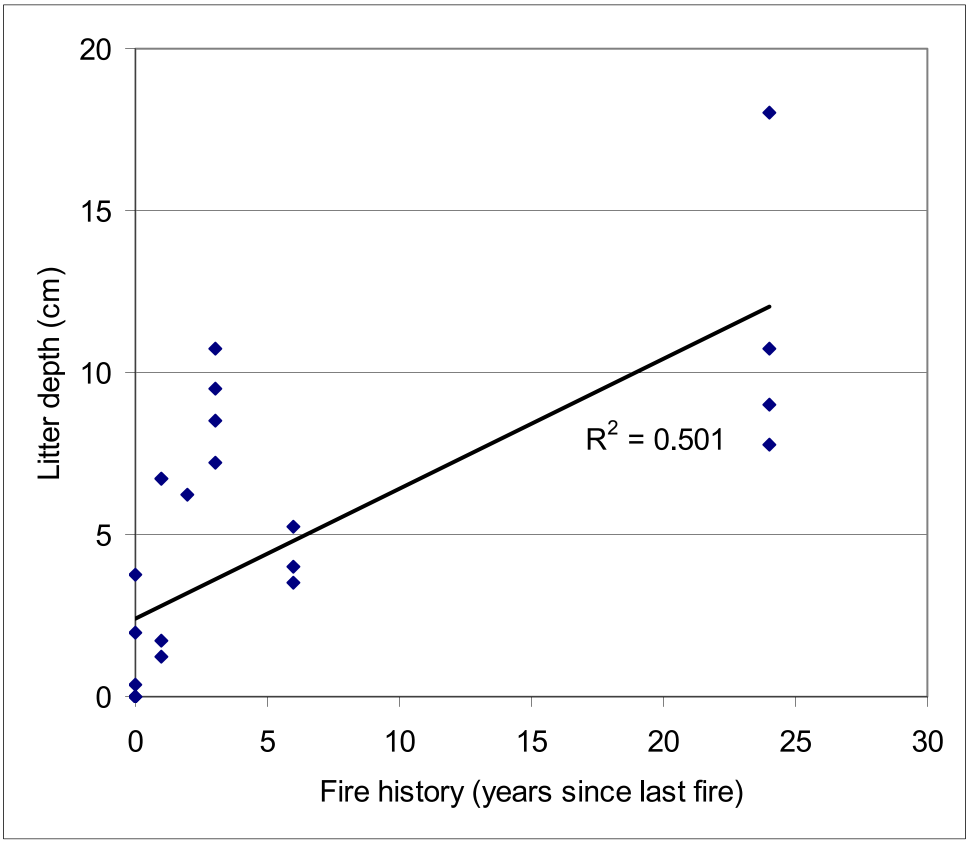


Figure 13. Relationship between fire history and litter depth, based on sample plot averages.

The expected dispersal mechanism (animal vs. wind) was also predicted for seedlings and saplings of different tree species in the pine plantations using plantation averages. Sapling dispersal medians were predicted with canopy coverage (%), ground vegetation height (cm) and litter coverage (%), which all had a positive relationship with animal dispersal (R^2= .987, P= .020). The strongest coefficient was the one representing canopy coverage. Seedling dispersal mechanism could not be statistically predicted.

The Sorensen and Jaccard similarity indices were calculated with plantation averages to find out similarities between tree size classes in each plantation (Table 3). It can be observed that the species similarity between mature trees and saplings is higher than the similarity between mature trees and seedlings. No significant differences could be found between the mature tree-seedling species and the sapling-seedling similarities.

It should be noted that the plantation averages used consisted of only seven observations per variable, which makes these results highly general and crude.

Table 3. Species similarities between, shown by Sorensen and Jaccard similarity indices, different tree layers in each plantation. (1=equal, 0=dissimilar in common species)

	Plantation						
	1	2	3	4	5	6	7
Tree-Seedling							
Sorensen Similarity	0.2	0.2	0.4	0.1	0.2	0.3	0.0
Jaccard Similarity	0.1	0.1	0.2	0.1	0.1	0.2	0.0
Tree-Sapling							
Sorensen Similarity	0.2	0.4	0.5	0.5	0.3	0.4	0.4
Jaccard Similarity	0.2	0.2	0.4	0.3	0.2	0.3	0.2
Sapling-Seedling							
Sorensen Similarity	0.2	0.1	0.3	0.2	0.2	0.3	0.0
Jaccard Similarity	0.1	0.1	0.2	0.1	0.1	0.2	0.0

4.3 Effect of fire on tree species composition

Plantation 5, Mae Chon Luang in Mae Chaem, offered an opportunity to compare vegetation characteristics of adjacent areas with different fire history, 6 and 24 years ago, respectively. It was presumed that fire is the most significant factor affecting the vegetation. Both fire history comparison areas were represented by five sample plot clusters.

Table 4. shows the average heights and diameters at breast height for each tree class. As expected, the mature trees are taller and have a higher diameter in the area with fire six years ago than in the area with fire 24 years ago. On the other hand the sapling layer is more developed in the latter area. The relative seedling frequency in each seedling height class was almost similar in the two areas (for sites with fire 24, and 6 years ago, respectively: h<30cm, 83.3 and 82.4 %, h≥ 30-50 cm, 8.3 and 0%; h>50-129.9 cm, 8.3 and 17.6%).

Most of the tree species found thrived well only in one of the fire-affected areas compared. The absence of fire clearly benefited sapling development and higher species richness, as there was a higher density of both saplings and mature trees in the 24 years ago burned area, fire seemed to have an opposite effect on the seedling layer (Tables 5-7). In the area with forest fire 24 years ago, the common dispersal mechanism for tree species was animal-dispersal, whereas wind-dispersal was more common in the area that had burned six years ago. This could be explained with differences in stand structures and species adaptations to different phases of the ecological cycle (Table 8).

Table 4. Diameter at breast height (dbh) and height of saplings and trees at two adjacent sites with different fire history.

	Seedlings	**Saplings**		**Trees**	
Years since fire	**h (cm)**	**dbh (cm)**	**h (m)**	**dbh (cm)**	**h (m)**
24	<30	2.7	4.1	20.6	16.6
6	<30	1.2	1.5	45.5	18.8

Table 5. Relative abundance (%) and number (n ha⁻¹) of selected seedling species groups at two adjacent sites with different fire history. Species with high seedling numbers are highlighted.

