

**Dipterocarpaceae:
Forest Fires and Forest Recovery**

Aldrianto Priadjati

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FOREST FIRES AND FOREST RECOVERY**

Aldrianto Priadjati

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Prof.dr.ir. L. Speelman,
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The Tropenbos-Kalimantan Series presents the results of studies and research activities related to sustainable use and conservation of forest resources in Indonesia. The multi-disciplinary MoF-Tropenbos Kalimantan programme operates within the framework of the international programme of the Tropenbos Foundation. Executing Indonesian agency is the Forest Research Institute, Samarinda, governed by the Forestry Research and Development Agency (FORDA). Other Indonesian executing agencies include the Association of Indonesian Concession Holders (APHI) and PT INHUTANI I.



Wageningen University, the Netherlands

Ministry of Forestry, Indonesia



PREFACE

The scientific results in this book were obtained in the framework of the International MoF-Tropenbos Kalimantan Programme, an international collaborative project of the Tropenbos Foundation, the Indonesian Ministry of Forestry and several other Indonesian institutions, like the Forest Research Institute of Samarinda (FRI) and the Association of Indonesian Forest Concession Holders (APHI).

My involvement in this project began when I was appointed as a counterpart and head of a research group on vegetative propagation and stand establishment, representing the Association of Indonesian Forest Concession Holders (APHI). My research focused on the vegetative propagation, stand establishment and forest rehabilitation of Dipterocarp species. It was most fortunate that many of the research results could be passed on through seminars, workshops and conferences, and could be implemented through training courses to most of the Indonesian forestry practice.

The plan of my PhD study was developed in the Netherlands in 1995 when I was given the opportunity to discuss a proposal for my doctorate research with Prof.dr.ir. R.A.A. Oldeman. I had to take some qualifying examinations and in 1996 I was accepted into the PhD sandwich programme of Wageningen University. Prof.dr.ir. Ishemat Soerianegara from Bogor Agricultural University (IPB) acted as my (former) Indonesian promotor. Unfortunately, during the period of the research, he passed away. Prof.dr.ir. Joedoro Soedarsono from Gadjah Mada University then took over as my Indonesian promotor and Prof.dr. Steph B.J. Menken from the University van Amsterdam (UvA) also acted as my promotor.

During the period of this study, some constraints had to be faced, ranging from limited equipment, financial problems, management reorganisation to catastrophic forest fires. On top of that, all the experimental plots in the fields disappeared during forest fires in 1997 and 1998. Two years of setting-up and monitoring these plots were blown away with the fires. As a consequence, I had to start again to make some adjustments to my PhD ideas in view of the new situation. Promotors, supervisors and friends were very helpful and supportive to overcome this period successfully. Some institutions like the UvA, the Faculty of Forestry Gadjah Mada University, Gibbon Foundation and LIPI Cibinong gave their best for the continuation of my study.

Just before I finished my manuscript, I received the news from my staff in Kalimantan that again my plots were burned and completely destroyed. This unfortunate fact emphasises the problems of forest fires. It is expected that the results of this study will contribute to the restoration of degraded forests, especially in Indonesia or other, related areas.

Wageningen, July 2002

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To my mother Rukimah,
My brother, sisters and their families

And

To the memory of
my late father, Praptono (1934 – 1989)
and my late brother, Arman Riyanto Prasetyo (1960 – 1996)

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CHAPTER 1

GENERAL INTRODUCTION

1.1 DEFORESTATION IN INDONESIA

Tropical forests are considered to belong to areas richest in diverse species of plants (Heywood and Watson, 1995). Among the sub-regions in Asia-Pacific, South East Asia is considered the richest in plant diversity, and particularly those found in its tropical forests. Within S.E. Asia, Indonesia has the largest areas of forest (Sastrapradja, 2001). In fact, Indonesia is listed amongst the seven countries (Russia, Brazil, Canada, the United States, China, Indonesia, and the Congo) wherein 60% of the remaining world's forests are found. Of those seven countries the forests of Brazil, Indonesia, and Congo are of a tropical nature (Abramowitz, 1998). An estimated 25.000 species of flowering plants (van Steenis, 1971; Whitmore, 1990) including more than 500 dipterocarp species (Jacobs, 1981), the most valuable commercial timber trees, are indigenous to Indonesian forests.

Forests have been playing an important role in Indonesia since the early 1970s, after the Government enacted the Foreign and Domestic Investment Law in 1967 and 1968. The forests belonged and still belong to the main natural resources for the economic growth of the country. After natural gas and oil, forest products (mainly plywood, sawn timber, and rattan) are the second highest foreign exchange earners for Indonesia. In 1995, Indonesia exported for US\$ 4.728 million in forest products (Abramowitz, 1998). Compared to the 1970 figures, Indonesia increased its forest products export by 1267%, an amazing jump that has worried most conservationists (Sastrapradja, 2001). The natural forest is now receiving more attention from the Government since environmental issues appeared on the agenda in the last decade of the last century (cite Bandung Declaration, Global Forest Conference 1993, a follow-up of Rio 1992).

The Indonesian forest area covers 141.2 million hectares, 92.4 million of which are planned to be retained as forested area. These forests are managed in the form of concessions given out to private and state-owned companies. There are 483 concessions (HPH) in Indonesia, covering an area of 55.6 million hectares (Ardjoewono, 1995). During the last 25 years of forest exploitation in concessions, an area of about 40 million hectares throughout Indonesia has been logged-over (Yasman, 1998). The condition of the logged-over areas varies from alang-alang (*Imperata cylindrica*) grassland, belukar (secondary shrub) to high potential logged-over forest, depending on the way the logging operations were carried out and the format of land use after logging.

Logging activities by mechanical systems using heavy machinery in production forests have ecological effects, especially on the microclimate and hydrological conditions (Soerianegara, 1992; Rukmantara 1998). After logging, poles and saplings, resulting from regeneration by natural seedlings, appear to be few. Planting attempts in this field showed that many seedlings died because of hot soil (up to 45°C), lethal for the development of Dipterocarp ectomycorrhizae (Smits, 1983a, 1994; Noor and Smits, 1988). Such seedlings can not develop their symbiotic root system to absorb water swiftly. The mortality rate depends not only on their capability to survive in new environments, but also on water availability in the soils. Water indeed directly or indirectly controls most processes within the plant body (Rossignol *et al.*, 1998).

Forest degradation is one of the major issues reducing the environmental functions of forests. Causes of forest degradation are multiple, complicated and varying from place to place. The main causes of forest degradation are over-exploitation of forests, rapid population increases and urbanisation, industrialisation, agricultural exploitation and wildfire (Mori *et al.*, 2000; Lee, 2001). Based on data from the World Bank (2000) and Kartodihardjo and Supriono (2000), the deforestation rate between 1984 and 1997 in Indonesia was 1.67 million hectares per year. The main cause of deforestation is forest conversion. Production forests also decreased, but on a par with the increase of protected forest areas, whereas the area of conservation forest remained the same. Kartodihardjo and Supriono (2000) add that forest degradation is one of the important factors that must be included in the causes of a decreasing forest area. They assume that the forest degradation rate is around 830 thousand hectares each year so that damaged and disappeared forests together total 2.5 million hectares per year.

The deforestation rate in East Kalimantan is similar to the national one, only on a smaller scale. Within the period 1983 to 1996, the forest area decreased by up to 1.13 million hectares (approx. 90 thousand hectares/year [9.10^4 ha.y^{-1}]). This amount varies among the districts. In the Berau district, for example, between 1997 and 2000 the deforestation rates increased by 42.5 thousand hectares per year [$425.10^2 \text{ ha.y}^{-1}$] (Steenis, 2001). Shimokawa (1988) and Schindele *et al.* (1989) explained the impact of logging and fires on soils. Within ten years after logging or four years after a fire, the erosion rates increased by 10 times (2.3 to 4.65 mm/year of soil thickness lost), in contrast to the erosion rates in primary forests, which are very low (0.13 to 0.35 mm/year lost in topsoil).

1.2 FOREST FIRES

The opening up of lowland forests by logging, land conversion to timber estate and the continuing encroachment of human settlements starting at the forest edges lead to a situation that makes secondary and primary forests increasingly drier and

susceptible to forest fires (Slik, 2001; Indrabudi 2002). Clear-cutting, illegal logging and shifting agriculture resulted in large areas of grassland and secondary forest (Kartawinata and Vayda, 1984; MacKinnon *et al.*, 1996). These areas, especially grasslands, burn easily during dry periods.

Box 1: Fire classification (after Brown and Davis, 1973)

Ground fire

A ground fire consumes all organic material beneath the surface litter of the forest floor. A ground fire may and often does follow a surface fire, depending on the moisture content of the organic layer; and spreading within rather than on top of the organic mantle. It is characterized by a slowly smouldering edge with no flames and little smoke. Ground fires are often hard to detect and are the least spectacular and slowest moving. However, they are the most destructive of all fires, and the most difficult to control.

Surface fire

A surface fire is a fire that burns surface litter, other loose debris on the forest floor, and small vegetation. This is the most common type of fire in timber stands of all species. It may be a mild, low energy fire in grass and litter, or it may be a very hot, fast moving fire where slash, flammable understory shrubs, or other abundant sources of fuel prevail. A surface fire may and often does burn up into the taller vegetation and tree crowns as it progresses.

Crown fire

A crown fire is a fire that advances from top to top of trees or shrubs more or less independently of both the surface-fire and the height of the crown canopy. In dense forest stands on steep slopes or on level ground, with a brisk wind, the crown fire may race ahead of the supporting surface fire. This is the most spectacular kind of forest fire. A crown fire does not necessarily run ahead of the surface fire but can also lag behind.

By definition, a forest fire is any wild-land fire not prescribed for the area by an authorized plan. A more descriptive definition is “uncontained and freely spreading combustion, which consumes the natural fuels of a forest, that is duff, litter, grass, dead branch wood, snags, logs, stumps, weeds, brush, foliage, and to a limited degree, green trees” (Brown and Davis, 1973). Fires in forests are caused by a

combination of three elements: oxygen, heat and fuel. There are many kinds of fire sources, e.g. fires used for land preparation at timber estates and shifting agriculture, fires due to logging or a natural fire source (the long-lasting fires of coal (lignite) seams).

A forest fire is essentially unconfined and free to spread. One of the characteristics of the forest fires in Indonesia is that the fire sources usually are distributed over a wide area simultaneously (Mori, 2000). A very useful synonym, increasingly used, is 'free-burning'. A 'free-burning fire' is a fire free to respond to its non-human environment. Natural forest fire dynamics are partly driven by chance factors (Brünig, 1969; Oldeman, 1990). Combinations of natural fuels, weather, and topography, influence fire behaviour. A 'free-burning fire' may long remain only a smouldering spot, or it may quickly develop into a very big fire. A useful and accepted classification of fires is based on the degree to which fuels from mineral soil up to treetops are involved in combustion (Box 1). This classification distinguishes all fires as ground, surface, or crown fires (Brown and Davis, 1973). In actual fire situations, these three kinds of fire may occur simultaneously and in all kinds of combinations and sequences. Surface fires are by far the most common, and nearly all fires start as such. A surface fire may spread into the crowns and develop into a sweeping crown fire. A crown fire may drop to the ground and become a surface fire. Similarly, a surface fire may develop into a ground fire that may vex control forces for days or weeks.

In East Kalimantan, most forest fires from the El Niño Southern-Oscillation (ENSO) in 1982-83 and 1997-98 were surface fires and resulted from the interaction between severe droughts and the creation of numerous fire sources connected closely with human activities (Mori, 2000, 2001; Toma *et al.*, 2001).

Indonesia has experienced 6 severe droughts since the late nineteenth century: 1887-88, 1903-04, 1914-15, 1941-42, 1972, and 1982-83 (Leighton, 1984; Goldammer and Seibert, 1990). Large forest fires occurred from June 1982 to April 1983 and were linked to a particularly pronounced ENSO event (Goldammer *et al.*, 1996). During the ENSO event, there were two rainless periods from July to October in 1982 and January to April in 1983, with large wild fires occurring during these rainless periods (Toma *et al.*, 2000a) and low amounts of precipitation in November and December 1982 (Oldeman, pers. comm., 2001). These fires occurred in East Kalimantan damaging approx. 3.5 million hectares of land and forest (Smits *et al.*, 1987; MacKinnon *et al.*, 1996; Nykvist, 1996; Dennis, 1998; Hoffmann *et al.*, 1999). Lennertz and Panzer (1984) estimated that 0.8 million ha of the total area was primary rain forest, 1.4 million ha logged-over forest, and 0.55 million ha peat swamp biome. Since then, fires occurred regularly in the area (1987, 1991, 1994 and 1997-98), with the largest and most destructive ones in 1997-98 (Fatawi and Mori, 2000; Mori, 2000).

Induced by the ENSO climatic phenomenon in 1997-98, widespread and drought-linked forest fires raged in South East Asia. This region suffered its worst drought in five decades. This ENSO event lasted longer and was more pronounced than the ENSO event in 1982-83. Two rainless periods, July to October 1997 and January to April 1998, occurred in East Kalimantan during this ENSO event that were quite similar to those during the pronounced ENSO event in 1982-83. Droughts and fires were more intense in the second rainless period compared to those in the first period. Unusual high atmospheric temperatures and a low air humidity combined with relatively strong winds from the north-north-east were recorded during the drought in the second year (Mori, 2000; Toma *et al.*, 2000a).

After moderate damage by the fires in 1997, huge areas were burnt between January and May 1998 (Dennis, 1998). These fires caused extremely severe smog (smoke and fog). Due to air pollutants suspended in this smoky atmosphere, the health of millions of humans suffered serious damage. The impact on normal life was also strong, because of air pollution, chaos in naval and road transportation, accidents costing human lives, economic losses, and food shortages (Buongiorno *et al.*, 1997). These extensive fires ravaged millions of hectares, both in forest and non-forest areas in Indonesia, especially in Kalimantan and Sumatra. The area most severely damaged was East Kalimantan (Hoffmann *et al.*, 1999). The coastal area of East Kalimantan is known to be drier than other parts of the island of Borneo (Whitmore, 1984; MacKinnon *et al.*, 1996). Hoffmann *et al.* (1999) and von Gemmingen (2001) estimated that the latter fires alone burned around 5.2 million hectares of East Kalimantan forest, including some of the last residues of primary forest left, or about 25% of the entire province (see Table 1.1 and Appendix 1). About 2.3 million hectares belonged to concessionaires, 380 thousand hectares to estates, 440 thousand hectares were conservation areas and 1.1 million hectares were under other forms of use. The damage classification in Table 1.1 is based on 3 damage classes which generally correspond with the damage classification later released in the Indonesian Government regulation (SE 1200/VI-PHH/1999).

Table 1.1 Damage classes and total burned areas of East Kalimantan in 1997-98 (after Hoffmann *et al.*, 1999 and von Gemmingen, 2001).

Damage class caused by fire	Burned area	
	(ha)	(%)
25-50% damage	1.249.564	23.9
50-80% damage	2.195.493	42.1
> 80% damage, but biomass still existing (mostly peat swamp)	618.364	11.9
> 80% damage, biomass mostly burned (secondary shrub, alang-alang grassland)	1.152.347	22.1
Total	5.215.768	100.0

1.3 *Shorea leprosula* Miq.

Members of the Dipterocarpaceae family predominate in the humid lowland rain forests in the region of South East Asia. This family is the most important group of providers of timber trees in the region, because it supports around 50% of the worlds' total export of tropical timber (ITTO, 1990). In 1990, the tropical rain forests dominated by Dipterocarpaceae covered approx. 210 million hectares in South East Asia, extending from Myanmar, Thailand, through Malaysian peninsular, to the Indonesian archipelago and Papua New Guinea (Smits, 1992).

The family of the Dipterocarpaceae which is naturally spread throughout the islands of Indonesia, consists of at least 8 genera (Symington, 1974) and about 500 species (Jacobs, 1981), 273 of which and 20 subspecies are found in the island of Borneo (Newman *et al.*, 2000). Among these, 155 are endemic (Ashton, 1982). *Shorea* is the most important dipterocarp genus, both in terms of species (well over 100) and economically (Haggarsson *et al.*, 1994; Smits, 1994). *Shorea leprosula* is one of the fastest growing species of dipterocarp up to about its twentieth year, but it is later surpassed by other dipterocarp species. This species regenerates profusely. *S. leprosula* can grow in a wide variety of site conditions with flat topography found throughout hilly areas, frequently found on well drained soil, on deep clay soils or on swampy soil in the mixed Dipterocarp forests of the lowlands and hills up to 700 m above sea level, but it is a strongly light-demanding species (Meijer and Wood, 1964; Masano, 1985; Yasman, 1995; Omon, 2002). There are probably few areas in its geographical region in which it does not occur, and locally, especially in slightly swampy forest, it is the most abundant form of *S. leprosula* (Meijer and Wood, 1964; Symington, 1974; Ashton, 1982).

The species is widely distributed in South East Asian rain forests, from peninsular Thailand (Changwat Pattani) throughout the Malay Peninsula (excluding the seasonal areas), Sumatra, Bangka and Belitung, to Borneo (Meijer and Wood, 1964; Ashton, 1982). It is most abundant in the islands of Sumatra and Borneo (Meijer and Wood, 1964; Masano, 1985). No *S. leprosula* are found north of 7°N (Fig. 1.1). lat. in the Malay Peninsular. According to older sources, the distribution is closely related to the absence of a distinct and prolonged dry season (Foxworthy, 1932).

The trade name for *S. leprosula* is red meranti or meranti merah. The vernacular names for *S. leprosula* are Meranti tembaga (Brunei, Sarawak), m. betul, m. bunga, m. lampong, m. temak, m. hijau, m. sabut, m. kait kait (Malaya, Sumatera), m. sepang (Palembang), Lampong (Kutai), Perawan lop (Sarawak), seraya tembaga (Sabah), Kontoi (Melawi), awang, a. punuk, banti, barit, bekunsu, belaitok, belito, buluan, damar, d. busak, d. gunung, d. kepala tupai, d. kumbang, d. lahung, d. laki, d. marambung, d. merah, d. payau, d. ranggas, lampong (Kutai), Lentang (Sampit) mengkorau (Dayak Benuag), perawan lop (Sarawak), and many others (Ashton, 1982).

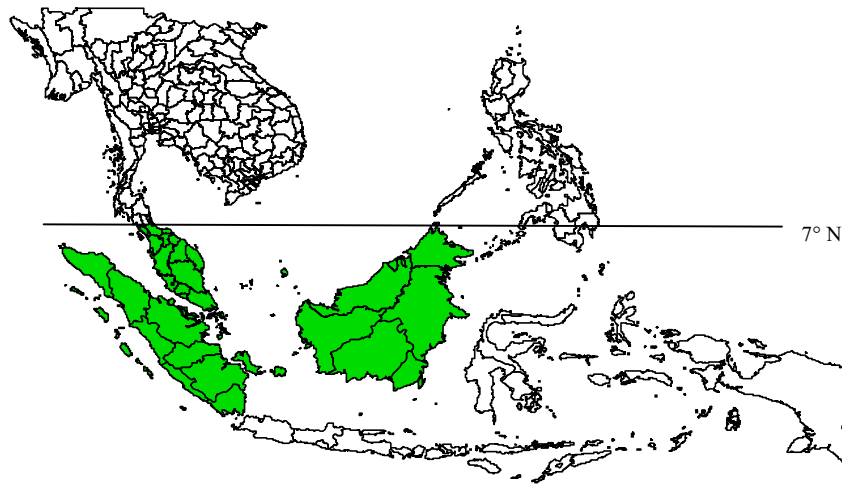


Figure 1.1 Geographical distribution of *Shorea leprosula* Miq. No national borders shown. The Thai sites are in the southernmost provinces of Thailand.

1.3.1 Tree architecture of *Shorea leprosula* Miq.: The model and its reiteration

For the design of silvicultural systems it is necessary to recognize the behaviour of trees (Oldeman and Sieben-Binnkamp, 1994). The best way to study the development of a tree species under certain circumstances is to study several individual trees during their whole lifetime. In this way one can develop a growth-model of the tree. However, this is difficult to do, because trees live longer than people. For that reason, the development of a tree species needs to be studied phase by phase (Hallé and Oldeman, 1970; 1975).

As a practical alternative, in order to understand the growth of a species, one may start by looking at the initial growth phase in a particular environment. A diagram of the sequence of developmental phases gives an indication of the young tree's autoecological interactions. The meaning of these 'silvicultural diagrams' is to observe and understand important influences on seedling and later tree behaviour. Schreuel and Stegeman (1986) constructed an example of such a diagram for certain legume trees in an agroforestry environment in Central Java.

To study a tree in its environment, it is important to know how an individual tree behaves and in which way it responds to changing external factors. For this reason, next to the taxonomical data, the architectural model and its reiteration will be described in *S. leprosula*. Hallé *et al.* (1978, p. 269) define reiteration as: "Any modification of the tree's architecture not inherent in the definition of its model and which is occasioned by damage, environmental stress or supra-optimal conditions". An architectural tree model, according to these authors (Hallé *et al.*, 1978, p. 74-75) is "the tree growth program which determines the successive architectural phases", where architecture is "the visible, morphological expression of the genetic blueprint of a tree at any one

time”. Hence, it gives rise to a differentiation sequence from juvenility to maturity. Oldeman (1990, p. 39, citing Edelin 1984, who authored the concept) defines metamorphosis as: “a programmed period of tree development, in which the repetition of the patterns displayed in early branching can be found back in each of the sub-crowns that are building the whole crown of the tree”. Metamorphosis, therefore, is a process that entails the inner reprogramming of an expanding tree crown, while the outer layer obtains its final properties in an early period of tree development (Oldeman, 1990).

During its development, a tree is exposed to environmental stress, so it seldom develops completely in accordance with its architectural model (Oldeman, 1974a-b, 1990, 1992; Edelin, 1977, 1984; Rossignol *et al.*, 1998). The tree responds to this situation e.g. by activating resting buds or by reiteration. Basically two forms of reiteration can be distinguished: traumatic reiteration and adaptive reiteration. Traumatic reiteration very commonly occurs when the apical meristem is destroyed and one or more lateral buds take over. Adaptive reiteration is a development strategy of the tree subjected to environmental stress. In individual trees, Hallé *et al.* (1978) speak of ‘adjustment’ of an individual tree instead of ‘adaptation’, the latter involving genetic change, i.e. population effects.

Architectural analysis of Dipterocarpaceae

Among the 23 architectural models that have been defined for trees so far (Hallé *et al.*, 1978), the 2 models shown in Figure 1.2a-b and Table 1.3 are important for Dipterocarpaceae species: i.e. those of Roux and Massart (Edelin, 1984). Roux’s architectural model (Fig. 1.2a) is considered the most frequent model among the Dipterocarpaceae. The architecture of this model is determined by “a monopodial orthotropic trunk meristem, which shows continuous growth; branches are plagiotropic (but never by apposition) and inserted continuously (rarely diffusely). Leaf arrangement is spiral on the trunk but in contrast most often distichous on the branches. Flowering is variable, but mainly lateral on the branches and does not influence the architecture” (Table 1.2) (Hallé *et al.*, 1978, p. 200). Besides Roux’s model, four other architectural models were distinguished in Dipterocarpaceae.

Leano (1977) identified the first architectural models of Massart (Fig. 1.2b) and Roux in the Dipterocarp family. She studied the importance of tree architecture for Dipterocarp taxonomy and analysed the distribution of the architectural models among the species. Massart’s model is determined by “an orthotropic, monopodial trunk with rhythmic growth, and which consequently produces regular tiers of branches at levels established by the growth of the trunk meristem. Branches are plagiotropic either by leaf arrangement or symmetry, but never by apposition. The position of flowers is not significant in the definition of the model” (Hallé *et al.*, 1978, p. 191). Hallé (1979) identified a third model within the family, the model of Rauh (Fig. 1.2c). Rauh’s model is determined by “a monopodial trunk, which grows rhythmically and so develops tiers of branches, the branches themselves

morphogenetically identical with the trunk. Flowers are always lateral and without effect on the growth of the shoot system” (Hallé *et al.*, 1978, p. 221). During the second Dipterocarp Round Table Conference in 1981 the existence of the Troll model (Fig. 1.2d) was confirmed, which characterized the African species *Monotes kerstingii*. Kostermann (*ex* Suselo, 1983) found a fifth architectural model, the model of Corner (Fig. 1.2e), in Sri Lanka with the species *Stemonoporus moonii*.

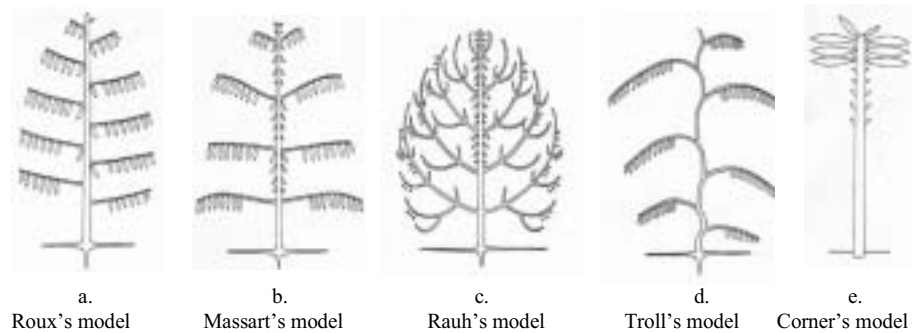


Figure 1.2 Architectural models of Dipterocarp species.

Table 1.2 The characteristics of the 3 (three) main architectural models of Dipterocarp species.

Model	Growth	Ramification	Trunk	Branches	Flowering
Roux	Continuous	Continuous	Orthotropic	Plagiotropic	Lateral or Terminal
Massart	Rhythmic	Rhythmic	Orthotropic	Plagiotropic	Lateral or Terminal
Rauh	Rhythmic	Rhythmic	Orthotropic	Orthotropic	Lateral

Table 1.3 Architectural models of Dipterocarp species.

Species	Architectural model	References
<i>Dipterocarpus costulatus</i> v. Sloot.	Massart	Hallé <i>et al.</i> (1978)
<i>Dipterocarpus trinervis</i> Bl.	Massart	Hallé <i>et al.</i> (1978)
<i>Dipterocarpus zeylanicus</i> Thw.	Roux	Hallé <i>et al.</i> (1978)
<i>Dryobalanops aromatica</i> Gaertn.	Roux	Hallé <i>et al.</i> (1978), Suselo (1983); Edelin (1984)
<i>Dryobalanops lanceolata</i> Burch.	Roux	Hallé <i>et al.</i> (1978)
<i>Hopea acuminata</i> Merr.	Roux (absence of reiteration)	Suselo (1983)
<i>Hopea odorata</i> Roxb.	Roux	Hallé and Oldeman (1970); Hallé <i>et al.</i> (1978)
<i>Monotes kerstingii</i>	Troll	Kostermans <i>ex</i> Suselo (1983)
<i>Shorea foxworthii</i> Sym.	Roux	Hallé <i>et al.</i> (1978)
<i>Shorea leprosula</i> Miq.	Roux (apical reiteration)	Hallé (1979), Suselo (1983), Edelin (1984)
<i>Shorea macrophylla</i>	Roux (apical reiteration)	Bujadoux and Munsch (1981)
<i>Shorea ovalis</i> (Korth.) Blume	Massart	Hallé <i>et al.</i> (1978)
<i>Shorea pinanga</i> Scheff.	Roux	Hallé <i>et al.</i> (1978)
<i>Shorea stenoptera</i>	Roux	Edelin (1984)
<i>Stemonoporus moonii</i>	Corner	Kostermans <i>ex</i> Suselo (1983)

Tree architecture of *Shorea leprosula* Miq.

Edelin (1984) described *S. leprosula*'s basic architecture, according to Roux's model, and he observed three reiteration types, which are (1) absence of reiteration; (2) lateral reiteration and (3) apical reiteration. This means that a limited number of plagiotropic branches are transformed into vigorously growing orthotropic branches. According to Edelin (1984, pp. 83,86,88,90,92 – uneven pages carry illustrations), the seedling of *S. leprosula* (Fig. 1.3a) comprises a monopodial, orthotropic trunk with leaves arranged in a spiral. Every leaf axil bears one unique bud, latent and potentially orthotropic.

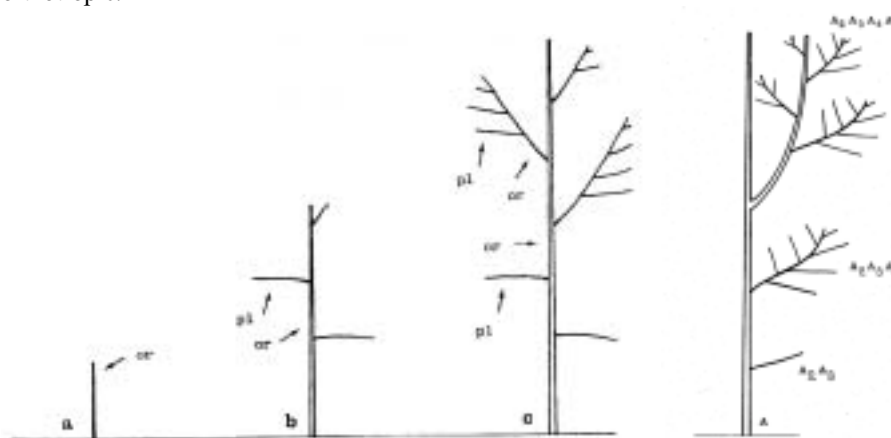


Figure 1.3 Differentiation sequence in the branched tree model of *Shorea leprosula* (after Edelin, 1984). or: orthotropic, pl: plagiotropic, A: axis

When branching develops (Fig. 1.4a), the sylleptic lateral branches are plagiotropic with leaves arranged in two rows. Not far from their base, these axes bear two sub-opposed and rapidly deciduous prophylls. Their bracts have supernumerary buds in their axils, with orthotropic potential to the left of the sylleptic branch. In this growth phase, the lateral axes emit some leaves before arresting their development definitively.

Table 1.4 The general organisation of the axes of *S. leprosula* (after Edelin, 1984).

Axes no.	A ₁	A ₂	A ₃	A ₄
Growth	Orthotropic, vertical	Orthotropic, vertical	Plagiotropic, horizontal	Plagiotropic, horizontal
Branching	Rhythmic	Rhythmic	Rhythmic	Rhythmic
	Continuous	Continuous	Continuous	No branching
Leaf arrangement	Spiral	Spiral	Distichous	Distichous
Growth	Indefinite	Definite mean term	Definite short term	Definite short term
	(deciduous)	(deciduous)	(deciduous)*	(deciduous)*

Note: * means that A₃ and A₄ are simultaneously deciduous

Taking height, the trunk remains monopodial and orthotropic, and keeps branching continuously while its plagiotropic distichous branches grow ever longer. These branches are branched and the twigs A_3 are produced diffusely to the right and the left side of the branches A_2 , a feather-like architecture. These twigs are plagiotropic with the leaves in two rows (distichous) and develop in the plane of the branch. At their base, they have two sub-opposed and rapidly deciduous prophylls, and the assimilating leaves all have axillary buds. These may remain resting, but often they immediately show a beginning of extension growth before drying out and falling off (syllepsis).

When the tree reaches a height of 10 to 20 m, its architecture is modified. Then its crown is heterogeneous, a mixture of plagiotropic and orthotropic axes. The first ones, except for their size, are similar to the plagiotropic branches described above. The most developed among them, which persist longer on the trunk, frequently possess axes A_4 . The orthotropic axes include a monopodial axis A_2 with leaves in a spiral and branch continuously. The monopodial A_2 laterally bears plagiotropic A_3 twigs, distichous, and diffusely branched. The numerous axes A_4 are plagiotropic too, and their leaves are in two rows (distichous). The branched complexes of axes A_3 and A_4 have a limited growth and are deciduous. Sometimes the axis A_4 succeeds in growing out in reality, but this is a rare event, at least at this development phase of the organism.

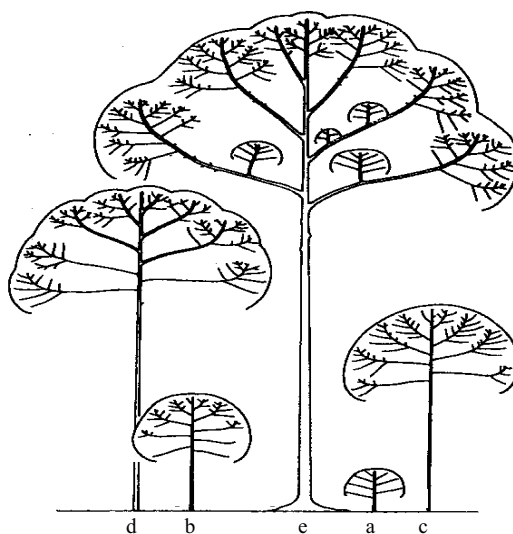


Figure 1.4 Tree architecture of *Shorea leprosula* Miq. a. Model-conforming phase, Roux's model. b. At the top, the first formation of orthotropic branches, bearing plagiotropic branches, Roux's model but small. c. No plagiotropic branches left on the trunk, all are in small Roux's models at the end of the orthotropic branches (first step in metamorphosis) d. process repeated on second-order orthotropic branches (second step in metamorphosis) e. Adult tree with third step in metamorphosis, and reiteration (unprogrammed, opportunistic), Roux's model (after Edelin, 1984 ex Oldeman, 1990)

To be more precise, the structure of the branches differs according to their place in the crown. The lowest ones are orthotropic only at their ends, their basal parts remaining plagiotropic with two rows of distichous leaves. However, this basal portion diminishes gradually and higher branches are orthotropic from the beginning. The direction of growth of the branches, and their symmetry are linked directly to their degree of ramification. Branches $A_2+A_3+A_4$ are orthotropic with spiral symmetry. Branches $A_2 + A_3$ are, as we saw in Fig. 1.3A, plagiotropic and dorsiventral (flat, with a belly and a back, plagiotropic). The transition between these two stages goes together with a progressive increase in the number of axes A_4 which are formed.

The phase that marks the appearance of orthotropic branches is relatively short. When the architectural metamorphosis of the tree is complete, it continues growing and approaches the forest canopy. It then emits more and more ramified branches, on which axes of the 5th order (A_5) start to appear (see Fig. 1.3A and Table 1.4).

This appearance, modest at first, then profuse, is accompanied by a complete reorganisation of the branches concerned. The axes A_2 lose their capacity to self-prune; their diameter gets stronger and their vertical orientation becomes marked. The axes A_3 , plagiotropic till then, rise also to become orthotropic with leaves in a spiral and radial symmetry, whereas their ramification ceases to be diffuse and becomes continuous. The twigs A_4 and A_5 always remain plagiotropic and constitute deciduous branch complexes. These branches are architecturally similar to the tree in its preceding growth phase; they correspond to reiterated complexes (r_1). Branching themselves once more, they build the master branches of a second order, which functionally are small secondary trunks (r_2) bearing a reiterated crown, amplifying and reinforcing the composite crown of the whole tree.

Proleptic reiterated complexes (rp) then develop on this infrastructure. Formed by an orthotropic trunk bearing plagiotropic branches when young, they obtain orthotropic branches when they become larger. Their developmental sequence, hence, is identical to that of the initial tree, but the phase of growth they may reach is ignored. Those observed were still quite young (rp) and showed a great architectural disparity (rp), perhaps linked to their date and the ecological conditions of their initiation and growth.

Tree architecture is adaptive. This makes it significant for forest management, because each management measure provokes architectural responses in the trees. The initial model is a response to the half-shaded undergrowth where saplings live. Metamorphosis is the response to increasing diffuse light, water and nutrients required by a rapidly expanding crown with flexible and efficient photosynthesis. This requires many plagiotropic axes. Finally, reiteration is the opportunistic response to the vicissitudes of life in the forest canopy, under the raw impact of the macroclimate. In terms of wood production, these processes should be guided to stimulate the formation of a long, thick free trunk and the avoidance of forks, knots or wavy trunks in order to optimise wood quality (Oldeman and Sieben-Binnenkamp 1994).

1.3.2 The taxonomical characteristics of *Shorea leprosula* Miq.

Seedling (Fig. 1.5A)

A *S. leprosula* seedling has an epigeal germination, cotyledons equal and spreading vertically with first leaves opposite (Foxworthy, 1932). The seedlings are very easy to recognize because they have domatia at the back of the leaf along the main nerve but these will become less abundant when the seedling reaches pole size. Furthermore, Meijer and Wood (1964), Yasman (1994), Newman *et al.* (2000) and Sidiyasa (2001) describe the seedling of *S. leprosula* as follows: **Main stem**, twigs and petioles glabrous or with soft hairs; **Stipules** 0.5 by 0.1 to 0.2 mm, oblong, reddish green, *c.* 4-nerved, stellate pubescent, persistent; petiole 0.7 cm; **Leaves** 4 to 5.6 by 9 to 12.7 cm, oblong or oblong lanceolate including 0.7 cm long gradually tapering acumens, glabrous above except for minute stellate hairs on midrib and nerve bases, 12 to 15 nerves, glabrous below except for fine, small stellate hairs on the midrib, on upper surface margin of midrib swollen by the domatia, center sunken, below elevated and densely longitudinally channeled; base rounded or almost truncate; nerves sharply turned up at the margin; petiole 0.3 in. long; **Domatia** present on lower surface, arranged continuously along the main nerve (midrib) or sometimes up to half the base of the secondary nerve when young.



Figure 1.5 Seedling (A) and sapling (B) of *Shorea leprosula* Miq.

Sapling (Fig. 1.5B)

Quite young trees adopt a characteristic corymbose method of branching, which gives the crown a flattened appearance. Leaves with pale domatia, often in a continuous line and with exterior glands, are common along the midrib and bases of the nerves, and such immature leaves may be present on quite large trees. Domatia will become less abundant when the seedling reaches pole size (Yasman, 1994; Newman *et al.*, 2000).

Tree.

According to Meijer and Wood (1964), Ashton (1982), Keßler and Sidiyasa (1994) and Newman *et al.* (2000) the taxonomical characteristics of adult trees are as follows: Trees up to 60 m tall, approx. 1 m in diameter. **Buttresses** prominent, but usually not very large, approx. 1.5 m tall and long. **Crown** pale coppery yellow-brown from below, wide, umbrella-shaped, with a persistent leader. **Damar** yellow. **Bark** greyish brown, shallowly fissured, V-shaped. Outer bark dull purple brown, rather hard, brittle, inner bark fibrous, dull brown or yellowish brown grading to pale at the cambium, sapwood pale or cream, resinous, heartwood dark red or light red-brown. **Twigs** c. 1.5 mm Ø apical, slender, becoming glabrous, terete, ridged when young, much branched, smooth. **Stipules** c. 10 mm long, c. 3.5 mm wide, scars short, horizontal, obscure, oblong to broadly hastate, obtuse, fugaceous, falling off early. **Petioles** 0.9-2.3 cm long, with indumentum of dense, yellow-brown, short hairs and scales together. **Bud** 2 to 3 by 3 to 5 mm, compressed, broadly ovoid, sub-acute. **Leaves** elliptic to ovate, 8 to 14 cm long, 3.5 to 5.5 cm wide, cream scaly, thinly leathery, base obtuse or broadly cuneate, apex acuminate, up to 8 mm long, secondary veins 12 to 15 pairs, slender, curved towards margin, set at c. 40° to 55°; tertiary veins densely ladder-like (scalariform), very slender, obscure except in young trees; midrib narrow and depressed above and prominent beneath, in young trees beset from the base up more or less its length with lines of small, pale, domatia confluent, at least in young trees present. **Petiole** 1.0 to 1.5 cm long. **Panicle** to 14 cm long; terminal or axillary, terete, lax, slender, sparsely or densely evenly persistently pale brown to cream pubescent; regularly single, rarely double, branched, branchlets short, bearing approx. 12 secund flowers; **Bracteoles** to 3 by 2 mm, elliptic, obtuse, shortly pubescent, fugaceous. **Flower bud** to 6 by 3 mm, fusiform, sub-acute. **Calyx** densely pale brown pubescent outside, glabrous within; 3 outer lobes narrowly ovate, obtuse; 2 inner lobes broadly ovate, shorter, shortly acuminate. **Petals** pale yellow, narrowly oblong, densely pale yellowish grey pubescent on parts exposed in bud. **Stamens** 15, the inner 5 twice as long as the others and reaching half the length of the style; filaments long, tapering gradually; anthers subglobose; appendage to connective short, becoming reflexed. **Ovary** and **stylopodium** ovoid, glabrous; style filiform, twice as long as ovary and stylopodium, glabrous. **Fruit** pedicel to 2 mm long, calyx sparsely pubescent, 3 longer lobes up to 10 cm long, approx. 2 cm wide, spatula-like (spatulate), obtuse, approx. 5 mm broad above the to 8 by 6 mm thickened elliptic shallowly saccate base; 2 shorter lobes up to 5.5 cm long, approx. 0.3 cm wide, unequal, similarly saccate at base. **Nut** approx. 2 cm long, approx. 1.3 cm in diameter, ovoid, densely pale buff pubescent, style remnant approx. 2 mm long, tapering, acute.

Brandis included *S. leprosula* in the *Mutica* section of the genus, according to the number of stamens, the shape of the anthers, the appendage of the connective, the style and stylopodium and the configuration of the fruiting calyx. It flowers only once in six years (Ridley, 1901 p. 56, cited by Foxworthy, 1932) and the period from flowering to seed fall is about ten weeks. *S. leprosula* may contract a pest caused by insects and often shows exudations of resin where an insect has entered. Various forms of galls are found on *S. leprosula* leaves and young twigs (Foxworthy, 1932).

1.4 SIGNIFICANCE OF THE STUDY

Since forest fires are important issues in the complex ecosystem of a dipterocarp forest (Lee, 2001), their role in large-scale forest dynamics may be much more important than was previously realised. Only a few studies (cf. Oldeman, 1990; Mori, 2000; 2001; van Nieuwstadt, 2002) have reported on the role of forest fires in the natural regeneration and forest restoration after forest fires. The present study therefore has the following aims:

1. To investigate the role of forest fires in the natural regeneration of a dipterocarp forest ecosystem, especially the relationship between natural regeneration, environmental conditions and time;
2. To examine the role of forest restoration after fires in relationship with the population genetics of planting material, light, soil and ectomycorrhizae.

A better silvological understanding (Oldeman, 1990) of complex dipterocarp forest ecosystems will in turn lead to recommendations for a better management of forest dynamics by the application of correct silvicultural guidelines.

1.5 OUTLINE OF THE BOOK

The present book is a synthesis of several years of work in forest restoration and deals with forest fires. It aims to provide a comprehensive ecological understanding of fires, the natural regeneration after fires, and the restoration of the forest by *S. leprosula*. The book consists of seven chapters.

Chapter 1 the general introduction, provides an overview of the status of forests in Indonesia, forest fires and droughts during 1997 and 1998, and comprehensive information about *S. leprosula*, including its architectural model.

In Chapter 2 the focus is on the development of forest biodiversity after fires, in terms of natural regeneration of forest and butterfly communities. The dynamics of the natural regeneration of a tree species and the climatic conditions change in the natural forest after forest fires.

In Chapter 3 the levels of genetic variation, as related to phenotypic variation and relatedness in *S. leprosula* are examined in three Dipterocarp forest sites representative for populations in Kalimantan, Indonesia.

Chapter 4 deals with the preparation of planting material in the nursery. The influence of the origin of seedlings and soil, and the influence on *S. leprosula* of soil types, pasteurisation of media and mycorrhizal inoculation are studied in this chapter.

Chapter 5 examines the influence of light and site conditions on the growth of *S. leprosula* and mycorrhizae. This chapter is closely related to a study on shading by *Peronema canescens* on the growth of *S. leprosula* in Chapter 6. These chapters try to elaborate on the acceleration of succession in mixed plantations composed of pioneer and climax species.

Chapter 7 finally synthesizes the results presented in the preceding chapters, so as to present an integral overview of forest fires and forest restoration in dipterocarp forests. The application of knowledge obtained by the implementation in silvicultural practice for sustainable forest management in Indonesia is also discussed in this chapter.