Seedling species group	**Relative abundance, % (n ha^{-1})**	
	24 yr. from fire	**6 yr. from fire**
Azadiracha indica A. Juss. var. *siamensis* \	0	100 (1250)
Elaeocarpus lanceaefolius Roxb.	0	100 (1250)
Ficus sp.	0	100 (1250)
h <30cm	39 (7170)	61 (11081)
Mallotus sp.	100 (1250)	0
***Pinus kesiya* Roy. ex Gord.**	0	100 (1500)
Sapium sp.	100 (1250)	0
Unidentified 8	0	100 (1000)
Untranslatable 18	100 (1250)	0
Untranslatable 22	0	100 (1250)
Total (n ha^{-1})	10920	18581

Table 6. Relative abundance (%) and number (n ha⁻¹) of selected seedling species groups at two adjacent sites with different fire history. Species with high sapling numbers are highlighted.

Sapling species group	**Relative abundance, % (n ha^{-1})**	
	24 yr. from fire	**6 yr. from fire**
Alangium chinense (Lour.) Rehd.	100 (10)	0
Alstonia scholaris (L.) R. Br.	100 (80)	0
Antidesma sp.	100 (10)	0
Averrhoa carambola L.	0	100 (10)
Azadiracha indica A. Juss. var. *siamensis*	100 (20)	0
Carpinus sp.	50 (10)	50 (10)
***Carpinus viminea* Wallich.**	23 (150)	77 (510)
Castanopsis sp.	0	100 (10)
Colona sp.	0	100 (10)
Dalbergia sp.	100 (10)	0
Diospyros glandulosa Lace	100 (10)	0
Elaeocarpus sp.	100 (10)	0
***Fagaceae* spp.**	100 (600)	0
Ficus sp.	100 (20)	0
Garcinia sp.	100 (30)	0
***Litsea cubeba* (Lour.) Pers. *L. citrata* Bl**	100 (140)	0
***Macaranga denticulata* (Bl.) M.-A.**	100 (110)	0
***Mallotus* sp.**	100 (120)	0
Melientha suavis Pierre	0	100 (10)
Musa sp.	88 (70)	12 (10)
Schima wallichii (DC.) Korth.	86 (60)	14 (10)
Syzygium sp.	100 (10)	0
Tarenna sp.	100 (10)	0
Toona ciliata M.Roem	100 (20)	0
Unidentified (7 species)	100 (140)	0
Untranslatable (13 species)	100 (220)	0
Total (n ha^{-1})	1860	580

Table 7. Relative abundance (%) and number ($n\ ha^{-1}$) of selected seedling species groups at two adjacent sites with different fire history. Species with high mature tree number are highlighted.

Mature tree species group	Relative abundance, % ($n\ ha^{-1}$)	
	24 yr. from fire	**6 yr. from fire**
Alangium chinense (Lour.) Rehd.	100 (1.6)	0
Canarium subulatum Guill.	100 (0.8)	0
Carpinus sp.	100 (0.8)	0
Castanopsis sp.	100 (0.8)	0
Colona sp.	100 (1.6)	0
Dalbergia ovata Graham ex Bentham	100 (0.8)	0
Dalbergia sp.	0.0	100 (4.0)
Dillenia sp.	100 (2.4)	0
***Diospyros glandulosa* Lace**	17 (1.6)	83 (8.0)
Elaeagnus angustifolia L.	100 (0.8)	0
Elaeocarpus sp.	0.0	100 (1.6)
Engelhardtia sp.	100 (2.4)	0
Fagaceae spp.	33 (0.8)	67 (1.6)
Garuga pinnata Roxb.	100 (3.2)	0
Litsea cubeba (Lour.) Pers. L. *citrata* Bl.	100 (1.6)	0
Macaranga denticulata (Bl.) M.-A.	100 (1.6)	0
Mallotus sp.	100 (0.8)	0
Michelia sp.	100 (0.8)	0
Sapindus rarak dc.	100 (0.8)	0
***Schima wallichii* (DC.) Korth.**	41 (13.5)	59 (19.9)
Siphonodon celastrineus Griff.	100 (0.8)	0
Untranslatable (2 species)	100 (1.6)	0
Wendlandia scabra Kurtz	100 (3.2)	0
Total ($n\ ha^{-1}$)	42.2	35.0
Pinus kesiya Roy. ex Gord.	344.4	460.0
Total ($n\ ha^{-1}$) with *P. kesiya*	386.6	495.0

Table 8. Dispersal mechanisms frequencies for broadleaved trees and saplings.

Dispersal mechanism	Percent		Valid percent	
	24 yr.	**6 yr.**	**24 yr.**	**6 yr.**
Animal	64.5	30.0	76.1	30.8
Wind	20.3	67.5	23.9	69.2
Unknown	15.2	2.5		
Total	100	100	100	100

4.4 Seed dispersal mechanisms in pine plantations

Tree species occurring in pine plantations were categorised based on their known seed dispersal mechanisms into animal-dispersed and wind-dispersed classes. Unfortunately several species had to be classified as having an unknown dispersal mechanism, due to lack of information or, as in case of many seedlings, lack of identification because of a height less than 30 cm. (Tables 9-11). The high relative abundance of animal dispersed species can be noticed in sapling and mature tree classes.

Table 9. Dispersal mechanism proportions of seedling species in each plantation.

	Unknown mechanism		Animal-dispersed		Wind-dispersed	
Plantation	**(n ha^{-1})**	**Relative abundance (%)**	**(n ha^{-1})**	**Relative abundance (%)**	**(n ha^{-1})**	**Relative abundance (%)**
1	10000	29.6	22500	66.7	1250	3.7
2	13750	73.3	3750	20.0	1250	6.7
3	7857	57.9	1786	13.2	3929	28.9
4	3929	68.8	1786	31.3	0	0.0
5	23000	78.0	5000	16.9	1500	5.1
6	8500	68.0	4000	32.0	0	0.0
7	5000	100.0	0	0.0	0	0.0

Table 10. Dispersal mechanism proportions of sapling species in each plantation.

	Unknown mechanism		Animal-dispersed		Wind-dispersed	
Plantation	**(n ha^{-1})**	**Relative abundance (%)**	**(n ha^{-1})**	**Relative abundance (%)**	**(n ha^{-1})**	**Relative abundance (%)**
1	0	0.0	250	71.4	100	28.6
2	0	0.0	950	76.0	300	24.0
3	14	0.9	714	43.9	900	55.3
4	143	11.4	400	31.8	714	56.8
5	370	15.2	1210	49.6	860	35.2
6	980	21.2	3460	74.9	180	3.9
7	1400	53.8	1040	40.0	160	6.2

Table 11. Dispersal mechanism proportions of mature tree species in each plantation.

	Unknown mechanism		Animal-dispersed		Wind-dispersed	
Plantation	**(n ha^{-1})**	**Relative abundance (%)**	**(n ha^{-1})**	**Relative abundance (%)**	**(n ha^{-1})**	**Relative abundance (%)**
1	0	0.0	52	81.3	12	18.8
2	12	13.6	48	54.5	28	31.8
3	9	6.6	30	21.5	99	71.9
4	2	0.4	598	94.6	32	5.0
5	2	2.1	40	51.5	36	46.4
6	33	9.6	240	69.3	73	21.1
7	75	30.3	131	52.9	41	16.8

5. Discussion

5.1 Regeneration of broadleaved tree species and *Pinus kesiya*

Regeneration of native tree species clearly occurred after plantation establishment, and a development towards a mixed stand was observed in each plantation studied. This is in agreement with earlier study by Parrotta (1997).

Regeneration of broadleaved trees in these seven *P. kesiya* plantations was affected by fire disturbance, light intensity and the presence of mature seed producing trees (Figure 14). Seedling recruitment was mainly facilitated by lack of fire disturbance, which caused high litter coverage. The accumulation of litter was more pronounced in plantations that had been undisturbed by fire for a longer period of time and which had high density of saplings. This obvious increasing effect of saplings on litter accumulation is surprising giving the fact that the litter layer mainly consisted of pine needles. The role of saplings in litter accumulation could be affected by sparser fire frequency, which then would allow the broadleaved tree density to increase and thus the litter production of the plantation to rise further. Lack of information on plantation fire frequencies prevented an examination of this possibility. It was, however, concluded that the main reason behind an increased litter coverage, litter depth and seedling density was the absence of fire.

Seedlings grew taller when the mature broadleaved tree density was high and canopy coverage was not. A high mature broadleaved tree density increased the seed rain, thus also increasing the probability of the establishment of site-adapted seedlings in favourable microhabitats, as suggested by Monyrak (1997). High canopy coverage causes a decrease in light intensity that hinders the growth of tree seedlings (Whitmore 1991).

According to the analysis, litter depth and the basal area of broadleaved trees in the plantation played key roles in sapling establishment. It was concluded that these two factors acted mostly as predictors for primary reasons, absence of fire and low pine basal area. The litter layer was found to be deeper in areas which had not recently suffered from forest fire. In other words, the density of saplings was higher when they were not killed by fire. The reduction of the basal area in pines was compensated by an increase of that in broadleaved trees. This supports the results obtained earlier by Oberhauser (1997) who suggested a compensation of a lost pine basal area by an increase in the non-pine basal area. Similar conclusions were made by Lugo (1992) who observed good results in secondary succession when a *P. caribaea* stand was thinned. Two possible reasons were considered, firstly, light conditions were more favourable for secondary species, as Whitmore (1991) suggested, and, secondly, pines hinder the successional development towards a mixed stand by increasing the risk of fire (Brown and Davis 1973).

The average height of saplings is higher under conditions in which fire kills small saplings. A larger diameter seemed to protect the tree saplings better than a taller height. This was probably due to a thicker bark in seedlings with larger diameter and the small bark area that is affected by moving fire.

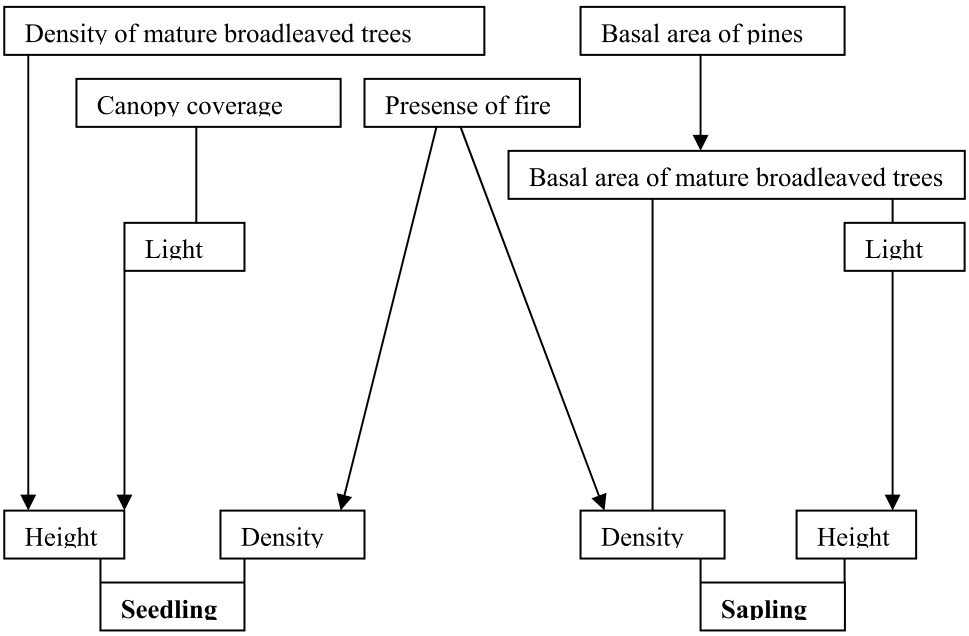


Figure 14. Limiting factors of forest regeneration in Pinus kesiya plantations of northern Thailand.