CHAPTER 2

THE INITIAL IMPACT OF FOREST FIRES ON PLANT AND BUTTERFLY COMMUNITIES IN THE SUNGAI WAIN FOREST RESERVE IN EAST KALIMANTAN, INDONESIA

Doniel F.R. Cleary and Aldrionto Priodjoti

ABSTRACT

The main goal of this study was to analyse the initial response of butterflies and plants, seedling and sapling communities to forest fires and the edge between forests in a burned and in an unburned state caused by these fires. There was a significant impact on the forest microclimate caused by forest fires. The burned forest was characterised by elevated levels of light intensity and heat, and significantly reduced levels of humidity. There was a highly significant variation in sapling and seedling density, diameter, and species richness between burned and unburned forest. Seedling height was significantly greater in unburned than in burned forest. Seedling growth was significantly greater in burned forest. Sapling height was significantly greater in burned than in unburned forest. Compared to unburned forest all saplings shorter than 5 m died. Only 2.5% of saplings survived the fire. There was no significant difference between the growth of saplings in burned and unburned forest. The growth of both saplings and seedlings was completely unaffected by any edge effect in both forest states. The species richness and density of seedlings was significantly lower in burned than in unburned forest. The diverse seedling community of unburned forest was replaced by a species-poor community of pioneers dominated by Euphorbiaceae. The butterfly community in the burned area had high densities of pioneer species associated with disturbed habitats. Burning caused a significant shift in the forest butterfly community.

2.1 INTRODUCTION

In 1997 and 1998 record-breaking fires occurred in areas in Indonesia and Brazil that wrongly used to be considered too moist to burn (Abramovitz and Dunn, 1998). While the moist microclimate of a closed forest naturally limits fires, climatic variability helped by anthropogenic alteration can make fires both possible and likely (Uhl and Kauffman, 1990). Forests are initially affected by human activities, such as logging, or slashing and burning agriculture, which create areas especially susceptible to burning due to local or regional desiccation of the forest soil and accumulation of burnable debris. During severe droughts a fire can also reach an undisturbed, dried-out virgin forest where it destroys most of the vegetation in its

poth. The resultant mosaic is a combination of severely perturbed burned vegetation and unburned forest eco-units. With each new burning the area of burned forest increases and the total forest biomass decreases. During the 1997-98 forest fires alone an estimated 20 thousands square kilometers of forest burned in Indonesia and 52 thousands square kilometers in Brazil, including large areas of national parks and forest reserves (Abramovitz and Dunn, 1998).

In Borneo droughts are more severe in the East than in the West. This has an important impact on the forest dynamics of each region (Becker *et al.*, 1998). The climate is also generally drier in Eastern Borneo with the driest region centered in the coastal Balikpapan-Samarinda area. The relationship between climate and forest type distribution can, however, be complicated by factors such as the ability of deep roots to extract ground water (Nepstad *et al.*, 1994; Oldeman, 1990).

2.1.1 Hypotheses tested

The structure of a butterfly community responds differentially to different forest dynamics and architecture, relative to an undisturbed condition. At the very severe level (forest fires) a collapse is expected, leading to radical species restructuring and local extirpation of sensitive species. The presence of a large unburned source, however, co-determines how the community will respond. The ecotone created by the burn will also permit a precise study of the community's response to a severe external impact, and the effect of the edge on the biotic community.

Butterflies, being short-lived organisms, exhibit a significantly different response to such influences than the plant community, which requires a much longer reaction time. Response from a butterfly community also occurs at a different spatial scale because plants are immobile and animals move. The rapid response from butterflies means that they are ideal indicators of forest dynamics, and may complement plant indicators by revealing patterns at a different (landscape) scale.

The methodology of the present investigation allows to study the impact of the edge effect on butterfly and plant communities and to study the effect of a severe environmental impact at the shortest possible scale between an undisturbed and disturbed area. Standard hypothetico-deductivist tests were used to test significant shifts in species richness and density of butterflies and plants, and a monotonic variation in various abiotic and biotic variables as a result of the edge effect.

In addition to standard hypothetico-deductivist statistics, community structures were analysed using correspondence analysis. Correspondence analysis is an exploratory statistical technique, based on a philosophical orientation that emphasises the development of models that fit the data, rather than the rejection of hypotheses based on the lack of fit (Greenacre, 1984). Therefore, no statistical significance tests exist that are applicable to the results of a correspondence analysis. The main purpose of

the technique is to produce a low-dimensional mathematical representation of the complex multi-dimensional mathematical information of the biotic community.

2.1.2 Choice of study site, taxa and sampling

The area of this study is the Sungai Wain forest reserve in East Kalimantan, Indonesia (Fig. 2.1). The reserve is strictly protected by law, which prohibits all forms of economic activity within the officially recognised boundaries. Unfortunately, the boundaries of the park are not respected, and there is a considerable encroachment in the southern and eastern portions. The major environmental impact, though, occurred during the forest fires of 1997 and 1998, when two-thirds of the reserve burned, including all the surrounding forest, which was an economically exploitable buffer zone. The forest fires destroyed most of the affected forest with some small patches left unburned. The burning of the reserve is tragic. Now it is one of the last remaining, moderate, large areas of tropical lowland rainforest in the coastal region of Eastern Kalimantan. Tropical lowland rainforest in a mature state 'equilibrium' (Oldeman, 1990) is now very rare all over East Kalimantan. The other large area of coastal tropical lowland rainforest was the Kutai National Park, but this was almost completely burned during the 1997-98 forest fires. Most other forest areas in East Kalimantan are either mountain forests or are located in logging and/or mining concessions. The reserve is also the location of a reintroduction project for orangutans, victims of the pet trade that had been confiscated. As yet it is unclear how many survived the forest fires.

In order to estimate the impact of the forest fires we decided to calculate the community structure of all saplings ($\text{dbh} \leq 8 \text{ cm}$ and height $> 1.5 \text{ m}$) and seedlings (height $\leq 1.5 \text{ m}$) belonging to woody plants, as well as all butterflies (Papilionoidea and Hesperoidea). Saplings and seedlings show the greatest response to fire in terms of mortality and regeneration. All plants were identified to the species level if possible. This proved rather problematic with the seedlings due to a lack of diagnostic organs (fruits or flowers). With the butterflies, all families were included so that the full monophyletic community is represented. Families in which identification of the species is difficult, such as the Lycoenidae, provide very important information on community shifts and should not be simply ignored as is often done (Hill *et al.*, 1995; Homer *et al.*, 1997; Spitzer *et al.*, 1997).

All butterflies were sampled within a 300 x 20 m plot. Within this plot a 200 x 20 m plot was used to sample saplings in systematically spaced 5 x 5 m subplots. Within these subplots seedlings were sampled in 2 x 2 m subplots. Each plot in an unburned area is contiguous with a plot in a burned area so that the total overall plot size is 400 x 20 m for plants and 600 x 20 m for butterflies. Three main sites in Sungai Wain were sampled (Fig. 2.1). Within each site three plots were placed in burned and unburned areas (Fig. 2.1). In total 18 plots were sampled, nine in burned and nine in unburned areas. The whole area was designed so as to try to capture the

maximum diversity within the area, while avoiding an undue bias due to possible pseudo replications.

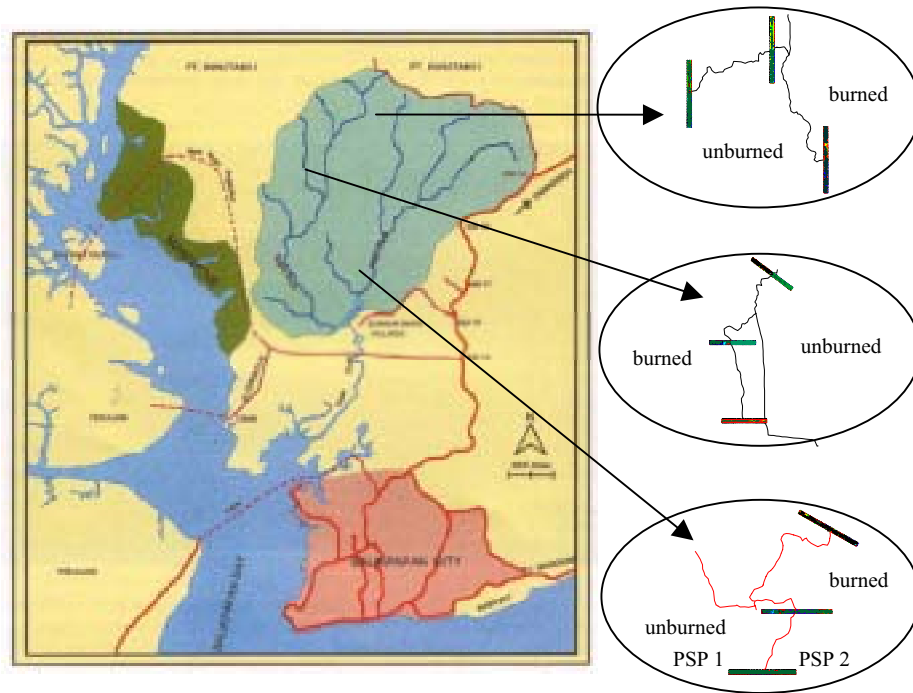


Figure 2.1 Situation map of Balikpapan, Sungai Wain (burned and unburned) forests reserve, East Kalimantan and Permanent Sampling Plots (PSP) locations.

All individual plants were sampled within their respective subplots, and 200 butterflies were sampled per total plot. Standardising sample size is preferable for mobile animals because sampling regimes based on a standard amount of sampling days can introduce an unacceptable bias when weather conditions are adverse. Relative density in this case is the frequency of encounter (number of individuals per species divided by sampling time). The area sampled is the same for all plots. The frequency of encounter can be used to estimate the density based on the total length of the transect sampled, crypsis and effective search width (MacKinnon *et al.*, 1996) all of which are standardised here so that only the actual frequency is given. The collection was discontinued under adverse weather conditions (rain). In addition to limiting weather bias, standardising sample size facilitated the comparison of species richness, since species richness is a function of the sample size.

2.2 MATERIAL AND METHODS

2.2.1 Edge effects

During the 1998 fires in Sungai Wain, regular patrols and a firebreak protected the unburned part of the reserve that remained. The firebreak, which is approximately 1 m wide, was clear-cut so that the fire could not easily enter the unburned area. This area now forms the border between burned and unburned forest. Since all transects are perpendicular to this border this creates an opt situation for analysing the immediate impact of the edge on both burned and unburned forest states. Visually, immediately after the fire, the edge looked very sharp because the fire crept right up to the edge and burned most of the vegetation on its side of the break.

The analyses of the effects of the edge concentrated on two main topics. These are 1) the measurement of abiotic data, which are relative humidity, light intensity and atmospheric temperature and 2) quantitative measurements, density, and species richness of saplings and seedlings. The data for category-1 were collected in a single month (November 1998) along a single transect (Plot 1-2). The data were measured three times a day at 07.00, 12.00 and 16.00 hrs. The total transect distance was 200 m with 100 m in the burned area and 100 m in the unburned area. Relative humidity, light intensity and atmospheric temperature were measured at specific points marked by poles every 10 m. Light intensity was measured with an Extech foot candle/ lux meter with 1 lux resolution, a sampling time of 0.4 seconds and 5% accuracy. The lux option was used in the 0 to 50.000 lux range. Atmospheric temperature and relative humidity were measured with a HANNA thermohygrometer. The atmospheric temperature range is 0 to 60°C with an accuracy of approx. 0.4°C. The relative humidity range is 10 to 95% with an approx. 2% accuracy.

A regression analysis is used to analyse the impact of the edge on abiotic and biotic variables, including species richness and density in both seedlings and saplings in addition to pooled data for seedling and sapling height and sapling diameter. The dependent variable in all analyses is composed by the pooled data of all subplots where negative values indicate a subplot in the burned area and positive values a subplot in the unburned areas. The x value indicates the actual distance from the edge (firebreak).

2.2.2 Species richness

Butterfly niches were divided into 11 distinct groups based on important ecological characteristics. The two characteristics used are larval food type and microhabitat preference. Both these characteristics are believed to be of primary importance in determining the abundance and habitat preference of adult butterflies. The larval food plant is the most fundamental determinant of the amount of butterflies present, and determines the search behaviour of females for suitable host plants and the search behaviour of males for females. Larval food is grouped into 5 main choices, 1) herbs, 2) vines, 3) shrubs, 4) trees and 5) predatory. The plant growth form is a

more conservative aspect of the interaction between butterflies and their host plants, than plant phylogeny (Janz and Nylin, 1998). It is apparently easier for a butterfly to make a host shift from one tree to an unrelated tree than from a tree to a herb. This is probably due to habitat constraints and because herbs, non-woody lianas and vines often have a whole series of secondary chemicals that inhibit phytophagous feeding. Unfortunately, butterflies are not only divided into strictly herb eaters, strictly tree eaters etc, but all types and combinations of the above categories occur. Since using all possible combinations would create too many categories, the butterflies are divided into 5 distinct classes based on habitat type. The classes are 1) herb and/or vine feeders, 2) mixed feeders 3) shrub or shrub and tree feeders, 4) strict tree feeders and 5) predatory. The mixed feeders are a rather heterogeneous group of species that do not fit neatly into the other categories. The predatory category is a distinct monophyletic sub family of the Lycoenidae (Miletinae) that are strictly zoophagous and prey on aphids, coccids, membracids and ant larvae. The larval host plant categories are believed to represent important habitat types in forest ecosystems. Shrubs, for example, tend to be fragmented at the forest edge and in open or young secondary forest, and vines and herbs can be very abundant in natural or logging induced gaps. Most large woody lianas grow lavishly in clearings and edges with high light intensity, and can inhibit the growth of new forest (MacKinnon *et al.*, 1996).

As an additional functional component of niche space, microhabitat preference is used. Microhabitat preference is divided into 3 distinct categories. These are 1) edge, 2) gap and 3) understory species. These categories are based on extensive personal and literature surveys of the preferred microhabitat of butterfly species. With a few exceptions category 1 closely follows the habitat preference used by Corbet and Pendlebury (1992) for species associated with secondary vegetation and edges. These species can also be found in primary habitats, but are almost always restricted to the edge or very large gaps. Category 2 contains species that are usually found in large open gaps, along rivers or in the canopy. Category 3 includes all the species that are usually restricted to the forest understory.

In total 11 categories (functional groups) have been composed. These are 1) herb-vine-edge, 2) herb-vine-gap, 3) herb-vine-understory, 4) mixed-edge, 5) mixed-gap and 6) mixed-understory, 7) predatory, 8) shrub-edge, 9) shrub-gap, 10) shrub-understory and 11) tree-understory. Most predatory and strict tree feeders were understory species, so that they are all included in a single category. Exceptions, such as *Cupha erymanthis*, a strict tree feeder that has a pronounced preference for edge habitats, are placed in the shrub-edge functional group.

Variation in species richness for butterfly and seedling populations is tested with a two-way Ancova. An Ancova is used to remove the impact of abundance since species richness is a function of abundance. Forest state (burned or unburned) and site (1, 2 or 3) are the independent variables. Relative abundance is the covariate for

the butterflies and density is the covariate for the seedlings. The dependent variables are total species richness for the seedlings and various categories of butterflies based on the functional group.

Besides species richness, the variation in density of both butterflies and seedlings is tested with a standard two-way Anova using the same independent and dependent variables as mentioned above.

2.2.3 Community structure

The community structure of both community types is analysed with correspondence analysis, using canonical standardisation of the axes. In the correspondence analysis the natural logarithm (+1) of the relative abundance is used per site (site scores) for the butterflies and the natural logarithm (+1) of the density is used for the plants. In both groups very rare ($n = 1$) and rare ($n < 6$) individuals are pooled into two cases. Rare species may have an unduly large influence on the analysis (ter Braak and Šmilauer, 1998).

Correspondence analysis (CA) is similar to the popular Canonical correspondence analysis (CCA), but whereas CCA creates a bi-plot where the axes are a linear combination of environmental variables, CA uses the actual site scores and thus represents the real community structure. This can be advantageous since CCA has been found to be overly sensitive to spurious environmental variables (McCune, 1997).

Numbers generated by the correspondence analysis are used to test the sensitivity of species to burning of their environment. Species with very high and very low values along the axis most strongly associated with burning, were grouped into two categories (preference for burned or unburned forest). The species used were species present in the proximate Wolariset experimental forest which were sampled (Cleary, unpublished data) using the same method as in Sungai Wain, both before (1997) and after (1998 and 1999) the 1997-98 forest fires. The Wolariset experimental forest is a smaller area of forest to the North of Sungai Wain contiguous with Sungai Wain in the past. The area was especially hard hit by the fires, with most of the area severely burned and only two relatively small, unburned fragments (ca. 2 and ca. 10 hectares) remaining. All species used were coded as being present (1) or absent (0) after the 1997-98 fires. Logistic regression analysis was then used, with presence-absence as the categorical variable and the CA-1 axis site scores as the independent variable, in order to see if there was a significant relationship between the presence in the severely burned Wolariset forest and the forest type preference as indicated by the correspondence analysis. This analysis can indicate either the ability or the inability of 'modest' fragments (ca. 10 hectares) to sustain species through severe environmental perturbations and can show the importance of the remaining unburned forest of Sungai Wain as a refuge for those species that have been extirpated from outlying areas.

For the four most abundant butterfly and seedling species, the significant preference for either burned or unburned forest is tested with a χ^2 test for significant deviation from a standard set arbitrarily at a 50:50 distribution of the species in burned-unburned forest.

2.3 RESULTS

2.3.1 Edge effects

There is a significant impact on the forest microclimate caused by forest fires. The burned area is characterised by elevated levels of light intensity and heat, and significantly reduced levels of relative humidity. Statistically, the differences are significant (Table 2.1). The variation in light intensity shows the most extreme variation between both forest states. There is no variation in relative humidity and atmospheric temperature between burned and unburned forest at 7.00 hrs and maximum variation at 12.00 hrs (Fig. 2.2). The amount of variation reflected by statistical regression in both forest states is generally very low. The single exception to this is light intensity in the unburned forest where the regression coefficient yields a highly significant value. Relative humidity and heat also give consistent and significant results in the unburned area contrary to the burned area, but as mentioned earlier, the amount of variation reflected by the statistical model is relatively low.

There is a highly significant variation in sapling and seedling density, diameter, and species richness between burned and unburned forest (Table 2.2; Figure 2.3). There is not, however, any evidence of an edge effect, with the sole exception of a significantly higher height of seedlings in burned forest, away from the edge. In the burned area there was a small patch of unburned forest in plot 4 in subplots 7 and 9. This area can be seen in Figure 2.3. When it is excluded it is evident that the fire eliminated all saplings below 5 m high. In total only 2.5% of saplings below 8 cm dbh survived the fire.

The growth of both saplings and seedlings was completely unaffected by any edge effect in both forest states, but the growth rate of seedlings over the total transect length had a significantly negative slope indicating a higher growth rate in the burned area.

2. The Initial Impact of Forest Fires on Plant and Butterfly Communities in the Sungai Wain Forest

Table 2.1 The impact of forest fire on abiotic environmental variables.

Category	Transect	Time	R ²	Sig	Int-est	SE	T-stat	Slope-est	SE	T-stat
Humidity	Total	7:00	0.00	Ns	99.62	0.06	1822.00	0.00	0.01	0.38
		12:00	0.20	***	82.98	0.39	214.00	0.81	0.06	12.64
		16:00	0.13	***	90.09	0.37	246.70	0.59	0.06	9.75
	Burned	7:00	0.04	**	100.10	0.18	573.10	0.09	0.03	3.31
		12:00	0.00	Ns	79.20	1.28	61.67	0.20	0.21	0.95
		16:00	0.01	*	89.02	1.41	63.35	0.46	0.23	2.04
	Unburned	7:00	0.05	***	100.10	0.13	752.80	-0.09	0.02	-4.10
		12:00	0.09	***	82.95	0.93	89.05	0.89	0.16	5.63
		16:00	0.02	*	91.78	0.69	133.70	0.32	0.12	2.75
Light	Total ¹	7:00	0.62	***	4.80	0.02	202.90	-0.13	0.00	-32.20
		12:00	0.56	***	6.45	0.03	241.00	-0.12	0.00	-27.96
		16:00	0.59	***	5.54	0.03	194.40	-0.14	0.01	-30.31
	Burned	7:00	0.00	Ns	291.40	15.00	19.42	0.39	2.42	0.16
		12:00	0.00	Ns	1389.00	52.50	26.47	-9.71	8.46	-1.15
		16:00	0.03	**	605.10	48.80	12.39	-23.33	7.87	-2.96
	Unburned ²	7:00	0.48	***	206.60	7.91	26.11	-61.45	3.54	-17.36
		12:00	0.45	***	1130.00	44.90	25.14	-326.50	20.1	-16.25
		16:00	0.39	***	443.50	21.00	21.13	-135.80	9.39	-14.47
Temp.	Total	7:00	0.00	Ns	25.12	0.03	862.80	0.00	0.01	0.89
		12:00	0.05	***	30.12	0.08	376.30	-0.07	0.01	-5.54
		16:00	0.03	***	28.64	0.07	391.30	-0.05	0.01	-4.46
	Burned	7:00	0.02	*	24.90	0.10	254.20	-0.04	0.02	-2.32
		12:00	0.00	Ns	30.62	0.25	120.60	0.02	0.04	0.50
		16:00	0.00	Ns	28.81	0.25	117.70	-0.02	0.04	-0.58
	Unburned	7:00	0.03	**	24.97	0.07	365.30	0.03	0.01	2.97
		12:00	0.06	Ns	30.55	0.20	151.60	-0.16	0.03	-4.59
		16:00	0.02	*	28.76	0.18	162.60	-0.08	0.03	-2.63

Note: 1. Exponential $Y = \exp(\alpha + bx)$,
2. Square root $Y = \alpha + b \sqrt{x}$
Both the y-intercept and slope coefficient are given including α t-test to see if either significantly differs from zero. All regressions except light intensity in unburned forest over the total transect length, are based on standard linear regressions. Light intensity in unburned forest gives a much better fit with a square root x model, over the total transect length with an exponential model. Note that while there is a significant variation in burned and unburned forest, most variation takes place over the total transect.
Humidity and temperature show no significant variation between unburned and burned forest at 7.00 hrs, and a maximum variation at 12.00 hrs.

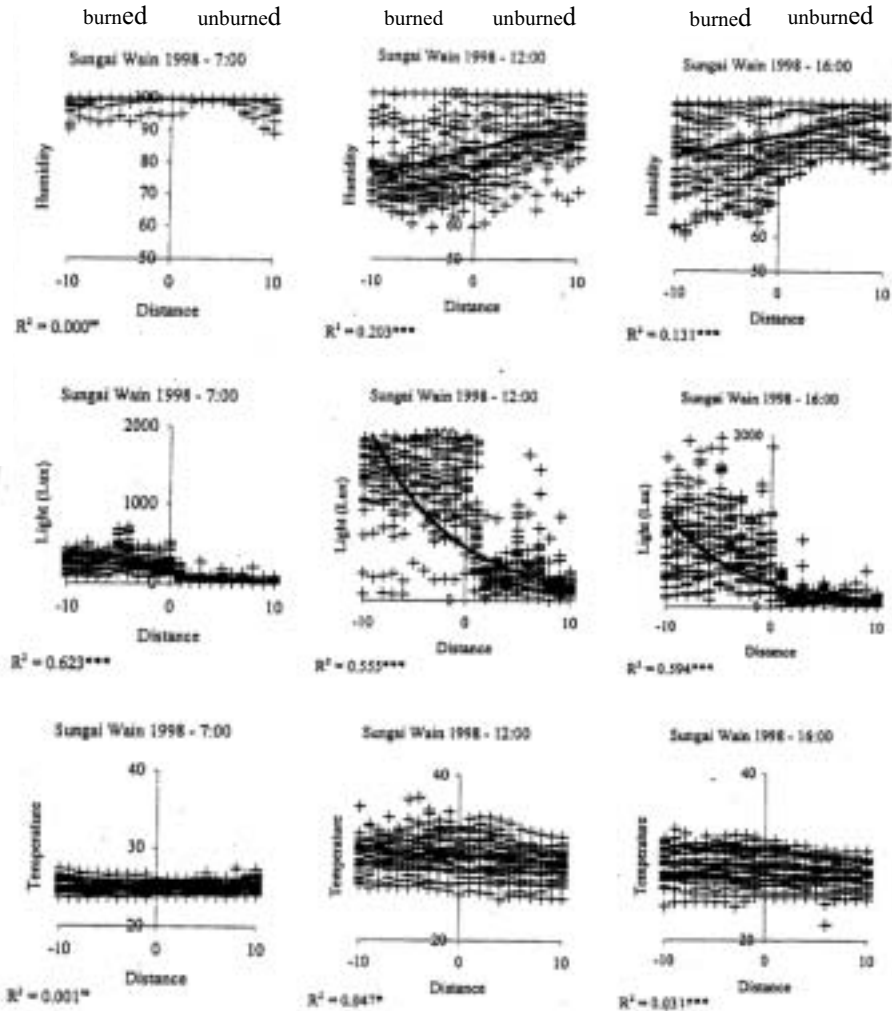


Figure 2.2

Distance from the edge versus three abiotic variables. Data points are daily measurements over a 30-day period. Humidity and temperature follow a standard linear model. Light follows an exponential model. Both temperature and humidity show no significant pattern at 07.00 hrs and a maximum variation between burned and unburned areas at 12.00 hrs. Average maximum and minimum are calculated at the extremes of the 200 m transect. Maximum average humidity is 91.07% ($\pm 1.47\%$) and minimum average humidity is 74.88% ($\pm 1.47\%$) which is a difference of 16.18% between burned and unburned forest. The maximum average temperature is 30.85°C (± 0.30) and the minimum average temperature is 29.39°C (± 0.30) which is a difference of 1.46°C between burned and unburned forest. Light is even more extreme and ranges from 183.428 Lux in unburned forest to 2170.16 Lux in burned forest, which is more than a ten-fold increase in light intensity.

2. The Initial Impact of Forest Fires on Plant and Butterfly Communities in the Sungai Wain Forest

Table 2.2 Responses of various seedling and sapling variables to forest burning.

Category		Transect	R ²	Sig.	Int-est	SE	T-stot	Slope -est	SE	T-stot
Sopling	Density	Total	0.52	***	9.40	0.6	16.36	0.69	0.1	13.89
		Burned	0.00	Ns	0.63	0.3	2.08	0.02	0.0	0.62
		Unburned	0.01	Ns	16.86	1.9	8.67	0.15	0.2	0.88
	Diameter	Total	0.01	***	24.73	0.7	34.08	-0.27	0.1	-4.39
		Burned	0.09	Ns	31.94	7.3	4.37	-1.42	0.7	-1.92
		Unburned	0.00	Ns	21.33	0.8	26.29	0.02	0.1	0.22
	Growth (d) ¹	Total	0.00	Ns	0.34	0.0	9.80	0.00	0.0	0.48
		Burned	0.00	Ns	0.55	0.6	0.92	0.02	0.1	0.37
		Unburned	0.00	Ns	0.34	0.0	8.81	0.00	0.0	0.47
	Growth (h) ²	Total	0.00	Ns	3.99	0.5	8.15	0.01	0.0	0.20
		Burned	0.00	Ns	8.61	6.4	1.34	0.09	0.7	0.13
		Unburned	0.00	Ns	3.27	0.6	5.95	0.07	0.0	1.46
	Height	Total	0.01	**	453.50	11.0	39.77	-2.85	1.0	-2.90
		Burned	0.01	Ns	667.90	104.0	6.44	-5.03	11.0	-0.47
		Unburned	0.00	Ns	409.50	13.0	31.88	0.86	1.1	0.78
Species	Total	0.55	***	6.89	0.4	17.46	0.51	0.0	14.78	
	Burned	0.00	Ns	0.57	0.3	1.94	0.01	0.0	0.50	
	Unburned	0.02	Ns	11.75	1.3	8.95	0.16	0.1	1.39	
Seedling	Density	Total	0.12	***	5.03	0.4	14.07	0.16	0.0	5.03
		Burned	0.01	Ns	3.66	0.7	5.51	0.05	0.1	0.93
		Unburned	0.00	Ns	6.49	1.3	5.13	0.05	0.1	0.41
	Growth (h) ²	Total	0.13	***	9.78	0.5	21.08	-0.44	0.0	-10.93
		Burned	0.01	Ns	12.56	2.3	5.52	-0.32	0.2	-1.54
		Unburned	0.00	Ns	5.42	0.7	7.90	-0.08	0.1	-1.41
	Height	Total	0.16	***	37.82	1.3	28.47	1.43	0.1	12.44
		Burned	0.06	***	9.64	1.9	5.21	-0.64	0.2	-3.76
		Unburned	0.00	Ns	55.07	3.2	16.99	0.11	0.3	0.40
	Species	Total	0.20	***	3.04	0.2	17.11	0.10	0.0	6.77
		Burned	0.01	Ns	2.01	0.3	6.62	0.02	0.0	0.89
		Unburned	0.01	Ns	3.83	0.6	6.03	0.05	0.1	0.87
Species	Climox	Total	0.59	***	14.05	2.3	6.05	1.02	0.2	5.07
		Burned	0.00	Ns	0.67	0.6	1.21	-0.00	0.0	-0.06
		Unburned	0.01	Ns	8.94	5.6	1.60	0.04	0.2	0.20
	Pioneer	Total	0.48	***	9.11	1.6	5.58	-0.59	0.1	-4.10
		Burned	0.24	Ns	23.21	4.2	5.59	0.59	0.4	1.61
		Unburned	0.49	*	2.25	0.6	3.49	-0.16	0.1	-2.77

Note: 1. Diameter,
2. height

Both the y-intercept and slope coefficient are given including α t-test to see if either significantly differ from zero. All regressions are based on standard linear models over the total transect length, and in burned and unburned forest separately. The latter tests for any edge effect. Note that almost all variation is between burned and unburned forest. There is very little variation within either burned or unburned forest. The only variable to show a significant edge effect is the seedling height, which has a significantly negative response in burned forest.

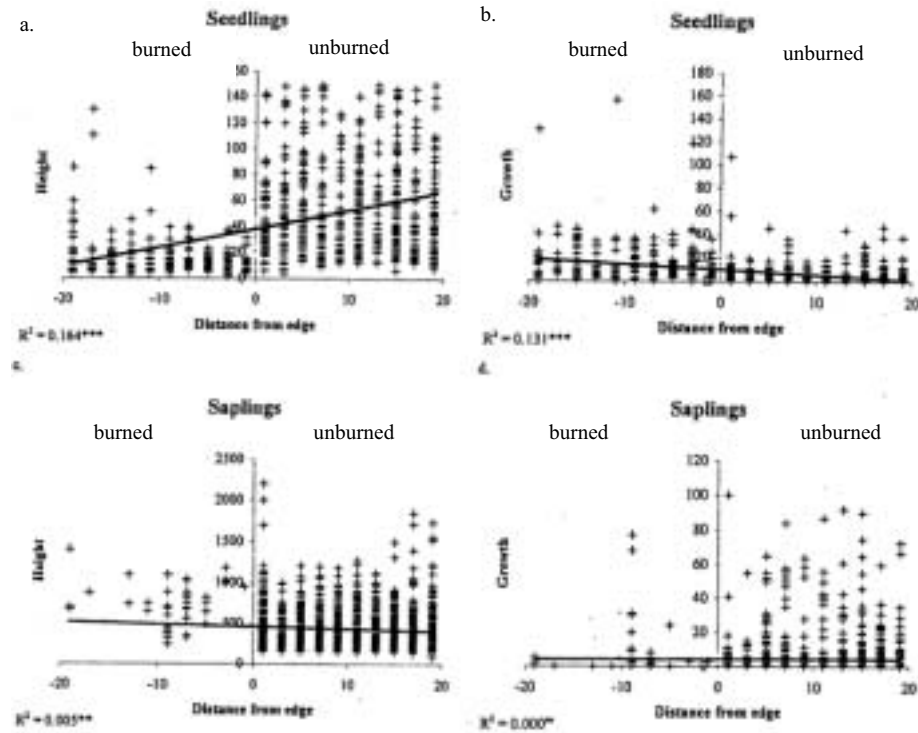


Figure 2.3 Distance from the edge versus height (cm) and growth of seedlings and saplings. Data points are measurements of individual plants in 2 x 2 m subplots (seedlings) and 5 x 5 m subplots (saplings). Seedling height (a) is significantly greater in unburned than in burned forest. Seedling growth however, is significantly greater in the burned forest. Those data points greater than 100 in plot (b) all belong to either *Mallotus mollissimus* or *Mallotus paniculatus* (Euphorbiaceae). Sapling height (c) is significantly greater in burned than in unburned forest. Compared to unburned forest all saplings shorter than 5 m died. In the burned area there is a patch of unburned forest (Plot 4, subplots 7 and 9) that can be seen in plot (c). There is no significant difference between the growth of saplings in burned and unburned forest. It is evident, however, that there was very little growth for saplings outside the unburned patch in the burned forest.

2.3.2 Species richness and density

The species richness (Ancova) and density (Anova) of seedlings is significantly lower in burned than in unburned forest (Table 2.3). In butterflies, only the tree-und functional group has significantly fewer species in burned forest than in unburned forest. However, there is much stronger variation in pooled functional group density with significantly higher densities of mix-gap, mix-und, shrub-und and tree-und butterflies in unburned forest. The mix-edge functional group has a significantly

higher density in burned forest. This indicates that despite α spillover as indicated by the paucity of significant variation between both forest states, there is still α significant restructuring of the burned forest community relative to the unburned forest.

Table 2.3 Results of two-way Anova's and two-way Ancova's for butterflies and seedlings. Type is burned (B) or unburned (U). In the Ancova for butterflies relative density is the covariate, and in the Ancova for seedlings the natural logarithm of density (LnDensity) is the covariate.

					Ancova		Anova		
Community	Category	Sp.	Corr.	p-level	p- level	LSD	p-level	LSD	
Butterflies	Herb.	Edge	10	0,73	0,001	0,075	0,235		
		Gop	12	0,59	0,10	0,246	0,225		
		Und.	1	0					
	Mix	Edge	27	0,57	0,014	0,347	0,034	B>U	
		Gop	27	-0,25	0,323	0,849	0,022	U>B	
		Und.	8	0,68	0,002	0,272	0,009	U>B	
	Shrub	Edge	6	0,20	0,421	0,734	0,468		
		Gop	13	0,17	0,509	0,956	0,125		
		Und.	7	0,39	0,112	0,668	0,034	U>B	
	Tree	Und.	26	0,86	0,000	0,015	U>B	0,000	U>B
	Predatory		7	0,75	0,000	0,412		0,139	
	Total		144	0,13	0,609	0,183		0,118	
Seedlings	Total				0,000	U>B	0,000	U>B	

Species richness of the mix-edge functional group shows α significant variation between states, and there is α significant forest state-site interaction for the herb-edge and mix-edge functional groups. The density of shrub-edge and tree-und functional groups, and the total species shows α significant variation between sites. Site 3 in particular has α lower overall species richness than both other sites, while the overall density is highest at site 2.

2.3.3 Community structure

The community structure of plants and butterflies is shown in biplots of the butterfly (Figure 2.4), seedling (Figure 2.5) and seedling and sapling community (Figure 2.6). When the burned area is excluded (Figure 2.6) the spatial variation between the sites is the most important explanatory variable of the plant community. Variation between the seedling and sapling communities is moderately correlated (0.46) with the fourth correspondence axis, which explains 9.96% of the total variation.

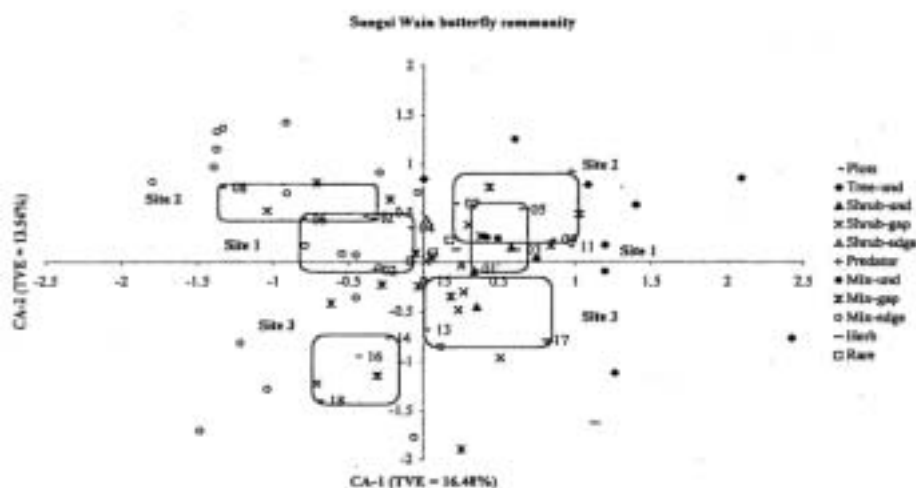


Figure 2.4 Biplot of the butterfly community from the correspondence analysis of all butterfly species ($n > 5$). The largest amount of variation (16.48%) in the butterfly community is between burned and unburned states along CA-1. Species to the extreme left of the biplot (low CA-values) are strongly associated with unburned forest, i.e. *Arhopala pseudomuta* and *Arhopala norda*. Species to the extreme right of the biplot are associated with burned forest, i.e. *Appias paulina* and *Eurema lacteola* (Appendix 2).

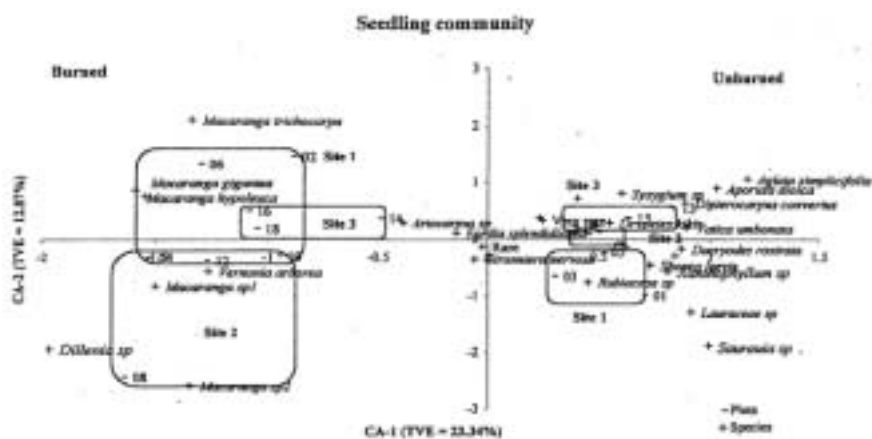


Figure 2.5 Biplot of the seedling plant community from the correspondence analysis. As in the butterfly community the largest amount of variation (23.34%) is between burned and unburned sites along CA-1. Plant species to the extreme right are strongly associated with unburned forest i.e. *Aglaia simplicifolia* (Meliaceae) and *Dipterocarpus convertus* (Dipterocarpaceae). Plant species to the extreme left are strongly associated with burned forest, i.e. *Dillenia sp.* (Dilleniaceae) and *Macaranga gigantea* (Euphorbiaceae). The latter are typical pioneer species (see Appendix 3).

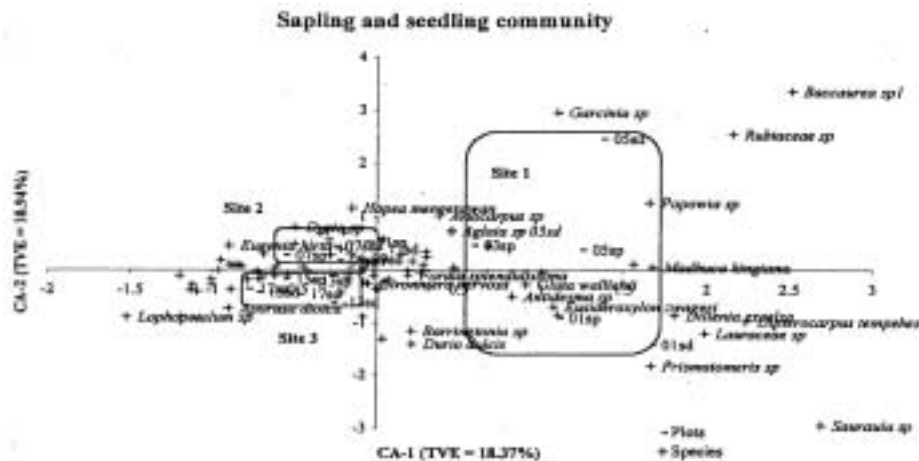


Figure 2.6 Biplot of the plant community (seedlings and saplings) in unburned forest from the correspondence analysis. The largest amount of variation (18.37%), is between plot 1 and both other plots. There is little difference between seedling and sapling communities. Note that site 1 has high densities of species such as *Saurauia sp* and *Dipterocarpus tempehes* is not found at the other two sites.

On the one hand the butterfly community in the burned area has high densities of pioneer species associated with disturbed habitats. These include grass feeding satyrids such as *Orsotriaena medus* and *Ypthima fasciata* and species from other families associated with open habitats such as *Neptis hylas* and *Saletara panda*, all of which belong to the mix-edge functional group (Appendix 2).

On the other hand, in the unburned area, the tree-und functional group is most prominent. The genus *Arhopala* (tree-und) is especially prolific in abundance and species richness in the unburned area and almost absent from the burned area.

The species used in the correspondence analysis are given in Appendix 2. Species with high or low scores along the first correspondence axis (CA-1) and high Cosine^2 (correlation's) with that axis are strongly associated with either burned or unburned forest. Species such as *Tanaecia clathrata* and *Terinos terpander* (shrub-edge and shrub-gap functional groups; $\text{Cosine}^2 = 0.00$) show no preference for either habitat type and are abundant in both areas.

CA-1 is clearly a gradient associated with burning. All unburned plots are located to the right of the vertical axis (CA-2), and all burned plots to the left. There is also a clear spatial partitioning of the sites along CA-2. Both sides to the left and right of CA-2 are almost mirror images of one another with site 3 having positive values along CA-2, site 1 intermediate values, and site 1 negative values. Site 3 clearly has the most diverse community. The pattern in Figure 2.4 indicates a similar and site

dependent response of the butterfly community to fire disturbance. This is the result of α spillover into the burned area from the unburned area, and the colonisation of the burned area by α similar pioneer species complex.

The functional groups are also discretely partitioned along the first axis with all understory groups to the right of the axis and all edge groups to the left. The gap functional groups are intermediate. Only two herb-vine species have an abundance greater than 5, so both of these are included in α single category. The pooled rare and very rare categories (open boxes) are both close to the origin.

A comparison of the butterfly and seedling communities with CA is illuminating. The first four eigenvalues of the butterfly community are 0.134 (16.48), 0.11 (13.54), 0.087 (10.73), and 0.081 (9.95). The first four eigenvalues of the seedling community are 0.494, (23.35), 0.272 (12.88), 0.257 (12.12), 0.211 (9.96). The amount of variation explained is given between brackets. In the seedling community the eigenvalue of the first axis is almost twice that of the second axis indicating α rather clear gradient. The value (0.494) is also close to 0.5, indicating α rather long gradient. Long gradients indicate that there is α large amount of species turnover.

In the butterfly community, there is little relative difference between the eigenvalues of successive axes, indicating that the gradients are not clear, contrary to the gradients in the seedling community. The first 4 gradients are also far below 0.50 denoting short gradients (ter Braak, 1987). Short gradients indicate that there is more variation on species relative abundance than species replacements.

The unburned forest of Sungai Wain functions as α refuge for species that have gone extinct locally, outside the reserve where the fire caused relatively more damage leaving α few isolated forest fragments only, in α matrix of burned forest. To test this hypothesis, α logistic analysis is used with species that were sampled before the 1998 forest fires at the Wolariset research forest. There is α significant (Figure 2.7) relationship between the CA-1 score of α species (in Sungai Wain) and its presence in the Wolariset forest outside the Sungai Wain reserve. Species that avoid burned forest have all gone extinct locally in the Wolariset forest, while species with no preference or α preference for burned forest either survived the 1998 fires, or were able to recolonise the area α year after the fires. Some species such as *Drupadia theda* which prefer unburned forest were only able to survive the 1998 fires in the Wolariset forest in the small patches of unburned forest and still cannot be found outside these patches.