Most of the mature tree species were animal-dispersed and belonged to the same forest type as natural forests close by, except in plantation 3, where wind-dispersed species dominated the canopy layer and in Plantation 5, where the relation between species having these different dispersal mechanisms were equal. This suggests that the seed dispersal originally occurred from these natural forests and probably still continues from them, since plantations are more attractive habitats to seed-dispersing animals than open agricultural fields or sapling stands (Fimbel 1995, Parrotta 1995, Hardwick *et al.* 1997, Yirdaw 2002).

Even though a high sapling density seemed to affect the seedling density positively, it was concluded that, of the two tree categories (h> 1.3 m), the mature trees acted as the principal seed source in those species that where found in the lower tree layers. The Jaccard similarity index indicated that the mature tree layer had a species composition more similar to that in the sapling layer than to the one found in the seedling layer. This result can be seen as showing an increase in tree species diversity, successively when more seeds arrive from outside of a plantation. However, it can also be assured that large mature trees act as a first key seed source for an emerging sapling layer that subsequently can contribute to seed dispersal and in this way have an affect on seedling density.

On the other hand, only few of the germinating trees survive to develop into saplings. This was supported by dispersal mechanism analysis results, which suggested that, in the absence of fire and with a high canopy coverage and tall ground vegetation, species belonging both to the wind and animal dispersal type are germinated, but predominantly only species with larger, animal-dispersed seeds could survive to develop into saplings.

These effects could especially be observed in Plantation 5. The particular area burned 24 years ago had both more species and a higher density of trees belonging to the sapling and mature tree categories than an area with fire disturbance only six years ago. Large-seeded climax species generally have a good shade tolerance (Hardwick *et al.* 1997, Montyak 1997), and denser vegetation has an ability to resist colonisation by wind-dispersed species as it simultaneously attracts seed-dispersing animals, thus making the environmental conditions more favourable for animal-dispersed species than for wind-dispersed ones.

Coppicing was found to play an important role in regeneration, as Bazzaz (1991) and De Rouw (1993) have found in their earlier studies in other regions. In the present study only three (Plantation 1, 2 and 3) had a weak coppice production.

Even though, plantations were mixed with different tree species, *P. kesiya* could still be considered as the main species, as indicated by height (m), dbh (cm) or basal area (m^2 ha^{-1}). Mortality of pines was noted, which has earlier also been observed by Oberhauser (1997); underlying reasons may include a too high stand density, an environment that is too moist for pines and damage caused by kindling collectors. Pine regeneration was almost absent. Pine seedlings were found only on three sample plots. These observations support forest fires as a reason for the lack of both pine and broadleaved species seedlings. Similar results have been reported in earlier studies by Turnbull *et al.* (1980), Goldammer (1985) and Savage (1994).

5.2 Forest type development

The broadleaved species composition corresponded with the original forest types of the areas. The only exception was Plantation 1 in the Mae Sa Noi catchment, where seedling and sapling layers of an originally hill evergreen forest were dominated by species belonging to the deciduous and dry dipterocarp forest types and species that favour open areas. The canopy layer, apart from *P. kesiya*, was dominated by indicator species of the hill evergreen forest type. In this disturbed plantation, both sapling and mature broadleaved densities where the lowest among all plantations surveyed in the present study. This, along with fire disturbance, a southerly aspect, a ditch, and an agricultural field bordering the plantation downhill, could explain the peculiar forest type alteration in this specific case. A large-sized remnant *Dalbergia froribunda* Roxb. had probably caused a high seedling density of this particular species in the plantation in question.

5.3 Limitations of present study

There were certain limitations in the present study. Even though the inventory was carried out systematically, the sample plots could not be spread evenly in the larger plantations of Mae Chaem and Khun Khong, due their large size and lack of time available for more comprehensive work. Because of this, the plantation averages presented on these two plantations should be examined with caution.

Species identification could not be done in the best possible way, since herbaceous specimens were not collected for later identification during the field work. Due to this very fact, all the species in Fagaceae and ten other species were unidentified by a scientific name. In addition, some species were identified only by family.

The analysis conducted on dispersal mechanisms was to some extent biased a as large proportion of the seedling density consisted of unidentified species. The sapling and mature broadleaved tree dispersal data in plantation 7 should also be examined with care for the same reason. The median type of dispersal mechanism (animal/wind) was predicted for seedlings and saplings using plantation averages with only seven variables per factor thus making these results very general, but as the results nevertheless seemed to indicate certain trends they were considered valid. Lack of species identification did not hinder the rest of the analysis, since the study focused mainly on factors limiting the ecological succession and determined by plantation structure and disturbance history.

6. Plantation management recommendations

6.1 General considerations

Because of an unclear future of forest management settings in northern Thailand as far as forest laws are concerned, a management system that enables different future utilisation possibilities is to be recommended for the plantations in Mae Sa, Mae Chaem and Khun Khong. Two separate approaches are proposed: (1) management as catchment area, with an emphasis on biodiversity conservation and rehabilitation, and (2) management as catchment but with a possibility for harvesting for industrial and other purposes.

Both of these scenarios should include the participation of local people in order to generate income for them (May 1995, Kunarattanapruk *et al.* 1998) and to prevent conflicts (Ming-Lii 1999). A successful natural resource management model in Thailand in relation to forest protection provides the local people with opportunities to initiate and participate in decision-making and in the management of their living environment with outside support by the state, NGOs and international organizations (Phimphisut 1997).

One way to make this possible in both of these management options is the establishment of buffer zones around critical watershed areas in the same way as done in national parks elsewhere in Thailand. Community-managed buffer zones composed of sub-catchments with suitable watershed classes could be both conserved and utilised with the desired sustainable aims and means by that would also prevent illegal utilisation of the protected plantations.

The results of this study suggest that new reforestation should be done with mixed species matching the site. In general, *P. kesiya* should be avoided when pursuing for higher biodiversity through rehabilitation or for watershed protection services, even though it is a better alternative than no planting at all. This species limits the growth and development of other species in the stand if not thinned. Previous studies (Pukjaloon *et al.* 1985, Walters 1997, Tangtham 1999) show that Khasi pine does not offer the desired watershed protection services, apart from excessive transpiration, nor does it offer economic possibilities for the local people, both being qualities that should be included in successful rehabilitation. *P. kesiya* is also known for its crooked stem form and heavy branching, characteristics which make it a poor species choice for commercial use (Armitage and Wood 1980).