In contrast to the butterfly community, which has α species-rich component adapted to dynamic situations, the diverse seedling community of unburned forest has been replaced by α species-poor community of pioneers dominated by various Euphorbiaceae (Appendix 3), notably of the genus *Macaranga*. All the dipterocarps have completely disappeared from the burned area.

The biplot (Figure 2.5) of the seedling community is superficially similar to the butterfly community in that the first axis is clearly associated with fire. All unburned seedling plots are to the right of CA-2, and all burned plots are to the left. The amount of variation explained by CA-1 in the seedling community is, however, higher (23.34%) than that explained in the butterfly community (16.48%). CA-2 is also completely different. The seedling community shows no evidence of a mirror image. The reason for this is that different pioneer seedling species have become dominant at different sites while the same small complex of forest trees (*Fordia splendidissima* and others) have been able to germinate in the burned area. The pattern of pioneer colonisation thus determines the community structure in the burned area. Different species of *Macaranga* were dominant in different sites. Davies *et al.* (1998) found that *Macaranga* species in northern Borneo have significant preferences for a particular soil texture. This fits in with the marked differences in pioneer distribution found in this study although the soil texture was not determined in this study.

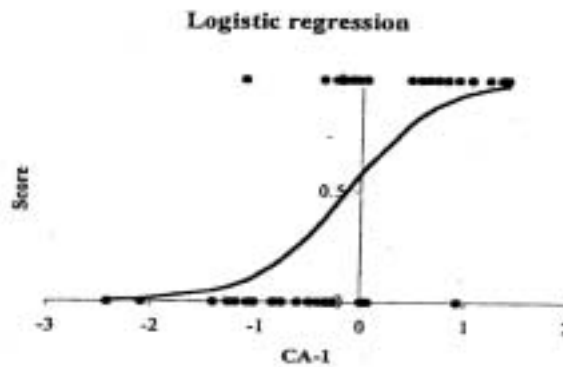


Figure 2.7

Estimate of the impact of burning on butterfly species CA-1. Data points are butterfly species that were recorded at the Wonoriset research forest prior to the 1997-98 forest fires. The x-axis is the score of the same species recorded in Sungai Wain after the forest fires along CA-1. The y-axis indicates the presence (1) or absence (0) after the 1997-98 forest fires. Species with low CA-1 values at Sungai Wain are significantly more likely to be absent from the more severely burned Wonoriset forest, despite having often had high relative densities before the forest fire. This shows both the sensitivity of these forest dwelling species to severe forest perturbation and the importance of Sungai Wain as a local source of these species which have now been extirpated from much of their former range. It should be noted that areas outside Sungai Wain and Wonoriset were generally more severely burned (often totally) since they received no forest fire protection whatsoever in contrast to the Sungai Wain and Wonoriset forests. The function used in the plot is

$$Y = \frac{e^{a+bx}}{1 + e^{a+bx}} \quad \text{where } a = 0.331 \text{ to } 0.420 \text{ and } b = 2.373 \text{ to } 0.743.$$

The proportion of deviance explained by the model is 0.356. The model is (21.196***) highly significant while the residuals (38.392) are not significant indicating an adequate fit of the logistic model.

The sapling community is not shown in the burned area since very few saplings were able to survive the burning. Instead the sapling and seedling communities are combined in a single dataset, excluding the burned areas. This gives an estimation of the pre-fire gradient within the plant community. Including the sapling community dramatically increases both the total amount of species, and the amount of species with a density greater than 5. The total number of sapling species recorded during this study is 246 ($N(>5) = 76$; $n = 1691$) while the total number of seedling species is 145 ($N(>5) = 32$; $n = 848$). The number between brackets represents n and the number of species with a density greater than 5. Nonetheless, there is little differentiation between both plant type communities in the biplot. CA-1 (18.37%) clearly differentiates site 1 from sites 2 and 3. It is unclear, however, what causes the underlying gradient.

The only species of pre-fire forest trees that have been able to germinate successfully (greater than 10% of total population) in the burned area are *Ardisia* sp. (Myrsinaceae), *Artocarpus* sp. (Moraceae), *Eugenia* sp. (Myrtaceae), *Eurycoma longifolia* (Simaroubaceae), *Fordia splendidissima* (Fabaceae), and *Gironniera nervosa* (Ulmaceae). All these species are abundant ($n > 5$) components of the unburned forest community. The most successful and abundant of these species is the nitrogen fixing *F. splendidissima*. The ecological adaptability of this species could mean that it is an important species in forest regeneration and it could provide important services in rehabilitating degraded areas.

Of the pioneer species the following have been able to germinate in the unburned forest: *Vernonia arborea* (Compositae), *Litsea firma* (Lauraceae), *Macaranga hypoleuca*, *M. sp1*, *M. sp2*, *M. trichocarpa*, and *Mallotus mollissimus* (all Euphorbiaceae). All of these species are either absent or very rare in unburned forest.

The distribution of the most abundant butterfly and plant species in Sungai Wain can be seen in Figure 2.8. Most species of butterflies and seedlings show a significant preference for one of either forest states, with the exception of the butterfly species *Tanaecia clathrata*. Habitat preference, though, is generally clearer for seedling species.

The density of saplings is an indicator of the presence of each seedling species in the pre-fire forest community. The pioneer *Macaranga gigantea* was apparently completely absent from the pre-fire forest, because there are no saplings of this species and it is completely restricted to the burned area. The other three species were all abundant in the pre-fire forest community as indicated by the presence of saplings. However, they all show different responses to the burned forest environment. The seeds of emergent canopy of *Shorea laevis* (Dipterocarpaceae) were unable to germinate in burned forest. The seeds of understory/subcanopy tree *Macaranga lowii* were able to germinate in burned forest, but showed a highly

significant preference for unburned forest. The seeds of understory tree *Fordia splendissima* were clearly the most successful of the pre-fire trees although it also showed a significant preference for unburned forest.

It is interesting (see Figure 2.8) that many typical forest butterflies such as *J. pura*, various *Tanaecia* species and *Erites elegans* (not shown) exhibited a rather abnormal behaviour by their often pronounced presence in severely perturbed, burned areas. Normally these species are confined to the forest.

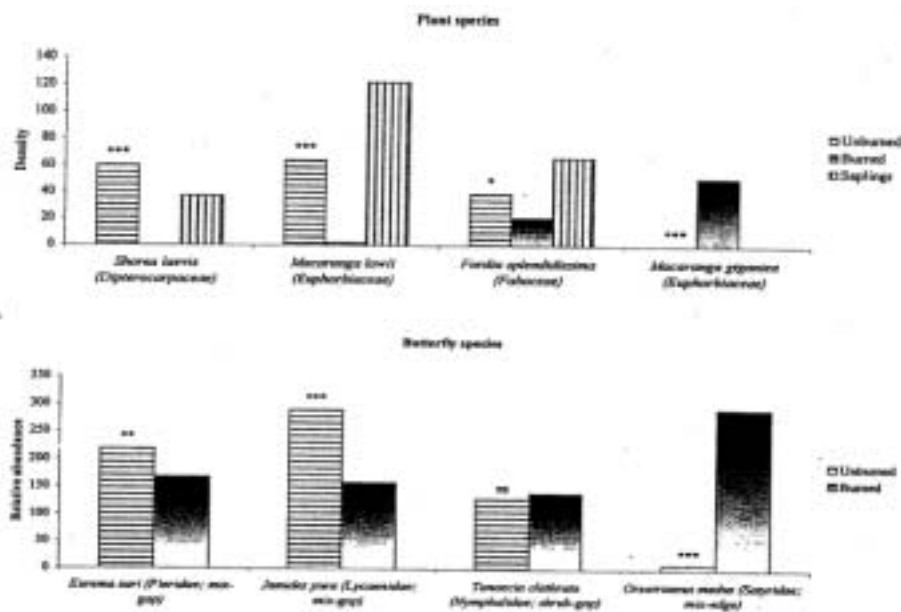


Figure 2.8

Distribution of the four most abundant butterfly and seedling species in the Sungai Wain forest. All species except *T. clathrata* show a significant preference for either burned or unburned forest. The preference of germination for seedlings is marked with almost no germination of rainforest trees such as *S. laevis* and *M. lowii* in burned forest and no germination of the pioneer *M. gigantea* in unburned forest. With the seedling species the third column indicates the number of saplings. Saplings indicate the prefire forest community and most of them died in the burned forest. The pioneer *M. gigantea*, for example, was absent from the prefire forest as indicated by the complete lack of saplings. The butterfly species *O. medus* is also a typical pioneer associated with secondary vegetation. The relatively high proportion of butterflies in burned forest is related to both the proximity of the burned and unburned plots and the very open nature of the forest edge.

2.4 DISCUSSION AND CONCLUSION

The main goal of this study was to analyse the initial response of plants and butterflies communities to forest fires and the edge between forests in a burned and in an unburned state caused by these fires. Although both plants and butterflies showed a very strong response to both habitats, there was little or no evidence of a pronounced biotic edge effect, at least not at the early stages of regeneration studied here. The edge was clearly discernible, but it had a very fuzzy character. Both plants and butterflies showed a very rapid response to burning with a new and dynamic community of organisms both recolonising and colonising the area affected by the fires. The new seedling plant community was largely composed of pioneer species that are absent or rare in the unburned forest. The new butterfly community was composed of both pioneer species and forest species spilling over from the unburned forest.

2.4.1 Fires

Although the forest fires of Indonesia have received enormous media attention this is largely due to their negative impact on human health (respiratory problems) and business (airport closures). Interest in the consequences for Indonesia's particular ecosystems was only secondary and while the consequences for forests and biodiversity are simple to predict they are much more difficult to calculate (Brown, 1998). They cannot be calculated precisely because forests are complex systems (Oldeman, 2001; Rossignol *et al.*, 1998).

Often moist unburnable forests lose their resistance to fire as logging operations perforate the forest canopy and allow the moist, cool interior to dry and burnable debris to accumulate. This can also happen when severe ENSO events cause mass shedding of leaves and a significant build-up of the forest fuel layer (Nepstad *et al.*, 1998).

Logging, logging and drought increase the vulnerability of affected forest to future burning, and during severe ENSO episodes this can potentially double net carbon emissions to the atmosphere (Nepstad *et al.*, 1999). Large areas of forest burn every year, and this process had catastrophic proportions in certain years (i.e. 1983 and 1998) when the ENSO altered the normal climatological conditions prevalent in Borneo and many other tropical countries.

There is evidence that ENSO events have increased in both strength and duration during the last 20 years as a result of global warming (Trenberth and Hurrell, 1996), as a consequence of cyclic solar activity (Rossignol *et al.*, 1998). Mean global temperatures are claimed to have risen in the last century, and it is predicted that the warming will continue for the next 50 to 100 years (Easterling *et al.*, 1997). This has already caused significant shifts in the distribution of butterfly species by altering

the ratios of extinction to colonisation in Europe (Parmesan *et al.*, 1999). Butterflies have been shown to be sensitive to heat (Dennis, 1993).

Burning causes radical microclimate alterations in the forest as the naturally cool, humid, and obscure understory is replaced by a hot, dry, open area. Besides, the botanical composition of pioneer forest becomes radically different from both burned surfaces and undisturbed forest.

In addition to initial tree mortality following fires there can be a considerable residual mortality. In a study of tree mortality following natural fires in the Amazonian rainforest, Holdsworth and Uhl (1997) found that during the 1.5 years following fires 44% of trees (DBH > 10cm) died in burned forest while only 3% died in unburned forest. At the same time pioneer species density increased dramatically.

Although the fireline intensity of tropical fires is very low, it is nonetheless deadly because it tends to heat the soil at levels lethal to mycorrhizal fungi (Smits, 1994) and to burn or expose tree bases for long periods. Most tropical trees are characterised by thin bark (Uhl and Kouffman, 1990) so that they are very sensitive to damage by fire. The thickness of the bark is also diameter dependent, which is why smaller trees are more susceptible to fire than their larger conspecifics. Typical burns kill 40% of trees with less than 10 cm DBH (Cochrane, 1998). The burn at Sungai Wain can thus be categorised as extremely severe, considering that 97.5% of saplings of less than 8 cm DBH were killed.

First time fires have the most impact on small trees and usually destroy only as little as 10% of the total living biomass. However, a second fire can kill as much as 40% of the living biomass leaving large trees with no survival advantage over smaller trees. Succession of fires and their consequences have been studied in shifting agriculture, e.g. in Mexico by Von der Wal (1999).

Indeed, severe fires can degrade a primary rainforest to a state resembling that of secondary vegetation on recently abandoned agricultural land (Cochrane, 1998). This is the case in Sungai Wain. The burned area is now covered with a scrub of ferns and small pioneer plants typical of abandoned agricultural areas. It had never been logged, so the importance of logging as a fire promoting factor is not universal.

The type of forest break-up caused by fires can cause a cascade of deleterious effects for the whole ecosystem. Jennersten (1988) examined the impact of fragmentation on a butterfly-pollinated herb, and found that plants in the fragmented area received much fewer visits than those in the mainland area. Seed set was much lower, and the plants produced more selfed seeds. Lei and Honski (1998) found that the superior competitor, but inferior disperser of two parasitoids was exceptionally sensitive to declines in host density, demonstrating that a locally stronger competitor with a

limited dispersal capacity can become endangered in a highly fragmented landscape. Their conclusion was that a specialist predator or parasitoid of an endangered butterfly species is extremely endangered indeed.

While forest fires remain complex processes recent models based on self-organised criticality show that the initiation and propagation of forest fires exhibit power-law frequency-area statistics over many orders of magnitude. The practical application of this result is that the distribution of small and medium fires can be used to estimate the risk of large fires (Molamud *et al.*, 1998).

Unless access to forested lands via roads, electrical grids and water transport systems is sharply curtailed, large areas of forest will continue to burn with potentially disastrous consequences for the biota and people of Indonesia.

2.4.2 Seedling plant community

The new plant community was clearly not a nested subset of species left over from the fire. Even though a few saplings and trees survived the fire, and the burned area was adjacent to a large unburned source, very few seeds originating from the unburned forest were able to germinate in the burned area. Noticeable exceptions are *Fordia splendidissima* and *Girardinia nervosa* in addition to a few other species. Even though the dispersal distance from unburned to burned forest was clearly within reach of even the weakest dispersing butterflies, there was still a significant variation in species richness and density between burned and unburned forest.

The burn has created a rapidly evolving ecotone where two distinct plant and animal communities meet. The early stages of this process show that there is a certain degree of spillover between both communities, which is as would be expected over the short distance between both types. There is, however, little evidence of a biotic edge effect.

As the area regenerates, pioneer species are gradually replaced by mature forest species which is a very complex process (Vester, 1997). A fuller understanding of this mechanism is crucial if one is to understand the natural forest dynamics which play such an important role in the well-being and preservation of all forest organisms, including all the well known flagship species such as the orangutan. At present these species have lost large portions of their former habitat. The quality and quantity of disturbed forest are certain to be a crucial factor in their eventual survival and that of all lesser known plants and animals including most butterfly species.

2.4.3 Edge effects

Williams-Linera *et al.* (1998) found that the average soil temperature increased significantly with the distance from interior habitats toward the edge. They also found that the vegetation in old edges (>15 years) was so well developed that there

was no difference between the edge vegetation and forest edge-posture. Edge and gap conditions can greatly favour lianas (Putz, 1984; Oldeman, 1990; Oliveira-Filho *et al.*, 1997).

Edges can significantly influence forest environment and structure (Murcia, 1995; Laurence and Yensen, 1991), but Oliveira-Filho *et al.* (1997) found that the overall effect of edges on tree community structure and dynamics was less pronounced than that caused by disturbance. However, various edge effects can interact with each other so that a conclusive monotonic variation with distance is often obscured (Murcia, 1995).

Of the plant species it was the pioneers which exhibited an edge sensitivity in both habitat types. The height was significantly higher away from the edge in burned forest. The seeds were able to travel only 50 m into the unburned forest and germinate, and then at considerably lower densities than in the burned forest.

The butterflies could not really be used to measure edge effects since the minimal sampling unit stretched over the total plot and was not divided into subplots, unlike the plant community. However, typical pioneer butterflies were able to penetrate through the entire unburned plot, but at much lower densities than in the burned forest, as exemplified by the significant difference in the density of the mix-edge functional group between both forest types. The establishment of typical edge species and their host plants, up to several hundred meters into forest fragments, is among the most faithful indicators of major ecosystem restructuring following large scale forest disturbance (Brown and Hutching, 1997).

Butterflies clearly react to large-sized ecosystem setbacks at a different spatial scale to plants. The butterfly community showed a more diffuse character to disturbance than the very discrete nature of the plant community. Natural dispersal of the adult stage, however, does not always indicate that the adults are dispersing into a viable butterfly habitat. The burned area could indeed act as a large sink to the forest butterflies with few larval host plants of low quality and an abundance of light-loving predators. There was a marked abundance of dragonflies along the edge that were frequently observed to hunt and kill butterflies. Although important, it is impossible to measure accurately the impact of burning on butterfly larvae, for this would entail climbing into the often very high trees of the unburned forest, and raising the larvae to adult imagoes. Unfortunately, there are few reliable keys of butterfly larvae that allow reliable identification to the species level. Accumulation of life history data is, however, essential to obtain a better understanding of the butterfly community's ecology and its evolutionary response to disturbances.

From the present study, however, it is evident that burning caused a significant shift in the forest butterfly community. Despite the differences with the plant community there are also clear similarities. Both respond to burning by a radical restructuring of

their respective communities and on accumulation of typical pioneer species in the disturbed habitat type. However, the response at the spatial scale used here is much clearer within the seedling community.

CHAPTER 3

GENETIC VARIABILITY OF *Shorea leprosula* Miq. IN KALIMANTAN, INDONESIA

ABSTRACT

The genetic variability of *Shorea leprosula* was assessed based on isozyme variation. Leaf samples were collected from three sites viz. two sites located in East Kalimantan (Tarakan and Laham), representing what is here called the eastern and central populations respectively, and a site in West Kalimantan (Kalbar) representing the western population. A total of six enzyme systems, namely EST, MDH, PER, 6-PGD, PGM, and SDH were visualised on starch gels. The complex banding patterns of each enzyme system did not allow for a straightforward genetic analysis. Therefore, phenotypic variation was used to get a provisional idea about the relatedness of the three populations of *S. leprosula*. Phenotypic diversity ranged from 4 in EST to 8 for PER and 9 for SDH. PGM, PGD and MDH each had 5 phenotypes. An estimate of similarity was calculated from the phenotypic frequencies of four of the six isozyme systems viz. EST, PER, PGM, and SDH. Laham and Tarakan had the highest similarity (98.8%), whereas Laham and Kalbar, and Tarakan and Kalbar exhibited lower similarities (90.7% and 90.2%, respectively). Geographically, Tarakan is nearest to Laham whereas Kalbar is further away from Laham and much further away from Tarakan. This indicates that the three sites are generally closely related to each other and may be sub-populations of *S. leprosula* in Kalimantan. An understanding of the genetics of this allozyme variation through controlled crosses is needed for further population genetical research in *S. leprosula*.

3.1. INTRODUCTION

The framework of most Indonesian tropical rain forests is formed by a species-rich dipterocarp tree community, which contains predominantly allogamous species pollinated by insects (Bawa, 1998). The highest diversity is found amongst the Dipterocarpaceae, with 267 species in Borneo. Of those species, 155 are endemic (Ashton, 1982). The wide range of diversity in the Dipterocarpaceae is also shown by the diversity of their ecological characteristics, such as growth rate, reaction to light, drought and soil properties. Most species of this family are valuable timber species, such as meranti, bangkirai (*Shorea* species), kapur, keruing and others. *Shorea* is the most important dipterocarp genus, both in terms of species, well over 100, and economically (Haggarsson *et al.*, 1994; Smits, 1994). *Shorea leprosula* is one of the fastest growing species of dipterocarp, with a maximal growth rate of over two cm

diameter increment per year (Meijer and Wood, 1964; Masano, 1985; Yasman, 1995). It is classified, following the trade name, in the 'light red meranti' group of dipterocarp species, and it is mainly used for construction timber, veneer and plywood. In view of its economic importance, it is understandable that a very intensive use of its timber must be balanced by regeneration from a supply of material from high quality stands in order for the productivity to remain sustainable. In order to support sustainability in the use of *Shorea leprosula* we must have knowledge of the variability that exists in the natural population. Based upon this knowledge we may consider selection practices. A selection of genotypes or at least phenotypes of *S. leprosula* with a good silvicultural performance is the most logical approach. Effective selection for beneficial characteristics can be achieved only if genetic variation exists. If it does exist, it is especially necessary to select genotypes, suitable to the specific conditions are prevalent in most enrichment planting sites (Weidelt, 1996). The degree of genetic variation and its spatial distribution are important clues to some aspects of tropical forest management. Protection forest is expected to have a maximum genetic variation at the species level (Whitmore, 1990). If there is no information on variation and distribution of genotypic/phenotypic variation, decisions on selecting the optimal sites to be protected are difficult to make.

The intensive logging activities at the scale of the landscape have influenced not only the deforestation and degradation of tropical forest, but also have broken up continuous forests, in which surviving fragments became progressively smaller and/or more isolated, containing low-density populations of most species. The size of the remaining fragments of forest habitat has an inverse relationship with species diversity, and the distance between the isolated forest fragments plays an important role in the conservation of species.

Therefore, an understanding of the consequences of fragmentation on genetic diversity is very important for future forest management practices. Very little research has been conducted on this subject in South East Asia (Young *et al.*, 1993; Sudarmonowati *et al.*, 2001). Some authors have claimed that genetic variability of *S. leprosula* has declined due to the Indonesian Selective Cutting practices, which cut all the best trees, and the genetic quality of the remaining wildlings is not as varied as it was prior to logging. Therefore, they claim that the sustainability potential of this species, especially in terms of its quality, is assumed to have been reduced (Suseno, 2001). Smits (pers. comm., 2002), however, believes it is not yet possible to reach this conclusion since the younger trees are still not big enough to produce seeds; so the older trees, even though showing deficiencies because of their age, are still the ones yielding seedlings of their high genetic quality. Moreover Smits (1994) thinks that there may be an early selection against deviating genetic types due to the special ectomycorrhizal relationship of the Dipterocarpaceae, in which mother trees tend to supply their seedlings with carbohydrates through the hyphal pathways of the ectomycorrhizal fungi (Yasman, 1995).

Unfortunately, so far tropical tree species have seldom been examined as to the degree and distribution of their genetic variation. Some studies however have been conducted (Liengsiri *et al.*, 1990; Sudarmonowati *et al.*, 1997). Gan *et al.* (1981) found moderate degrees of variation and differences of genetic distribution in space of two species of Dipterocarpaceae in Malaysia.

Allozyme or isozyme electrophoresis is a common technique to describe the genetic variation and organisation of species in their natural populations. This technique is the most practical method for genetic analyses (Liengsiri *et al.*, 1990; Seido, 1993). Furthermore, Seido (1993) explains that the objective of isozyme analysis is to know the genetic structures in natural forest populations with the aim to improve selection for seed orchards and natural forest stand conservation. Other objectives are to identify seed sources, to investigate pollination systems in natural forest stands and plantations, and also to maintain seed orchards and collections arboreta for clone identification. Since the introduction of allozyme electrophoresis in population genetic studies (Lewontin and Hubby, 1966), this has led to the accumulation of vast amounts of information about the levels and structuring of variation (Brown *et al.*, 1978; Hamrick *et al.*, 1979). A number of methods have been developed to characterise patterns of isozyme variation, including Wright's F statistics (Wright, 1978), Nei's diversity statistics (Nei, 1973) and genetic distance (Nei, 1972; Reynolds *et al.*, 1983). Allozymes have been used for genetic studies of both experimental and natural populations (Mitton *et al.*, 1979; Ledig, 1986; Hamrick and Godt, 1989).

According to Pasteur *et al.* (1988), bands generated from isozyme analysis may correspond to:

- 1) the products of the expression of several genes at several loci;
- 2) the products of the expression of several alleles of a given gene at a given locus;
- 3) molecules produced by conformational changes of a given protein molecule;
- 4) molecules synthesised by a given gene or group of genes, which have undergone various post-translational modifications.

The objective of this study is to examine the amount and distribution of genetic variation of *S. leprosula* in three dipterocarp forest sites representative of populations in Kalimantan, Indonesia using isozyme markers. This is, off course, far away from the ambitious aim like the definition of 'genetic quality' as a generic property, but it is a first step in a field of knowledge where every advance is useful.

3.2. MATERIALS AND METHODS

3.2.1 Location

Wildlings of *S. leprosula* collected from forests were grown in the nursery at the Wanariset Samboja research station, in the Kutai district, East Kalimantan since Nov. 99. Isozymes were analysed in the laboratory of the Research Centre for

Biotechnology-LIPI, at Cibinong in Bogor, West Java during a 7-month period from September 2001 to March 2002.

3.2.2 Materials

Type and Source of Material

Leaf samples of *S. leprosula* wildlings collected from underneath known mother trees in three populations were studied to represent parts of its whole natural population in Kalimantan, Borneo's part of Indonesia (Fig. 3.1). The location of each population is described in detail in another part of this thesis (Appendix 4).

The three populations are:

1. The Tarakan population in East Kalimantan (from 2°45' to 3°15' latitude North and from 116°28' to 116°34' longitude East) in the eastern region of Kalimantan.
2. The Laham population in East Kalimantan (from 0°19' to 0°38' latitude North and from 115°29' to 115°39' longitude East) in the central region of Kalimantan.
3. The Kalbar population, consisting of Sanggau (0°06' to 0°10' latitude North and from 110°43' to 110°50' longitude East), Sintang (0°12' to 0°17' latitude North and from 111°00' to 111°15' longitude East), and Kaburai sub-populations (0°25' to 0°30' latitude South and from 111°30' to 111°45' longitude East) in West Kalimantan in the western region of Kalimantan.

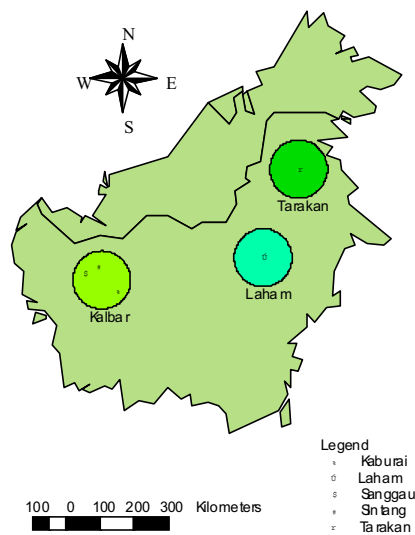


Figure 3.1 The three regions of origin of the *S. leprosula* populations studied

Table 3.1 Number of *S. leprosula* wildlings used for electrophoresis and the environmental conditions of each population. The geographic distance was measured from the Kalbar population, except for the number between brackets, which represents the distance between the Laham and Tarakan populations.

Population	No. Wildlings	No. family	Area (km ²)	Distance (km)	Soil type	Topography	Site condition
Kalbar	76	25	609		Red yellow podzols	Undulating (10-20%)	Forest fragments
Laham	577	84	647	429	Red yellow podzols	Undulating (10-15%)	5 years before selectively logged
Tarakan	732	74	616	717 (375)	Orthic Tropodults	Mountainous (25-40%)	20 years before selectively logged
All	1385	183					

3.2.3 Methods and data analyses

Enzyme Extraction

Horizontal starch gel electrophoresis of isozymes followed the method developed by Sudarmonowati *et al.* (1997) with some modifications. Leaf tissue was used for the assay of 6 enzyme systems. The number of samples used for the assay is shown in Table 3.1. Fresh leaves were ground in liquid nitrogen to a fine powder to which about 6 ml of cold extraction buffer (Wickneswari and Norwati, 1992 with an addition of 1% Tergitol) was added to create a slurry. After mixing it well, the mixture was transferred to Eppendorf tubes and was then centrifuged at 10.000 rpm for 15 minutes at 4°C, and the resulting clean extract was collected in the new Eppendorf tubes that were kept at -20°C until being used.

Electrophoresis

A Tris Histidine pH 6.0 gel buffer and Tris-Citric Acid pH 6.0 electrode buffer was used in this study. This electrophoretic buffer system was prepared based on the recipe of Horry (1989). Separation of 6 enzyme systems, namely Esterase (EST), Malate dehydrogenase (MDH), 6-Phosphogluconate dehydrogenase (6-PGD), Phosphoglucomutase (PGM), Peroxidase (PER), and Shikimic acid dehydrogenase (SDH), was carried out on 13% starch gel. Electrophoretic separation of enzymes was carried out for 1 hour at 40 mA followed by 4 to 5 hours at 45 mA. References of staining methods are EST (Wickneswari and Norwati, 1992), 6-PGD, PGM, SDH, MDH (Hartati and Prana, 1999), and PER (Seido 1993; Vallejos, 1983).

3.3. RESULTS

Banding pattern variation was observed in 6 enzyme systems, namely Esterase (EST), Malate dehydrogenase (MDH), 6-Phoshogluconic acid dehydrogenase (6-PGD), Phosphoglucomutase (PGM), Peroxidase (PER), and Shikimic acid dehydrogenase (SDH).

The zymograms of each of the enzyme systems analysed for all three populations of *S. leprosula* is presented in Figure 3.2. The number of different banding patterns (allozyme phenotypes) varied between 4 and 9. The most common number of phenotypes in the banding patterns was 5, which was observed in PGM, PGD and MDH. The highest number of banding patterns was noted in SDH, i.e. 9 phenotypes, which was followed by PER (8 phenotypes). The lowest number of banding patterns was 4 in EST (see also Table 3.2).

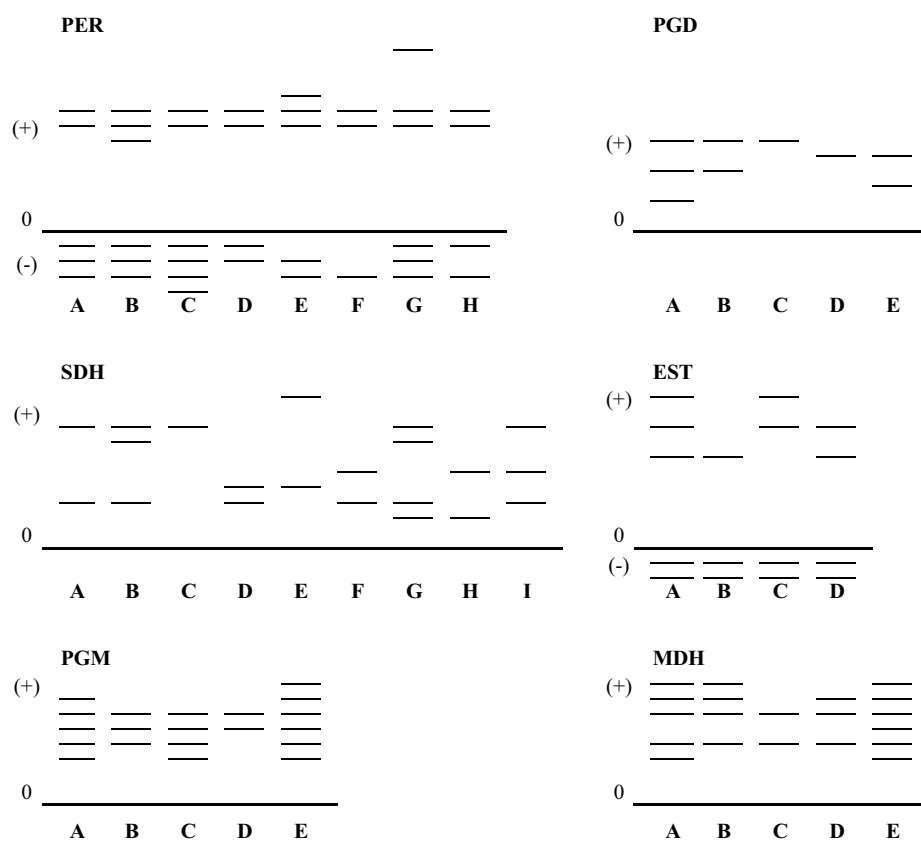


Figure 3.2 Zymogram of 6 enzyme systems extracted from leaves of *S. leprosula*.

As shown in Figure 3.2, the banding patterns for EST, SDH and PGM, look variable at monomeric enzyme loci with 2-banded heterozygotes. However, due to the complex patterns a straightforward genetic interpretation could not be given. This holds even more for the MDH and PGD patterns: both enzymes are dimers but no 3-banded patterns could be observed although a lot of variation appears to exist in the banding patterns. We, therefore, stick to a description of variability levels only by a phenotype.

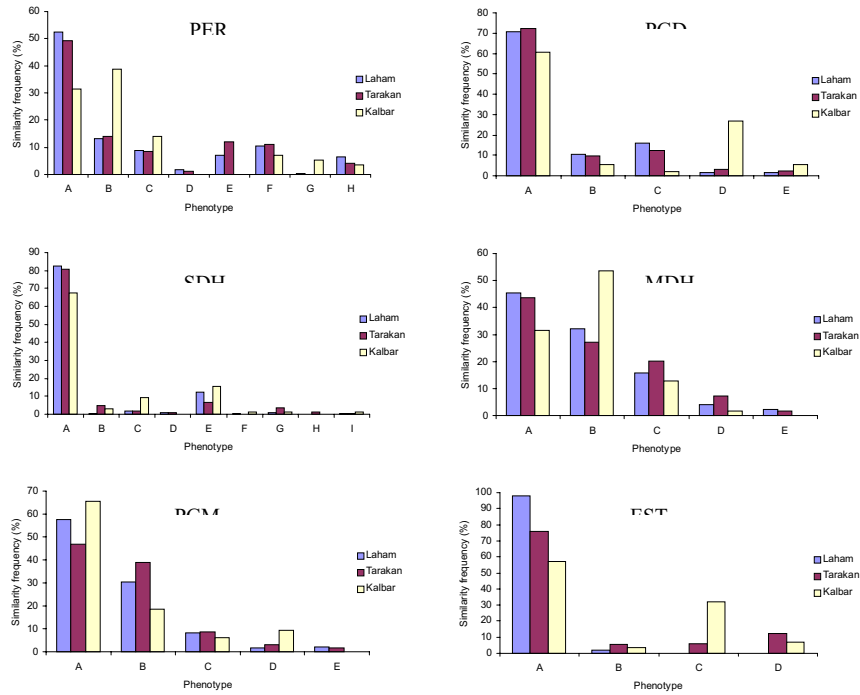


Figure 3.3 Frequencies based on isozyme phenotype for the three locations.

Similarity frequency based on isozyme phenotype revealed 4 enzyme systems, namely PER, SDH, PGM and EST, extracted from leaves of *S. leprosula*. Figure 3.3 shows variations of similarity frequency in phenotype for the various enzyme systems of three *S. leprosula* populations. Based on Nei's genetic distance (using allozyme phenotypes instead of alleles), the percentage of similarity for all populations ranged between 79.9% (between the Laham and Kalbar populations using PER enzyme system) and 99.6% (between the Laham and Tarakan populations using SDH enzyme system). The measures of the similarity frequency between three *S. leprosula* populations for four enzyme systems are summarised in Table 3.2.

Table 3.2 Similarity estimate (calculated with Nei's genetic similarity) and geographic distance between three *S. leprosula* populations.

Populations	Similarity					Geographic distance (km)
	PER	SDH	PGM	EST	Average	
Laham vs Tarakan	0.994	0.996	0.979	0.983	0.988	375
Laham vs Kalbar	0.799	0.990	0.971	0.866	0.907	429
Tarakan vs Kalbar	0.804	0.983	0.912	0.909	0.902	717

The frequency distribution in the three populations was used to calculate similarity at each of the four loci (viz., PER, SDH, PGM, and EST) as well as an average similarity between these four. The other two enzyme systems were not used because of the uncommon banding patterns (no 3-banded heterozygotes), although the overall pattern does not change if data of these two enzyme systems are included. Finally, the similarity matrix was converted into a dendrogram.

The result of frequency similarity of isozyme phenotype, which has been converted to a distance diagram (Fig. 3.4), clearly shows that the Laham and Tarakan populations are phenotypically and probably genetically closely related and both are more different from the more geographically distantly located Kalbar population.

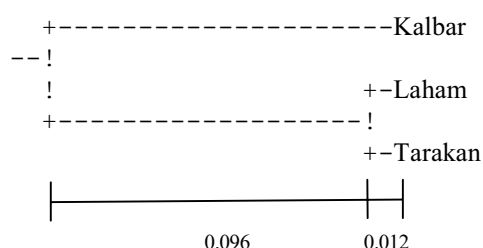


Figure 3.4 Diagram of *S. leprosula* based on the similarity frequency of isozyme phenotype.

3.4. DISCUSSION

Electrophoretic banding patterns (so-called zymograms) normally allow for a straightforward interpretation in terms of alleles and loci. However, the zymogram of *S. leprosula* appears to be so complicated that a genetic interpretation with no backing up of controlled crosses is at best questionable (Pasteur *et al.*, 1988). To give an extreme example, in MDH and PGD nowhere a clear three-banded pattern characteristic of a heterozygote for a dimeric enzyme was observed. For this reason the similarity estimates were restricted to the four, most likely, monomeric systems.

In this study a high degree of homogeneity in phenotypic similarity between the localities was encountered, which is surprising when compared with existing knowledge in other plant species. However, Smits (1982 and 1994) postulated that due to the special close physiological relationship with ectomycorrhizal fungi and the special transport of carbohydrates from the mother tree to its seedlings through the mycorrhizal hyphae, there should be a selection against genotypes deviating from the type of the mother tree, which might explain the high degree of homogeneity found here.

There are several indications to support this view. Ashton (1969) reported that Dipterocarpaceae, more so than any other plant family in South East Asia, show very little morphological variation over their wide range in the Sunda shelf region. Another typical aspect of the dipterocarp regeneration is that there is a virtual absence of hybrids. Ashton (1969) is of the opinion that selection against hybridisation takes place in dipterocarps. Indeed hybrids do occur but are extremely rare in natural forest within the natural distribution range of the dipterocarps (Smits, 1994). Tropical species have been reported to have a low genetic differentiation (Hamrick and Loveless, 1989). Genetic differentiation values of locally distributed tropical species, flowers of which are pollinated by animals and seeds dispersed by gravity, have values of 0.119, 0.092 and 0.131 each (Hamrick *et al.*, 1992). Some authors like Chan and Appanah (1981) noticed that the *Shorea* spp. is all pollinated by dispersal limited Thrips (Thysanoptera, Thripidae). In the morning they fall down with the corollas to the soil, only to fly up again in the evening with the upraising air. In this way they can at most reach neighbouring trees only, thereby limiting the exchange of pollen to nearby trees.

Most of the dipterocarp tree species grow in clumps, also because of their special regeneration mechanism and the role of the obligate ectomycorrhizal fungi (Smits, 1994; Yasman, 1995). Therefore, locally the trees should resemble each other more with possible signs of inbreeding especially because of their little migrating pollinators. Chan and Appanah (1981) also noticed that the *Shorea* spp. showed staggered flowering, with very little overlap between the different species. So again this might contribute to a lower exchange of genetic variation and a more homogeneous population in terms of genetic diversity. Janzen (1974) speculated that the Dipterocarpaceae are totally different from other plant species in their regeneration system, focusing more on irregular, wide spaced mass fruiting, to deal with the predator populations in the forest. In this case also very few seedlings survive the onslaught of the predators, but the predator population becomes lower in the years in between the mass fruiting years since Dipterocarpaceae make up most of the upper canopy and fruit bearing trees in the lowland forests of Borneo. In such case according to Smits (pers. comm., 2002) the loss of a few extra seedlings due to the severe selection against deviating genotypes would be of lesser consequence.

The total number of different phenotypes looks rather low (see Fig. 3.2), under the assumption that each enzyme system at least is encoded for by 2 loci and both loci have at least 2 alleles. Part of the band variability might come from post-translational modification or from other organisms like bacteria. From the results in this chapter, we can see that at least the phenotypic differentiation is indeed very limited between the wide-spread populations. Still it can be seen that the geographically closer populations are also more similar in their banding patterns and, therefore, may be expected to be genetically more similar. Smits (1983b) proposed the term 'ecological mutation', in which both the fungus and the associated plant (mycobiont and phytobiont) could be selected due to small ecological niches, for instance different soil types. That would be an explanation for the high degree of endemism in the Dipterocarpaceae in Malesiana. At the same time, if the adaptation is indeed towards speciation into very small ecological niches it would mean that a deviation from the newly established combinations, involving the mutualistic symbiotic association with the intricate physiological processes involved, including even the transport of sugars from mother trees to their seedlings, would be highly disadvantageous for the plants. Therefore it may very well be that Dipterocarpaceae indeed show the more homogeneous pattern even between geographically distant populations as postulated by Smits (1982) and indicated by the facts of morphological homogeneity and virtual absence of hybrids.

On the possibility of gene flow in *Shorea leprosula* we noticed that the phenology was very specific. The flowering and fruiting is very unpredictable and only occurs once every three to five years, for some other dipterocarp species even only once every thirteen years (Smits, 1982). The breeding system of a species determines the genetic variability at species and population levels. *Shorea leprosula* is a highly outcrossing species (Nagamitsu *et al.*, 2001), pollinated by dispersal-limited insects (Chan, 1981). *Shorea leprosula* is a widely distributed species and, as such, it would be expected to maintain more variation than narrowly distributed species (Hamrick and Godt, 1989). *Shorea leprosula* has winged fruits. During incidental gusts of winds it is possible for the seeds to be carried over considerable distances. The seeds can also be carried by fresh water, which might help them travel larger distances. In this way as well as the natural spread through the extension of the clumps of *S. leprosula* genetic exchange could still take place at least on an evolutionary timescale. In the latter case, the spread is very slow, since *S. leprosula* trees only start flowering when they reach full overstorey light, which takes a considerable amount of time.

According to Hamrick *et al.* (1979) and proved by Hiebert and Hamrick (1983), long-lived trees have a high level of heterozygosity. This is important for the survival of a species in a changing environment, especially when natural selection occurs with high stress levels (Rossignol *et al.*, 1998). High levels of genetic diversity can be associated with population history, strategy and life history of the

species like outcrossing, long life and stress history, breeding system, geographic distribution and high fecundity.

Knowledge of gene flow and mating systems is essential for understanding the reproductive processes of outcrossing plants. A restricted level of gene flow reduces the effective population size, and causes inbreeding depression in outcrossing species (Slatkin, 1985; Wang *et al.*, 1999). Thus, a restricted gene flow presents a threat to the viability of populations of outcrossing plants. Restricted gene flow caused by selective logging may also reduce the population viability of tropical trees. Disturbance to natural populations, such as selective logging of dipterocarp species does not immediately reduce the genetic diversity of the species. It does, however, reduce the outcrossing rates, which means that the probability of inbreeding will increase (Siregar, 2001). However, no estimates on outcrossing rates in *S. leprosula* have been reported so far. Generally, *S. leprosula* ($2n = 14$, Kaur *et al.*, 1986) produced single embryos but seeds with 2 embryos were also detected by Wickneswari *et al.* (1996). Many Dipterocarpaceae show polyembryony. Several Dipterocarpaceae are known to be triploids or tetraploids (Kaur *et al.*, 1978) which produce seeds through apomixis. Chan and Appanah (1981) reported *S. leprosula* to be self-incompatible in an *ex situ* area. Such information besides being useful for the designing of seed orchards, would also be useful in determining numbers for conservation (both *ex situ* and *in situ*) and for enhanced regeneration of production forests.

So again, on the one hand it would be disadvantageous to have more homogeneous populations of *S. leprosula*, but on the other hand it is a fact that the species is homogeneous and highly successful. In this chapter we have presented results that show that for some bands, which potentially might represent alleles, there is a high degree of homogeneity while other bands occur rarely. This may be explained in the following way. Dipterocarpaceae have developed a very successful formula to become the most dominant species in the upper canopy of the lowland rainforests of Malesiana. Their success story starts with the first appearance of the ectomycorrhizal associations in the Tertiary. The ectomycorrhizal relationship has developed so far that it seems that now the Dipterocarps have become completely dependent upon the mycobiont to provide it with certain basic substances needed for a normal development. Smits (1983b) showed that *in vitro* *Shorea cf. obtusa* needed certain vitamins and other supplements for normal development. Even normal non mycorrhizal seedlings reacted positively to a foliar application of thiamine (Vit. B1). So it may well be that strong purifying selection acts on certain genes in order for the plant to co-live with their ectomycorrhizal fungi that bring them many other benefits. For instance, the mycobionts allow the Dipterocarps to let their seedlings survive under the mother tree, they help the Dipterocarps to benefit from direct nutrient cycling thereby enabling them to gain higher biomasses in the forest (Smits, 1994) and they also help to take up important nutrients from the soil as well as water, while also providing more drought stress resistance.

It may also be the case that the special fungicides and insecticides in the resin of Dipterocarpaceae, which are so important for the survival of long lived trees make it necessary that certain genes should remain constant while other less important ones like those that encode the shape of stipules, may vary. This and the mechanism with the mycobionts mentioned above might explain the strange pattern we found here where some band patterns seem to indicate a high degree of homogeneity for certain phenotypes, while others are still highly variable. Actually the same pattern was also found in a Malaysian study from the Forest Research Institute Malaysia (FRIM) (Lee *et al.*, 1996).

In defining the biotopes to which *Shorea* species are ceaselessly adapting, the high stress of drought, fire and logging, recurring every few decades, should be predominant. Not only the reproductive diversity in these *Shorea* genomes is then to be considered. The vegetative adaptive response by somatic mutation, leading to precisely known symptoms in chromosomes and cells, described by Rossignol in Rossignol *et al.* (1998, their chapter 2 and 3) also plays a highly diversifying role in stressed environments. This aspect should be included in further research in genetic diversity and adaptation in dipterocarps.

In three populations studied, the intensive logging activities broke up continuous forests, surviving fragments in the remaining forests becoming smaller so that *S. leprosula* became increasingly more isolated in these remaining forest fragments. On the whole, the three populations of *S. leprosula* showed a quite homogeneous (uniform) pattern along approx. 717 km of geographic distance. Geographically, Tarakan is nearest to Laham whereas Kalbar is furthest from Tarakan. This is indicating that the three sites are generally closely related to each other and may be sub-populations for *S. leprosula* in Kalimantan. Wickneswari *et al.* (1996) indicated that six populations of *H. odorata* in Peninsular Malaysia were also closely related to each other with a mean genetic distance of 0.104, with values ranging from 0.184 to 0.007. This fact can be explained by the selection on the basis of the relationship between plant (Dipterocarpaceae) and ectomycorrhizae on carbohydrate exchange that expressing in protein metabolism. Smits (pers. comm., 2002) indicated that the older the tree, the more genetically homogeneous. The narrowing down of the genetic variability does not seem to have limited the survival potential of dipterocarp species, some being very widespread and common throughout a large distribution range and indeed constant in morphological appearance throughout (Smits, 1994).

The cuttings originating from wildlings from Laham and Tarakan populations were further studied in field experiments in relation to their ability to cope with environmental stress conditions (see Chapter 5 and 6). The present results indicated that the two sources of materials were genetically probably similar, so there was no variation between the two different populations used.

Additional information on life-history characteristics are needed before a final management plan can be formulated for this species (Lee *et al.*, 1996). We, therefore, recommend the following studies for *S. leprosula*:

1. Since DNA-based markers are known to be more sensitive and in most cases result in a higher value of diversity, this technique needs to be used (in combination with crosses).

2.

Controlled crossings to genetically understand the banding patterns with isozyme analysis is needed. Smits (pers. comm., 2002) indicated that *S. leprosula* materials to be studied is available in the Haurbentes demonstration forest of the Forest and Nature Conservation Research and Development Center in West Java (see also Chapter 4). In this forest, this species has a relatively regular phenology cycle in one to two years. This uncommon phenomenon is due to the fact that the species is grown out of its ecological distribution and adjusts opportunistically with this condition.

3.5. CONCLUSION

Variability of *Shorea leprosula* in three populations in Kalimantan was examined by observing banding patterns of isozymes. It was found that the three populations showed a high level of phenotypic variability, which is quite homogeneous (uniform) along approx. 717 km. Similarity in banding patterns decreases with increasing geographic distance.

As a biological group, *Shorea* species known show an exceptional diversity compared to tropical hardwoods in general. They also grow in highly stressed environments with regular, strong impacts from droughts, fires and logging. The biological mechanisms of their adaptation should be studied thoroughly, also taking into account the somatic adaptive responses in stressed plants that were demonstrated by Rossignol *et al.* (1998).

An appropriate conservation strategy needs to be undertaken as illegal logging has drastically reduced the populations, especially in Kalbar. Procurement of planting materials from other sites in East Kalimantan, even across provinces i.e West Kalimantan is possible as they were proven homogeneous. A further investigation into the factors that may play a role in determining the genetic structure of *S. leprosula* in Kalimantan, Indonesia, is needed to support the present finding.

Further study of *S. leprosula* with DNA markers into the genetical population structure as well as inbreeding occurrence and confirmation of the relationship between mother trees and their progeny, however, needs to be undertaken to strengthen the present study and to obtain more comprehensive results.

CHAPTER 4

THE IMPACT OF ENVIRONMENTAL CONDITIONS ON THE GROWTH OF *Shorea leprosula* Miq.: THE GREENHOUSE STUDIES

ABSTRACT

The objective of this study was to observe the effects of plant origin, soil type and mycorrhizal type upon growth of *S. leprosula*. To reach this objective, two greenhouse experiments were set up. The first experiment that ended after 20 months was laid out as a split-plot design with 4 soil types and 4 origins of the wildlings. Both wildlings of *S. leprosula* and soil were collected from the Carita, Haurbentes, Pasirhantap and the Darmaga demonstration forests. Every combination was done 5 times and each analogous group consisted of 5 wildlings. *S. leprosula* grew strongest at the Darmaga soil. *S. leprosula* from Haurbentes showed significantly higher growth rates. *S. leprosula* wildlings from Haurbentes grown in Darmaga soil attained the highest values of all growth parameters. The second experiment that ended after 16 months was carried out as a split-plot design with 3 soil types (loam, sandy loam and sandy clay loam), 2 pasteurisation levels (pasteurised and non-pasteurised) and 5 mycorrhizal types (*Amanita* sp., *Russula* sp., *Scleroderma columnare*, a cocktail of these fungi, and without inoculation). Every combination consisted of 3 cuttings. *S. leprosula* grew strongest at the sandy loam and loam soil medium. *S. leprosula* growth was significantly higher and bigger with pasteurised soil media and mycorrhizal inoculation. *Telephora* sp., *Laccaria* sp., *Reissiella* sp. and *Inocybe* sp. were dominant in colonising the roots of *S. leprosula* cuttings.

4.1. INTRODUCTION

The nature of the predominantly South East Asia dipterocarp trees, and their function in building the forests and as an economic mainstay, were discussed in the introduction to Chapter 1. Over 20 million ha of tropical forest in Indonesia have been deforested since the early 1970's and have now become unproductive degraded forest (Badan Planologi Kehutanan, 2000). Dipterocarps are the major commercial trees of the tropics and deforestation is threatening the existence of many of their species. These trees have a particular pattern of adaptation (cf. Oldeman and Fundter 1986). Consequently, *S. leprosula* will frequently grow on sites that are less hospitable than the sites in which the species evolved.

Dipterocarp species are mostly ectomycorrhizal (ECM), while many other tree species in tropical forest are vesicular arbuscular mycorrhizal (VAM). It is well known that mycorrhizae formation promotes the growth of host plants by improving the absorption of nutrients and water from soil or by protecting roots from pathogenic fungi (Harley and Smith, 1983; Smith *et al.*, 1994). The promotion of seedling growth of dipterocarps by the inoculation with mycorrhizal fungi has been studied (Lee, 1988; Mori and Marjenah, 1994; Smits, 1994). But only a few studies have been carried out on the selection of appropriate fungi for dipterocarp seedlings (Kikuchi, 1997; Omon, 2002).

A high quality planting stock in the nursery is an important factor for the recovery of depleted dipterocarp forests besides the initial plant condition at planting time. The following hypotheses for these experiments were formulated:

1. The origin of the planting material influences the growth of *S. leprosula*,
2. Environmental factors, in particular soil types and/or ectomycorrhizae, codetermine the photosynthetic performance in *S. leprosula*.

With these hypotheses in mind, the objective of this study was to observe the effects of plant origin, soil type and mycorrhizal type upon 'growth as an indicator of photosynthesis' in *S. leprosula*.

To reach this objective, two greenhouse experiments were set up. These experiments focussed on:

1. The influence of **soil types and original population** on *Shorea leprosula*. Assessment of factors buffering stress in *S. leprosula*; origin of plant material versus soil type.
2. The influence of **soil types, pasteurisation of the media, and mycorrhizae** on *Shorea leprosula*. Assessment of factors buffering stress in *S. leprosula*; interaction between mycorrhizal inocula, soil type and pasteurisation of the media.

In general, the same experimental limitations apply here that occur in all half-open greenhouse experiments (e.g. see Omon 2002, with the same species). Pasteurisation is not complete sterilisation, so that a few spores of wild fungi remain alive. Half-open conditions do not exclude some immigration of wild spores from outside or the subsequent contamination of experimental seedlings. Finally, the microclimate in the greenhouse still shows variations from place to place, due to shading objects outside and wind-flows guided by obstacles outside.

In the following, the terms describing the experiment have been adapted accordingly. The soil experiment is indicated as 'a preliminary reconnaissance' for lack of precise soil definitions. The soils were not defined chemically and physically, but only as to their origin and general type (experiment 1). The parallel series of experiments are 'similar treatments', not replications, for lack of complete spatial and temporal homogeneity in the greenhouse. Autoclaving does not sterilise,

but reduces the number of unwanted contaminant organisms, i.e. pasteurisation. The experimental result hence is only considered as far as the statistical outcomes are highly significant, because a significance at lower levels may be a false significance, due to 'environmental noise', i.e. a variation in environmental factors that is random in the context of the experiment.

In the light of laboratory science, such an experimental set-up is unsatisfactory. As a field experiment, it has the drawback of many artificial structures and factors. Still, it is preferred in the present book to remain closer to natural conditions than to perfect laboratory regulation of experimental conditions. Our experiments, therefore, have the virtue of streamlining mere empirical data from nursery practices while at the same time the results are directly relevant to silvicultural practices. This viewpoint will be evaluated in the discussion at the end of this chapter.

4.2 EXPERIMENT 1: THE INFLUENCE OF SOIL TYPES AND ORIGINAL POPULATION ON *Shorea leprosula*. Assessment of factors buffering stress in *S. leprosula*; origin of the plant material versus soil type.

4.2.1 Location and time of the experiment

The experiment was carried out in a greenhouse at the Wanariset Samboja research station (0°59'48" latitude South and 116°58'37" longitude East), located some 38 kilometers northeast of Balikpapan in Samboja village, Kutai district, East Kalimantan (Fig. 4.1). The experiment started in April 2000 by planting *S. leprosula* wildlings and ended after 20 months in December 2001.

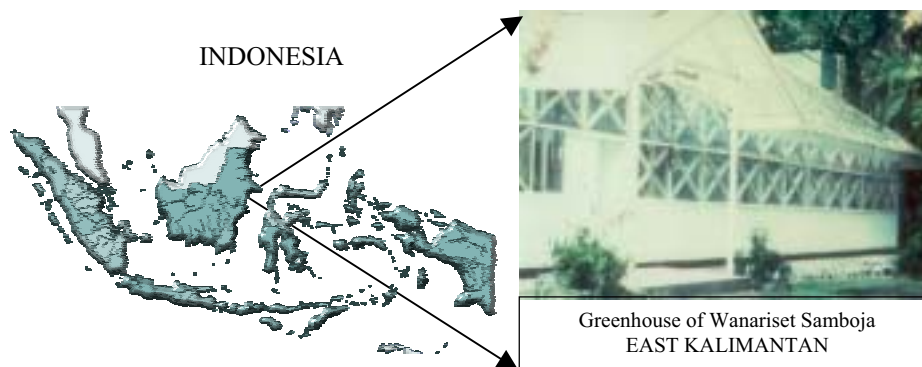


Figure 4.1 Map of the Wanariset Samboja research station, East Kalimantan and picture of the greenhouse

4.2.2 Preparation and experimental design

In March 2000, both wildlings of *S. leprosula* and topsoil were collected from 4 (four) different demonstration forests, namely the Carita, Haurbentes, Pasirhantap and the Darmaga demonstration forest of the Forest and Nature Conservation Research and Development Center in West Java and Banten (Table 4.1). Unfortunately, information about the origin of mother trees and their populations was not recorded. The only information available was that the *S. leprosula* trees in Carita and Darmaga were brought as seeds from Sumatera (Ardikoesoema and Noerkamal, 1955). According to the Schmidt and Ferguson classification (1951), the climates in West Java and Banten belong to type A (wet tropical climate).

According to Masano (1985), Soekotjo, (2001) and Subiakto *et al.*, (2001), *S. leprosula* grow on acid brown forest soil in Haurbentes, on alluvial soil that was formed from clay alluvial rock in Carita, and on poor of quartz soil formed from tuff vulcan intermediate rock in Pasirhantap. The other soil conditions in these experimental forests are pH 4.5 to 4.7, texture clay, structure granular. The soil drainage class is moderately to well drained. Effective soil depth is shallow to deep. Organic matter contents, nitrogen, and potassium are low to moderate, phosphor is low to high and the soil has a rather poor micro mineral content.

Table 4.1 Site description of the demonstration forests in West Java and Banten

Site name	Soil type	Rainfall (mm/year)	Elevation (m asl)	Total area (ha)	Establishment year
Carita (Banten)	Dark grey regosol	3959	50	50	1956
Haurbentes (West Java)	Red-yellow podzolic	3348	200	100	1940
Darmaga (West Java)	Brown-reddish latosol	3552	250	47	1954
Pasirhantap (West Java)	Dark brown latosol	3163	650	35	1957

The plants were grown in black polyethylene bags that were placed on a nursery bed of 1 by 6 m under a simple plastic cover surrounding the nursery bed. The experiment was laid out as a split-plot design with four soil types and four origins of the wildlings. Every combination was done five times and each analogous group consisted of five wildlings. A summary of the experimental design is presented in Table 4.2.

Table 4.2 Summary of the experimental design for testing the effects of different soil origins on the growth of *S. leprosula* wildlings from different sources. Soil types applied and wildlings used were named after their geographic origin

Treatment	Number of treatments	Description
Soil origin	4	Carita (S ₁), Darmaga (S ₂), Haurbentes (S ₃) and Pasirhantap (S ₄)
Wildling origin	4	Carita (W ₁), Darmaga (W ₂), Haurbentes (W ₃) and Pasirhantap (W ₄)
No. blocks	5	
Analogous group	5	
Total wildlings	400	

4.2.3 Data collection and analyses

A combined measuring device for temperature and humidity was hung inside the plastic cover to measure temperature and relative humidity of the atmosphere daily. The Photosynthetically Active Radiation (PAR) was measured using a PAR-measuring device (LICOR type LI-250) from May 2000 to December 2001. The light intensity was taken above the leaves of the cuttings. These three variables were measured twice a week at 08.00 hrs, 12.00 hrs, and 16.00 hrs.

The plant parameters, measured once a month since May 2000, were height and root collar diameter per wildling. The number of leaves was also counted monthly. Growth data (height, root collar diameter and number of leaves) of wildlings were treated in an analysis of variance (ANOVA). This was done to test and compare wildling behaviour between treatments. Data were analysed using SPSS version 10. Significant F-values found by ANOVA were further examined by pair-wise comparisons of means (Duncan's Multiple Range Test).

4.2.4 Results

The average atmospheric temperature and relative humidity at three moments of measurement (08.00 hrs, 12.00 hrs and 16.00 hrs) from February to November 2001 in the greenhouse ranged from 31 to 34°C and from 78 to 84%. The average temperature of the air was 32°C, with an average relative humidity of 82%. August to October were the hottest months with an atmospheric temperature of 34°C and the lowest relative humidity (78%) was achieved in September 2001. The data of atmospheric temperature and relative humidity in the greenhouse during the experiment period over the year 2001 can be seen in Appendix 6.

The average light intensity (PAR) at three moments of measurement (08.00 hrs, 12.00 hrs and 16.00 hrs) in the greenhouse was 8.5, 12.1 and 4.8 $\mu\text{mol m}^{-2}\text{s}^{-1}$, respectively. These values were 9.5, 7.1 and 9.4% from light intensity outside the greenhouse. The average light intensity (PAR) in the greenhouse was 8.5 $\mu\text{mol m}^{-2}\text{s}^{-1}$ or 8.2% of full daylight.

4.2.4.1 Effects of soil origin

The growth of *S. leprosula* in different soil origins is shown in Fig. 4.2 and Table 4.3. During the first two months, *S. leprosula* grew significantly better in the soil media from Pasirhantap. At the end of the experiment the soil from Darmaga had the highest growth rates, the soil from Haurbentes had the lowest and the soil from the other sites showed intermediate behaviour of the wildlings.

S. leprosula had the smallest diameter in the soil from Haurbentes and the differences with the others were significant as from the 6th month. Even though the diameter between the soil types did not differ except for soil from Haurbentes in the end of the experiment, there were differences between the diameter increment of *S. leprosula* in

the soil from Darmaga and Carita and that of *S. leprosula* in the soil from Pasirhantap and Haurbentes (see Fig. 4.2).

Table 4.3 Effects of soil origins (Carita, Darmaga, Haurbentes and Pasirhantap) on various growth parameters of *S. leprosula* wildlings 20 months after treatment. a: length of axes, h: height, Δh : height increment, Δd : diameter increment, d: diameter, Σa : number of axes, Σl : number of leaves

Soil type	a (cm)	h (cm)	Δh (cm)	d (cm)	Δd (cm)	Σa	Σl
Soil 1 (Carita)	41.4 ab	40.7 ab	18.9 a	0.51 ab	0.30 b	1.02 a	10.1 ab
Soil 2 (Darmaga)	48.5 c	45.0 b	23.6 b	0.52 b	0.32 c	1.11 a	10.7 bc
Soil 3 (Haurbentes)	40.1 a	39.5 a	19.0 a	0.45 a	0.26 a	1.11 a	8.8 a
Soil 4 (Pasirhantap)	45.2 bc	42.2 ab	19.5 a	0.50 ab	0.27 a	1.12 a	12.0 c

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

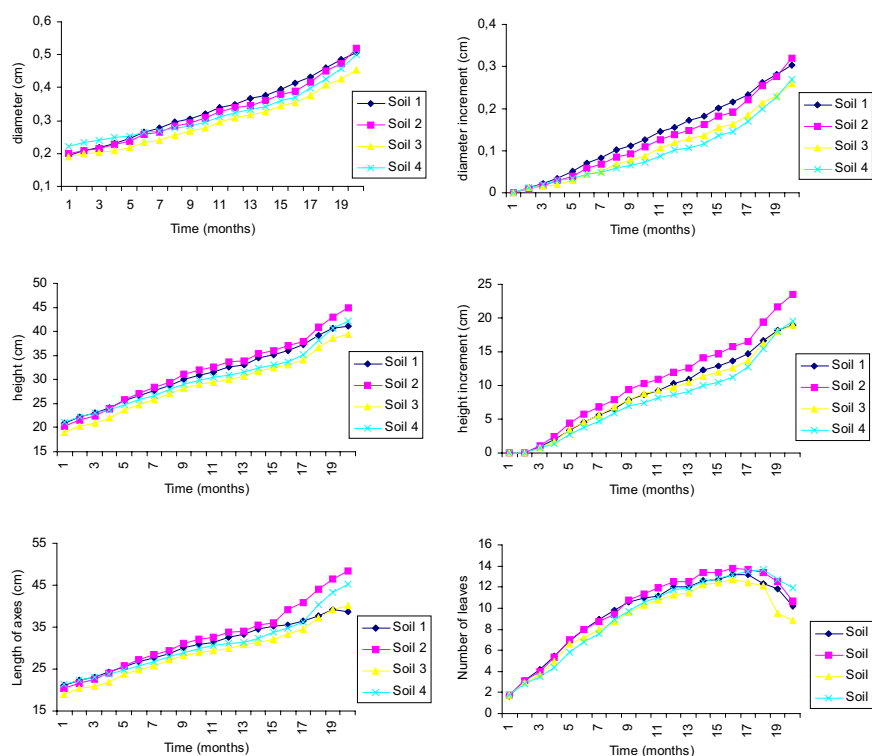


Figure 4.2 Effects of soil origin on some growth parameters of *S. leprosula* wildlings. Note that there are no great differences (1: Carita, 2: Darmaga, 3: Haurbentes, 4: Pasirhantap).

In the first month of the experiment, there were no significant differences in diameter increment on different soil origins. Each soil origin yielded significantly different diameter increments from the 2nd to 7th month and at the 9th, 13th, 16th, 19th and 20th month. At the end of the experiment, *S. leprosula* had the highest diameter increment in the soil from Darmaga.

There were significant differences in height growth of *S. leprosula* wildlings grown in the different soil origins in the 12th, 16th and 20th month. At the end of the experiment, *S. leprosula* had the highest height growth in the soil from Darmaga. As shown in Fig. 4.2, the branches developed as from the 15th month when a difference between height and length of axes appeared. There were no significant differences in the number of axes of *S. leprosula* wildlings grown in the different soil origins at the end of the experiment. The height increment of *S. leprosula* wildlings grown in the Darmaga soil was the highest as from the 4th month.

As from the 10th month, the increase in the number of leaves was not as high as before, the initial leaves in the plants were replaced by a fully new set of leaves. This indicates that the plants fully adapted to the greenhouse environment. The number of leaves decreased as from the 18th month.

4.2.4.2 Effects of the origin of wildlings

The growth of *S. leprosula* from different origins is shown in Fig. 4.3 and Table 4.4. In general, *S. leprosula* from Haurbentes showed significantly higher growth rates.

S. leprosula from Haurbentes had the smallest diameter during the first four months and the differences were significant. In the second four months, there were significant differences between the diameter of *S. leprosula* from Haurbentes and Darmaga and that of *S. leprosula* from Carita and Pasirhantap. *S. leprosula* from Darmaga had the smallest diameter and the differences with the others was significant as from the 10th month.

In the first two months of the experiment, there were no significant differences in diameter increment of *S. leprosula* from different origins. As from the 3rd month, the diameter increment of *S. leprosula* from Haurbentes was higher compared with other wildlings origin. There were clear differences between the diameter increment of *S. leprosula* from Haurbentes, from Carita and Pasirhantap and that of *S. leprosula* from Darmaga as from the 10th month (see Fig. 4.3).

During the experiment, significant differences appeared in the height of *S. leprosula* and at the end of the experiment the height was 32.7 cm (Darmaga), 40.1 and 42.5 cm (Carita and Pasirhantap) and 49.7 cm (Haurbentes), respectively. The height, height increment and the length of axes of *S. leprosula* from Darmaga were the lowest compared with the other origins as from the 5th month. As shown in Figure 4.3, even though *S. leprosula* from Darmaga had more axes (see Table 4.4), the length of the axes

was the same as their height. So the branches had not well developed. Contrary to the larger number of axes of *S. leprosula* from Pasirhantap, the length of their axes increased after 15 months. As from that moment, there were no significant differences in the length of the axes of *S. leprosula* between wildlings originating from Pasirhantap and Haurbentes.

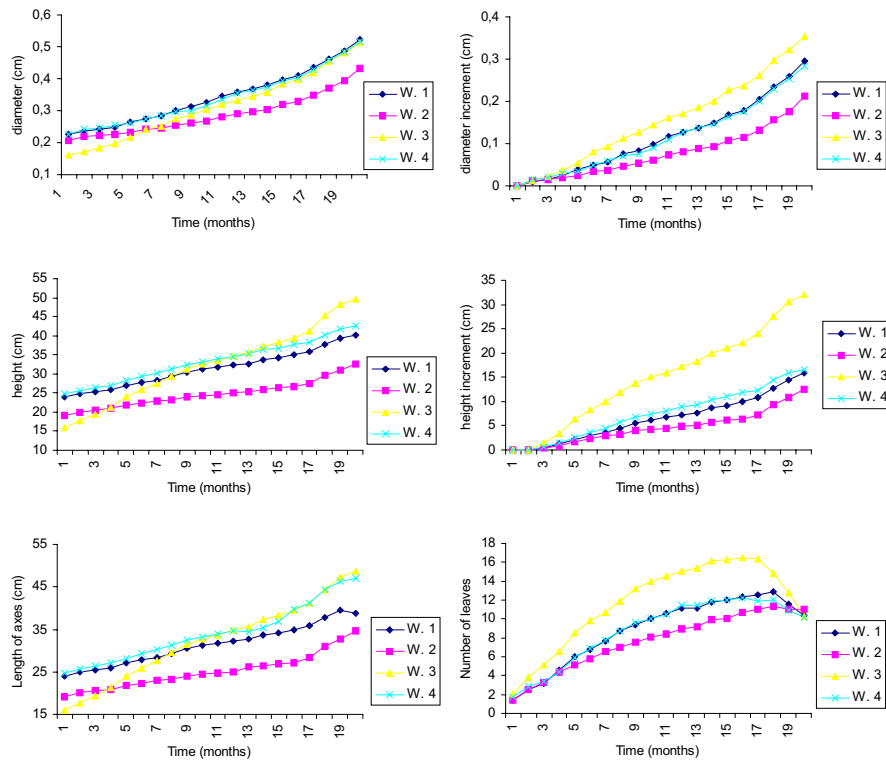


Figure 4.3 Effects of the origin of wildlings on some growth parameters of *S. leprosula* (W.1: Carita, W.2: Darmaga, W.3: Haurbentes, W.4: Pasirhantap).

After 10 months, the increase in the number of leaves was not as high as before, and the initial leaves were replaced by a fully new set of leaves. The number of leaves decreased after 17 months. There were no significant differences in the leaf number of *S. leprosula* at the end of the experiment.

Table 4.4 Effects of wildlings origin on various growth parameters of *S. leprosula* wildlings 20 months after treatment. a: length of axes, h: height, Δh: height increment, Δd: diameter increment, d: diameter, Σa: number of axes, Σl: number of leaves

Wildlings origin	a (cm)	h (cm)	Δh (cm)	d (cm)	Δd (cm)	Σa	Σl
W. 1 (Carita)	38.7 a	40.1 b	15.9 b	0.52 b	0.30 b	1.0 a	10.4 a
W. 2 (Darmaga)	34.6 a	32.7 a	12.4 a	0.43 a	0.21 a	1.2 b	11.0 a
W. 3 (Haurbentes)	48.7 b	49.7 c	32.1 c	0.51 b	0.35 c	1.0 a	10.2 a
W. 4 (Pasirhantap)	47.0 b	42.5 b	16.5 b	0.52 b	0.28 b	1.2 b	10.1 a

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

4.2.4.3. Effects of the origin of wildlings and soil

Significant differences between treatment combination appeared as from the 3rd month (height increment), 5th month (height), 8th month (diameter), 10th month (number of leaves) and the 13th month (length of axes). There were no significant differences as to the number of axes.

As shown in Table 4.5, *S. leprosula* wildlings from Haurbentes grown in soil from Darmaga attained the highest values of all growth parameters after 20 months.

Table 4.5 Effects of the soil and wildling origin on various growth parameters of *S. leprosula* wildlings, 20 months after treatment. a: length of axes, h: height, Δh: height increment, d: diameter, Δd: diameter increment, Σa: number of axes, Σl: number of leaves

Soil origin	Wildlings origin	a (cm)	h (cm)	Δh (cm)	d (cm)	Δd (cm)	Σa	Σl
S.1 (Carita)	W. 1 (Carita)	33.6	38.3	17.0	0.54	0.35 a	1.0 a	10.7 a
	W. 2 (Darmaga)	36.3	38.5	15.8	0.49	0.26 a	1.1 a	10.2 a
	W. 3 (Haurbentes)	41.0	44.2	27.8	0.49	0.32 a	1.0 a	10.8 a
	W. 4 (Pasirhantap)	41.3	41.3	16.7	0.52	0.29 a	1.0 a	9.0 a
S.2 (Darmaga)	W. 1 (Carita)	38.0	38.0	14.0	0.47	0.24 a	1.0 a	9.7 a
	W. 2 (Darmaga)	36.4	33.7	15.9	0.41	0.22 a	1.1 a	11.6 a
	W. 3 (Haurbentes)	61.7	61.7	47.0	0.64	0.49 a	1.0 a	7.9 a
	W. 4 (Pasirhantap)	54.2	43.0	16.6	0.52	0.29 a	1.3 a	10.9 a
S.3 (Haurbentes)	W. 1 (Carita)	36.0	36.0	14.5	0.45	0.23 a	1.0 a	10.9 a
	W. 2 (Darmaga)	30.6	30.0	13.3	0.42	0.21 a	1.3 a	8.8 a
	W. 3 (Haurbentes)	48.3	48.3	31.1	0.43	0.28 a	1.0 a	8.5 a
	W. 4 (Pasirhantap)	43.6	39.9	17.1	0.54	0.34 a	1.1 a	7.1 a
S.4 (Pasirhantap)	W. 1 (Carita)	49.6	49.6	23.2	0.64	0.38 a	1.0 a	10.2 a
	W. 2 (Darmaga)	35.7	28.8	8.4	0.41	0.15 a	1.2 a	13.4 a
	W. 3 (Haurbentes)	47.1	47.1	32.1	0.52	0.35 a	1.0 a	13.4 a
	W. 4 (Pasirhantap)	48.5	44.6	18.4	0.49	0.24 a	1.2 a	10.3 a

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

**4.3 EXPERIMENT 2:
THE INFLUENCE OF SOIL TYPES, PASTEURISATION OF THE
MEDIA, AND MYCORRHIZAE ON *Shorea leprosula*.**

Assessment of factors buffering stress in *S. leprosula*; interaction between mycorrhizal inocula, soil type and pasteurisation of the media.

4.3.1 Location and duration of the experiment

The experiment started on 4 July 2000 by transplanting *S. leprosula* cuttings into different soil types, followed by inoculation of these cuttings with certain mycorrhizal fungi in the greenhouse of the Wanariset Samboja research station, located at 38 kilometers north-east of Balikpapan in East Kalimantan. The greenhouse experiment ended after 16 months on 4 November 2001 by taking root samples for further mycorrhizal analysis.

4.3.2 Methods

Three different soil-types, namely loam (A₃), sandy loam (A₁) and sandy clay loam (A₂), were used as medium for the rooted cuttings. These soil types were collected from the area where the field experiment took place (see Chapter 5). These soil types are quite common in the province of East Kalimantan. Half of each of these soil types was pasteurised by means of heating at 80°C for 30 minutes in autoclave to eliminate harmful micro-organisms and weed seed, while some beneficial microbes remain (Davidson *et al.*, 1994); the other half was left untreated. The cuttings of *S. leprosula* were then planted in perforons (see Box 2). Each of the root-boxes (perforons) was planted with one rooted cutting of *S. leprosula*.

Box 2: The perforon



The perforon (root box) used was made of aluminum and had a rectangular bottom of 7.5 by 10 cm and a 10 by 12 cm top. The height was 32 cm. The front and back walls of the box were perforated with 14 holes of 12 mm in diameter, 4 cm apart from each other. At the sides of the perforated front and back wall there were double grooves, in which transparent plates in the back and covering aluminium plates in the front could be lowered down and lifted up (after Smits, 1994, Omon, 2002).

The four inocula used in this experiment contained the same ectomycorrhizal fungi as those used by Omon (2002) on *S. leprosula*, i.e. *Amanita* sp., *Russula* sp., *Scleroderma columnare* and a cocktail of fungi (mixture of the same three species). Plants with non-inoculated roots constituted the 'no treatment' group.

Fruiting bodies of these fungi were collected along the 'Wartono Kadri trail', located in a primary dipterocarp lowland forest, 4 km west of the Wanariset Samboja research station. The fruiting bodies of three ectomycorrhizal fungi were cut into pieces and further treated for a short time in a blender according to the method described by Mason and Ingleby (1997). Then the fungal material was mixed with water to form a suspension. The number of spores in one milliliter of this watery suspension was approx. 10.000 (Omon, 2002). The treatment without mycorrhizal inoculation was not given a clean water drop of one milliliter since this quantity was insignificant compared with the daily watering needs of the plants.

The experiment was carried out in the same greenhouse as the experiment I (see Chapter 4.2). The pots were placed in greenhouse beds of 1 by 6 m. The surface of the greenhouse beds was cleaned with antiseptic chemicals (calcium carbonate). To reduce the risk of fungal contamination, the cuttings were grown under a simple transparent plastic cover in separate chambers (compartments) for each mycorrhizal type. The cover maintained relative humidity and temperature of the air, minimized air movements and to some extent reduced the risk of an unwanted ectomycorrhizal inoculum entering the experiment and contaminating the plants. Under non-hermetic greenhouse conditions, there is still a chance of aggressive mycorrhizal fungi notably *Thelephora terrestris* to colonize the roots of dipterocarp cuttings. Therefore, the effect of inoculations could not be measured as a difference between plants with and without mycorrhizae, but as the difference between inoculated and non-inoculated plants, accepting the 'influence of nature' in the resulting numerical data (Omon, 2002). Watering was done once a day, except during unusually warm days when watering was more frequent to prevent wilting of the plants. The water came from a local deep well, considered free from ectomycorrhizal inocula.

This experiment was carried out as a split-plot design with 3 (three) soil types, 2 (two) pasteurisation levels and 5 (five) mycorrhizal types. Every combination consisted of 3 (three) cuttings. A summary of the design is presented in Table 4.6.

Table 4.6 Summary of the experimental design for testing the effects of different soil types and conditions on the growth of *S. leprosula* cuttings and the development of their mycorrhizae.

Treatment	Number of treatments	Description
Soil type	3	Sandy loam (A ₁), sandy clay loam (A ₂) and loam (A ₃)
Pasteurising of soil	2	Pasteurised and non-pasteurised
ECM inoculated	5	<i>Amanita</i> sp., <i>Russula</i> sp., <i>Scleroderma columnare</i> , cocktail of these fungi, and without inoculation
Similar blocks	3	
Total cuttings	90	

4.3.3 Data collection and analyses

The first measurements were taken two months after the transplantation and inoculation, to give the cuttings ample time to grow and to develop a sound symbiosis between their root system and the mycorrhizal fungi. The parameters measured monthly were total height, number and length of axes, root collar diameter growth, and number of leaves of each plant. No cutting died during these two months. At the beginning of the experiment, 10 (ten) cuttings were sampled and measured for their height, diameter, number of leaves and biomass. The fresh weight was determined on 4 July 2000, then the cuttings were oven-dried at 70°C for 60 hours to get their dry weight. The ratios of fresh weight/dry weight (biomass) and shoot/root dry weight were determined. Soil properties, such as soil type, mineral contents and pH were analysed in March 2000. Atmospheric temperature and relative humidity were measured twice a week at 08.00 hrs, 12.00 hrs and 16.00 hrs. At the end of the experiment, the number and types of ectomycorrhizae (ECM) formed were investigated in the laboratory at the Wanariset Samboja research centre.

The data obtained for the various growth parameters of the experimental plants were subjected to an analysis of variance (ANOVA) to test the significance of the effect of each factor, i.e. of soil type, of pasteurisation of the media, and of the inoculum. The SPSS version 10 was used. Significant F values obtained by the ANOVA tests were further examined by pair-wise comparison of means using Duncan's Multiple Range Test in the SPSS software.

4.3.4 Results

The average atmospheric temperature and relative humidity at three moments of measurement (08.00 hrs, 12.00 hrs and 16.00 hrs) from July 2000 to November 2001 in the greenhouse ranged from 28.5 to 34.2°C and from 78.3 to 91.3%. The highest atmospheric temperature and the lowest relative humidity were recorded in September 2001. The data of atmospheric temperature and relative humidity in the greenhouse during the experiment period over the year 2001 can be seen in Appendix 6.

According to Balsem and Buurman (1989), the textures of the soils used in the experiment are medium fine (sandy clay loam), medium (loam) to medium coarse (sandy loam). The soils in the experiment are acid ($4.92 \leq \text{pH} \leq 5.24$, see Table 4.7). The organic carbon is low (soil code A₂ and A₃) to moderate (soil code A₁). The total nitrogen content in the topsoil is low (0.13%). Available phosphorus content is very low (A₃), low (A₂) and high (A₁). The values of Cation Exchange Capacity (CEC) are low (10.2 to 13.27). The soils in the experiment have a low (A₂ and A₃) to moderate (A₁) base saturation. The soils have a very high (1.75), moderate (0.47) to low (0.39) exchangeable base of Ca, a moderate (0.53 to 0.68) exchangeable Mg base, a low (0.45 to 0.48) to very low (0.27) exchangeable K base, and a very low (0.58 to 0.71) exchangeable Na base. Based on the values of CEC, base saturation, C-organic and available phosphorus, the fertility of the soils in the experiment is classified as very low

(A₂ and A₃) to moderate (A₁). This rating system of the fertility status for land quality ‘nutrient availability’ is described in the FAO land suitability system (1977).

Table 4.7 Soil characteristics of the three experimental sites. Values represent the mean values of three samples collected from each site at a depth of 0 to 20 cm and analysed separately. Avl: available, BS: base saturation, CEC: cation exchange capacity, L: Loam, Meq: meq/100 g of soil, Org: organic, SCL: Sandy Clay Loam, SL: Sandy Loam, Tot: total.

Soil code	Clay (%)	Silt (%)	Sand (%)	Texture	pH H ₂ O	PH KCl	N avl. (ppm)	P avl. (ppm)	K avl. (meq)	C-org (%)
A ₁	12.56	19.95	67.49	SL	5.07	3.90	64.03	32.4	0.28	2.13
A ₂	21.80	22.70	55.50	SCL	5.24	3.68	75.01	13.9	0.28	1.42
A ₃	22.11	46.77	31.12	L	4.92	3.62	82.08	8.08	0.34	1.27

Soil code	C/N	N _{tot} (%)	BO (%)	CEC (meq)	Ca (meq)	Mg (meq)	Na (meq)	K (meq)	BS (%)	Fertility status
A ₁	16.38	0.13	3.67	7.35	1.75	0.68	0.70	0.27	46.3	Moderate
A ₂	20.28	0.07	2.46	7.05	0.47	0.53	0.58	0.48	29.2	Very low
A ₃	9.77	0.13	2.19	7.58	0.39	0.57	0.71	0.45	28	Very low

The results of the experiment are presented for the three main factors and their interaction, namely: soil type, soil pasteurisation and mycorrhizal inoculation. The effect of each factor and their interaction on plant growth and mycorrhizal development is presented consecutively, taking into account the statistical noise caused by the immigration of spores mentioned in the paragraphs on introduction.

The average height, root collar diameter and the number of leaves of *S. leprosula* cuttings at the beginning of the experiment were 12.2 (\pm 2.2) cm, 0.23 (\pm 0.04) cm and 1.85 (\pm 1.3), respectively. The biomass of leaves, stems and roots was 3.66, 3.66 and 4.34, respectively. The initial shoot root ratio of *S. leprosula* was 9.95.

4.3.4.1 Effects of soil type

The growth of *S. leprosula* in different soil origins is shown in Fig. 4.4 and Table 4.8. The analysis of variance (ANOVA) shows that the soil type was linked to the growth of *S. leprosula* cuttings until 15 months after transplanting into the greenhouse. This is especially the case with the parameters of the height increment (at the 11th, 14th and 15th month), and the number of leaves (at the 13th and 15th month). The soil type influenced the diameter and height of *S. leprosula* cuttings at the 15th month after transplanting. As from the 8th month, the height of *S. leprosula* cuttings grew faster and the branch developed for all soil treatments (see Fig. 4.4). *S. leprosula* cuttings took 8 months to adapt to the new environmental in the greenhouse, especially with soil types conditions. The soil type did not influence the length of axes and the number of axes of *S. leprosula* cuttings until 15 months after transplanting. There were no significant differences in the number of branches of *S. leprosula* cuttings grown in the different soil types at the end of the experiment. At the end of the experiment the sandy loam and loam soils had higher growth rates

whereas the sandy clay loam soil had the lowest growth of *S. leprosula* cuttings (see Table 4.8).

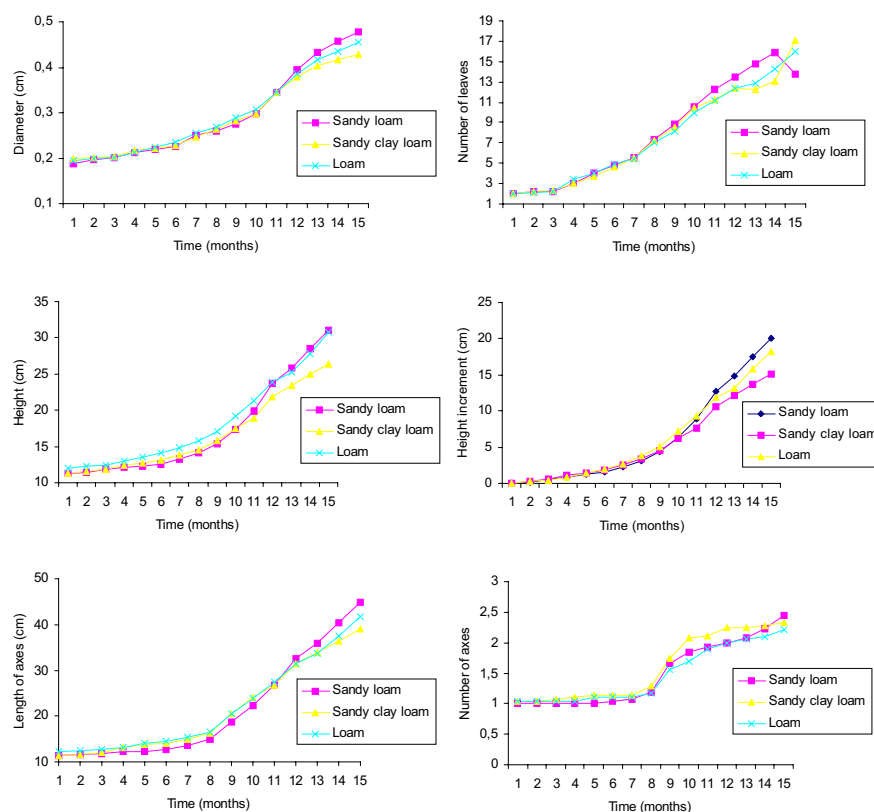


Figure 4.4 Effects of soil type on some growth parameters of *S. leprosula* cuttings.

Table 4.8 Effects of soil type on various growth parameters of *S. leprosula* cuttings after 15 months. a: length of axes, h: height, Δh : height increment, d: diameter, b: length of branches, Σa : number of axes, Σl : number of leaves

Soil type	a (cm)	h (cm)	Δh (cm)	d (cm)	b (cm)	Σa	Σl
Sandy loam	44.9 a	31.0 b	20.0 b	0.48 b	22.1 a	2.4 a	17.1 b
Sandy clay loam	39.1 a	26.4 a	15.2 a	0.43 a	18.8 a	2.3 a	13.8 a
Loam	41.8 a	30.7 b	18.2 b	0.46 ab	14.6 a	2.2 a	16.0 ab

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

4.3.4.2 Effects of pasteurisation of media

The results of the analysis of variance (ANOVA) show that the pasteurisation of the media was linked to the growth of *S. leprosula* cuttings. The pasteurisation of media stimulated their diameter growth (as from the 10th month), height growth (as from the 9th month), the height increment (from the 5th to 11th months) and the number of leaves (except at the 13th month). The increasing diameter growth influenced the energy balance in *S. leprosula* cuttings.