Prescribed fire in early dry season should be practiced in pine plantations with intervals of 2-4 years as suggested by de Ronde *et al.* (1990). More research is needed on the effects of fire frequency on tree regeneration and soil properties.

6.2 Management of watershed areas emphasising rehabilitation

Based on the present study, thinning of pines is highly recommended in *Pinus kesiya* plantations of Chiang Mai province, if the main purpose of plantations is watershed management and biodiversity protection. This is due to the negative effect of pines on seedling establishment and sapling development. Earlier studies of Tangtham (1999) and Pukjaloon *et al.* (1985) indicate pine plantations and forests to have a higher rain water interception and evaporation as compared to hill evergreen and dry dipterocarp forest. As reported in the current study, local people in Mae Chaem had also noticed this negative effect of pines and disliked pine plantations because of water shortages in their fields. The same opinion came up also in Hod. Officers explained the real reason to be the limited value of pines to locals and an assumption that because pines have many needles they transpire more than the deciduous broadleaved trees (Khonman, 2004).

The present study also concludes that if a more species-rich plantation is seen as a goal, it is more easily achieved if conditions supporting animal-dispersed species are facilitated. After surface fire, seedling establishment by germination of seeds and coppicing shoots is strong. Regeneration could be facilitated by protecting the plantation from fire for a couple of years, so as to allow the increment in tree size suitable to survive the next fire. Thinnest saplings found to have survived a fire of the inventory year had a diameter of 3.1 cm at breast height. The growth of seedlings could be further boosted with thinning of pines though keeping in mind the extra litter that is produced. Thinning would also create canopy openings necessary for further growth from saplings to mature trees. Enrichment plantings could be done to improve the species richness with desired native species.

Further more, earlier study of Wade and Lundsford (1990) show that after sufficient establishment of saplings, prescribed burning in early dry season should be practised to avoid risky litter accumulation until the pine needle proportion of the litter fall decreases. This burning should be done in a way that leaves patches of unburned ground to allow some seedlings to survive. Surface runoff and sedimentation can be reduced by leaving unburned buffer zones to border streams and by ensuring that the fire is light. When the species composition changes towards mixed stands with a smaller pine proportion, fire sensibility can be expected to decrease, at least in hill evergreen forest type areas. This will reduce the risk of high-intensity forest fires that destroy the whole canopy cover as has happened in Mae Chaem and Khun Khong. When the fire frequency is diminished surface erosion also decreases because of a thicker litter layer and an increment of the humus layer in the soil. Flooding risks and sedimentation of dams would consequently be reduced as well as shortages of water in the dry season (Brown and Davis 1973).

Several studies show that issues concerning land use rights are an important factor in natural resources management. When a future community forestry law is passed, and if the northern *Pinus kesiya* plantations are included, they would offer better economic alternatives to the local people after rehabilitation towards mixed forests (Kunarattanapruk *et al.* 1998, May 1995, www-document). Sharma (1996, 1999), recommends that watersheds should have production and conservation functions at the same time, and this can only be reached through participation of the local people. Local people could be included in the management planning process, as Randhava and Kanchanadul (1996) recommend and as is already done on some watershed units. It is recommended that this positive progress towards including the local people in management and the sustainable utilisation of their living environment would be based on the legislation and strongly supported by the government. Local resistance against reforestation is diminished if people are entitled to some of the benefits, non timber forest products (NTFPs), and a sense of powersharing. Income generation created by NTFPs could reduce deforestation caused by the legal and illegal expansion of vegetable farms, creating an alternative income source.

6.3 Management of watershed areas with possibility of future logging opportunities

This study indicates that if Khasi pine plantations are not thinned with the aim of single-species composition, they will change to natural forests with a diverse species composition that are harder to utilise commercially; in the future it would be hard to justify their conversion back to plantations. Continuous protection against forest fires in a plantation will cause a pine needle litter accumulation until a high intensity forest fire will destroy it completely.

Thinning should be directed at broadleaved trees and at pines in poor condition that prevent the stem volume increment of the rest of the pines (Jones 1969). One option is to use line or group thinning combined with prescribed burning of the litter layer, which would enable natural pine regeneration, possibly enhanced with planting or sowing of pines and other desired species.

7. Final conclusions

7.1 Aims of the study achieved

Forest regeneration was found to be extensive in all of the plantations surveyed. Especially the lower canopy layer, mostly formed by saplings was well developed with densities ranging between 350-4620 saplings/ha. Seedling densities were high as well, ranging between 5000-33,750 seedlings/ha.

Three major limiting factors of forest succession were discovered: fire disturbance, light intensity and the presence of mature seed producing trees. Forest fires effectively killed seedlings and saplings with a low diameter at breast height. Increment in canopy coverage, which was concluded to decrease light intensity, hindered the height growth of the seedlings. As the decrease in pine basal area was found to be compensated with an increased broadleaved tree basal area. A suggestion was made that decrease in pine basal area would improve light conditions of saplings and in this way promote the development of more species rich upper canopy layer. A high density of mature broadleaved species favoured the height development of seedlings. This was seen, to derive from the increased seed rain, thus making it more probable for site adapted seedlings to germinate. Mature trees were the main seed source in these plantations, although saplings also contributed to the seed rain.

The presence of forest fires favoured wind dispersed species over animal dispersed ones. Most likely fires also favoured species with a better adaptation to fire, but as there was little information to be found on the subject, this possibility could not be examined. Species richness was higher in plantation areas with absence of fire.

In environmental conditions with absence of forest fire, high canopy coverage and tall ground vegetation predominantly only animal dispersed seedlings developed into saplings.

Forest type alteration could not be noticed, except on one plantation in Mae Sa, where it was explained to derive from several disturbances, including selective cutting of trees, forest fires, a ditch and an agricultural field which bordered the plantation downhill.

A management system that enables different future utilisation possibilities is to be recommended for Khasi pine watershed plantations in Chiang Mai province. Two separate approaches were proposed for future plantation management. One, emphasising biodiversity conservation and rehabilitation and the other, taking into account the possibility for future harvesting for industrial and other purposes. Both of the approaches proposed included participation of local people, so that the plantations would have protection and production functions simultaneously. Thinning and prescribed fire should be practised to achieve the selected management aims.

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Appendix 1.

Table 12. Species list of plantation 1, with number and relative abundances per hectare.

Seedling

Species group	(n ha^{-1})	Relative Abundance (%)
Dalbergia floribunda Roxb.	16250	0.48
h <30cm	10000	0.30
Gluta obovata Craib	2500	0.07
Berrya mollis Wall. ex Kurz	1250	0.04
Ficus semicordata B.-H. ex J.E. Sm. var *semicordata*	1250	0.04
Gardenia sootepensis Hutch.	1250	0.04
Phyllathus emblica L.	1250	0.04
Total	33750	1.00

Sapling

Species group	(n ha^{-1})	Relative Abundance (%)
Berrya mollis Wall. ex Kurz	100	0.29
Aporosa villosa (Lindl.) Baill.	50	0.14
Callicarpa arborea Roxb.	50	0.14
Dillenia parviflora Griff.	50	0.14
Maesa glomerata K. Larsen & C.M. Hu	50	0.14
Styrax benzoides Craib	50	0.14
Total	350	1.00

Mature tree

Species group	(n ha^{-1})	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	250	0.80
Castanopsis armata (Roxb.) Spach Prodr.	16	0.05
Callicarpa arborea Roxb.	8	0.03
Schima wallichii (DC.) Korth.	8	0.03
Albizia chinensis (Osb.) Merr.	4	0.01
Berrya mollis Wall. ex Kurz	4	0.01
Dalbergia cultrata Grah. ex Bht. var. *cultrata*	4	0.01
Glochidion sphaerogynum (M.-A.) Kurz.	4	0.01
Lithocarpus sp.	4	0.01
Phyllathus emblica L.	4	0.01
Sterculia villosa Roxb.	4	0.01
Styrax benzoides Craib	4	0.01
Total	314	1.00

Table 13. Species list of plantation 2 , with number and relative abundances per hectare.

Seedling

Species group	($n\ ha^{-1}$)	Relative Abundance (%)
h <30cm	12500	0.67
Berrya mollis Wall. ex Kurz	1250	0.07
Castanopsis armata (Roxb.) Spach Prodr.	1250	0.07
Ficus semicordata B.-H. ex J.E. Sm. var *semicordata*	1250	0.07
Tristaniopsis burmanica (Griff.) Wils. & Wat.	1250	0.07
Vaccinium sprengelii (D. Don) Sleum.	1250	0.07
Total	18750	1.00

Sapling

Species group	($n\ ha^{-1}$)	Relative Abundance (%)
Castanopsis armata (Roxb.) Spach Prodr.	200	0.16
Dalbergia cultrata Grah. ex Bht. var. *cultrata*	200	0.16
Wendlandia tinctoria (Roxb.) DC. ssp. *tinctoria*	200	0.16
Viburnum inopinatum Craib	150	0.12
Canarium subulatum Guill.	100	0.08
Aporosa villosa (Lindl.) Baill.	50	0.04
Castanopsis diversifolia (Kurz) King ex Hk. f.	50	0.04
Colona fragrocarpa (Clarke) Craib	50	0.04
Eriolaena candollei Wall.	50	0.04
Gluta usitata (Wall.) Hou	50	0.04
Lithocarpus sp.	50	0.04
Phyllathus emblica L.	50	0.04
Stereospermum colais (B.-H. ex Dillw.) Mabb.	50	0.04
Total	1250	1.00

Mature tree

Species group	($n\ ha^{-1}$)	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	250	0.74
Castanopsis armata (Roxb.) Spach Prodr.	20	0.06
Shorea siamensis Miq.	16	0.05
Callicarpa arborea Roxb.	12	0.04
Lithocarpus sp.	8	0.02
Tristaniopsis burmanica (Griff.) Wils. & Wat.	8	0.02
Artocarpus lakoocha Roxb.	4	0.01
Canarium subulatum Guill.	4	0.01
Craibiodendron stellatum (Pierre) W.W. Sm.	4	0.01
Stereospermum colais (B.-H. ex Dillw.) Mabb.	4	0.01
Untranslatable (1 species)	4	0.01
Wendlandia tinctoria (Roxb.) DC. ssp. *tinctoria*	4	0.01
Total	338	1.00

Table 14. Species list of plantation 3 , with number and relative abundances per hectare.

Seedling

Species group	$(n\ ha^{-1})$	Relative Abundance
h <30cm	7857	0.58
Dipterocarpus obtusifolius Teijsm. ex Miq	3929	0.29
Gluta usitata (Wall.) Hou	1786	0.13
Total	13571	1.00

Sapling

Species group	$(n\ ha^{-1})$	Relative Abundance (%)
Dipterocarpus obtusifolius Teijsm. ex Miq	614	0.38
Gluta usitata (Wall.) Hou	329	0.20
Shorea obtusa Wall. ex Bl.	286	0.18
Fagacaea	214	0.13
Vaccinium sprengelii (D. Don) Sleum.	57	0.04
Terminalia chebula Retz. var. chebula	43	0.03
Wendlandia scabra Kurtz	43	0.03
Anneslea fragrans Wall.	14	0.01
Canthium sp.	14	0.01
Untraslatable (1 species)	14	0.01
Total	1629	1.00

Mature tree

Species group	$(n\ ha^{-1})$	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	486	0.78
Dipterocarpus obtusifolius Teijsm. ex Miq	93	0.15
Gluta usitata (Wall.) Hou	20	0.03
Untranslatable (2 species)	8	0.01
Shorea obtusa Wall. ex Bl.	6	0.01
Terminalia chebula Retz. var. chebula	6	0.01
Fagaceae spp.	3	0.01
Cratan sp.	1	0.00
Total	623	1.00

Table 15. Species list of plantation 4 , with number and relative abundances per hectare.