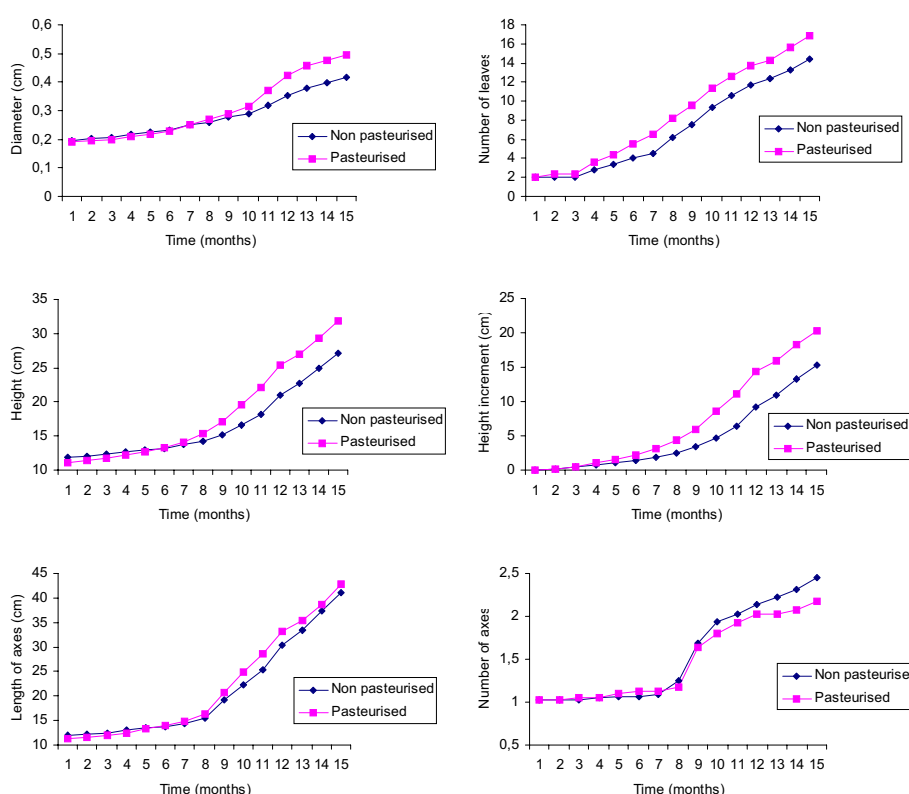


Figure 4.5 Effects of pasteurisation of media on some growth parameters of *S. leprosula* cuttings.

The pasteurisation of media did not influence the length of the branches, the number of axes and their length of *S. leprosula* cuttings during the 15-month of the experiment. As from the 8th month, *S. leprosula* cuttings started to branch (see Fig. 4.5). In general, pasteurisation of media supported the highest growth rates of *S. leprosula* (Fig. 4.5 and Table 4.9).

Table 4.9 Effects of pasteurisation of media on various growth parameters of *S. leprosula* cuttings 15 months after treatment. a: length of axes, h: height, Δh: height increment, d: diameter, b: length of branches, Σa: number of axes, Σl: number of leaves

Pasteurisation	a (cm)	h (cm)	Δh (cm)	d (cm)	b (cm)	Σa	Σl
Non-pasteurised	41.1 a	27.1 a	15.3 a	0.4 a	19.2 a	2.5 a	14.4 a
Pasteurised	42.8 a	31.8 b	20.3 b	0.5 b	16.9 a	2.2 a	16.9 b

Note: Values followed by the letters a or b in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

4.3.4.3 Effects of mycorrhizal inoculation

The results of the analysis of variance (ANOVA) show that the mycorrhizal inoculation influenced the growth of *S. leprosula* cuttings during the 15-month of the experiment. This is especially the case with the parameters of diameter growth (as from the 10th month), height growth (as from the 8th month), the height increment (from the 5th to 8th and at the 10th month) and the number of leaves (at the 2nd and from the 4th to 9th month). Mycorrhizal inoculation did not influence the length and the number of axes of *S. leprosula* cuttings during the 15 months of the experiment. *S. leprosula* seedlings inoculated with mycorrhizal fungi grew higher and bigger than non-inoculated seedlings (Table 4.10 and Fig. 4.6).

Table 4.10 Effects of mycorrhizal inoculation on various growth parameters of *S. leprosula* cuttings 15 months after treatment. a: length of axes, h: height, Δh: height increment, d: diameter, b: length of branches, Σa: number of axes, Σl: number of leaves

Mycorrhizal inoculation	a (cm)	h (cm)	Δh (cm)	d (cm)	b (cm)	Σa	Σl
0 No inoculation	35.7 a	24.8 a	13.2 a	0.41 a	17.4 a	1.9 a	13.5 a
1 <i>Amanita</i> sp.	43.6 a	32.8 b	18.8 ab	0.46 abc	13.2 a	2.4 a	15.0 ab
2 <i>Russula</i> sp.	45.5 a	33.0 b	22.2 b	0.47 bc	19.4 a	2.5 a	17.8 b
3 <i>Scleroderma</i> sp.	41.9 a	29.5 ab	18.7 ab	0.50 c	19.1 a	2.3 a	15.6 ab
4 Cocktail	42.6 a	26.8 a	15.8 a	0.43 ab	21.9 a	2.4 a	15.9 ab

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

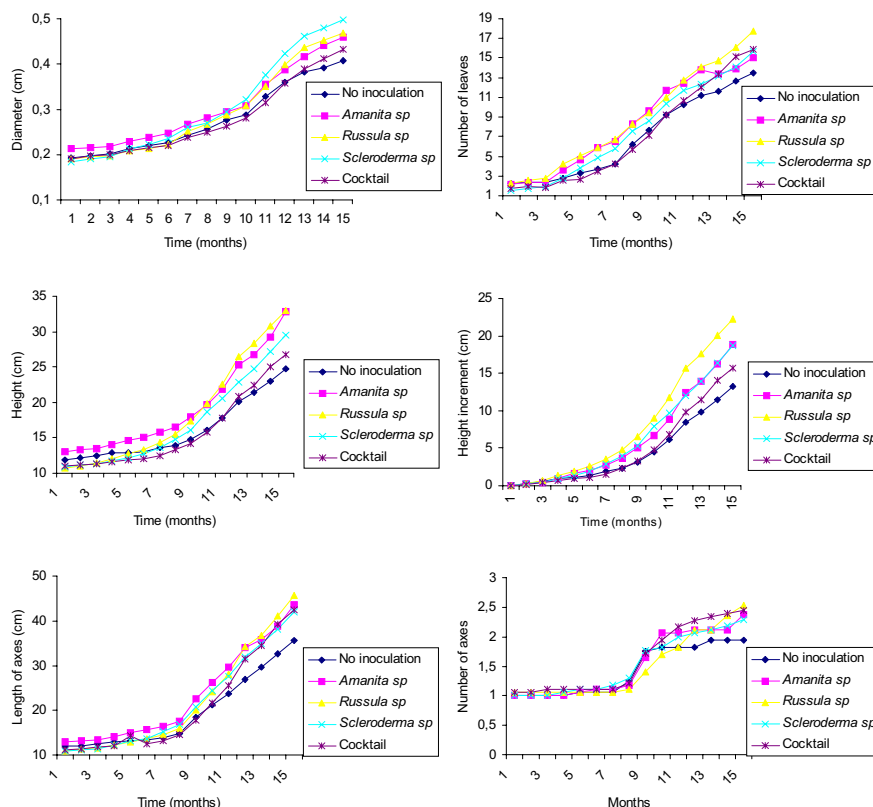


Figure 4.6 Effects of mycorrhizal inoculation on some growth parameters of *S. leprosula* cuttings. Note that the 'no treatment' cuttings consistently lag behind all treatments with mycorrhizal fungi.

4.3.4.4 Mycorrhizal development

The percentages of mycorrhizal seedlings, including the mycorrhizal species with various soil types, with different pasteurisation treatments and with different initial mycorrhizal inoculation are shown in Table 4.11.

The analysis of variance (ANOVA) shows that the colonisation of ectomycorrhizae (ECM) on *S. leprosula* cuttings was not linked to soil type, pasteurisation of the media or the initial inoculation until 15 months after transplanting into the greenhouse. The ECM of *S. leprosula* cuttings grown in various treatments varied from 84 to 93%.

Within the 15 months in the greenhouse, the mycorrhizal colonisation changed completely. There were no initial mycorrhizal fungi that had colonised the root of *S. leprosula* after the 15 months of the experiment. Aggressive, pioneer and ‘early stage’ mycorrhizal fungi dominated the colonisation of *S. leprosula* roots. *Laccaria sp.* was the most common one, followed by *Thelephora sp.*, *Riessiella sp.* and *Inocybe sp.*

Table 4.11 Ectomycorrhizae (ECM) percentage (%) of *S. leprosula* cuttings grown with various treatments 15 months after inoculation in the greenhouse.

Treatments	Mycorrhizal Roots (%)	Mycorrhizal species (%)			
		<i>Thelephora sp.</i>	<i>Laccaria sp.</i>	<i>Riessiella sp.</i>	<i>Inocybe sp.</i>
SOIL TYPE					
Sandy loam	93.0 a	15.6 a	66.0 a	10.3 a	1.2 a
Sandy clay loam	84.0 a	7.6 a	66.5 a	7.9 a	2.0 a
Loam	85.4 a	7.1 a	60.1 a	16.8 b	1.5 a
PASTEURISATION					
Non-pasteurised	86.2 a	8.5 a	67.5 a	8.2 a	2.0 a
Pasteurised	88.7 a	11.7 a	60.8 a	15.1 b	1.2 a
INOCULATION					
No inoculation	85.6 a	17.9 a	56.8 a	11.0 a	0.0 a
<i>Amanita sp.</i>	88.3 a	9.3 a	70.1 a	7.1 a	1.9 a
<i>Russula sp.</i>	85.8 a	9.0 a	59.6 a	16.8 a	0.7 a
<i>Scleroderma sp.</i>	89.5 a	7.1 a	72.7 a	9.2 a	0.5 a
Cocktail	87.9 a	7.2 a	61.7 a	14.3 a	4.8 b

Note: Values followed by the letters a or b in the same column indicate the significant differences at a 5% level according to Duncan’s Multiple Range Test.

The colonisation by *Riessiella sp.* on *S. leprosula* cuttings was linked to soil type and pasteurisation of the media, whereas the colonisation by *Inocybe sp.* on the roots of *S. leprosula* cuttings was linked to the initial mycorrhizal inoculum. *Riessiella sp.* developed well in loam soil and in pasteurised soil and the highest percentage of *Inocybe sp.* colonised the roots of *S. leprosula* that were inoculated with a cocktail at the beginning of the experiment.

Laccaria sp. was the most abundant mycorrhizal inoculum, and varied from 57 to 73%, followed by *Thelephora sp.* (7 to 18%), *Riessiella sp.* (7 to 17%) and *Inocybe sp.* (up to 5%).

4.3.4.5 Effects of interaction between soil type, pasteurisation of the media and mycorrhizal inoculation

The influence of the interaction between soil type, pasteurisation of media and inoculation with mycorrhizae on the growth of *S. leprosula* cutting can be seen in Appendix 5.

Interaction between soil type and pasteurisation of the media

The results of the analysis of variance (ANOVA) show that the interaction between soil type and pasteurisation of the media significantly influenced the growth of *S. leprosula* cuttings, in terms of height growth from the 6th to 7th month, the number of axes at the 3rd, 14th and 15th month, the diameter growth as from the 14th month, the length of axes at the 3rd, 6th, 7th, 14th and 15th month, and the number of leaves at the 8th, 11th, 13th, 14th and 15th month. The interaction between soil type and pasteurisation of the media did not influence the height increment of *S. leprosula* cuttings during the 15-month after transplanting into the greenhouse. In general, the interaction between soil type and pasteurisation of the media started to influence the growth of *S. leprosula* cuttings significantly as from the 14th months after transplanting. The significant differences for growth parameters before this month seem a variation in growth dynamics. *S. leprosula* reached the strongest growth if the loam soil media was pasteurised.

Interaction between soil type and mycorrhizal inoculation

The results of the analysis of variance (ANOVA) show that the interaction between soil type and mycorrhizal inoculation influenced the growth of *S. leprosula* cuttings, in terms of diameter growth and the length of axes during the 15 months after transplanting into the greenhouse. The significant differences appeared on the height growth (except at the 3rd and 5th month), height increment (at the 2nd, 6th and 9th month), the number of axes (at the 3rd, 9th, 10th and 11th month) and the number of leaves (as from the 9th months) of *S. leprosula* cuttings. *S. leprosula* reached the strongest growth if inoculated with *Russula sp.* and with loam soil as its substrate.

Interaction between pasteurisation of the media and mycorrhizal inoculation

The results of the analysis of variance (ANOVA) show that interaction between pasteurisation of the media and mycorrhizal inoculation influenced the growth of *S. leprosula* cuttings such as height growth at the 9th, 10th and 11th month, height increment at the 7th, 9th and 10th month, the number of axes at the 3rd month and the number of leaves at the 12th month. The interaction between pasteurisation of the media and mycorrhizal inoculation did not influence the growth of *S. leprosula* cuttings, in terms of the parameters of diameter growth and length of axes during the 15 months after transplanting into the greenhouse. *S. leprosula* reached the strongest growth if inoculated with *Russula sp.* and with pasteurised media.

Interaction between soil type, pasteurisation of the media and mycorrhizal inoculation

The results of the analysis of variance (ANOVA) show that the interaction between soil type, pasteurisation of the media and mycorrhizal inoculation influenced significantly the growth of *S. leprosula* cuttings. The differences appeared on growth parameters, namely height growth at the 11th, 12th and 13th month, height increment at the 6th and 7th month, the number of axes at the 3rd, 4th, 8th and 11th month and the number of leaves at the 2nd month. The interaction among soil type,

pasteurisation of the media and mycorrhizal inoculation did not influence the growth of *S. leprosula* cuttings, in terms of diameter growth and the length of axes during the 15 months of the experiment. *S. leprosula* reached the strongest growth if inoculated with *Russula sp.* and with pasteurised media and loam soil as its substrate.

4.4 DISCUSSION

Growth and performance of seedlings are primarily related to the nutrient content of the potting media and the sources of seedling. At nursery level, it is important to consider the source of the soil. Some soil is more favourable for some species and others are less suitable. Suhardi and Darmawan (1991) showed that in East Kalimantan, soil from Bukit Suharto was more suitable for mycorrhizal infection than that from Lempake. In this study, soil from Darmaga or wildlings from Haurbentes resulted in a higher value of growth parameters for *S. leprosula* and the combination of wildlings from Haurbentes and the soil media from Darmaga gave the highest values of growth parameters for *S. leprosula*.

In this experiment, sandy loam and loam gave the highest growth for *S. leprosula* followed by sandy clay loam in the nursery. A similar result was found by Omon (2002). Matching sandy loam with *S. leprosula* was continued in the field (see Chapter 5).

The aim of pasteurising soil substrates is to reduce the potential threat from pathogens and other micro-organisms that would limit mycorrhizal fungal growth on the roots. Overheating can be disadvantageous in soil media containing some types of acid soil because the release of toxic amounts of Mn can cause a Fe deficiency in containerised plants. The result of this experiment confirmed this. *S. leprosula* growth was significantly higher and bigger with pasteurised soil media after 15 months in the nursery. Overheating at 121°C for two hours, changed the chemical and physical soil properties (Chen *et al.*, 1991), decreased the nutrient availability to 1.4% and furthermore, reduced the growth of *S. leprosula* to 32% (Omon, 2002).

The primary objective of inoculation in nurseries is to produce healthy seedlings, suitable for planting in the field with roots colonised by selected fungus. The species of mycorrhizae inoculated in the beginning of the experiment were not well developed in the roots of *S. leprosula* after 15 months. A suitable mycorrhizal inoculum is a very important factor in the success of dipterocarp establishment (Julich, 1988; Smits, 1992). Brundrett *et al.* (1995) point out that in sites where ectomycorrhizal fungi are already present, the introduction of new isolates will only be possible if the introduced fungi are superior competitors. Four very common, pioneer and aggressive 'early stage' mycorrhizal fungi were dominant in colonising the roots of *S. leprosula* cuttings. These mycorrhizal species were *Telephora sp.*, *Laccaria sp.*, *Riessiella sp.* and *Inocybe sp.*

The initial inocula may not have disappeared but their percentage was probably very low (see Chapter 5 in this book). Even though only very few, initial mycorrhizal fungi may support the growth of *S. leprosula*. It can be seen in the significant differences in some parameters of growth of *S. leprosula* measured between mycorrhizal inoculation treatments. ‘No inoculation’ resulted in the lowest growth of *S. leprosula*.

Most ectomycorrhizal tree species are able to associate with a wide range of mycorrhizal fungi in adapting to different soils and other environmental conditions. Hilton *et al.* (1989) distinguished two different classes of ectomycorrhizal fungi regarding the soil preferred by mycorrhizal fungi, namely soil inhabiting fungi like *Laccaria* and litter inhabiting fungi like *Russula*, *Laccaria* and *Cortinarius*, species that are better adapted to exploit litter for nutrients. In the root observations (Table 4.11), it was shown that *Laccaria*, soil-inhabiting fungi, were more dominant than litter inhabiting fungi. There was little litter in the nursery, which could explain that litter-inhabiting fungi could not develop well. Furthermore, Mason and Ingleby (1997) distinguished two different classes of ectomycorrhizal fungi, namely ‘early stage’ (pioneer) mycorrhizal fungi (*Laccaria*, *Scleroderma*, *Inocybe*) and ‘late stage’ mycorrhizal fungi (*Russula*). Supriyanto *et al.* (1993) and Zarate *et al.* (1993) found that *Laccaria* and *Scleroderma* are the most common in mycorrhizal experiments. In 15 months in the greenhouse, the mycorrhizal colonisation changed completely. Omon (2002) explained that indigenous fungi ‘contaminating’ the experiment by arriving borne by air or by soil water did not negatively affect the growth of *S. leprosula* cuttings. Aggressive, pioneer and ‘early stage’ mycorrhizal fungi dominated the colonisation of *S. leprosula* roots. *Laccaria sp.* was the most common one, followed by *Thelephora sp.*, *Riessiella sp.* and *Inocybe sp.*

Since the environmental conditions in the greenhouse were relatively stable and supported with an adequate input of nutrients from soil with higher sand fraction and combined with mycorrhizal inoculation, *S. leprosula* seedlings with a higher number of leaves produced more energy in the photosynthetic process. The highest diameter and diameter increment would increase the distribution of energy inside the plant. Diameter has an important function in the distribution of energy. This sapstream influenced the growth of *S. leprosula* seedlings. Diameter increment of tree species is not only controlled by photosynthetic rate and environmental factors (Kramer and Kozlowski, 1979), but also depends on species and age (Baker, 1950). He stated that the height increment of a tree species was affected not only by nutrients, water, and light intensity, but also by internal factors of the species itself.

4.5 CONCLUSION

The origins of plant materials, the sources of soil substrates and their combinations influenced the growth of *S. leprosula* seedlings.

Sandy loam and loam are better than sandy clay loam as substrate media for dipterocarp, especially for *S. leprosula* cuttings. The growth of *S. leprosula* cuttings was higher in pasteurised soil media. Initial mycorrhizal inoculation in the greenhouse resulted in a higher growth rate of *S. leprosula*. The environmental conditions and the existence of mycorrhizae in a dipterocarp nursery are crucial to the development of mycorrhizae.

In 15 months in the greenhouse, the mycorrhizal colonisation changed completely. Aggressive, pioneer and ‘early stage’ mycorrhizal fungi dominated the colonisation of *S. leprosula* roots. *Laccaria sp.* was the most common one, followed by *Thelephora sp.*, *Riessiella sp.* and *Inocybe sp.*

CHAPTER 5

RESPONSES OF *Shorea leprosula* Miq. TO LIGHT AND SOIL

ABSTRACT

The objective of the study was to observe the effect of soil types and light intensity upon the growth of *S. leprosula* and the development of mycorrhizal types. The greenhouse experiment ended after 9 months by transplanting the cuttings into the field. The 12-months' field experiment was located in a secondary forest. The greenhouse experiment used a split-plot design with 3 soil types (loam, sandy loam and sandy clay loam) and 4 mycorrhizal types (*Amanita* sp., *Russula* sp., *Scleroderma columnare* and 'no treatment'). Every combination was done 5 times and each analogous group consisted of 5 cuttings. In the field study, a 'split-split plot' design was used with 3 different soil types, 4 mycorrhizal types and 3 shading levels (without shading, one layer of net shading and two layer of net shading). Each combination of treatments consisted of 7 *Shorea leprosula* cuttings. In the greenhouse, *S. leprosula* cuttings planted in loam and sandy loam showed the highest growth. *S. leprosula* cuttings inoculated with *Scleroderma* sp. showed the highest growth. *S. leprosula* reached the strongest growth if inoculated with *Scleroderma* sp. and with sandy loam or loam soil as its substrate. In the field, sandy loam supported the highest growth rates of *S. leprosula* cuttings. A light shading showed the highest results followed by moderate shading and no shading. The treatment 'no inoculation' was followed by the strongest growth of *S. leprosula* cuttings. After 22 months, *Scleroderma* sp dominated in all treatments.

5.1 INTRODUCTION

Indonesia has a programme for the rehabilitation of degraded land. This programme is referred to as industrial timber estate (HTI = Hutan Tanaman Industri). Timber estates are mainly established by reforestation, i.e. forestation with fast-growing species or dipterocarp species of useless land or marginal sites, such as degraded farmland, *Imperata* grassland (alang-alang), or abandoned mining areas. This choice of sites is due to the use of existing forest land under other forms of management for other purposes, such as selection silviculture, nature management, conversion to agricultural purposes and/or transmigration.

As a result of this complex context, *Shorea leprosula*, as a fast growing Dipterocarpaceae species and quite commonly used in the rehabilitation of degraded land, often has to be grown on sites less hospitable than the sites in which the

species evolved. On such sites, the availability of water and nutrients is often critical to plantation establishment. Planting attempts showed that many seedlings had died in this field because of a heated soil (temperature up to 45°C) which is lethal to the development of dipterocarp ectomycorrhizae (Smits, 1983a, 1994; Noor and Smits, 1988). Furthermore, Mason and Ingleby (1997) claimed that the damage of the forest due to natural causes or to human intervention can affect severely the size and effectiveness of populations of ectomycorrhizal fungi. These stressors include forest fire, soil erosion, soil compaction and logging. Many recurrent stressful impacts, hence, not only act upon the young trees, but also on the development of the natural ectomycorrhizal inoculum potential of the areas to be planted with dipterocarps. The dipterocarp planting stock, therefore, must be inoculated with suitable fungi before planting in order to grow well. However, conditions in nurseries are usually quite different from forest conditions and often certain early successional ectomycorrhizal fungi dominate the mycorrhizal community on the nursery planting stock (Omon, 2002). Therefore, ectomycorrhizal fungi used for inoculation in the nursery may later become unsuitable for the trees in the field. The use of early fungi may lead to the failure of dipterocarp seedlings, unable to establish themselves in the field (Smits, 1992).

Smits (1994) and Yasman (1995) reported the interaction between soil type, dipterocarp species, and the species of dipterocarp ectomycorrhizal fungi in any particular location. Mason et al. (1982) distinguished these fungi appearing on seedlings or in young plantations as 'early-stage' fungi, whereas 'late-stage' fungi replace the early stage ones during 'succession'. According to Last et al. (1984) and Smits (1994), a species succession of mycorrhizal fungi is related to the physiological age of the plants and the environmental conditions. The latter are linked to the development of the organic soil horizons during eco-unit or ecosystem development (Bernier, 1995, cited by Oldeman, 2002). The succession of mycorrhizal fungi may be explained by the sapstream (Omon, 2002), showing changes in the carbohydrate supply from the host tree (Dighton and Mason, 1985), increases in net photosynthesis and its concomitant distribution of sugars over shoot and root (Hintikka, 1988) or increases in the internal recycling of nutrients (Miller et al., 1979). Environmental factors that influence the development of mycorrhizal fungi on dipterocarp roots are light intensity, soil fertility (expressed as the availability of nitrogen and phosphorus), soil moisture, heat, aeration and pH (Yasman, 1995). They also include the momentary state of the whole microbial community in the rhizosphere (Oldeman, 2002).

Photosynthesis and transpiration are important physiological processes in plant growth. The rate of photosynthesis is controlled by a large number of internal and external factors. Internal factors include stomata aperture, chlorophyll content and leaf structure (area and thickness). External factors include light (intensity and quality), heat, carbon dioxide concentration, wind (velocity), water (supply), nutrients (supply). So, light intensity and nutrient availability are important environmental factors for the growth of

dipterocarp seedlings and indirectly for associated mycorrhizae. It is important to know the reaction of a plant to suitable fungi under the environmental stresses of new habitats or under new environmental conditions. A synthetic view of all these factors, their interactions and feedback is provided by sapstream diagrams, originally from Oldeman (1974a, also see Hallé *et al.* 1978) and adapted to dipterocarp biology, including root symbiosis by Omon (2002).

Considering the above facts, this study focussed on dipterocarp seedling growth under shading related to ectomycorrhizal development in different soil types. The hypothesis of this study was that environmental factors, in particular soil types, light intensity (vegetation types) and mycorrhizal types codetermine the photosynthetic response in *S. leprosula*. With this hypothesis in mind, the objective of the present study was to observe the effects of soil types and light intensity upon 'growth as an indicator of both photosynthesis', in *S. leprosula* (Dipterocarpaceae) and the development of mycorrhizal types.

5.2 MATERIAL AND METHODS

5.2.1 Location and Duration

The experiment started on 13 March 2000 by transplanting *S. leprosula* cuttings into different soil types in the greenhouse of the Wanariset Samboja research station, located at 38 kilometers northeast of Balikpapan in East Kalimantan. The greenhouse experiment ended after 9 months on 13 December 2000 by transplanting the cuttings into the field.

The 12-months' field experiment was located in a secondary forest of the KEM (Kelian Equatorial Mining) Rehabilitation Area in the Wanariset Samboja research forest area (0°58'10" latitude South and 116°58'37" longitude East), Bukit Suharto National Garden, at 42 km to the left of the main road from Balikpapan to Samarinda in East Kalimantan. This research location has an A climate type according to the Schmidt and Ferguson climate classification (1951). It is hot and wet throughout the year and typical of a tropical rain forest region (Toma *et al.*, 2000a).

5.2.2 Methods

The set-up of the half-open inoculation experiment in the greenhouse was the same as in the experiment described in Chapter 4.3, with only a few differences. The cuttings of *S. leprosula* were produced from wildlings according to the method developed by Yasman and Smits (1988). These wildlings were collected in their natural populations on PT Tunggul Yudi Hutani at Laham, Long Iram, Kutai, East Kalimantan on November 1999. The rooted cuttings were transplanted into black polyethylene bags, 15 cm high and 8 cm in diameter, in the greenhouse of the Wanariset Samboja research station. The different soil types, namely: loam (A_3), sandy loam (A_1) and sandy clay loam (A_2), were used for the rooted cutting medium. These media were pasteurised by

means of heating at 80°C for 30 minutes in autoclave. The soils were collected from the same area in which the field experiment took place. The soils were chosen on the basis of an available soil analysis (Iriansyah *et al.*, 1998). The cuttings of *S. leprosula* were then inoculated with certain mycorrhizal fungi. No cocktail of the three species of fungi was used, limiting the suspensions to *Amanita* sp. (C₁), *Russula* sp. (C₂), *Scleroderma columnare* (C₃) and 'no inoculation' (C₀). The greenhouse experiment used a split-plot design with 3 (three) soil types and 4 (four) mycorrhizal types. Every combination was done 5 (five) times and each analogous group consisted of 5 (five) cuttings.

Site preparation in the field was conducted a week before planting. An area 5 x 6 m was cleaned by slashing all vegetation, along-alang grassland and secondary tree species such as *Macaranga* spp. and *Mallotus* spp., and making planting holes approx. 25 cm deep. The 84 cuttings were transplanted into each soil type-site that was cleared over a surface of 40 x 40 cm. The cuttings were planted in the same soil type as used in the greenhouse and were shaded. The distance between each shading treatment was 1 m. Manual weeding was carried out by pulling the along-alang grasses out every month from January to December 2001.

In the field study, a 'split-split plot' design was used with 3 (three) different soil types, 4 (four) mycorrhizal types (including 'no mycorrhizal inoculation') and 3 (three) shading levels. Each combination of treatments consisted of 7 (seven) *Shorea leprosula* cuttings. The shading levels are:

1. Without shading (100% of full daylight), open area of along-alang grassland
2. One layer of net shading, light shading (approx. 70% of full daylight), corresponding with vegetation coverage under shrubs
3. Two layers of net shading, moderate shading (approx. 60% of full daylight), corresponding with vegetation coverage under secondary forest.

5.2.3 Data collection and analyses

5.2.3.1 Greenhouse experiment

Soil properties, such as soil type, mineral contents and pH were analysed at the beginning of the experiment. A combined atmospheric temperature and relative humidity measuring device (HANNA instrument) was used to measure atmospheric temperature and relative humidity in the greenhouse. The Photosynthetically Active Radiation (PAR) was measured using a PAR-measuring device (LICOR type LI-250) from June to December 2000. The light intensity was taken above the leaves of the cuttings. Atmospheric temperature, relative humidity and light intensity were measured twice a week at 08.00 hrs, 12.00 hrs and 16.00 hrs.

Height and root collar diameter growth was measured every month. The number of leaves was counted at transplanting time and repeated every month. After 9 months, the experiment was stopped. Some cuttings were sampled for further assessment and the others were planted out into the field for further research.

At the end of the experiment, the fresh roots of three samples per treatment combination samples, namely A_1C_0 , A_1C_2 , A_2C_0 , A_2C_1 and A_2C_2 , totalling 15 samples, were immediately stored in FAA (Formaldehyde Acetic Acid) to prevent any deterioration. These preserved roots were then taken to the Silviculture Laboratory, SEAMEO-BIOTROP, in Bogor for histological analyses of mycorrhizae.

5.2.3.2 Field experiment

Data on the weather conditions in 2001, such as rainfall, daily relative atmospheric humidity and temperature, were collected from the weather station at Tahura Bukit Suharto Education Forest (BSEF) of Mulawarman University. This station is located at 1° S latitude and 117° E longitude, 53 km from Balikpapan in the direction to Samarinda, Bukit Suharto National Garden, East Kalimantan and 11 km from the plot.

Height, root collar diameter, number of branches, length of branches and the number of leaves (at the stem, at the branch and in total) were measured and counted every month during the first four months, January, February, March and April 2001, and from then every two months, June, August, October and December 2001.

Stomatal conductance, photosynthesis, transpiration and vapour pressure deficit were measured twelve times at one-hour's intervals from 07.00 hrs using a portable photosynthetic system (Li-COR 6400). The chlorophyll content was determined using a portable chlorophyll meter (SPAD-501, Minolta Co. Ltd., Japan). The SPAD value is proportional to the chlorophyll concentration. The measurements of physiological properties were taken on the youngest fully expanded leaf of each treatment by sampling on clear (non-cloudy) days from 7 to 9 November 2001. Only the chlorophyll content was measured on 27 November 2001. To reduce errors due to measurement times, each block was measured under approximately the same light conditions.

Leaf area, leaf thickness, leaf biomass (fresh leaf weight/dried leaf weight) and Specific Leaf Weight (SLW) were determined on the same leaf of which the physiological processes were measured. The thickness of this leaf was measured in the field using a portable micrometer (FHK) on 27 November 2001. The leaf area was measured at the end of the experiment using an area meter system in a Silviculture laboratory, Pusrehut, Mulawarman University, Samarinda, East Kalimantan. The leaf was then dried at around 70°C using an oven for 36 hours for leaf biomass and Specific Leaf Weight (leaf area/leaf dry weight) determination at the laboratory of the Wanariset Samboja research station.

The biomass of leaves, stems and roots was measured by weighing the dried materials. These materials were dried at around 70°C using an oven for 36 hours for leaves and root material, and for 48 hours for stem material. After drying, two samples per combined treatment (soil and shading combinations with 'no mycorrhizal inoculation'), totalling 18 samples, were analysed for nutrient contents in the Natural Products

laboratory of SEAMEO-BIOTROP (South East Asian Ministers of Education Organisation-South East Asian Regional Center for Tropical Biology) in Bogor. The cuttings were cut up into leaves, stems and roots part. Carbon, nitrogen, phosphorus and potassium were determined in percentages of dry weight for each part of the cuttings.

At the end of the experiment, the fresh roots of two samples per treatment, totalling 72 samples, were immediately stored in FAA (Formaldehyde Acetic Acid) to prevent any deterioration. These preserved roots were further studied at the Wanariset Samboja research station. The number of infected and non-infected roots was counted. The data on ectomycorrhizae (ECM), such as the type of ECM formed and the number of each type of ECM, were also investigated. The root was then dried in an oven and weighed for the shoot-root dry weight ratio.

*The data were analysed using the SPSS programme version 10. Significant *F* values found by ANOVA were further examined by pair-wise comparisons of means (Duncan's Multiple Range Test).*

5.3 RESULTS

The above set-up is in line with the remarks made concerning the experimental methods in Chapter 4. The field experiment links the half-open greenhouse experiment to the forest rather than to 'closed' experiments in the laboratory, such as phytotron studies. This orientation is intentional and has its roots in the general orientation of the research programme at the Wanariset Station, which is aimed at understanding dipterocarps and dipterocarp ecosystems, so to become a source of vital knowledge needed by human society. This was the original line of research of the TROPENBOS programme (Tropenbos 1984).

5.3.1 Greenhouse experiment

The average atmospheric temperature and relative humidity at three moments of measurement (08.00 hrs, 12.00 hrs and 16.00 hrs) from April to December 2000 in the greenhouse ranged from 28 to 31°C and from 88 to 91%. The average temperature of the air was 29°C, with an average relative humidity of 90%. September and November were the hottest months with an air temperature of 31°C and the lowest relative humidity (88%) was observed in December 2000. The data of atmospheric temperature and relative humidity in the greenhouse during the experiment period over the year 2000 can be seen in Appendix 6.

The average light intensity (PAR) at three moments of measurement (08.00 hrs, 12.00 hrs and 16.00 hrs) in the greenhouse was 4.4, 10.9 and 6.2 $\mu\text{mol m}^{-2}\text{s}^{-1}$, respectively. These values were 5.9, 6.5 and 13.7% from light intensity outside the greenhouse. The average light intensity (PAR) in the greenhouse was 7.2 $\mu\text{mol m}^{-2}\text{s}^{-1}$ or 7.4% from outside.

The result of the greenhouse experiment is presented for two main factors and their interaction, namely: soil type and mycorrhizal inoculation. The effect of each factor and the interaction of both on plant growth and mycorrhizal development are presented below.

5.3.1.1 Effects of soil type

The data of soil characteristics of the three experimental sites can be seen in Table 4.7 (Chapter 4). Table 5.1 and Fig. 5.1 show that the growth of *S. leprosula* cuttings planted in loam and sandy loam performs better compared with those planted in sandy clay loam, confirming the results of Omon (2002).

Table 5.1 Effects of soil type on various growth parameters of *S. leprosula* cuttings 10 months after treatment. a: length of axes, h: height, Δh : height increment, Δd : diameter increment, d: diameter; b: length of branches, Σa : number of axes, Σl : number of leaves

Soil type	a (cm)	h (cm)	Δh (cm)	Δd (cm)	d (cm)	b (cm)	Σa	Σl
Sandy loam	23.2 b	22.2 b	12.8 b	0.13 b	0.29 a	19.5 a	1.1 a	8.6 a
Sandy clay loam	20.1 a	18.4 a	9.0 a	0.11 a	0.28 a	17.0 a	1.1 a	7.8 a
Loam	23.6 b	22.9 b	14.5 c	0.12 b	0.28 a	22.5 a	1.0 a	8.5 a

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test

The length of the axes, height and diameter increment of *S. leprosula* planted in sandy loam and loam were not significantly different from the beginning until the end of the experiment (Duncan's test at a 5% level of significance). The cuttings grown in sandy clay loam were significantly shorter and smaller.

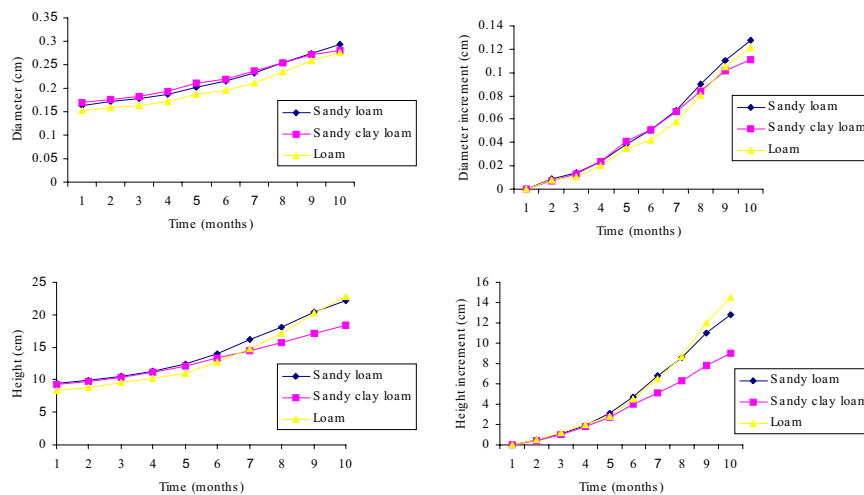


Figure 5.1 Effects of soil type on some growth parameters of *S. leprosula* cuttings.

There were no significant differences as to the length of branches, number of axes, number of leaves and diameter of *S. leprosula* between soil treatment for 10 months. Branching started at the 5th month on all soil substrates.

5.3.1.2 Effects of mycorrhizal inoculation

Table 5.2 and Fig. 5.2 show that the growth of *S. leprosula* cuttings inoculated with *Scleroderma* sp. performed better than without inoculation, or inoculation with *Amanita* sp. and *Russula* sp.

Table 5.2 Effects of mycorrhizal inoculation on various growth parameters of *S. leprosula* cuttings 10 months after treatment. a: length of axes, h: height, Δh : height increment, Δd : diameter increment, d: diameter, b: length of branches, Σa : number of axes, Σl : number of leaves

Mycorrhizal inoculation	a (cm)	h (cm)	Δh (cm)	Δd (cm)	d (cm)	b (cm)	Σa	Σl
No inoculation	23.2 ab	20.2 a	10.7 a	0.13 a	0.30 b	20.1 a	1.1 b	8.1 a
<i>Amanita</i> sp	21.6 ab	20.8 a	10.7 a	0.11 a	0.28 ab	29.8 a	1.0 a	8.6 a
<i>Russula</i> sp	20.7 a	20.3 a	12.0 a	0.11 a	0.26 a	10.7 a	1.0 a	7.9 a
<i>Scleroderma</i> sp	24.0 b	23.7 b	15.2 b	0.13 a	0.29 ab	10.8 a	1.0 a	8.7 a

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

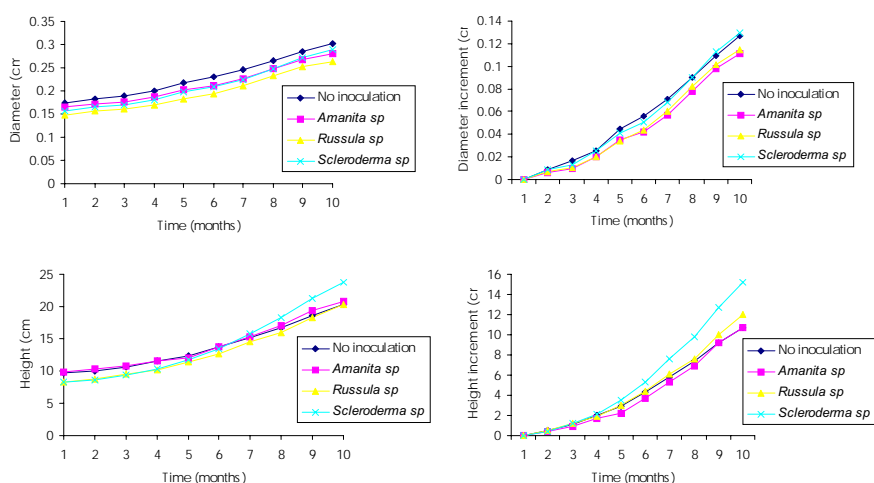


Figure 5.2 Effects of mycorrhizal inoculation on some growth parameters of *S. leprosula* cuttings.

The height and height increment of *S. leprosula* inoculated with *Scleroderma* sp was significantly higher compared with other inoculation treatments (Duncan's test at a 5% level of significance). There are significant differences as to the length of the axes and diameter growth of *S. leprosula* inoculated with mycorrhizae. *S. leprosula* without

mycorrhizal inoculation produced significantly more axes compared with those inoculated from the beginning to the end of the experiment.

During the 10 months of the experiment, there were no significant differences as to the number of leaves, length of branches and diameter increment of *S. leprosula* after the mycorrhizal inoculation. The branches developed in the 9th month in all cuttings with mycorrhizal inoculation.

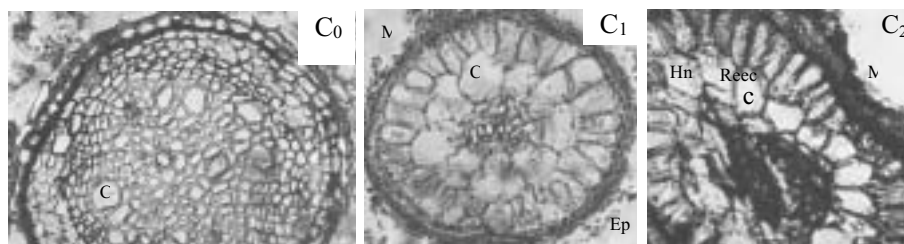


Figure 5.3 Histological analysis on sampled roots of *S. leprosula* cuttings 10 months after treatment. C₀: no inoculation treatment, C₁ & C₂: inoculation treatment, M: mantle, Hn: Hartig net, Ep: Epidermis, C: Cortex, Reec: Radially Elongated Epidermis Cells.

Histological analysis on sampled roots showed that mycorrhizal fungi were able to form a mantle and a Hartig net both in inoculated and in ‘no inoculation’ mycorrhizal roots of *S. leprosula*. Mycorrhizal roots formed Radially Elongated Epidermis Cells (REEC).

5.1.1.1 Effects of soil type and mycorrhizal inoculation

The combination of soil type and mycorrhizal inoculation gave significant differences only as to diameter, length of axes and height growth of *S. leprosula* cuttings 10 months after treatment. *S. leprosula* inoculated with *Scleroderma sp.* and planted in loam soil was the highest (27 cm), had the highest height increment (15.8 cm) and the longest axes (27.5 cm). The largest diameter (0.32 mm) was reached by *S. leprosula* planted in sandy soil without inoculation or inoculated with *Scleroderma sp.*. *S. leprosula* reached the strongest growth if inoculated with *Scleroderma sp.* and with sandy loam or loam soil as its substrate. This confirms the results of Omon (2002).

5.1.2 Field experiment

The average annual rainfall in 2001 was 2456 mm. Its monthly distribution was bimodal, with peaks of over 200 mm per month occurring in March, and September to December. The minimum and maximum monthly average rainfall was 0 mm (in June and July) and 664 mm (in November). The mean atmospheric temperature was about 28°C as daily maximum and 22.5°C as daily minimum, with a daily average of about 25°C. Diurnal ranges of atmospheric temperature were about 5.8°C. The mean annual relative atmospheric humidity was 72% as daily minimum and 90.5% on average (see Figure 5.4, 5.5 and Table 5.3).

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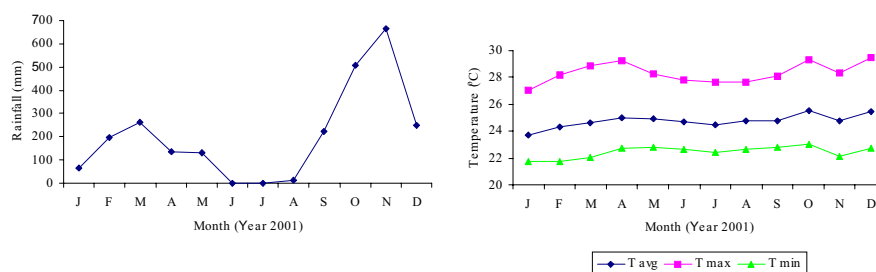


Figure 5.4. Average monthly rainfall and monthly mean of daily maximum (T_{max}), average (T_{avg}) and minimum (T_{min}) atmospheric temperature in 2001 (Meteorological station of BSEF).