Seedling

Species group	(n ha⁻¹)	Relative Abundance (%)
h <30cm	2143	0.38
Gluta usitata (Wall.) Hou	1786	0.31
Untranslatable (1 species)	1786	0.31
Total	5714	1.00

Sapling

Species group	(n ha⁻¹)	Relative Abundance (%)
Dipterocarpus obtusifolius Teijsm. ex Miq	343	0.27
Dipterocarpus tuberculatus Roxb.	329	0.26
Fagaceae spp.	200	0.16
Gluta usitata (Wall.) Hou	186	0.15
Untranslatable (2 species)	100	0.08
Unidentified (1 species)	43	0.03
Shorea obtusa Wall. ex Bl.	43	0.03
Canthium sp.	14	0.01
Total	1257	1.00

Mature tree

Species group	(n ha⁻¹)	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	557	0.88
Dipterocarpus tuberculatus Roxb.	17	0.03
Fagacaea spp.	15	0.02
Spondias pinnata (L.f.) Kurtz	13	0.02
Dipterocarpus obtusifolius Teijsm. ex Miq	11	0.02
Canthium sp.	7	0.01
Shorea obtusa Wall. ex Bl.	3	0.01
Ficus sp.	2	0.00
Gluta usitata (Wall.) Hou	2	0.00
Untranslatable (2 species)	2	0.00
Mallotus sp.	1	0.00
Wendlandia scabra Kurtz	1	0.00
Total	632	1.00

Table 16. Species list of plantation 5 , with number and relative abundances per hectare.

Seedling

Species group	**($n\ ha^{-1}$)**	**Relative Abundance**
h <30cm	18250	0.62
Untranslatable (2 species)	2500	0.08
Pinus kesiya Roy. ex Gord.	1500	0.05
Azadiracha indica A. Juss. var. *siamensis* Valeton	1250	0.04
Elaeocarpus lanceaefolius Roxb.	1250	0.04
Ficus sp.	1250	0.04
Mallotus sp.	1250	0.04
Balakara sp.	1250	0.04
Unidentified (1 species)	1000	0.03
Total	29500	1.00

Sapling

Species group	**($n\ ha^{-1}$)**	**Relative Abundance (%)**
Carpinus viminea Wall. ex Lindl.	660	0.27
Fagaceae spp.	600	0.25
Untranslatable 10	220	0.09
Litsea cubeba (Lour.) Pers. L. *citrata* Bl.	140	0.06
Mallotus sp.	120	0.05
Macaranga denticulata (Bl.) M.-A.	110	0.05
Unidentified (6 species)	110	0.05
Alstonia scholaris (L.) R. Br.	80	0.03
Musa sp.	80	0.03
Schima wallichii (DC.) Korth.	70	0.03
Garcinia sp.	30	0.01
Azadiracha indica A. Juss. var. siamensis Valeton	20	0.01
Carpinus sp.	20	0.01
Ficus sp.	20	0.01
Toona ciliata M.Roem	20	0.01
Alangium chinense (Lour.) Rehd.	10	0.00
Antidesma sp.	10	0.00
Averrhoa carambola L.	10	0.00
Castanopsis sp.	10	0.00
Colona sp.	10	0.00
Dalbergia sp.	10	0.00
Diospyros glandulosa Lace	10	0.00
Elaeocarpus sp.	10	0.00
Melientha suavis Pierre	10	0.00
Syzygium sp.	10	0.00
Tarenna sp.	10	0.00
Total	2440	1.00

Mature tree

Species group	(n ha^{-1})	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	386	0.83
Schima wallichii (DC.) Korth.	33	0.07
Diospyros glandulosa Lace	10	0.02
Dalbergia sp.	4	0.01
Garuga pinnata Roxb.	3	0.01
Wendlandia scabra Kurtz	3	0.01
Dillenia sp.	2	0.01
Engelhardtia sp.	2	0.01
Fagaceae spp.	2	0.01
Alangium chinense (Lour.) Rehd.	2	0.00
Colona sp.	2	0.00
Elaeocarpus sp.	2	0.00
Litsea cubeba (Lour.) Pers. L. *citrata* Bl.	2	0.00
Macaranga denticulata (Bl.) M.-A.	2	0.00
Untranslatable (2 species)	2	0.00
Canarium subulatum Guill.	1	0.00
Carpinus sp.	1	0.00
Castanopsis sp.	1	0.00
Dalbergia ovata Graham ex Bentham	1	0.00
Elaeagnus angustifolia L.	1	0.00
Mallotus sp.	1	0.00
Michelia sp.	1	0.00
Sapindus rarak dc.	1	0.00
Siphonodon celastrineus Griff.	1	0.00
Total	463	1.00

Table 17. Species list of plantation 6, with number and relative abundances per hectare.

Seedling

Species group	**(n ha⁻¹)**	**Relative Abundance**
h <30cm	7000	0.56
Fagaceae spp.	1000	0.08
Untranslatable (2 species)	1000	0.08
Albizia sp.	500	0.04
Flacourtia indica (Burm. f.) Merr.	500	0.04
Glochidion sp.	500	0.04
Gluta usitata (Wall.) Hou	500	0.04
Litsea sp.	500	0.04
Michelia sp.	500	0.04
Phoebe sp.	500	0.04
Total	12500	1

Sapling

Species group	**(n ha⁻¹)**	**Relative Abundance (%)**
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	1120	0.25
Untranslatable (5 species)	780	0.17
Flacourtia indica (Burm. f.) Merr.	740	0.16
Fagaceae spp.	680	0.15
Ficus semicordata B.-H. ex J. E. Sm.var *semicordata*	140	0.03
Michelia sp.	140	0.03
Diospyros glandulosa Lace	120	0.03
Toona ciliata M.Roem	120	0.03
Glochidion sp.	80	0.02
Magnolia lilifera var. *obovata*	80	0.02
Michelia baillonii (Pierre) Finet & Gagnep.	80	0.02
Bridelia retusa (L.) A. Juss.	60	0.01
Gluta usitata (Wall.) Hou	60	0.01
Helicia sp.	60	0.01
Phoebe sp.	60	0.01
Lannea coromandelica (Houtt.) Merr.	40	0.01
Phoebe lanceolata (Nees) Nees	40	0.01
Anthocephalus chinensis (Lmk.) A.	20	0.00
Elaeocarpus sp.	20	0.00
Eucalyptus camaldulensis Dehn.	20	0.00
Musa sp.	20	0.00
Schima wallichii (DC.) Korth.	20	0.00
Stereospermum sp.	20	0.00
Total	4520	1.00

Mature tree

Species group	(n ha¯¹)	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	386	0.53
Schima wallichii (DC.) Korth.	57	0.08
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	56	0.08
Fagaceae spp.	45	0.06
Gluta usitata (Wall.) Hou	24	0.03
Elaeocarpus sp.	22	0.03
Untranslatable (10 species)	22	0.03
Michelia sp.	18	0.02
Averrhoa carambola L.	11	0.02
Ficus semicordata B.-H. ex J. E. Sm.var *semicordata*	11	0.02
Stereospermum sp.	11	0.02
Tristaniopsis burmanica (Griff.) Wils. & Wat.	8	0.01
Alangium chinense (Lour.) Rehd.	6	0.01
Flacourtia indica (Burm. f.) Merr.	6	0.01
Spondias pinnata (L.f.) Kurtz	6	0.01
Albizia sp.	5	0.01
Bridelia retusa (L.) A. Juss.	5	0.01
Glochidion sphaerogynum (M.-A.) Kurz	5	0.01
Helicia sp.	5	0.01
Glochidion sp.	3	0.00
Phoebe sp.	3	0.00
Erythrina sp.	2	0.00
Anthocephalus chinensis (Lmk.) A.	2	0.00
Berrya mollis Wall. ex Kurz	2	0.00
Bombax anceps Pierre var. cambodience	2	0.00
Butea monosperma (Lmk.) Taub.	2	0.00
Diospyros glandulosa Lace	2	0.00
Docynia indica (Roxb.) Decne.	2	0.00
Parinari anamensis Hance	2	0.00
Phoebe acuminatissima Lundell	2	0.00
Schoepfia fragrans Wall.	2	0.00
Shorea siamensis Miq.	2	0.00
Total	733	1.00

Table 18. Species list of plantation 7 , with number and relative abundances per hectare.

Seedling		
Species group	**(n ha¯¹)**	**Relative Abundance**
h <30cm	4000	0.80
Untranslatable (2 species)	1000	0.20
Total	5000	1

Sapling		
Species group	**(n ha¯¹)**	**Relative Abundance (%)**
Dichroa febrifuga Lour.	860	0.33
Archidendron clypearia (Jack) Niels. ssp. *clyperia var. clyperia*	620	0.24
Unidentified (3 species)	360	0.14
Schima wallichii (DC.) Korth.	140	0.05
Ficus semicordata B.-H. ex J. E. Sm.var *semicordata*	120	0.05
Lannea coromandelica (Houtt.) Merr.	100	0.04
Fagaceae spp.	80	0.03
Untranslatable (2 species)	100	0.03
Garuga pinnata Roxb.	40	0.02
Magnolia baillonii Pierre	40	0.02
Tristaniopsis burmanica (Griff.) Wils. & Wat.	40	0.02
Glochidion sphaerogynum (M.-A.) Kurz	20	0.01
Litsea cubeba (Lour.) Pers. L. *citrata* Bl.	20	0.01
Mitragyna rotundifolia (Roxb.) O.K.	20	0.01
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	20	0.01
Wrightia sp.	20	0.01
Total	2600	1.00

Mature tree

Species group	(n ha^{-1})	Relative Abundance (%)
Pinus kesiya Roy. ex Gord.	300	0.55
Untranslatable (4 species)	68	0.12
Schima wallichii (DC.) Korth.	40	0.07
Archidendron clypearia (Jack) Niels. ssp. clyperia var	33	0.06
Fagaceae spp.	32	0.06
Elaeocarpus lanceaefolius Roxb.	11	0.02
Litsea glutinosa (Lour.) C.B. Rob. var. *glutinosa*	8	0.01
Tristaniopsis burmanica (Griff.) Wils. & Wat.	6	0.01
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	6	0.01
Styrax benzoides Craib	6	0.01
Vaccinium sprengelii (D. Don) Sleum.	5	0.01
Diospyros glandulosa Lace	5	0.01
Aporosa villosa (Lindl.) Baill.	5	0.01
Albizia odoratissima (L.f.) Bth.	5	0.01
Lannea coromandelica (Houtt.) Merr.	3	0.01
Wrightia sp.	2	0.00
Stereospermum colais (B.-H. ex Dillw.) Mabb.	2	0.00
Sapindus rarak D.C.	2	0.00
Litsea cubeba (Lour.) Pers. L. *citrata* Bl.	2	0.00
Gluta usitata (Wall.) Hou	2	0.00
Garuga pinnata Roxb.	2	0.00
Castanopsis diversifolia (Kurz) King ex Hk. f.	2	0.00
Averrhoa carambola L.	2	0.00
Total	547	1.00

Appendix 2.

Table 19. Species found to have coppicing ability and the relative abundance (%) of each species coppicing in each size class.

Seedlings	**Percentage of seedling sprouts**
Gluta obovata Craib	50.0
Ficus sp.	16.7
Litsea sp.	16.7
Phoebe sp.	16.7
Total	100.0

Saplings	**Percentage of sapling sprouts**
Dichroa febrifuga Lour.	17.4
Fagaceae spp.	15.9
Ternstroemia gymnanthera (Wight & Arn.) Bedd.	11.6
Dipterocarpus obtusifolius Teijsm. ex Miq	10.1
Archidendron clypearia (Jack) Niels. ssp. *clyperia* var. clyperia	8.7
Gluta obovata Craib	5.8
Carpinus viminea Wall. ex Lindl.	4.3
Dipterocarpus tuberculatus Roxb.	2.9
Lannea coromandelica (Houtt.) Merr.	2.9
Ficus semicordata B.-H. ex J. E. Sm.var *semicordata*	2.9
Shorea obtusa Wall. ex Bl.	1.4
Schima wallichii (DC.) Korth.	1.4
Diospyros glandulosa Lace	1.4
Elaeocarpus sp.	1.4
Flacourtia indica (Burm. f.) Merr.	1.4
Magnolia lilifera var. *obovata*	1.4
Michelia baillonii (Pierre) Finet & Gagnep.	1.4
Bridelia retusa (L.) A. Juss.	1.4
Tristaniopsis burmanica (Griff.) Wils. & Wat.	1.4
Phoebe sp.	1.4
Helicia sp.	1.4
Garuga pinnata Roxb.	1.4
Total	100.0