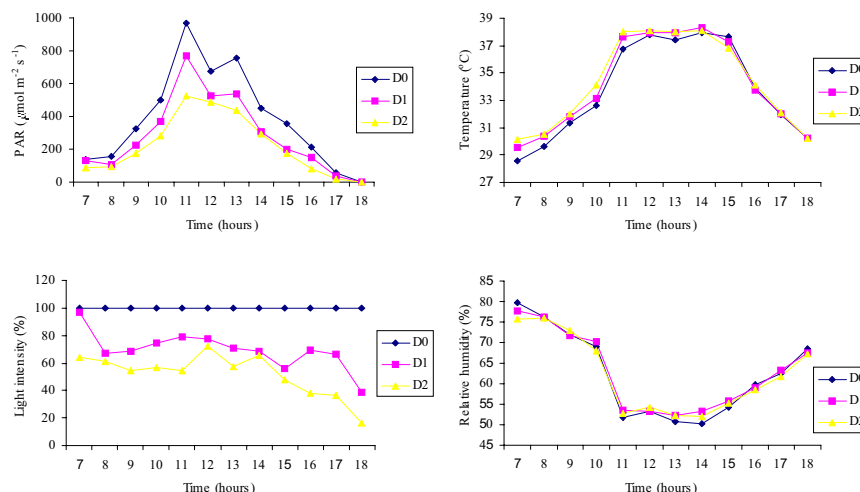


Figure 5.5 Daily climatic variables in the plot area measured every hour from 07.00 hrs to 18.00 hrs in November 2001.

Table 5.3 Climatic variables in the shading treatments measured every hour from 07.00 hrs to 18.00 hrs in November 2001. PAR_{avg} : Average light intensity, T_{air} : atmospheric temperature, T_{leaf} : leaf temperature, rH_{sc} : relative humidity at the leaf surface, rH : relative humidity.

Shading level	Light (%)	PAR_{avg} ($\mu mol m^{-2} s^{-1}$)	T_{air} ($^{\circ}C$)	T_{leaf} ($^{\circ}C$)	rH_{sc} (%)	rH (%)
D_0 = without shading	100	383.3	33.8	33.4	62.4	60.3
D_1 = light shading	73	279.5	34.2	33.3	62.8	59.5
D_2 = moderate shading	58	221.7	34.4	33.5	62.2	58.7

A linear relationship between atmospheric temperature and leaf temperature was demonstrated by a very high regression coefficient ($r^2 > 0.94$) at different shading levels and soil types, but there were no significant differences between shading levels and soil types. However, cuttings in the open site, without any shading, had a higher leaf and atmospheric temperature compared with the two other shading levels. This was to be expected.

5.3.2.1 Effects of soil type

The data of soil characteristics of the three experimental sites can be seen in Chapter 4 (Table 4.7). The growth of ***S. leprosula*** cuttings in different soil types can be seen in Figure 5.6 and Table 5.4. Most parameters measured testified in favour of a significant effect of the soil type in the field on the growth of ***S. leprosula*** cuttings in the first three months. This shows that the roots of ***S. leprosula*** entered the forest soil, from the greenhouse soil clod, within three months after transplanting.

The differences in diameter and axes increment were significantly influenced by the soil type from the 3rd month after transplanting. The number of leaves at the stem, length of axes and height growth increased from the 1st month whereas height increment was significantly influenced by the soil type from the 2nd month. The other growth parameters of ***S. leprosula***, such as diameter increment, the leaf number, the number of leaves at the branches and the length of the branches were significantly influenced by soil type as from the 4th month. The number of the branches and the number of the axes of ***S. leprosula*** were significantly influenced by soil type as from the 6th month.

Figure 5.6 clearly shows that sandy loam supported the highest growth rates of ***S. leprosula*** cuttings, followed by sandy clay loam and loam. At the end of the experiment, the sandy loam provided higher growth rates for ***S. leprosula*** cuttings, ranging from 25% (diameter growth) to 181% (leaf area) for most parameters measured as compared to those grown in loam. The growth increment of ***S. leprosula*** cuttings in sandy loam was also higher as compared to those grown in sandy clay loam, varying from 17.5% (number of leaves at stem) to 190% (leaf area)(see Table 5.4). The increment of leaf area represents the increment of the photosynthetic surface involved in feeding biomass production of the cuttings.

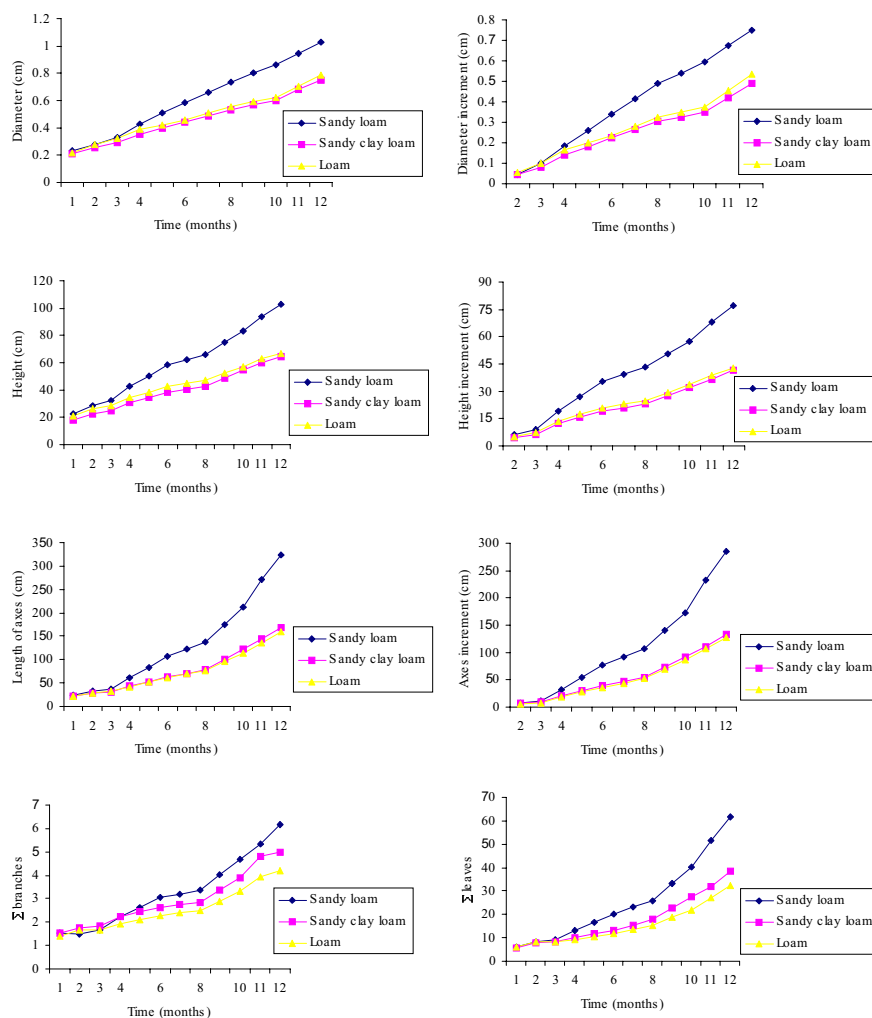


Figure 5.6 Effects of soil type on some growth parameters of *S. leprosula* cuttings.

The roots, leaves and axial biomass of *S. leprosula* cuttings, expressed either as their dry weight or ratio of fresh weight/dry weight, in sandy loam was higher than those in sandy clay loam and loam, except for the axial biomass in terms of fresh weight/dry weight. It looks as if the cuttings planted in sandy loam contained more water than those planted in sandy clay loam and loam. Fresh weight includes water, important in sap-stream dynamics.

5. Responses of *Shorea leprosula* Miq. to Light and Soil

Table 5.4 Soil type and various growth parameters of *S. leprosula* cuttings after 12 months in the field. SL: sandy loam, SCL: sandy clay loam, L: loam, a: length of axes, Δa : axes increment, h: height, Δh : height increment, d: diameter, Δd : diameter increment, b: length of branches, Σb : number of branches, Σa : number of axes, Σl : number of leaves, Σl_b : number of leaves at the branches, Σl_s : number of leaves at the stem, W_{RF} : root fresh weight, W_{RD} : root dry weight, W_{LF} : leaves fresh weight, W_{LD} : leaves dry weight, W_{AF} : axes fresh weight, W_{AD} : axes dry weight, B_R : root biomass, B_L : leaves biomass, B_A : axial biomass, SLW: specific leaf weight, L_l : leaves area, L_t : leaf thickness, Ch: chlorophyll contents

Soil type	a (cm)	Δa (cm)	h (cm)	Δh (cm)	d (cm)	Δd (cm)	b (cm)	Σb	Σa	Σl	Σl_b	Σl_s
SL	322.8 b	284.2 b	102.6 b	76.9 b	1.0 b	0.7 b	224.1 c	6.2 b	7.1 b	61.8 b	55.4 b	7.4 b
SCL	168.5 a	133.9 a	64.7 a	41.6 a	0.8 a	0.5 a	116.8 a	5.0 b	5.4 a	38.6 a	36.3 a	6.3 ab
L	159.6 a	128.4 a	66.9 a	42.9 a	0.8 a	0.5 a	100.6 a	4.2 a	4.9 a	32.3 a	29.3 a	5.3 a

Soil type	W_{RF} (g)	W_{RD} (g)	W_{LF} (g)	W_{LD} (g)	W_{AF} (g)	W_{AD} (g)	B_R	B_L	B_A	SLW	L_l (cm ²)	L_t (mm)	Ch
SL	17.3 b	6.8 b	38.7 b	16.5 b	596 a	19.5 b	2.5 c	2.4 ab	11 5 a	198 b	3019 b	0.4 a	39 b
SCL	6.2 a	3.0 a	14.0 a	6.5 a	15.6 a	7.2 a	2.1 a	2.2 a	2.1 a	185 a	1043 a	0.4 a	37 a
L	10.2 a	4.3 a	16.2 a	6.8 a	20.1 a	8.4 a	2.3 b	2.5 b	2.3 a	184 a	1073 a	0.4 a	37 a

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

The nutrient contents of leaves, stems and roots of *S. leprosula* cuttings grown in various soil types are presented in Appendix 8. There were no significant differences in the percentages of carbon and phosphorus in root and leaf of *S. leprosula* cuttings grown in various soil types and their means were 30.8, 34.9, 0.06 and 0.11%, respectively. The percentages of carbon and phosphorus in stems of *S. leprosula* cuttings grown in sandy loam were lower as compared to those grown in sandy clay loam and loam. Loam has higher potassium percentages on root and nitrogen percentages on leaf of *S. leprosula* as compared to the other soils whereas the other parts of *S. leprosula* have the same amount of these nutrients.

5.3.2.2 Effects of shading

In Fig. 5.7, a comparison is made between the mean values of plant diameter, diameter increment, height, height increment, length of axes, axes increment, length of branches and total number of leaves. It appears that for all these factors, a light shading (one layer of netting) showed the highest results followed by moderate shading (two layers of netting) and no shading.

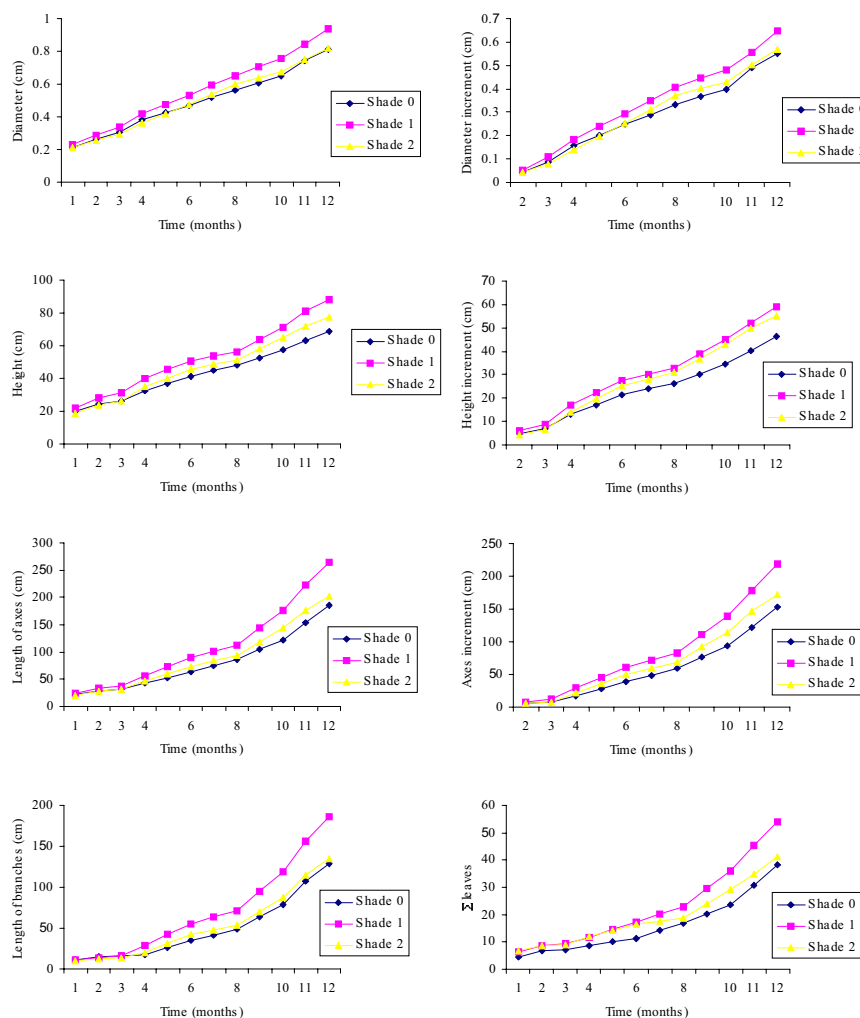


Figure 5.7 Shading and some growth parameters of *S. leprosula* cuttings.

Height growth of *S. leprosula* cuttings immediately responded to light. In 30 days, the height difference of the seedlings between shading levels was significant, about 2 cm. With time, the response in height growth became more apparent and the seedlings under light shade grew 59 cm or 28% more than those grown under full light. As to the development of leaves, the advantage of cuttings under light shade became more obvious with time (Fig. 5.7). In 30 days, the difference was 2 leaves, but in 12 months

5. Responses of *Shorea leprosula* Miq. to Light and Soil

after treatment there were 16 leaves or 42% more leaves on cuttings grown in light shading than on those in the open.

Based on Duncan's Multiple Range Test, during the whole experiment, the difference in total number of leaves and the number of leaves on the epicotyledonary stem of *S. leprosula* was significantly influenced by the shading level, whereas the number of branches and axes was not affected. The significant differences only occurred once during time series data for the growth parameter: height increment (at the 10th month), the number of leaves at the branches and the length of branches (at the 8th month). Differences in the number of leaves and the length of the axes were significant in the first 6 months.

Table 5.5 Shading and various growth parameters of *S. leprosula* cuttings after 12 months in the field. D₀: without shading, D₁: light shading, D₂: moderate shading, a: length of axes, Δa: axes increment, h: height, Δh: height increment, d: diameter, Δd: diameter increment, b: length of branches, Σb: number of branches, Σa: number of axes, Σl: number of leaves, Σl_b: number of leaves at the branches, Σl_s: number of leaves at the stem, W_{RD}: root dry weight, W_{LD}: leaves dry weight, W_{AD}: axes dry weight, W_{TD}: total dry weight, LWR: leaf weight ratio, RWR: root weight ratio, SLW: specific leaf weight, L_f: leaves area, L_t: leaf thickness, Ch: chlorophyll contents

Shade level	a (cm)	Δa (cm)	h (cm)	Δh (cm)	d (cm)	Δd (cm)	b (cm)	Σb	Σa	Σl	Σl _b	Σl _s
D ₀	186.2	153.4	68.8	46.2	0.8	0.6	128	4.9	5.5	38.1	36.1	5.1
	a	a	a	a	a	a	a	a	a	a	a	a
D ₁	265.1	219.4	88.1	59.0	0.9	0.6	187	5.7	6.4	54.0	49.8	6.8
	b	b	b	b	a	b	b	b	b	b	b	b
D ₂	203.1	172.0	77.5	55.0	0.8	0.6	135	4.8	5.5	41.1	36.6	7.0
	a	a	a	b	a	a	a	a	a	a	a	b

Shade level	W _{RD} (g)	W _{LD} (g)	W _{AD} (g)	W _{TD} (g)	LWR	RWR	SLW	L _f (cm ²)	L _t (mm)	Ch
D ₀	3.6	7.4	9.5	20.5	0.36	0.176	179.6	1145.8	0.42	35.2
	a	a	a	a			a	a	ab	a
D ₁	6.5	13.3	15.8	35.6	0.37	0.182	185.7	2374.2	0.44	37.8
	b	b	b	b			a	b	b	b
D ₂	4.1	9.0	9.9	23.0	0.39	0.177	202.3	1596.9	0.39	40.1
	a	a	a	a			b	a	a	c

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

One year after the shading treatment, the dry weight of the seedlings was determined for each light treatment (Table 5.5). The dry weight of *S. leprosula* seedlings represented structural matter, formed in interaction between ecological and physiological processes, and it was reduced at moderate shading and open site, as compared to light shading. There were no significant differences on the leaf and axial biomass, expressed as a ratio of fresh weight/dry weight. The roots, leaves and axial fresh weight of *S. leprosula* cuttings in light shading were significantly higher

than those in moderate shading and open site. **S. leprosula** showed significant changes in response to moderate light intensities.

The highest root weight ratio of **S. leprosula** was 0.182 in a light shading, followed by moderate shading (0.177) and by the open site (0.176). The deeper the shade, the higher the leaf weight ratio (see Table 5.5).

The nutrient contents of leaves, stems and roots of **S. leprosula** cuttings under different shading levels are presented in Appendix 8. There were no significant differences in the percentages of carbon, potassium, nitrogen and phosphorus in root, stem and leaf of **S. leprosula** cuttings under different shading levels.

5.3.2.3 Effects of mycorrhizal inoculation

The effects of mycorrhizal inoculation on **S. leprosula** cuttings are shown in Fig. 5.8. For all parameters measured, the treatment 'no inoculation' in the greenhouse was followed by the strongest growth of **S. leprosula** cuttings (see Table 5.6).

Based on Duncan's Multiple Range Test, during the whole experiment, the difference in diameter, length of axes, number of leaves and number of axes of **S. leprosula** was significantly influenced by the mycorrhizal inoculation whereas the number of leaves at the stem was not affected. Diameter, height, and axes increment and height increment increased from the 2nd month. The differences in the number of leaves at the branches, the length of the branches and the number of the branches were significantly influenced by mycorrhizal inoculation as from the 6th month.

At the end of the experiment, **S. leprosula** cuttings with 'no inoculation' treatment had higher growth rates for most parameters measured, ranging from 27% (height growth) to 83% (number of leaves and the length of the branches) as compared to those inoculated with **Amanita sp.**

Regarding the biomass of the seedlings, expressed as dry weight of the shoots (axes and leaves) and roots, the results show that there is a significant influence of different mycorrhizal inoculations (Table 5.6). **S. leprosula** with 'no inoculation' and inoculated with **Russula sp.** had a higher dry weight (biomass) and fresh weight than those inoculated with other mycorrhizal fungi. The differences in biomass of **S. leprosula** cuttings expressed as a ratio of fresh weight/dry weight were not significantly influenced by mycorrhizal inoculation.

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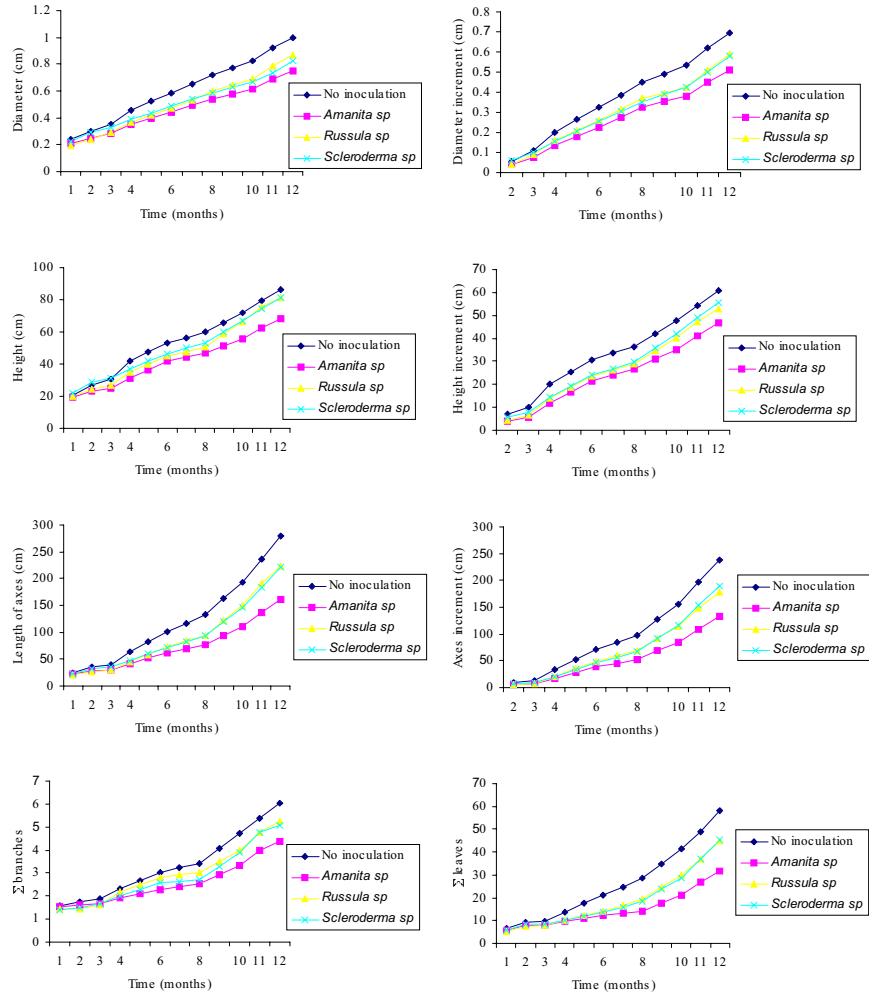


Figure 5.8 Mycorrhizal inoculation and some growth parameters of *S. leprosula* cuttings.

Table 5.6 Mycorrhizal inoculation and various growth parameters of *S. leprosula* cuttings after 12 months in the field. NO: no inoculation, A: *Amanita* sp., R: *Russula* sp., S: *Scleroderma* sp., α : length of axes, $\Delta\alpha$: axes increment, h : height, Δh : height increment, d : diameter, Δd : diameter increment, b : length of branches, Σb : number of branches, $\Sigma\alpha$: number of axes, Σl : number of leaves, Σl_b : number of leaves at the branches, Σl_s : number of leaves at the stem, W_{RF} : root fresh weight, W_{RD} : root dry weight, W_{LF} : leaves fresh weight, W_{LD} : leaves dry weight, W_{AF} : axes fresh weight, W_{AD} : axes dry weight, B_R : root biomass, B_L : leaves biomass, B_A : axial biomass, SLW : specific leaf weight, L_l : leaves area, L_t : leaf thickness, Ch : chlorophyll contents

Inoculation	α (cm)	$\Delta\alpha$ (cm)	h (cm)	Δh (cm)	d (cm)	Δd (cm)	b (cm)	Σb	$\Sigma\alpha$	Σl	Σl_b	Σl_s
NO	278.9 <i>c</i>	238.2 <i>c</i>	85.9 <i>b</i>	60.9 <i>b</i>	0.99 <i>c</i>	0.69 <i>b</i>	193.0 <i>b</i>	6.0 <i>c</i>	7.0 <i>c</i>	58.2 <i>c</i>	51.8 <i>b</i>	6.3 <i>a</i>
A	161.3 <i>a</i>	133.4 <i>a</i>	67.9 <i>a</i>	46.7 <i>a</i>	0.75 <i>a</i>	0.51 <i>a</i>	105.4 <i>a</i>	4.4 <i>a</i>	4.9 <i>a</i>	31.8 <i>a</i>	28.8 <i>a</i>	6.2 <i>a</i>
R	223.2 <i>b</i>	178.5 <i>b</i>	81.1 <i>b</i>	53.1 <i>b</i>	0.87 <i>b</i>	0.59 <i>b</i>	154.3 <i>b</i>	5.2 <i>bc</i>	5.8 <i>b</i>	44.8 <i>b</i>	42.1 <i>b</i>	6.1 <i>a</i>
S	221.1 <i>b</i>	188.5 <i>b</i>	81.0 <i>b</i>	55.5 <i>b</i>	0.83 <i>ab</i>	0.58 <i>b</i>	151.7 <i>b</i>	5.1 <i>ab</i>	5.7 <i>ab</i>	45.3 <i>b</i>	41.6 <i>b</i>	6.9 <i>a</i>

Inoculation	W_{RF} (g)	W_{RD} (g)	W_{LF} (g)	W_{LD} (g)	W_{AF} (g)	W_{AD} (g)	B_R	B_L	B_A	SLW	L_l (cm ²)	L_t (mm)	Ch
NO	13.7 <i>b</i>	6.0 <i>b</i>	24.9 <i>b</i>	10.9 <i>bc</i>	34.3 <i>a</i>	13.9 <i>bc</i>	2.2 <i>a</i>	2.3 <i>a</i>	2.4 <i>a</i>	183 <i>a</i>	1841 <i>bc</i>	0.4 <i>a</i>	36a
A	6.7 <i>a</i>	2.9 <i>a</i>	13.7 <i>a</i>	5.9 <i>a</i>	704 <i>a</i>	6.8 <i>a</i>	2.3 <i>a</i>	2.4 <i>a</i>	145 <i>a</i>	189 <i>ab</i>	1026 <i>a</i>	0.4 <i>a</i>	39 <i>a</i>
R	17.3 <i>b</i>	6.9 <i>b</i>	34.0 <i>c</i>	14.6 <i>c</i>	44.0 <i>a</i>	17.3 <i>c</i>	2.4 <i>a</i>	2.3 <i>a</i>	2.4 <i>a</i>	190 <i>ab</i>	2442 <i>c</i>	0.4 <i>a</i>	38 <i>a</i>
S	7.8 <i>a</i>	3.3 <i>a</i>	19.9 <i>ab</i>	8.6 <i>ab</i>	22.9 <i>a</i>	9.4 <i>ab</i>	2.3 <i>a</i>	2.3 <i>a</i>	2.2 <i>a</i>	197 <i>b</i>	1584 <i>ab</i>	0.4 <i>a</i>	38 <i>a</i>

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test

5.3.2.4 Mycorrhizal development

After 12 months in the field, the mycorrhizal roots of *S. leprosula* were dominated by *Scleroderma* sp. in sandy loam (56%), sandy clay loam (51%) and loam (61%). *Scleroderma* sp. was also dominant in the shading treatment as well as after the mycorrhizal inoculation. The highest percentage of *Scleroderma* sp. in the roots of *S. leprosula* was in the open site (65%), followed by moderate shading (55%) and by light shading (51%).

Certain mycorrhizal fungi were inoculated at the beginning of the experiment. After 22 months, 10 months in the greenhouse and 12 months in the fields, the mycorrhizal fungi colonisation had developed. *Scleroderma* sp. dominated in all treatments. The percentage of *Scleroderma* sp. in non-inoculated, inoculated with *Amanita* sp., *Russula* sp. and inoculated with *Scleroderma* sp. were 61%, 50%, 62% and 55%, respectively (see Table 5.7).

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Table 5.7. Ectomycorrhizae (ECM) percentage (%) of *S. leprosula* cuttings grown after various treatments after 12 months in the field.

Treatments	Mycorrhizal roots (%)	Mycorrhizal species (%)		
		Scleroderma sp.	Inocybe sp.	Amanita sp.
SOIL TYPE				
Sandy loam	50.8 <i>a</i>	28.3 <i>a</i>	16.3 <i>a</i>	6.2 <i>b</i>
Sandy clay loam	58.5 <i>a</i>	30.1 <i>a</i>	27.3 <i>a</i>	1.2 <i>a</i>
Loam	84.2 <i>b</i>	51.6 <i>b</i>	28.7 <i>a</i>	3.9 <i>a</i>
SHADING				
No shading	61.5 <i>a</i>	40.0 <i>a</i>	19.2 <i>a</i>	2.3 <i>a</i>
Light shading	63.9 <i>a</i>	32.5 <i>a</i>	28.9 <i>b</i>	2.4 <i>a</i>
Moderate shading	68.5 <i>a</i>	37.8 <i>a</i>	23.9 <i>a</i>	6.7 <i>b</i>
INOCULATION				
No inoculation	66.0 <i>a</i>	40.2 <i>a</i>	21.0 <i>a</i>	4.8 <i>a</i>
Amanita sp.	61.4 <i>a</i>	30.6 <i>a</i>	28.4 <i>a</i>	2.5 <i>a</i>
Russula sp.	61.5 <i>a</i>	38.1 <i>a</i>	20.4 <i>a</i>	3.1 <i>a</i>
Scleroderma sp.	69.5 <i>a</i>	38.3 <i>a</i>	26.3 <i>a</i>	4.9 <i>a</i>

Note: Values followed by the letters, a or b in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

5.3.2.5 Effects of soil type, shading and mycorrhizal inoculation

The analysis of variance of *S. leprosula* cuttings growth after 12 months of observation in any possible treatment combination shows no significant differences in seedling growth in many parameters measured (Appendix 9).

The diameter of *S. leprosula* cuttings was influenced by all possible treatment combinations, such as the combination of soil and shading, combination of soil and mycorrhizal inoculation, combination of shading and mycorrhizal inoculation, and combination of soil type, shading level and mycorrhizal inoculation, contrary to height increment, number of branches, number of axes and number of leaves at the stem parameters. The combination of soil type and shading influenced the axes' growth, height, diameter, diameter growth, length of branches and number of leaves at the branches of *S. leprosula* cuttings. The combination of soil type and mycorrhizal inoculation influenced the growth of *S. leprosula* cuttings, in terms of length of the axes, diameter and the number of leaves. Only the diameter parameter was influenced by the combination of shading level and mycorrhizal inoculation.

The nutrient contents of *S. leprosula* cuttings grown in soil and shading treatment combination are presented in Appendix 8. There were no significant differences in the percentages of carbon, potassium and nitrogen in *S. leprosula* cuttings under different shading levels and soil types, except nitrogen percentages in the leaves. The percentages of phosphorus in the stems of *S. leprosula* cuttings were significantly different between soil and shading level combination but for roots and leaves, there were no significant differences.

5.3.2.6 Effects of shading on physiological processes

Photosynthesis rate (Pn)

From the data collected on clear days between 7 and 9 November 2001, the maximum photosynthetic rate was $11.5 \mu\text{mol m}^{-2}\text{s}^{-1}$ in open area in sandy loam soil at 12.00 hrs and the minimum was $-9.3 \mu\text{mol m}^{-2}\text{s}^{-1}$ in light shading in sandy clay loam soil at 06.00 hrs. A fitted curve of the relationship between PAR and the photosynthetic rate for all sampled seedlings is shown in Figure 5.9. A curve was fitted by using the equation of hyperbola.

The equations of the photosynthesis curve, maximum photosynthetic, dark respiration, irradiance saturation point and irradiance compensation points for seedlings growing under different light intensities derived from the equation of each curve are presented in Table 5.8.

Table 5.8 Maximum photosynthetic (P_{max}), dark respiration (R_d), irradiance compensation point (I_c) and irradiance saturation point (I_s) for *S. leprosula* seedlings growing under different shading levels and soil types. A_1 : sandy loam, A_2 : sandy clay loam, A_3 : loam, D_0 : no shading, D_1 : light shading, D_2 : moderate shading.

Soil type	Shading level	R_d	I_c	P_{max}	I_s	Equation	R^2
A_1	D_0	-0.79	21.5	10.87	623.3	$Y = -3E-05x^2 + 0.04x - 0.789$	0.81
	D_1	-0.73	15.3	9.15	405.8	$Y = -6E-05x^2 + 0.05x - 0.729$	0.90
	D_2	-1.15	17.7	4.78	172.3	$Y = -2E-04x^2 + 0.07x - 1.154$	0.84
A_2	D_0	-0.58	20.5	6.43	483.3	$Y = -3E-05x^2 + 0.03x - 0.581$	0.30
	D_1	-1.56	82.6	3.70	512.5	$Y = -2E-05x^2 + 0.02x - 1.556$	0.49
	D_2	-1.04	55.0	3.96	500.0	$Y = -2E-05x^2 + 0.02x - 1.040$	0.52
A_3	D_0	-1.97	137.8	5.44	962.5	$Y = -8E-06x^2 + 0.02x - 1.970$	0.35
	D_1	-2.24	99.9	5.20	610.0	$Y = -2E-05x^2 + 0.02x - 2.239$	0.71
	D_2	-1.93	131.4	4.47	800.0	$Y = -1E-05x^2 + 0.02x - 1.930$	0.54

The angle formed by the tangent of the curve at the compensation point is used to estimate the 'biochemical efficiency' of the plant in photosynthesis. The value of this angle can be calculated by a derivation from the equation. Higher values indicate that plants are biochemically more efficient (Yasman, 1995). The analysis of data of different plots showed that there were significant differences in the angles (tangent values) of these curves. Sandy loam supported the highest photosynthetic efficiency of *S. leprosula* seedlings, followed by sandy clay loam and loam. *S. leprosula* in the open site had the highest photosynthetic efficiency, followed by light shading and moderate shading.

As a comparison, the fitted curve of photosynthetic-PAR response for planted seedlings in the morning between 07.00 hrs and 10.00 hrs and in the afternoon between 15.00 hrs and 18.00 hrs is shown in Figure 5.10 and Table 5.9.

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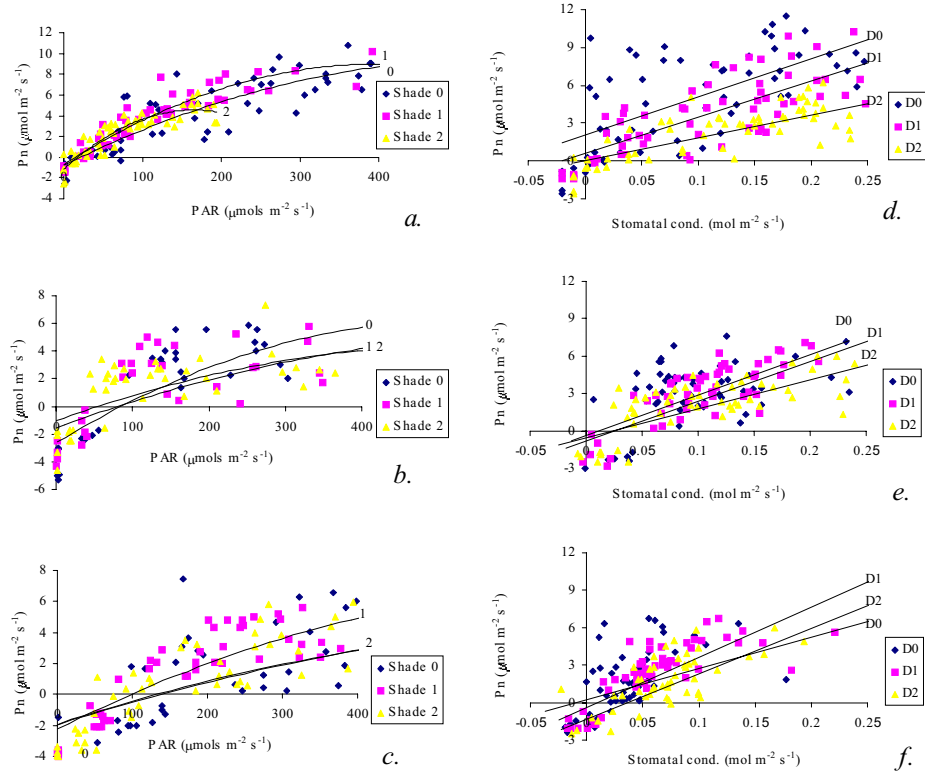


Figure 5.9 Relationship between photosynthetic rate (Pn) and light intensity (PAR) and between photosynthetic rate (Pn) and stomatal conductance under different shading levels on three soil types. a and d: Sandy Loam, b and e: Sandy Clay Loam, c and f: Loam.

Table 5.9 Maximum photosynthetic (P_{max}), dark respiration (R_d), irradiance compensation point (I_c) and irradiance saturation point (I_s) of *S. leprosula* seedlings measured in the morning and in the afternoon. SL: sandy loam, L: loam.

Soil type	Time	R_d	I_c	P_{max}	I_s	Equation	R^2
SL	Morning	-0.39	8.33	9.05	396.7	$Y = -6E-05x^2 + 0.05x - 0.392$	0.80
	Afternoon	-1.21	26.35	5.27	268.3	$Y = -9E-05x^2 + 0.05x - 1.210$	0.84
L	Morning	-1.17	40.93	4.47	625.0	$Y = -4E-05x^2 + 0.03x - 1.173$	0.56
	Afternoon	-3.94	139.80	1.21	271.4	$Y = -7E-05x^2 + 0.04x - 3.944$	0.66

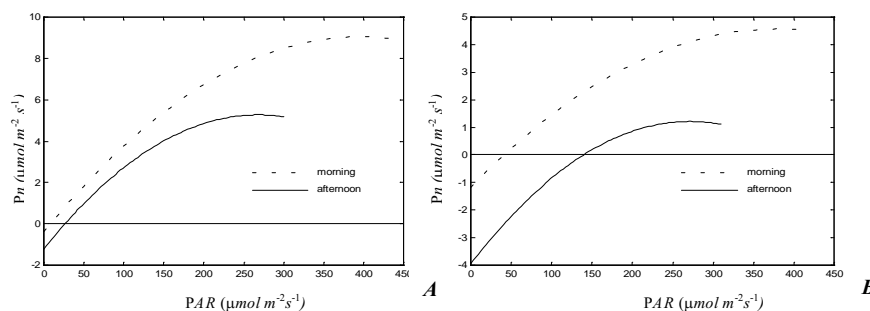


Figure 5.10 Photosynthetic-PAR response curve of *S. leprosula* seedlings measured in the morning and in the afternoon. A: Sandy Loam, B: Loam.

Regarding the relationship between photosynthetic rate and CO_2 concentration, vapour pressure deficit (vpd) at the leaf surface and transpiration with different shading levels and soil types, the regression analysis indicated a weak to moderate correlation. The results cannot be conclusive.

Regarding the relationship between photosynthetic rate and stomatal conductance, the regression analysis indicated that there are no significant differences between the different shading levels. The data of different soil types showed that there were differences in the angles (tangent values) of these curves.

Transpiration rate

Based on Figure 5.11, the transpiration rate was higher in moderate shading (D_2), followed by light shading (D_1) and open site (D_0). There are no differences in the transpiration rate of *S. leprosula* seedlings between soil types. Figure 5.11 also shows that there are no differences in the relationship between transpiration rate and stomatal conductance between the different shading levels and between the different soil types.

Regarding the relationship between transpiration rate and CO_2 concentration and vapour pressure deficit (vpd) at the leaf surface with different shading levels and soil types, the regression analysis indicated a weak to moderate correlation. The results cannot be conclusive.

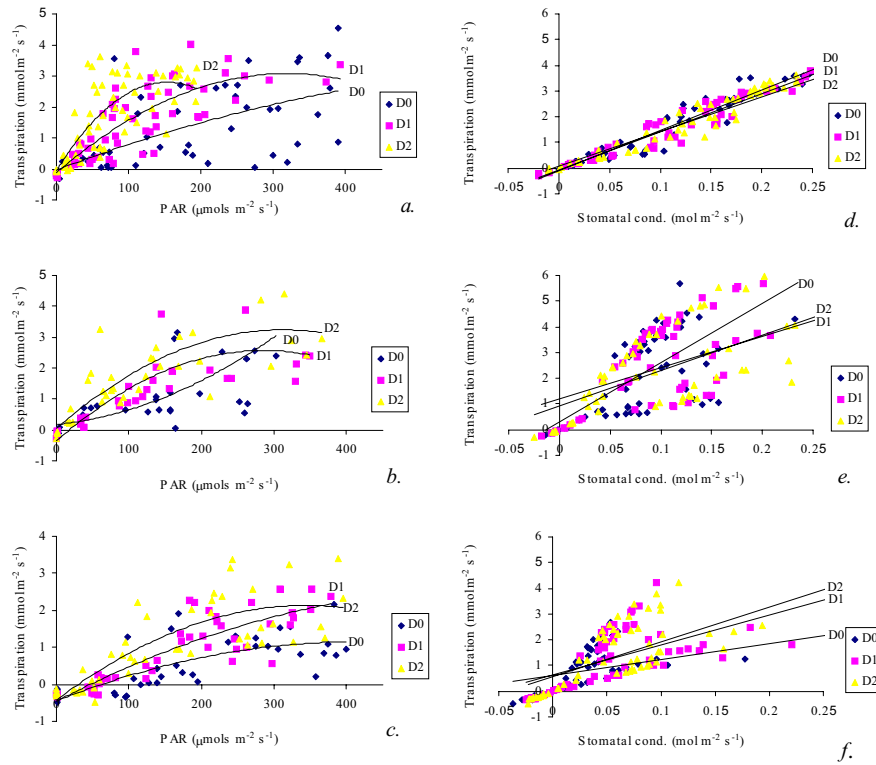


Figure 5.11 Relationship between transpiration rate and PAR, and between transpiration rate and stomatal conductance under different shading levels on three soil types. a and d: Sandy Loam, b and e: Sandy Clay Loam, c and f: Loam.

Stomatal conductance

As in the relationship between transpiration rate and light intensity (PAR), the relationship between stomatal conductance and light intensity also has similar tendency whereas the stomatal conductance was higher in moderate shading (D_2), followed by light shading (D_1) and open site (D_0). Stomatal conductance of *S. leprosula* seedlings in sandy loam was higher compared with those in the two other soil types.

Figure 5.12 shows an unclear relationship between stomatal conductance and CO₂ concentration between shading level within soil types and between soil types. Regarding the relationship between stomatal conductance and vapour pressure deficit (vpd) and temperature at the leaf surface with different shading levels and soil types, the regression analysis indicated a weak to moderate correlation. The results cannot be conclusive.

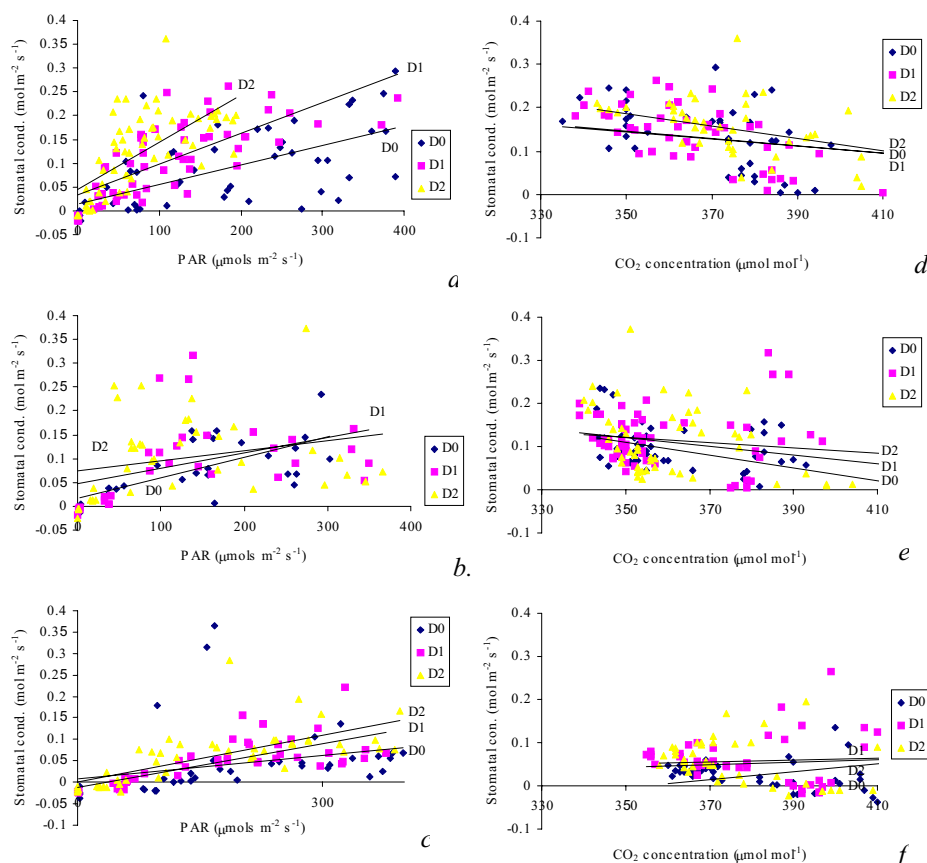


Figure 5.12 Relationship between stomatal conductance and PAR, and between stomatal conductance and CO_2 concentration under different shading levels on three soil types. a and d: Sandy Loam, b and e: Sandy Clay Loam, c and f: Loam.

5.4 DISCUSSION

The effects of the soil type (sandy loam, sandy clay loam or loam), shading level (without shading, light or moderate shading) and mycorrhizal inoculation (no inoculation, *Amanita* sp., *Russula* sp. or *Scleroderma* sp.), on the growth of *S. leprosula* cuttings and mycorrhizal development is discussed below.

Soil type

Soil texture is one of the most important factors governing soil properties in primary forest (Ohta *et al.*, 2000). The growth of *S. leprosula* cuttings planted in loam and sandy loam substrates was higher compared with the growth of those planted in sandy clay loam during the 10 months in the nursery. Omon (2002) also found that sandy loam gave the highest growth for *S. leprosula* cuttings in the nursery. When the growth continued into the field for another 12 months, sandy loam gave the highest growth for *S. leprosula* cuttings, followed by sandy clay loam and loam. It seems that the initial plant condition at planting time is a critical factor for successful planting in the field. *S. leprosula* cuttings adjusted their growth in adapting to new environmental in the field by reducing the diameter and the number of leaves to 27.3% and 40.7% respectively. The decrease in diameter and the number of leaves was a strategy of *S. leprosula* seedlings to reduce their physiological processes. *S. leprosula* could recover from this stress condition in the field relatively fast in only 4 months (see also Chapter 4).

Regarding the physical properties of the soil substrates (Table 4.7), the sand fraction in sandy loam (67.5%) is higher than in sandy clay loam (55.5%) and lowest in loam (31.1%), whereas as to clay fraction it is the other way around, namely 12.6%, 21.8% and 22.1%, respectively. The differences in sandy and clay fractions between these soil substrates have an impact on the plant growth in terms of aeration. The higher the sand fraction in the soil the better the aeration. The oxygen availability is important not only for roots to breathe but also for mycorrhizal development (Harley, 1989; Oldeman and Iriansyah, 1993).

Janos (1985) suggested that a low availability of phosphorus and a low humidity in tropical soil may cause survival and growth of tropical species to depend on mycorrhizal activities. A high soil temperature reduces the number of mycorrhizal infections in dipterocarp seedlings (Noor and Smits, 1988), whereas the critical soil temperature for ectomycorrhizal development is about 32°C (Smits *et al.*, 1987).

Failure of plantations is more related to competing weeds and a weak mycorrhizae infection, than to unfavourable light conditions (Seibert, 1990). As far as a dipterocarp plantation is concerned, more attention must be paid to the soil environment, which must be more suitable for the necessary ectomycorrhizae than for the dipterocarps themselves.

Mycorrhizal inoculation

The significantly fastest growth of *S. leprosula* cuttings was obtained after initial inoculation with *Scleroderma* sp. followed by 'no inoculation', inoculation with *Amanita* and with genera *Russula* prior to the age of 10 months. Ingleby *et al.* (1990), Smits (1992) and Yasman (1995) observed that aggressive fungi like *Thelephora terrestris* and *Scleroderma* sp. often occur in a dipterocarp nursery, as pioneer fungi or 'early stage' mycorrhizae, and may infect dipterocarp seedlings if there is no

*inoculum introduced. Based on these results, the abundantly occurring **Scleroderma** sp. with their aggressive behaviour, may well adapt to dipterocarp nursery conditions, may support **S. leprosula** also inoculated with the same species of fungi. **S. leprosula** without mycorrhizal inoculation could grow as well as if inoculated with **Amanita** sp., due to the reason given above. Similar results were found by Smits (1994) who observed that the growth of **S. leprosula** was faster after inoculation with **Amanita** sp., while when inoculated with **Russula** and **Lactarius** there was no significant difference. Inoculation with **Russula** sp. did not give as much support to the growth of **S. leprosula** as the other mycorrhizae because this mycorrhizal fungus may not well adapt to nursery conditions and therefore be not suitable (Noor and Smits, 1988; Yasman and Smits, 1988; and Yasman, 1995). Another reason is that each mycorrhizal fungus may play a specific role in promoting the growth of the plant. The ability of each mycorrhizal fungus to colonize the dipterocarp is also species-dependent (Smits, 1994; Smith and Read, 1997; Omon, 2002).*

*After 12 months in the field, the root colonisation by mycorrhizae had changed from **Laccaria** sp. dominated mycorrhizal fungi (see also Chapter 4) into **Scleroderma** sp. dominated mycorrhizal fungi. **Scleroderma** sp. dominated the colonisation, followed by **Inocybe** sp. and **Amanita** sp. Mycorrhizal of **Scleroderma** sp. are dominant in nursery and field planted seedlings for reforestation (Supriyanto et al., 1993; Zarate et al., 1993; Kikuchi, 1997, 1998). **Scleroderma** sp. is considered to be a good mycorrhizal fungus for seedlings for many species of dipterocarps although the effect of this fungus varied among tree species (Kikuchi, 1997). Furthermore, Kikuchi and Ogawa (1995) confirmed that nitrogen-fixing bacteria co-exist around the ectomycorrhizae of **Scleroderma** spp. associated with dipterocarps. Suhardi (1997) predicted that after five years **Laccaria laccata** will be more dominant than **Scleroderma**. Unsuitable ectomycorrhizal species used for inoculation in the nursery may lead to the failure of dipterocarp seedlings to establish in the field (Smits, 1992). It seems that specificity of dipterocarp ectomycorrhizae might occur (Omon, 1994; Smits, 1994; Yasman, 1995).*

*Yasman (1995) found that different inocula did not significantly influence the growth of **S. leprosula** seedlings prior to the age of 18 months. He assumed that the effect of different inocula on the growth of **S. leprosula** seedlings was significantly revealed after 3.5 years. These differences with the above mentioned results can be explained by the fact that environmental factors influence the development of mycorrhizal fungi. Noor and Smits (1988), Yasman and Smits (1988), and Yasman (1995) reported that light intensity, soil fertility (expressed as the availability of nitrogen and phosphorus), soil moisture, soil heat, aeration and pH influence the mycorrhizal development on dipterocarp roots.*

The percentages of mycorrhizal roots found in sandy loam, sandy clay loam and loam were 51%, 59% and 84%, respectively (Table 5.7). The pH levels of these soil types

were 5.1, 5.2 and 4.9, respectively (see Table 4.7). Omon (2002) found a higher percentage of mycorrhizal roots (67%) in a sandy loam substrate with pH 5. Harley (1989) stated that the optimum pH for mycelia growth of mycorrhizal fungi is always on the acid side of neutrality and each species has its own pH reference whereas *Amanita* sp prefers pH 3.5 to 4.5. Hence, the mycorrhizal development in those soils was affected by soil pH, at least for *Amanita* sp. An increase in soil pH levels does not affect mycorrhizal formation, but it reduces the effectiveness of different fungi in promoting plant growth.

Light effect

While the soil conditions for dipterocarp species are not regarded as critical as long as the plantations are not situated on deteriorated land, the light intensity and temperature regime in plantation forests often limits the success of the plantation. In this study, a light shading (73% of full daylight) showed optimum growth for *S. leprosula* seedlings in the first 12 months in the field followed by moderate shading (58% of full daylight) and open area (100%). This is in accordance with the results obtained by Nicholson (1960), Koyama (1981) and Effendi et al. (2001). Nicholson (1960) found that *S. leprosula* seedlings had the highest height growth under around 50% light intensity in 13 months. The higher the light intensities the lower the height growth. Nicholson's results (1960) indicate a fair shade tolerance. Dipterocarps generally appreciate shade for the first 1.5 years, but are more light tolerant or even light demanding afterwards. Koyama (1981) found that the species reacts positively to an increased photosynthetic active radiation up to about $500 \mu\text{mol m}^{-2}\text{s}^{-1}$, corresponding to about 25 to 30% relative intensity.

Yasman (1995) found similar results in the greenhouse experiment in which *S. leprosula* grew faster under a light intensity of 40 and 60% than under a light intensity of 25 and 90% in 18 months. Suhardi (1997) found that *S. leprosula* grew higher and showed a good mycorrhizal formation in an open area in the early stages of growth. It could be that the soil temperature was not so high. Mori (1980) found that the fastest growth of *Hopea helferi* was obtained under a light intensity of 33% and observed a decrease in growth above and below this light intensity. Furthermore, Sasaki and Mori (1981) showed a faster growth of some dipterocarp seedlings at a 30 to 50% light intensity for shoot growth and 50 to 60% light intensity for root growth. In general, dipterocarp seedlings need a light intensity level between 30 and 70% of full sunlight for optimum growth (cf. Whitmore, 1984). This optimal light requirement changes when the seedlings reach the sapling or tree stage. Furthermore, Yasman (1995) related the light intensity with mycorrhizal development to soil temperature. The high light intensity can increase the soil temperature to exceed the critical point for growth of ectomycorrhizae (Smits, 1983a; Smits et al., 1987; Noor and Smits, 1988). Suhardi (1997) showed that the average mycorrhizal formation in a shady area is about 26% while that in an open area is about 6%.

Dipterocarps which are commonly regarded as shade species react very positively to an artificially opened canopy, and trees of a diameter of around 20 cm are still able to react very rapidly to a change in their light environment (Seibert, 1990). It seems that the light intensity is the most important factor for the growth of dipterocarp seedlings and indirectly for associated mycorrhizae. Furthermore, Becker (1983) found that seedlings growing under different light conditions showed different degrees of ectomycorrhizal colonisation.

S. leprosula seedlings were affected by the shade levels. Growth rates were reduced at moderate shading, and somewhat suppressed in full sunlight (Table 5.5). Reductions in growth rates under moderate shading and open area can be explained by the influence of light intensity on the seedling architecture. Lee **et al.** (2001) added that besides irradiance, spectral quality influenced the development of seedlings.

One year after the shading treatment, the dry weight of the seedlings at moderate shading and open area was reduced. Leaf weight ratio and root weight ratio shown in Table 5.5, indicated that photosynthetic products were distributed more to leaves rather than to other parts, resulting in a decrease in root weight at the moderate shading and open area. Morphological and photosynthetic properties of the leaves changed in response to the light intensity levels. The leaf morphology of **S. leprosula** changed significantly in moderate shading, causing an increase in Specific Leaf Weight (SLW) and a decrease in leaf thickness (Table 5.5). Plants grown under moderate shading levels distributed much of the photosynthetic products to leaves and spread out thinner leaves than those under light shading. This phenomenon is regarded as one of the adaptations to weak light conditions through an increase in the photosynthetic leaf area. Tange **et al.** (1998) showed similar results as to the effect of shading on the distribution of photosynthetic products. They showed that the leaves of **Dryobalanops lanceolata** (Dipterocarpaceae) changed morphologically less by light conditions than those of **S. leprosula**. It is known that the morphological plasticity to light conditions is larger in light-demanding species than in shade-tolerant species (Bazzaz, 1979).

Physiological characteristics

Although the irradiance saturation point at light shading was similar to that in the open, this point declined significantly at moderate shading, indicating that the seedlings adapted to weak light conditions. Tange **et al.** (1998) showed that **S. leprosula** decreased in photosynthetic rates immediately after release from shading and substantially recovered the photosynthetic rate after 18 days. Therefore, **S. leprosula** is one of the species adaptable to sudden exposure to high light intensity, and suitable for reforestation in degraded open land.

In this study, maximum net photosynthetic rates (NPR) for **S. leprosula** were significantly higher in light shading and open area (9.2 to $10.9 \mu\text{mol m}^{-2}\text{s}^{-1}$) than in

moderate shading ($4.8 \mu\text{mol m}^{-2}\text{s}^{-1}$). Ishida *et al.* (2000) found similar results in that the NPR values of this species was $11 \mu\text{mol m}^{-2}\text{s}^{-1}$ in small gap and was higher than in large gap ($5.4 \mu\text{mol m}^{-2}\text{s}^{-1}$). He found also that these values were higher than the NPR of *Macaranga gigantea*, a pioneer species.

S. leprosula seedlings responded differently in Photosynthetic Active Radiation (PAR) with the time, in relation with photosynthesis rate depending on the time. The same amount of PAR in the morning and in the afternoon gave quite significant differences in the photosynthesis rate of *S. leprosula*. PAR received in the morning had a greater effect on the photosynthesis rate than in the afternoon. Rossignol *et al.* (1998) related this condition to the effect of the phases of the moon and light spectrum. Evers (*pers. comm.*, 2002) indicated that the difference in photosynthesis is the result of the plant condition in the morning and in the afternoon. He related this condition to the stomatal conductance mechanism.

Differences in growth rates are partially explained by maximum photosynthesis rates (Table 5.8); those of *S. leprosula* in light shading were higher than in open area and were much higher than in moderate shading.

Koch *et al.* (1991) has shown that tropical tree leaves heated by the sun around noon close their stomata and stop transpiring. The leaves observed here seem to do the opposite, the stomatal conductance growing strongly above approx. 29°C leaf temperature. For the moment this can not be explained, but that these leaves are malfunctioning under heat stress cannot be excluded.

5.5 CONCLUSION

The growth of *S. leprosula* cuttings planted in loam and sandy loam substrates was higher compared with the growth of those planted in sandy clay loam during the 10 months in the nursery. When the growth continued into the field for another 12 months, sandy loam gave the highest growth for *S. leprosula* cuttings, followed by sandy clay loam and loam. The higher the sand fraction in the soil the better the plant growth.

S. leprosula seedlings reduced their diameter and number of leaves when transplanted into the field. This stress condition could be recovered by *S. leprosula* for 4 months. Therefore, *S. leprosula* is one of the species adaptable to sudden exposure to high light intensity, and suitable for reforestation in degraded open land.

The fastest growth of *S. leprosula* cuttings was obtained after initial inoculation with *Scleroderma* sp, followed by 'no inoculation', inoculation with *Amanita* and with genera *Russula* prior to the age of 10 months. After 12 months in the field, *Scleroderma* sp. dominated the root colonisation, followed by *Inocybe* sp. and *Amanita* sp.

*A light shading (one layer of net), corresponding to about 70% relative light intensity, showed optimum growth for **S. leprosula** seedlings in the first year in the field followed by moderate shading (approx. 60% relative light intensity) and open area. Therefore, **S. leprosula** can be classified as a light demanding species.*

*Photosynthetic Active Radiation (PAR) received in the morning had a greater effect on the photosynthesis rate of **S. leprosula** than in the afternoon. The photosynthetic efficiency of **S. leprosula** seedlings growing in sandy loam was higher compared with the efficiency of those planted in sandy clay loam and loam during the 12 months in the field.*

CHAPTER 6

INITIAL GROWTH OF *Shorea leprosula* Miq. CUTTINGS UNDER THE SHADE OF *Peronema canescens* Jack.

Aldrianto Priadjati and G.W. Tolkamp

ABSTRACT

The main objective of this chapter is to unite knowledge useful to help accelerate the reforestation of alang-alang (*I. cylindrica*) grassland to dipterocarp dominated vegetation by creating suitable conditions for dipterocarp species, to be provided by indigenous pioneer species. The experiment started by planting *S. leprosula* cuttings among *P. canescens* trees in December 1998 and ended in December 2001. A randomised complete block design was used, with 4 different shading levels (open area, semi-closed stand, closed stand and semi-open area). Every shading level was arranged in 8 rows as blocks and each similar treatment consisted of 3 *S. leprosula* cuttings. Border plants surrounded each treatment. After 18 months, differences between shading levels in survival rates of *S. leprosula* cuttings were not significant, and varied from 67% to 83%. There was no mortality after 11 months. Seedlings under moderate shading of *P. canescens* (closed stand) and in semi-open areas with some shading by secondary shrubs ('young shrubs') were significantly higher and bigger than those under light shading by pruned *P. canescens* trees (semi-closed stand) and in open areas. Within almost 3 years, *S. leprosula* trees in a closed stand and in a semi-open area reached a height of 281 to 283 cm and a diameter of 33 to 34 mm, whereas in the open area and under the semi-closed canopy of *P. canescens* they were only 165 to 193 cm high and 22 to 27 mm in diameter.

6.1 INTRODUCTION

6.1.1 Background

With 141.2 million hectares of forest areas, Indonesia has the largest surface of dipterocarp forests in South East Asia (Yasman, 1998). In the last decade, more than 1.5 million hectares of natural primary forests have disappeared annually. The remaining ones are residual or secondary forests or even degraded alang-alang (*Imperata cylindrica* (L.) Beau.) grasslands. The appearance of unproductive alang-alang grasslands cannot be ignored as a degraded area of tropical rain forest in Indonesia. They cover an enormously large area. The Centre for Soils and Agroclimate Research (CSAR) estimates the alang-alang grassland area in Indonesia to cover approx. 8.6 million hectares or 4.5% of the land area of Indonesia. Sumatera and Kalimantan have the largest alang-alang areas, approx. 2.13 and 2.19

million hectares, respectively. According to MacKinnon *et al.* (1996), almost one-quarter of South Kalimantan, 900.000 hectares, is covered with alang-alang grasslands, increasing at a rate of 10.000 hectares per year mainly due to non-appropriate agricultural practices. ITTO (1990) stated that the total alang-alang area in Indonesia already covered 20 million hectares in 1990. These grasslands have become more extensive due to human activities that also caused disturbances of the rain forests. Human impact is continuously intensified by over-exploitation, clear-cutting, forest conversion into mining areas, agricultural lands and shifting fields by using slash-and-burn methods and also by fires.

After clearing of a forested surface, alang-alang (*I. cylindrica*) grassland can cover the area in a very short time. It is difficult for other species than this grass to grow in the same area. The remaining forest cannot re-invade the grasslands spontaneously, because alang-alang does not leave any resources for forest regeneration, with such different regeneration environments, a high light intensity and heated soil and air. Alang-alang spreads by means of its airborne seeds as well as by its rhizomes. These rhizomes rapidly sprout after burning. Alang-alang has the ability to thrive on infertile soils by having low nutrient requirements and a high efficiency of nutrient uptake (Saxena, 1983 in Brook, 1989) so that there is no relationship between soil C/N ratio and the growth of alang-alang (Soerjani, 1970). The extensive occurrence of endomycorrhizae on alang-alang has been observed by Tjitrosemito *et al.* (1994) *ex* Tolkamp (1999). Alang-alang produces allelopathic toxins that retard or hinder the germination and growth of many plant species. Alang-alang can monopolise resources in this way, so few biotopes, if any, are left for other plant species (Sabarnurdin, 1991). *I. cylindrica* tolerates no shade, however, so that shading equally reduces shoot and root rhizome mass (Soerjani, 1970) and reduces the relative growth rate in both shoot and root rhizomes (Eussen, 1981).

The present chapter elaborates on an alternative reforestation system for alang-alang grasslands by planting trees. The essential elements in reforestation of *I. cylindrica* grasslands are species and provenance selection, intensive mechanical site preparation, fertilisation, careful plantation design and maintenance and effective fire protection (Otsamo *et al.*, 1995, Tolkamp and Priadjati, 1998, Tolkamp, 1999, Murniati in prep.). The selection of tree species, of course, is very important for both natural regeneration and planting. The tree species must be able to establish themselves by occupying and shaping the right surrounding biotopes. They require a high survival rate, fast growth, a wide crown and an early closure of the canopy, high tolerance to a strong light intensity and also fire resistance. Besides, the tree must possess a tolerance against biotic impacts, low soil pH, water and nutrient scarcity. It must also be accepted locally and have a potential for various end-users (Soerjani, 1970; Sajise, 1980; Soerianegara, 1980; Evans, 1984; DelaCruz, 1986, 1993; Hadi *et al.*, 1990; Ohta, 1990; Appanah and Weinland, 1993; Kartawinata, 1994; Tolkamp, 2001). Not too many species can compete with or grow on alang-alang grassland. *Peronema canescens* is one of a promising indigenous pioneer

species that can compete with alang-alang grasslands. This species has a high survival rate with a remarkable re-growth after forest fires (Hatta, 1999; Tolkamp, 1999; 2001). Plantation mixtures of indigenous pioneer species, like *P. canescens* and dipterocarp species need further study (Otsamo, 1996b).

So, the main objective of this chapter is to unite knowledge useful to help accelerate the reforestation of alang-alang land to dipterocarp dominated vegetation by creating suitable conditions for dipterocarp species, to be provided by indigenous pioneer species. The hypothesis is that shading by the suitable pioneer species can reduce the growth of alang-alang and can create a suitable microclimate for climax species (Dipterocarpaceae). The research question that could be answered through this experiment is how great the effect is of *I. cylindrica* grassland and shading of *P. canescens* trees on the growth of *Shorea leprosula* (Dipterocarpaceae). The results of this experiment are very important to accelerate the transition from alang-alang grassland to dipterocarp dominated forest through planting *P. canescens*, to make a suitable microclimate needed for the successor species by its shading. The following hypotheses were formulated and tested:

1. Early survival and health conditions of *S. leprosula* cuttings differ between the open sites and under the *P. canescens* stand.
2. *S. leprosula* cuttings will adapt to the new environment in the field by changing both physiological processes and characteristics of the tree body.
3. Shading *P. canescens* has a stronger influence on the growth (height, diameter) of *S. leprosula* seedlings than the open grassland situation.

6.1.2 *Peronema canescens* Jack.

Westphal and Jansen (1989) and Kebler (2000) describe the general characteristics of the family *Verbenaceae* and in particularly *P. canescens* Jack. This species is a pioneer species occurring in the Malaysian peninsular. Geographical distribution in Indonesia: West and South Sumatera, West Jawa and all over Kalimantan. It is cultivated in Indonesia, Malaysia and Thailand. It is sometimes difficult to decide whether the plants are of natural origin or planted.

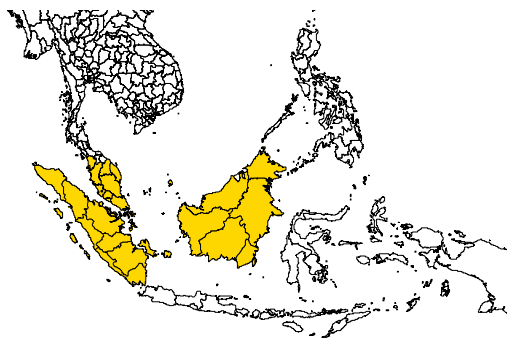


Figure 6.1 Distribution of *Peronema canescens* Jack.

Peronema occurs in residual forests on dry and slightly moist soil at an altitude up to 600 m. Luxuriant natural regeneration may occur in open areas, such as bushlands, *I. cylindrica* grasslands, fallow or logged-over forest. Dominant natural populations of this species were present on infertile black soil hills in the ITCI concession area (a large timber concession near Balikpapan) in 1998. This indicates that the species may have the capacity to rehabilitate critical land, such as grasslands and mining sites.

The trade name of *P. canescens* is Sungkai and the vernacular names for this species are sungkai (Kalimantan), sekai, sungkit (Sumatera), jati sabrang (Jawa) and many others. The wood of Sungkai is mostly used locally for roof trusses, bridge constructions and furniture. The attractive, beautiful linear figures in the wood make Sungkai suitable for fancy veneer, cabinets, carvings etc., and is exported to Japan. For that reason, natural populations with mature old trees are on their way to extinction in Kalimantan and Sumatera. Various parts of this plant are used medicinally. The decoction of the leaves has been traditionally prescribed for the treatment of malaria and the chemical structures of seven peronemins have been elucidated on the basis of their chemical and physiochemical properties (Kitagawa *et al.*, 1994)

Diagnostic characteristics of *P. canescens* (Fig. 6.2): Evergreen or deciduous shrubs or small to medium-sized trees up to 30 m tall, the length of the clear bole is up to 15 m, the diameter is 60 cm or over, heartwood is pale, yellow or pale brown, with pale red tinge. The outer bark is grey or light brown, with shallow grooves and peels off in small, thin pieces. The twigs are covered with fine hairs. Leaves opposite, imparipinnate, with a purplish tinge when young; leaflets in 3 to 11 opposite or subopposite pairs, sessile or shortly stalked, lanceolate, up to 35 cm by 7.5 cm. Inflorescence paniculate, terminal or in the axils of the uppermost leaves, large and widely branched, erect, 25 to 60 cm, dense (Hatta, 1999).

Peronema trees bear fruits throughout the year, especially in March to June. There are about 262,000 seeds per kg. Dry seeds have a 95% germination capacity. Artificial regeneration is carried out by planting branch cuttings, 2.5 cm in diameter and 25 cm long at an angle directly in the field on 1 to 2 m wide strips. Planting branch cuttings directly in polyethylene bags in the nursery is more common, and transplanting takes place about 4 to 6 months later. Spacing in the field is commonly 2 m by 3 m or 2 m by 4 m.

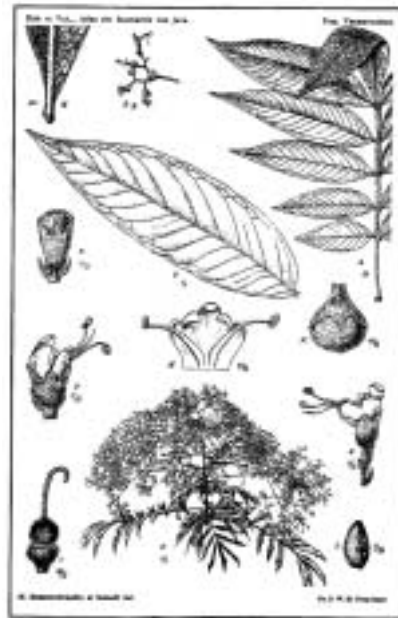


Figure 6.2 General botanical characteristics of *Peronema canescens* Jack. A leaf, B leaflets, B1 part of the lower of leaf surface, C flowering branch, D part of inflorescence, E flower bud, F-I flower with analysis, K, L fruit with analysis (after Koorders and Valetton, 1914 *ex* Hatta, 1999).

Tree architecture: Branch modules are orthotropic with definite growth. The main trunk is monopodial with indefinite, rhythmic growth, bearing sympodial branch complexes. In its early development, the branch shows a repetition of the monopodial growth of the trunk, then sympodial branches appear, due to terminal flowering. Each branch complex is three-dimensional, but not symmetric as in *Leeuwenberg's model*. Each module has spirally arranged leaves (phyllotaxis is opposite-decussate)

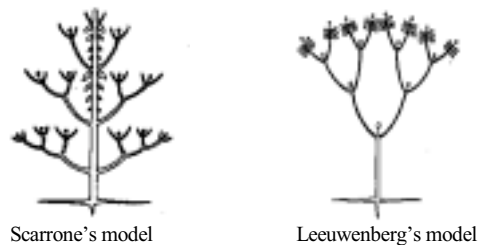


Figure 6.3 The tree architecture of *Peronema canescens* (after Hallé *et al.* 1978)

The architecture of Sungkai represents the model of Scarrone, converging when older with *Leeuwenberg's model* (Hatta, 1999). This conversion takes place by reiteration processes and replacement of terminal flowering by terminal flushing. According to Hallé *et al.* (1978, p. 213 and p. 145), *Scarrone's model* has the following characteristics: “an orthotropic rhythmically active terminal meristem which produces an indeterminate trunk bearing tiers of branches, each branch-complex orthotropic and sympodially branched as a result of terminal flowering”. *Leeuwenberg's model* consists of “equivalent orthotropic modules, each of which is determined in its growth by virtue of the ultimate production of a terminal inflorescence. Branching is three-dimensional to produce the several equivalent modules and is correlated with flowering”. Hatta (1999) conceived Sungkai as belonging to *Scarrone's model* because of the existence of a well-developed monopodial trunk, especially in the pole phase. Sungkai belongs to *Scarrone's model* once it is out of the seedling phase. The abundant reiteration of the model obscures the distinctive single, rhythmic trunk. He also explained that some characteristics of *Leeuwenberg's model* occur in Sungkai, such as its orthotropic modules with definite growth, the three-dimensional sympodial branching, and the terminal inflorescences. However, this convergence with *Leeuwenberg's model* only occurs in very young trees and in older trees at the end of the branch complexes (see Figure 6.3).

Sungkai are capable of abundant reiteration (‘traumatic reiteration’, i.e. formation of model-like branch complexes after damage to the tree body) and the changeover from *Leeuwenberg's model* to *Scarrone's model* or from *Scarrone's model* to *Leeuwenberg's model* gives a great plasticity of development because the meristem may function either sexually (*Leeuwenberg's model*) or vegetatively and rhythmically (*Scarrone's model*) as needed (Fig. 6.4).



Figure 6.4 The architecture of *Peronema canescens* with its profuse reiteration capacity is strongly adapted to regeneration after forest fires (after Hatta, 1999)

6.2 MATERIAL AND METHODS

6.2.1 Location and duration

The plantation trial plot was laid out some 35 km Northeast of Balikpapan (1°1'05" latitude South and 116°57'34" longitude East), in the village of Samboja, in the Kutai district, East Kalimantan. The experimental plot burned in October 1994 and in August 1997, so the vegetation on the experiment site was dominated by alang-alang (*I. cylindrica*) grassland. The experiment started by planting *S. leprosula* cuttings among *P. canescens* trees during the rainy season in December 1998 and ended in December 2001.

Table 6.1 Monthly climate data in the Wanariset Samboja area, from 1999 to 2001. Data were collected from the weather station of the Tahura Bukit Suharto Education Forest (BSEF) of Mulawarman University (20 km from the plot)

Month/ Year	Average Humidity (%)			Average temperature (°C)			Total Rainfall (mm)			Rainday (days)		
	1999	2000	2001	1999	2000	2001	1999	2000	2001	1999	2000	2001
January	88.1	90.3	91.2	24.9	24.6	23.7	401	375	66	20	17	5
February	88.3	90.3	89.0	24.7	24.4	24.3	419	352	196	15	18	13
March	88.5	82.6	85.5	24.8	24.9	24.6	357	387	264	21	15	22
April	86.6	67.4	80.6	25.3	24.8	25.0	518	278	136	20	23	8
May	89.2	87.5	77.6	24.8	25.4	24.9	520	482	133	17	17	8
June	88.7	91.0	98.4	24.6	24.3	24.7	386	464	0	10	19	0
July	89.5	88.6	97.6	24.4	24.3	24.5	334	473	0	7	8	0
August	87.1	87.1	92.2	24.0	24.0	24.7	497	502	13	11	10	5
September	82.0	85.3	95.7	24.6	25.7	24.8	448	301	225	15	17	25
October	89.8	42.2	93.7	25.4	25.2	25.5	314	476	508	20	3	27
November	89.6	58.7	93.0	24.8	24.6	24.8	297	270	664	20	11	30
December	90.5	84.3	91.7	25.3	25.5	25.4	285	290	251	19	12	16
Average	88.1	79.6	90.5	24.8	24.8	24.7	390	388	205	16	14	13
Total							4676	4651	2456	195	170	159

The soil in the experimental plot areas has developed on weathered tertiary claystone. The soil is deep with a well-developed structure. The thin A-horizons are mostly loam to clay loam with a clay texture on the subsoil horizons (see Appendix 10). Drainage is good to moderate. The pH of the soil is 4.5 to 5.1 and the soil is very poor in nutrients. It can be classified as typical hapludults according to the soil taxonomy (SSS, 1987) or Haplic Alisols in the FAO-UNESCO system (FAO, 1988). The topography of the experiment area is relatively undulating at an elevation of approx. 50 m above sea level.

The coastal area of East Kalimantan, where the experimental plot is situated, is known to be drier than other parts of the island of Borneo and has a tropical rainforest climate: hot and wet throughout the year (Whitmore, 1984; MacKinnon *et al.*, 1996). The mean annual rainfall in this area during the period of 1999 to 2001 ranges between approx. 2456 and 4676 mm and the average annual rainfall was 3928 mm. The months of June

through August 2001 were dry months, with less than 100 mm monthly rainfall (Table 6.1).

The average monthly relative atmospheric humidity is about 85%, with extremes of 96% in the wettest months (van Bremen *et al.*, 1990). Toma *et al.* (2000a) measured that the yearly mean in relative atmospheric humidity during 1988 to 1998 was around 59% and 93% for daily minimum and daily maximum, respectively. The average daily amplitude of the relative atmospheric humidity was larger than the monthly one.

The monthly mean atmospheric temperature of this area is recorded as 27°C. Maximum day atmospheric temperature is 35°C and the minimum night atmospheric temperature is 19°C (van Bremen *et al.*, 1990; van den Berg, 1998). Toma *et al.* (2000a) add, that the changes in the daily maximum and minimum atmospheric temperatures per month were much smaller than the range per day.

6.2.2 Methods

Cuttings from one selected mother tree of *P. canescens* at Samboja in East Kalimantan, were propagated directly in small polyethylene bags in May 1995 and were transplanted into bigger polyethylene bags in November 1995 at the Wanariset Samboja nursery.

Cuttings of *Shorea leprosula* used in this study originated from wildlings that grew in natural populations at Tarakan, East Kalimantan (see Appendix 4). The cuttings were produced according to the method developed by Yasman and Smits (1988). The media used in black polyethylene bags, 15 cm high and 8 cm in diameter, were a mixture of topsoil and white sand at a ratio 3:1. The cuttings were also grown in the Wanariset Samboja nursery.

Site preparation was executed a week before planting, in January 1996, by line slashing the alang-alang grassland in one-meter wide rows, followed by making planting holes of approx. 25 cm deep. The vegetation, dominated by alang-alang grasses and about one meter wide between the lines, stayed untouched. The 240 cuttings of *P. canescens* were transplanted into 12 rows and every row consisted of 20 cuttings in the cleared ground at a distance of 1 m by 2 m in February 1996. Manual weeding was carried out in the form of strip clearance by slashing the alang-alang every three months from March to December 1996. The forest fires in August 1997 burnt this plantation and made *P. canescens* reiterate vigorously. In November 1998, the six rows of *P. canescens* were pruned and the other six rows were not pruned.

A month after pruning some *P. canescens*, *S. leprosula* were planted between the rows of *P. canescens* trees and outside the *P. canescens* stands in alang-alang grassland, in a pattern of 2 m by 2 m. A randomized complete block design was used, with four different shading levels. Every shading level was arranged in eight rows as blocks and each similar treatment consisted of three *S. leprosula* cuttings.

Border plants surrounded each treatment. The following shading levels were applied:

1. Open area (without shading of *P. canescens* trees or pure *I. cylindrica* grassland)
2. Semi-closed stand. Light shading by pruned *P. canescens* trees
3. Closed stand. Moderate shading by intact *P. canescens* trees
4. Semi-open area with some shading by shrubs, the so-called 'young shrubs'.

6.2.3 Data collection and analyses

Light availability

Light intensity (PAR) was measured on each *S. leprosula* cutting every hour from 06.00 hrs to 18.00 hrs during a cloudy day on 2 November 1999 and from 07.00 hrs to 18.00 hrs on 13 November 2001, which was a bright day. The PAR was recorded at 50 cm above the ground next to each *S. leprosula* seedling as standard with a LI-COR light meter (Model LI-250) on 2 November 1999 and at the leaf where physiological properties were measured with a LI-COR 6400 on 13 November 2001. The hourly measurements were added up to obtain the total daily PAR.

Soil temperature and soil humidity

The soil temperature was measured three times, 3 months after planting (on 12 March 1999) for all *S. leprosula* planted between the *P. canescens* trees and by sampling in the open area, on 14 September 2000 (day 643) for all of *S. leprosula* and on 14 November 2001 at every hour from 06.00 hrs to 18.00 hrs. The temperature data were then averaged. Relative soil humidity was measured for all *S. leprosula* planted every hour from 06.00 hrs to 18.00 hrs on 14 November 2001.

*Survival and growth of planted *S. leprosula* cuttings*

Surviving and damaged cuttings were recorded and the height was measured in December 1998 (just after planting) to November 2001. These assessments were recorded successively 1, 326, 550, 643, 738, 818 and 1067 days (or 11, 18, 21, 24, 27 and 30 months) after planting. However, the root collar diameter was measured on day 326 (at the 11th month) towards the end of the experiment. Several cuttings of *S. leprosula* were excluded from the analyses of height and root collar diameter increment, since they had broken branches or suffered from die-back of the leading shoot.

*Crown diameter of *S. leprosula* and *P. canescens**

The crown diameters of *S. leprosula* were determined twice by measuring the projection of the crown in two perpendicular directions, along the row and at a 90° angle, on 23 March 2001 and on 12 November 2001.

The crown diameters of *P. canescens* were measured three times with the same method as *S. leprosula*, at the beginning of the experiment, on 23 March 2001, and on 24 November 2001, at the end of the experiment.

Physiological properties of planted *S. leprosula* cuttings

Photosynthesis, transpiration and stomatal conductance were measured using a portable photosynthetic system (Li-COR 6400). The chlorophyll content was determined using a portable chlorophyll meter (SPAD-501, Minolta Co. Ltd., Japan). SPAD value is in proportion to the chlorophyll concentration. The measurements of physiological properties were taken on the youngest fully expanded leaf by sampling on 3 plants of each shading level on a clear (non-cloudy) day on 13 November 2001. The chlorophyll content was measured on 27 November 2001. To reduce errors due to measurement time, each treatment was measured under approximately the same light conditions as assessed by eye.

Leaf area, leaf thickness, leaf biomass and Specific Leaf Weight (SLW) were determined on the same leaf of which the physiological properties were measured. The thickness of this leaf was measured in the field using a portable micrometer (FHK) on 27 November 2001. The leaf area was measured using an area meter system in a Silviculture laboratory, Pusrehut, Mulawarman University, Samarinda, East Kalimantan. The leaf was then dried at around 70°C using an oven for 24 hours for leaf dry weight and Specific Leaf Weight (leaf area/leaf dry weight) determination at a laboratory of the Wanariset Samboja research station.

Data analyses

The total daily light intensity within the four different shading levels was compared and analysed by the two-way ANOVA procedure. A regression analysis, however, assessed the dependence of the cuttings' height and diameter increments on the total daily light intensity (PAR).

The influence of early survival and health conditions of *S. leprosula* cuttings on shading levels (Hypothesis 1) was compared and analysed using both the Mann-Whitney Test (for two dependent samples: dead and alive) and the Kruskal-Wallis test (for several independent samples: dead, damaged and healthy plants).

The early growth of *S. leprosula* cuttings was studied by comparing the log-transformed growth data in the two (semi) open grassland sites and in the two (semi) closed *P. canescens* stands. Therefore, plot mean data were analysed by the two-way ANOVA procedure and Tukey's HSD-test of means, and divided into statistically homogeneous groups. The Mean Annual Increment (MAI) was calculated and analysed conform the above-mentioned method over a period of 741 and 1067 days for diameter and height, respectively. For the MAI calculation the following formula was used:

$$\begin{aligned}\text{MAI-diameter} &= (\text{Diameter increment within 741 days} / 741) \times 365 \\ \text{MAI-height} &= (\text{Height increment within 1067 days} / 1067) \times 365\end{aligned}$$

6.3 RESULTS

6.3.1 Light availability

The mean total daily light intensity (PAR) on 2 November 1999 varied from 1803 to 3069 $\mu\text{mol m}^{-2}\text{s}^{-1}$ along the closed *P. canescens* stands in the open grassland area. Clear differences in the light conditions between these two sites were observed, while the semi-open and the semi-closed stands formed a slightly different group under the same light conditions. This was proven by the homogeneous test of Tukey HSD ($P = 0.05$). The differences in PAR between the sites would have been much larger if damaged plants and/or border plants had been included in the analyses, but they were not. At noon (13.00 hrs), the mean and maximum total daily light intensity (PAR) were 999 and 2710 $\mu\text{mol m}^{-2}\text{s}^{-1}$ in the open grassland area, and 428 and 907 $\mu\text{mol m}^{-2}\text{s}^{-1}$ in the closed stand. For the semi-open grassland area, the PAR varied from a mean of 593 to 821 $\mu\text{mol m}^{-2}\text{s}^{-1}$ maximum, while the semi-closed stand showed a higher variation from 626 average until 974 $\mu\text{mol m}^{-2}\text{s}^{-1}$ maximum.

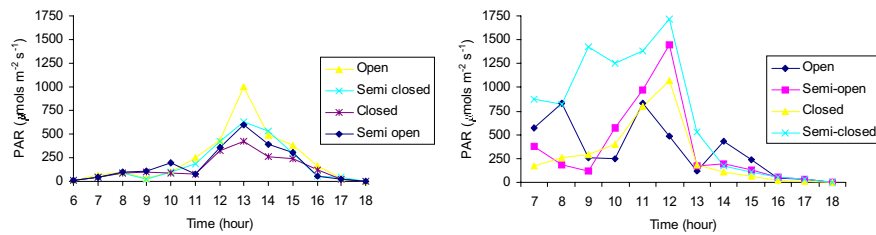


Figure 6.5. Development of the light intensity (PAR) on a cloudy day on 2 November 1999 (left) and on 13 November 2001 (right).

Based on an ANOVA, there were no significant differences in light intensity (PAR) among the shaded conditions on 2 November 1999 at 6.00 hrs, 8.00 hrs and 12.00 hrs. Open area had a significantly higher light intensity (PAR) at 7.00 hrs, 11.00 hrs, 13.00 hrs to 17.00 hrs. Figure 6.5 (right fig.) shows a high light intensity in the morning until 12.00 hrs and drop afterwards. A linear relationship between atmospheric temperature and leaf temperature was demonstrated by a high regression coefficient ($r^2 > 0.9$) at different shading levels. The average leaf temperature ranged from 31°C (in the open grassland area) to 33°C (in the semi-open grassland area).

Table 6.2. Site characteristics in the plot area. PAR_{avg}: Average light intensity; T_{air}: Air temperature; T_l: Leaf temperature; T_s: Average soil temperature; rH: Relative humidity at the leaf surface; rH_s: Soil relative humidity.

Shading level	Light ¹ (%)	Light ² (%)	PAR _{av} ¹ ($\mu\text{mol m}^{-2}\text{s}^{-1}$)	PAR _{av} ² ($\mu\text{mol m}^{-2}\text{s}^{-1}$)	T _{air} ² (°C)	T _l ² (°C)	T _s (°C)	RH ² (%)	RH _s (m^3m^{-3})
Open area	100	55	256	399	32	31	30	69	30
Semi closed	79	49	201	350	32	32	32	69	31
Closed	59	38	150	273	32	32	32	66	32
Semi open	74	100	190	720	33	33	33	64	33

Note: ¹ : Measured on 2 November 1999
² : Measured on 13 November 2001

A very high light intensity in the semi-open area at the second measurement (Table 6.2) resulted in a change in the percentages of light for all conditions. The ratio between light intensity at the first and the second measurement in the semi-open area was 0.26 whereas that in the other levels ranged from 0.55 to 0.64.

6.3.2 Survival of *S. leprosula* seedlings

Over an 18-months' period the survival rate of *S. leprosula* cuttings was higher under shaded conditions than under full light. After 18 months, the difference in average survival rates (including the damaged plants) between shading levels of *S. leprosula* cuttings were not significant (Mann-Whitney Test, $P=0.14$), varied from 67% (open grassland), 71% (semi-open grassland), 79% (semi-closed *P. canescens* stand) to 83% (closed *P. canescens* stand) (Fig. 6.6). There was no mortality after 11 months. Differences in plant performance (dead, damaged and healthy plants) were not conclusive (Kruskal-Wallis Test, $P = 0.08$). In closed stand conditions, natural pruning and die-back at the top occurred for almost all *S. leprosula* plants at the end of the experiment.

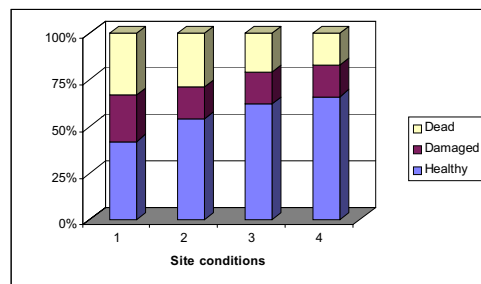


Figure 6.6. *S. leprosula* cuttings performance after 18 months in open grassland (1), in semi-open grassland (2), in the semi-closed *P. canescens* stand (3) and in the closed *P. canescens* stand (4).

6.3.3 Height and diameter increment

The growth of *S. leprosula* in different shading levels is shown in Table 6.3 and Fig. 6.7. There were no significant differences as to the initial mean height of *S. leprosula* (74 cm) between shading levels (Duncan's test at a 5% level of significance). Figure 6.7 shows that one-year-old cuttings in semi-open grassland (young shrubs) grew much faster (52 cm height increment) than cuttings under the other three shading levels with a mean height increment of 18 to 23 cm. However, the cuttings in closed stand recovered and demonstrated later a progressively faster growth than even the cuttings in the semi-open area. The growth of cuttings in the open grassland area decreased in the second year, while the growth of the cuttings in the semi-closed stand increased progressively.

When the cuttings were 18 months old two separate groups were significantly distinguished as to both height and diameter (Tukey HSD, $P = 0.05$), which are:

1. the fast growing *S. leprosula* seedlings (the mean height and the mean diameter varied from 165 to 174 cm and from 19 to 20 mm, respectively) in the closed stand and in semi-open grassland with a mean total daily PAR of 1803 to 2284 $\text{mmol m}^{-2}\text{s}^{-1}$ and
2. the slower growing seedlings (the mean height and the mean diameter varied from 124 to 128 cm and from 15 to 16 mm, respectively) in the semi-closed *P. canescens* stand and open grassland with a mean total daily PAR of 2414 to 3069 $\text{mmol m}^{-2}\text{s}^{-1}$.

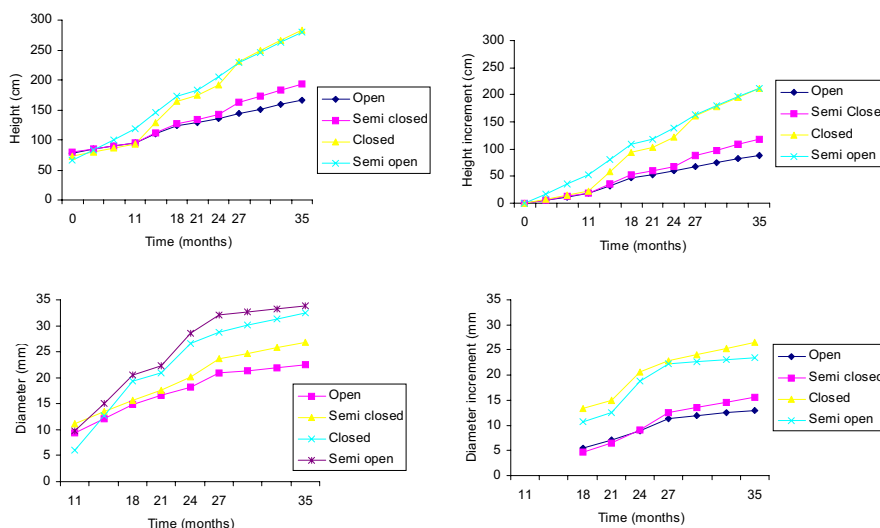


Figure 6.7. The height and diameter growth of *S. leprosula* cuttings under four different shading levels during 35 months.

After 18 months, the growth of *S leprosula* cuttings in the closed stand and in semi-open grassland were significantly higher than in the semi-closed *P. canescens* stand and open grassland. At the age of 35 months, the mean height and the mean diameter of *S. leprosula* cuttings under four different shading levels varied from 165 to 283 cm and from 22 to 34 mm, respectively.

A general indicator for growth is the mean annual increment (MAI) of *S. leprosula* cuttings, which varied from 35 to 80 cm for height and from 7 to 14 mm for root collar diameter under the four shading levels during 35 months. The MAI for both height and root collar diameter of the cuttings was also much lower in open grassland and semi-closed stand compared with the MAI of cuttings in the closed stand and in the semi-open grassland (Tukey HSD, $P = 0.05$). The latter two sites with the highest MAI showed also a greater variation between the individuals in their growth response than the cuttings in the other sites. This tendency was shown for all the cuttings after an 18-month growing period.

A (non-linear) relationship between the growth of each cutting and its total daily light intensity (TD-PAR) was not demonstrated throughout the whole experimental period of 35 months, although there was a clear relationship between the mean TD-PAR and the shading levels.

The regression coefficient was very low ($R^2 < 0.3$) in all situations. This is the relationship between height and root collar diameter increment, respectively of *S. leprosula* cuttings at different ages. The daily PAR of the trees was measured individually in October 1999.

Table 6.3 Effects of shading on various growth parameters of *S. leprosula* cuttings after 35 months in the field. h: height, Dh: height increment, d: diameter, Dd: diameter increment.

Shade condition	h (cm)	Dh (cm)	d (mm)	Dd (mm)
Open area	165.4 a	88.7 a	21.51 a	12.98 a
Semi-closed stand	192.7 a	118.1 a	26.80 a	15.64 a
Closed stand	282.7 b	212.3 b	32.55 b	26.50 b
Semi-open area	280.5 b	212.5 b	33.85 b	23.42 b

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

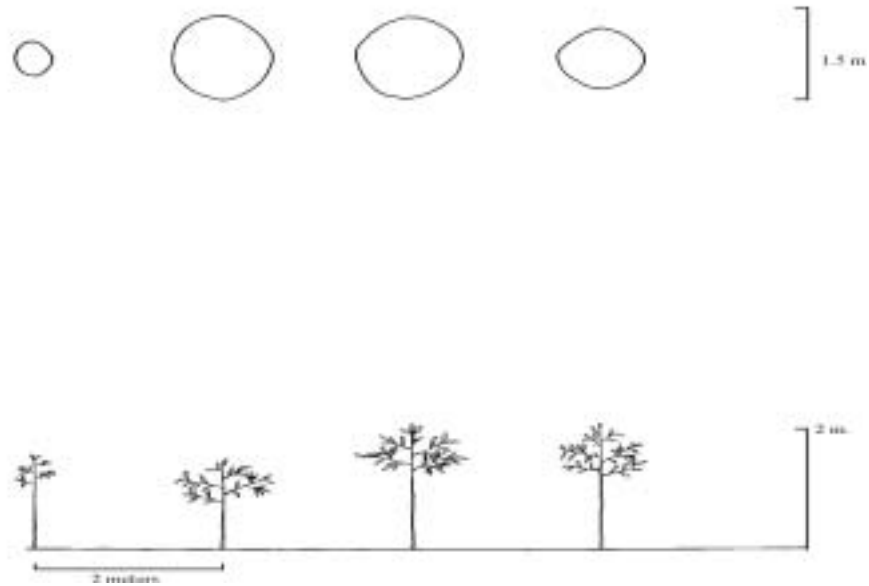


Figure 6.8. The plant performance and crown diagram of *S. leprosula* in open area (pure *I. cylindrica* grassland or without shading of *P. canescens* stand) after a 3-year period.

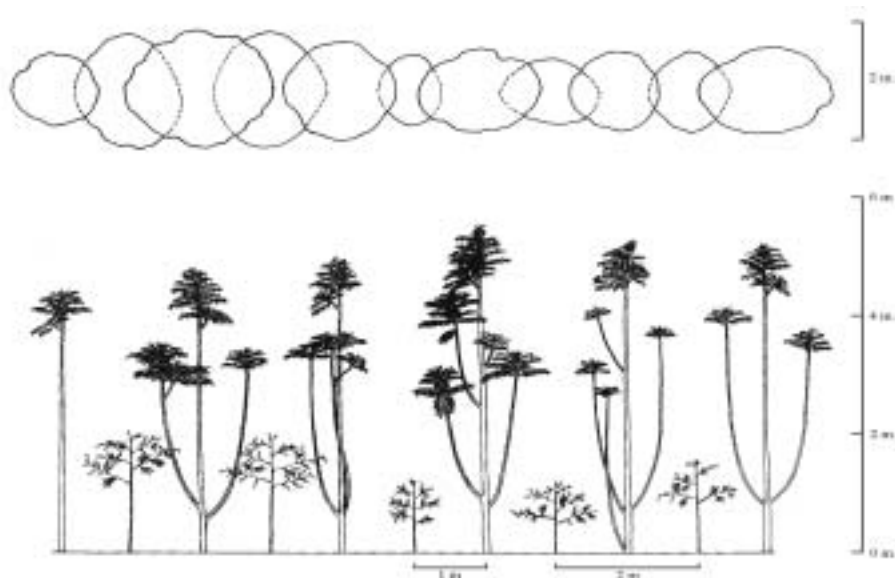


Figure 6.9. The plant performance and crown diagram of *S. leprosula* under pruned *P. canescens* stands (semi-closed condition) after a 3-year period.

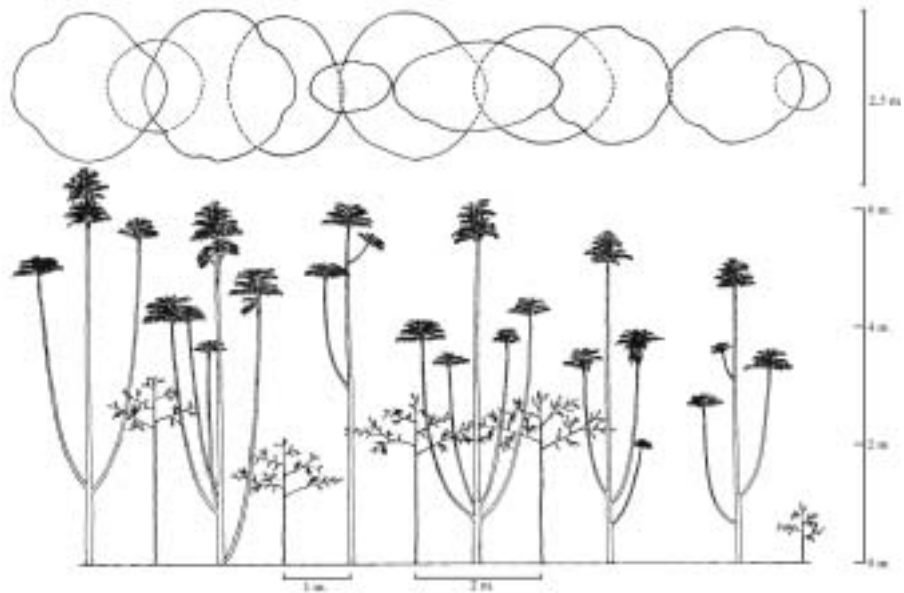


Figure 6.10. The plant performance and crown diagram of *S. leprosula* under *P. canescens* stands (closed condition) after a 3-year period.

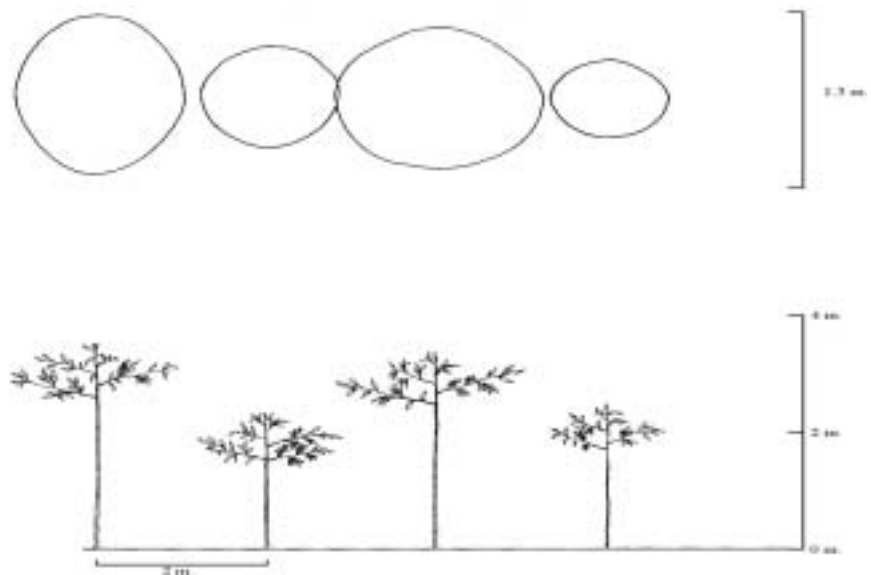


Figure 6.11. The plant performance and crown diagram of *S. leprosula* in semi-open area with some shading by shrubs, the so-called 'young shrubs' after a 3-year period.

6.3.4 Morphology and physiology of *S. leprosula*

Two years after the shading treatment, the morphology of leaf (leaf area, leaf thickness, leaf fresh weight, leaf dry weight, SLW, and chlorophyll content) was determined for each shading level. The leaf morphology of *S. leprosula* changed significantly in low light intensities, causing a decrease in leaf thickness but an increase in leaf area, leaf dry weight, SLW and chlorophyll content (Table 6.4).

Table 6.4. Effects of light conditions on morphological and photosynthetic properties of *S. leprosula* leaves. SLW: specific leaf weight.

Treatment	Leaf area (cm ²)	Leaf thickness (mm)	Leaf fresh weight (g)	Leaf dry weight (g)	SLW	Leaf biomass	Chlorophyll Content
1. Open area	42.0 a	0.613 b	0.91 ab	0.365 ab	117.9 a	2.5 a	33.2 a
2. Semi-closed	38.3 a	0.58 ab	0.80 a	0.316 a	119.9 a	2.5 a	32.0 a
3. Closed	55.1 b	0.545 a	0.98 b	0.391 b	142.7 b	2.5 a	41.1 c
4. Semi-open	38.5 a	0.639 b	0.79 a	0.323 ab	119.2 a	2.5 a	37.7 b

Note: Values followed by the letters a, b, or c in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test.

Photosynthetic rate

There was a moderate correlation between photosynthetic rate and light intensity (PAR), as shown in Figure 6.12. The higher the light condition, the higher the photosynthetic rate until the optimum photosynthesis was reached. The optimum photosynthetic rate was reached at an irradiance saturation point between 1208 (semi-open area) and 1463 $\mu\text{mol m}^{-2}\text{s}^{-1}$ (open area). A positive value of dark respiration and a negative value of irradiance compensation point in all conditions, except in the semi-open area, were calculated by a derivation (Y') from the photosynthetic-PAR response curve (Y) (see Table 6.5).

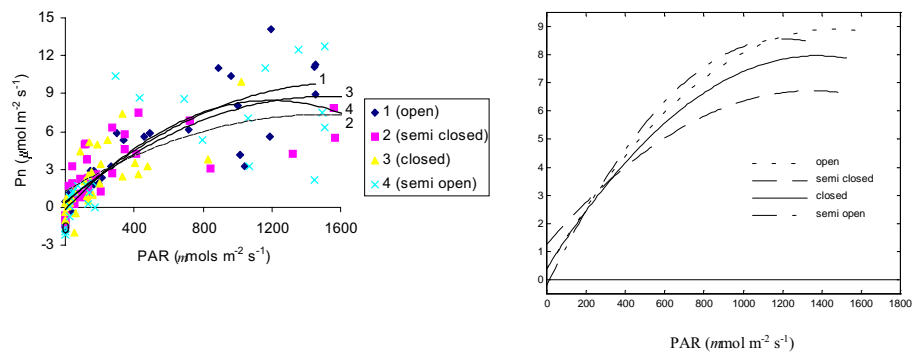


Figure 6.12. Relationship between photosynthetic rate (P_n) and light intensity (PAR) under different shading levels.

Table 6.5 Maximum photosynthetic (P_{\max}), dark respiration (R_d), irradiance compensation point (I_c), irradiance saturation point (I_s) and biochemical efficiency ($tg\ a$) for *S. leprosula* seedlings growing under different shading levels.

Shading level	R_d	I_c	P_{\max}	I_s	$tg\ a$	Equation	R^2
Open	0.37	-30.97	8.92	1463	0.60	$Y = -4E-06x^2 + 0.0117x + 0.3662$	0.76
Semi closed	1.25	-146.67	6.72	1350	0.48	$Y = -3E-06x^2 + 0.0081x + 1.2526$	0.54
Closed	0.40	-36.11	7.96	1375	0.57	$Y = -4E-06x^2 + 0.0110x + 0.4024$	0.65
Semi open	-0.20	13.96	8.56	1208	0.69	$Y = -6E-06x^2 + 0.0145x - 0.2013$	0.59

The biochemical efficiency of the photosynthesis by the plant was tested by using the tangent of the curve at the irradiance compensation point (Table 6.5). *S. leprosula* cuttings in semi-open area were biochemically more efficient than those in other areas.

The photosynthetic rate decreased with an increase in CO_2 concentration at the leaf surface until about $420\ \mu\text{mol mol}^{-1}$ and increased with an increase in CO_2 concentration.

Regarding the relationship between photosynthetic rate (P_n) and vapour pressure deficit (V_{pd}) at different shading levels (Fig. 6.13), the regression analysis indicated a weak correlation ($R^2 \leq 0.51$). The vapour pressure deficit at the leaf surface had a positive relationship with the photosynthetic rate.

A positive relationship between photosynthetic rate and transpiration rate can be seen in Fig. 6.13. In general, the higher the photosynthetic rate, the higher the transpiration rate. In the beginning, until the transpiration rate reaches approx. $1\ \text{mmol m}^{-2}\ \text{s}^{-1}$, the deeper the shade, the lower the photosynthetic rate. Semi-open and closed shading areas had a higher photosynthetic rate followed by the open and semi-closed areas after $2\ \text{mmol m}^{-2}\ \text{s}^{-1}$ of transpiration rate.

Photosynthetic rate and stomatal conductance show the similar relationship. The higher the stomatal conductance, the higher the photosynthetic rate. At a low stomatal conductance, the lower the shading level, the higher the photosynthetic rate. At a stomatal conductance higher than approx. $0.12\ \text{mol m}^{-2}\ \text{s}^{-1}$, *S. leprosula* grown in semi-open and closed shading had a higher photosynthetic rate compared with those in semi-closed and open site.

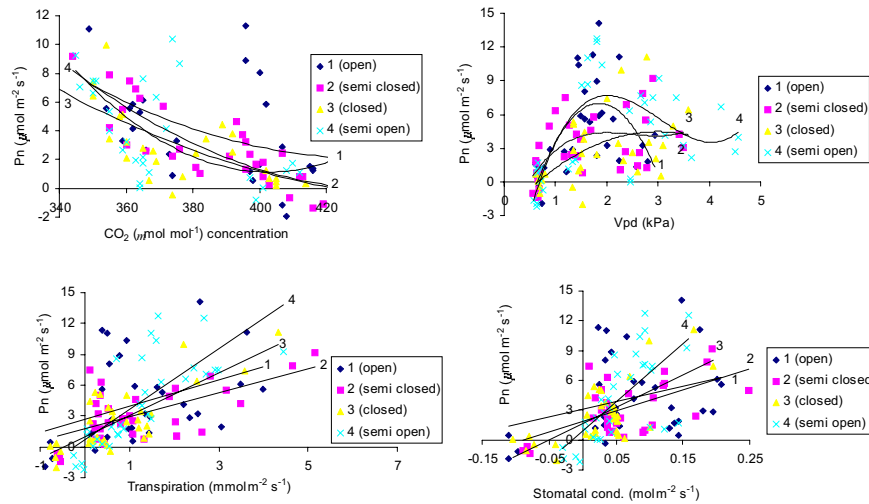


Figure 6.13. Relationship between photosynthetic rate (Pn) and CO₂ concentration, vapour pressure deficit (Vpd), transpiration rate, under different shading levels.

Transpiration rate

The positive correlation between the transpiration rate and light conditions can be seen in Figure 6.14. In an open area, *S. leprosula* transpired more than in the three other areas but the transpiration rate decreased after approx. 800 mmol m⁻²s⁻¹ whereas in the three other areas, *S. leprosula* increased their transpiration rate with an increasing light intensity (PAR).

The increasing vapour pressure deficit resulted in an increasing transpiration rate. This phenomenon can be seen in Figure 6.14. The open area (open and semi-closed stand) had a higher transpiration rate compared with the two other areas (semi-open and closed stand).

There were no differences in the relationship between transpiration rate and CO₂ concentration at different shading levels ($R^2 \leq 0.42$), but the closed stand had the lowest transpiration rate at CO₂ concentration between 350 and 420 μmol mol⁻¹. As shown in Fig. 6.14, due to the availability of CO₂ concentration, the data were concentrated in a very short range, from 350 to 420 μmol mol⁻¹, only within a range of 70 μmol mol⁻¹ (see also Fig. 6.15) so that the decreasing CO₂ concentration resulted in an increasing transpiration rate. The negative relationships on the curves were probably caused by oscillations around mean. This ecological phenomenon of oscillation curve was also described by Oldeman (1974a).

The relationship between transpiration rate and stomatal conductance of *S. leprosula* seedlings in different shading levels is shown in Fig. 6.14. The regression analysis between both transpiration rate and stomatal conductance indicated a relatively high correlation ($R^2 \leq 0.79$).

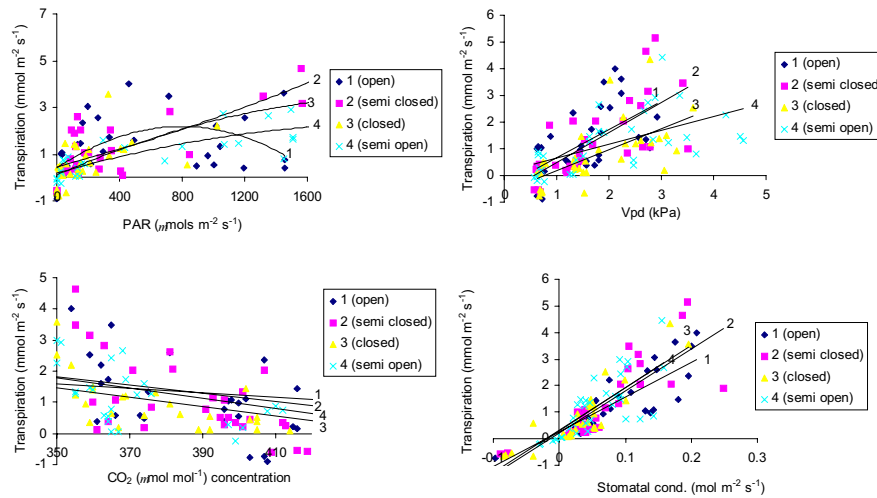


Figure 6.14 Relationship between transpiration rate and light intensity (PAR), vapour pressure deficit (Vpd), CO₂ concentration and stomatal conductance under different shading levels.

Stomatal conductance

The relationship between stomatal conductance and light intensity (PAR), vapour pressure deficit (Vpd), CO₂ concentration and leaf temperature of *S. leprosula* seedlings at different shading levels is shown in Fig. 6.15. The regression analysis indicated very weak correlations between stomatal conductance and light intensity ($0.02 \leq R^2 \leq 0.27$), vapour pressure deficit ($0.01 \leq R^2 \leq 0.21$), CO₂ concentration ($0.09 \leq R^2 \leq 0.49$) and leaf temperature ($0.04 \leq R^2 \leq 0.32$) of *S. leprosula* seedlings at different shading levels.

As shown in Fig. 6.15, stomatal potential restriction of taking CO₂ did not appeared below 350 $\mu\text{mol mol}^{-1}$, due to the availability of CO₂ concentration, the data were concentrated in a very short range, from 350 to 420 $\mu\text{mol mol}^{-1}$, only within a range of 70 $\mu\text{mol mol}^{-1}$.

The stomatal conductance of *S. leprosula* grown in semi-open area was relatively unaffected by the changing of light intensity (PAR), vapour pressure deficit (Vpd), and leaf temperature measured.

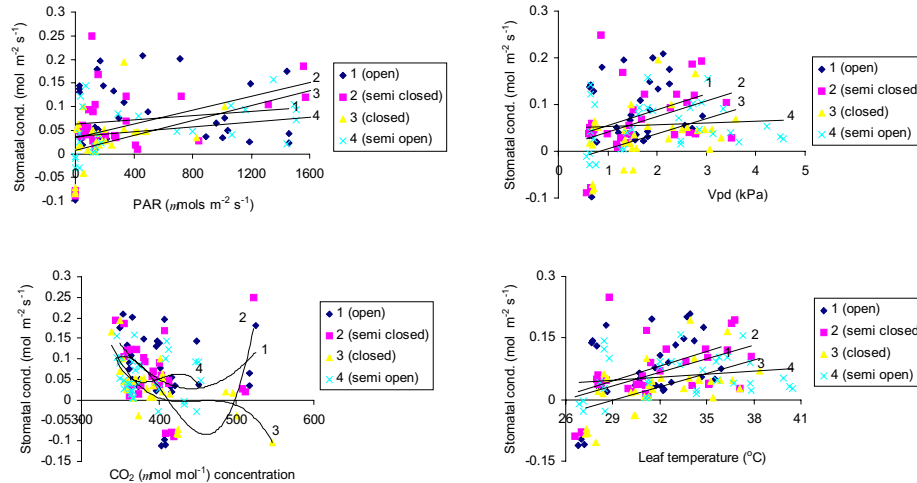


Figure 6.15. Relationship between stomatal conductance and light intensity (PAR), vapour pressure deficit (Vpd), CO₂ concentration and leaf temperature under different shading levels.

6.4 DISCUSSION

Seedling survival of dipterocarps was discussed thoroughly by Whitmore (1984) who found large differences in survival rates between species. Furthermore, Noor and Smits (1988) described that there is a correlation between different site conditions, such as primary forest, secondary forest, strip plantation and open places, and the mortality of the planted seedlings due to the high soil temperature. Suhardi (1997) stated that *S. leprosula* could survive in dry areas with relatively high temperatures. Hardiwinoto *et al.* (1997) found that there were no significant differences in mortality rates in dipterocarps under the shade of fast growing species. The present experiment also showed that differences between shading conditions in average survival rates, including the damaged plants of *S. leprosula* cuttings, were not significant, and varied from 67% to 83%, after 18 months. Survival was so high due to the soil not being too hot, with a temperature low enough not to be lethal for mycorrhizal development (see Table 6.2). There was no mortality after 11 month. More detailed investigations as to proliferating organisms that consume seedlings, and the provision of high quality, resistant seedlings need to be undertaken, since stem borers attacked some plants in the closed stands at the end of the experiment. Otsamo *et al.* (1996a) found that two years after planting, *S. leprosula* showed a survival rate of 60%. Survival rates of *S. leprosula* in our earlier research were about 84% and 74% after 12 and 43 months, respectively, in secondary forest (Priadjati and Tolkamp, 2001). Effendi *et al.* (2001) found similar

results in 3-year-old *S. leprosula* showing a survival rate of about 74% in a secondary forest dominated by *Macaranga sp.*

Light is the main environmental factor to be considered in any plantation activities due to its influences on all aspects of the ecosystem. In forests which contain forest patches and canopy architecture in many development phases (Percy, 1983; Oldeman, 1990), the determination of the total amount of light reaching the forest floor becomes more complicated because the light will be partly reflected, transmitted or absorbed. The distribution of green plants, their crowns, sub-crowns, branches, leaves and leaflets indeed is so complex and is structured at so many scale levels, that it may seem to result in an irregular chaos (Vester 1997).

For most calculations, a simplified image of the light regime is therefore used. In this view, light within the forest consists of diffuse light and sunflecks (Koop 1989). Diffuse light is composed of light reflected and transmitted through leaves. Therefore, diffuse light is 'light in the shade' at a low light intensity. On the other hand, sunflecks consist of short bursts of direct sunlight penetrating canopy gaps and moving over the soil with the daily movement of the sun. The light quality of sunflecks is quite different from that of diffuse light (Sasaki and Mori, 1981). The sunflecks contain much of the red light of the spectrum which is composed of uniform spectral energy between 400 and 800 nm, whereas open sunlight has a peak at 450 nm with a gradual decline towards the red light spectral region. As the seedlings utilise the red light for photosynthesis more effectively than the blue light, and as far red light has trigger functions in the germination process (e.g. see Rossignol *et al.*, 1998), the sunflecks may be the most effective light for seedling growth (Bazzaz, 1989). Although the average radiation received by understorey plants may be below the compensation point of photosynthesis, short periods of beam radiation received by the plants through small forest openings are enough for a positive net photosynthetic rate. Particularly when temporary deficiencies are compensated by an input of tree metabolites through mycorrhizal 'bridges' between seed tree and seedling (Yasman 1995), sunflecks yield sufficient energy for the survival and growth of plants receiving it low down in the forest.

The tree architecture of *Peronema canescens* and its profuse reiteration after the fires influenced the growth of *S. leprosula*. In circumstances without stress by fire or cattle, a young *P. canescens* tree has a well-developed monopodial trunk with a light canopy so that the light intensity under this species is very high or almost the same as at the open site. This shade level (semi-closed stand) is not very suitable for *S. leprosula* seedlings when under-planted under this species. The capacity of *P. canescens* after fires to reiterate abundantly ('traumatic reiteration') and converge architecturally from *Scarrone's model* to a physiognomy resembling *Leeuwenberg's model* (Hatta, 1999) provided more favourable environmental conditions (closed stand) for *S. leprosula* to grow under the canopy of these trees. Seedlings under moderate shading of *P. canescens* (closed stand) and in semi-open areas with some shading by secondary

shrubs ('young shrubs') were significantly higher and bigger than those under light shading by pruned *P. canescens* trees (semi-closed stand) and in open areas. Durant (1940) and Ang *et al.* (2001) observed that *S. leprosula* requires partial shade for its early establishment.

Concerning stand and light conditions the dipterocarps are often regarded as a delicate family. It is argued that the young plants do not tolerate, but require a relatively dense shade for survival and first growth (Omon, 2002). This viewpoint is based on experiments, and will be discussed later in the next paragraph.

First, an overview of the abundant literature on the subject is given. Dipterocarps indeed survive in the darkness of the lower reaches of a jungle, but need a considerable amount of light for better growth later when growing up. Many dipterocarps adapt themselves easily to new situations and show opportunistic behaviour by growing abundantly in forest gaps. Sasaki and Mori (1981) stated that the reduction of growth at higher than optimum levels of light is caused by the strong irradiation of the direct sunlight, which renders growth conditions unsuitable for seedling growth, by the detrimental effect of ultraviolet light. In general, dipterocarps require 30 to 50% shade for the first year and a half but tolerate, or demand, more light afterwards (Nicholson, 1960; Mori, 1980; Koyama, 1981; Sasaki and Mori, 1981; Whitmore, 1984; Seibert, 1990; Appanah and Weinland, 1993). Suhardi (1998) observed a case of *S. leprosula* growing well in an open site.

A high light intensity in the open and semi closed areas, coupled with high relative humidity, may cause photoinhibition (Brown, 1990) but it did not cause a rise in soil temperature up to the heat level lethal to mycorrhizal fungi. For mycorrhizal development, some requirements should be fulfilled, such as an optimum temperature, soil condition, appropriate inoculum, good mulching etc (Suhardi, 1997). As found by Omon (2002) and confirmed by the present study (see Chapter 4) mycorrhizal fungi require a sand fraction sufficiently large to provide ample aeration and pore volume. *S. leprosula* can grow vigorously to the age of five years under full sunlight with a treatment of mulching, as long as the soil temperature does not rise to levels lethal to mycorrhizal fungi (Smits, 1994). The slow growth of *S. leprosula* in the open and semi-closed areas is probably due to a lower relative humidity of the soil. The modest performance of *S. leprosula* may be attributed to a lack of mycorrhizal fungi known to be crucial for dipterocarps (Julich, 1988; Seibert, 1990). The mycorrhizae may have suffered from drought combined with relatively hot soils and a low relative humidity at the planting site.

This fits in with the higher porosity of soils suited to fungi, because soils with abundant and large pores also risk desiccation by leaking and evaporation. The complexity of the rhizosphere here is apparent. No factor, such as porosity or heat, may be seen as independent from other factors, so every factor can be either favourable or unfavourable to fungi, depending on the web of interactions in which it is caught. Omon (2002)

emphasised the need for aeration and cited Vander Wal (pers. com., 2001) in claiming that larger pores have a better network of water adsorbed at the walls and serving as a highway for micro-organisms, among other fungal spores. Hence, if heat kills the mycorrhizal fungi physiologically (Smits 1994), it also dries out porous soils and so hampers the distribution of their spores, which is an ecosystem function. Mulching is one way to regulate both soil heat and humidity, keeping them in suitable brackets.

The slow growth of *S. leprosula* in the open area may also be caused by a decrease in photosynthesis around noon, when the leaf temperature is high (Roy and Salanger, 1989). This 'siesta' of high forest trees, accompanied by stomatal closure, was also found by researchers of a canopy raft campaign in the crowns of large Guyanese forest trees. In the present experiment, the chlorophyll content in the leaves of young *S. leprosula* plants was also significantly different between the sites. Chlorophyll determines the photosynthetic rate in plants. The present study also showed that plant behaviour, in terms of build-up and photosynthetic properties of the leaves changed in response to different light conditions. The leaf properties of *S. leprosula* changed significantly in closed stands, causing an increase in Specific Leaf Weight (SLW) and leaf area, and a decrease in leaf thickness. In contrast, *S. leprosula* had a smaller leaf area but thick leaves in open sites or under semi-closed and semi-open conditions. This type of leaves has been known for over a century as 'sun leaves', formed in particular in crowns having reached the hot and dry climate of the forest canopy (e.g. Schimper, 1903; Richards, 1952). We may assume therefore that these leaves are the adaptive response of young *S. leprosula* to high light intensity and atmospheric heat, so as to maintain photosynthesis at efficient levels while avoiding dehydration through respiration (also see Tange *et al.*, 1998).

Planting under established stands of fast growing species gave promising results for *Shorea leprosula* that reached an average height of 6.4 m in 6 years under *Paraserianthes falcataria*, formerly known as *Albizzia falcataria*. *Anisoptera marginata* (Dipterocarpaceae) reached an average height of 5.3 m in 7 years under *Acacia mangium* and of 8.6 m in 8.5 years under *P. falcataria*. Direct planting of dipterocarps on *Imperata cylindrica* grasslands is not a viable alternative, because very expensive high-tech means would be needed. A nurse tree stand, hence, is indispensable to provide suitable growing conditions for dipterocarp seedlings (Otsamo *et al.*, 1996b). The mixed planting of both dipterocarp and nurse trees at the same time leaves the nurse trees no time to create a suitable microclimate for the establishment of the dipterocarps. Nurse trees should, therefore, be planted first, dipterocarp seedlings later (Watson, 1935). Suhardi (1997) showed that shaded plants are higher and bigger in height and diameter than those in an open area. He found that the mycorrhizal formation was higher in the shade than in an open area. Poor performance of planted dipterocarps in open grassland has also been reported in the Philippines (Zabala, 1986).

The results of the present study support the claims of the above authors. Within almost 3 years, *S. leprosula* trees in a closed stand and in a semi-open area reached a height of

281 to 283 cm and a diameter of 33 to 34 mm, whereas in the open area and under the semi-closed canopy of *P. canescens* they were only 165 to 193 cm high and 22 to 27 mm in diameter. Effendi *et al.* (2001) similarly found that the height increment of 3-year-old *S. leprosula* was 227 cm under *Macaranga sp.* Kustiawan and Unger (1991) reported the height of 1-year-old *S. leprosula* and *S. parvifolia* planted under *P. falcataria* of 1.4 to 1.8 m. Heights of 1.4 to 1.9 m have been reported for 2-year-old *S. leprosula* and *S. parvifolia* line-planted in secondary forest, (Adjers *et al.*, 1995).

For photosynthesis as the basic process for any plant growth, plants need light of a certain range of wavelengths, which is between about 400 to 700 nm (McCree, 1972). Gross photosynthetic rates, i.e. the formation of carbohydrates binding electromagnetic energy by combining CO₂ components of air and water, is partly compensated by the CO₂ respiration of the leaves. The latter prevails at night, and during the day largely depends on leaf temperature. Only above a certain level of light, the irradiance compensation point, the net photosynthesis becomes positive in value. Respiration and net photosynthesis increase to a certain degree and reach saturation at high light intensities.

S. leprosula with high values of both irradiance compensation (1.3 klux) and irradiance saturation (ca 40 klux) is assumed to be light-demanding (Meijer and Wood, 1964; Symington, 1974; Koyama, 1981). Furthermore, Koyama (1981) measured average net photosynthetic rates (NPR), at irradiance saturation and corresponding photosynthetically active radiation (PAR) for *S. leprosula* at 12.6, 15.1 and 1688 $\mu\text{mol m}^{-2}\text{s}^{-1}$, respectively. The species reacts positively to increased photosynthetic active radiation up to about 500 $\mu\text{mol m}^{-2}\text{s}^{-1}$, corresponding to about 25 to 30% of the relative intensity.

The whole image of photosynthesis as a process inserted in a web of interactions is as complex as what we saw above in the rhizosphere. There is no doubt that young cuttings of *Shorea leprosula* are shade-demanding. This was experimentally established by Omon (2002, his chap. 3.3.4). He obtained graphs of photosynthetic response peaking in the morning and late afternoon, and also referred to Yasman (1995) in explicitly stating young *S. leprosula* to be shade-requiring and not merely shade-tolerant. The results of the present study show this to be one specific case in the very complex context of dipterocarp photosynthesis.

The interactions between photosynthesis and soil type as a major facilitator of nutrient transfer compensating local deficiencies throughout the ecological 'Yasman network' of higher plants and their symbiotic partners are one important feature explaining the differences in photosynthetic response patterns. Other sets of factors are the interwoven heat load of atmosphere and soil, and the hydrological state of the soil. The heat itself, lethal to mycorrhizal fungi above a certain level, is also a source of energy for the evaporation of soil water. It sets into motion a whole ecological machinery, involving movement of micro-organisms and spores, aeration

of underground plant and animal respiration, and opening or closing soil pores to roots and/or root hairs.

It is no wonder, that scientific efforts to find regularities in nutrient regimes and effects of fertilisers up till now have yielded heterogeneous and sometimes contradictory results (Omon 2002). In the complex network sketched above, nutrients are mobilised, transported or fixed biologically where and when necessary in the ecosystem. Mean contents per surface units then are without meaning, because the nutrients are not randomly distributed in time and space, as is the prerequisite of statistical analysis. It has been proven that statistics can only make a diagnosis of such a 'determinate chaos' by considering the chaotic appearance as 'random', but that statistics can not reach the underlying causes and regularities (Gleick 1987, pp. 250 ff.).

6.5 CONCLUSION

With a rapid increase in the rate of deforestation, dominance of grasslands area and fires render these areas unsuitable for dipterocarp forest ecosystems. Therefore, introducing dipterocarps to degraded grasslands, species like *S. leprosula* with a wide ecological amplitude are preferable. The mixture planting method with indigenous pioneer species can be used both in terms of wood production and gradual restoration of the natural ecosystem.

Based on this field experiment it can be concluded that *S. leprosula* require partial shade in their early establishment stage. It is preferable to plant a indigenous fast growing nurse before introducing the dipterocarps. Shading by abundant reiteration on *P. canescens* after fires gave suitable conditions for the growth of *S. leprosula* cuttings. *S. leprosula* is a promising dipterocarp species in mixed plantations with reiterated *P. canescens* in alang-alang grassland or in degraded forests lands.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

7.1. FOREST FIRES AND FOREST RESTORATION

7.1.1. Forest fires: a historical perspective

Since the last ice age and the rise of the sea levels leading to the present situation with the islands of Sumatra and Borneo separated from the former Sunda shelf, the climate has been rather stable. Although we do not have a complete record of the events that took place many thousands of years ago, we have a number of indications from the presence of charcoal in sedimentary layers and in peat that some fires, which must have been the result of long drought periods have occurred widely over Borneo.

If we look at the last few centuries, it has been found that there is a recurrent pattern of the El Niño Southern-Oscillation (ENSO), which occurred once every 80 to 85 years (Weinland, 1983) during that period. However, in the last few decades the El Niño periods have become much more frequent and much more severe than before. The first period with big fires seemed still to coincide with what was more or less the expectation for a severe drought period in 1982-83. But then, in 1992-93 another severe drought and consequent fires occurred. Then another even drier event with more resulting fires occurred again in 1997-98. Now in 2002 we are experiencing another El Niño event, which may again become of disastrous proportions.

So what is going on? What is causing this climate change and what are the factors contributing to the fires?

First lets look at the climate change issue. Since the industrial revolution levels of greenhouse gases have risen constantly, but much more dramatically so in the last few decades. It seems that there is a clear correlation between this rise and the ever more frequent occurrence of the El Niño phenomenon and therefore the occurrence of fires. But this in itself is not enough to explain the extent of the fires.

In the past, forests were cut and opened only in a few locations close to human settlements. In the past, transportation by rivers was the usual method of travel while road connections were not developed well or absent. As a consequence, human settlements were almost exclusively encountered along the rivers. It is a well-known fact that virgin rain forest does not burn well. In the past, it was even believed that it could not burn at all, but in the 1997-98 fires we noticed that in the Meratus protected forest fires were able to enter a virgin lowland rain forest for a distance of almost 30 kilometres. Local people mentioned that they could not recall any such event before, even not from the stories of their ancestors. So, it seems logical to assume that the climate change is for real and contributing to the intensity and extent of the fires.

Fires mostly start as a result of human activities. This may be in the form of burning under shifting cultivation schemes, fires from hunter camps that spread, or fires set to hunt animals, as for instance described for bare mountain tops in Sulawesi by van Steenis in the fifties (Smits, pers. comm. 2002). Recently, fires set to save money on land preparation costs for large-scale plantations also have contributed greatly to the start of extensive and serious forest fires. Forest fires can also start from lightning strikes and once fires have gone through an area, many subterranean coal seam fires may continue smouldering. These smouldering coal layers may ignite new forest fires during a drought event. The soil may crack, more oxygen reaches the burning coal, and flames may arise and set the many dry dead leaves on fire, forming the start of new fires. But again, humans cause almost all fires, directly or indirectly.

So, in the past, the fires did not spread into the larger forest blocks and along the rivers the impact on the slightly wetter soils was not so great. So, the effect of ENSO, drought and fire were locally limited. Drought did not much affect trees next to the rivers. Humans did not yet have a big impact on the forest opening. This, however, changed dramatically with the new Indonesian Forestry Law of 1967. Based upon this law and the 'Domeinverklaring' which stated that all land belonged to the state, a timber boom started that had already taken its toll on the Philippines.

The commercial exploitation in itself does not necessarily lead to the destruction and disappearance of the forests. After all only few commercial trees can be harvested from the species rich forest in mechanical harvesting operations. What trees are harvested and how many depends only upon economical factors. For instance the Dipterocarpaceae, and in our case, *Shorea leprosula*, do not have durable, neither strong nor specially fancy timber. Still the timber has achieved important commercial status because the timber is rather homogeneous in quality, it comes in big sizes, there are large quantities of it and the timber floats in water. Marketing and industrial processing cannot deal with the hundreds of other species that only occur in small quantities in the forest. Therefore, indeed the commercial exploitation does remove only a small part of the trees and biomass of the forest.

However, when the wrong equipment is used (eg. too heavy bulldozers), or no directional felling, skid road planning, etc is practised then the damage to the forest can be quite severe. Still real long lasting damage only occurs when wood thieves and shifting cultivators, and hunters make use of the access via the forest roads that the concessionaires have constructed. So, commercial harvesting of tropical timbers is but the first step in the process of degradation. The forest after logging has many dead trees, and much debris that can easily burn during a drought period and in the presence of sources of fire from humans.

Fires, especially when repeated, lead to the disappearance of the forest. This then in turn also leads to changes in the local climate. For instance near the Wanariset station, working in the village of Samboja, Schmidt and Ferguson (1951) described

for the area a type A climate which now, only a few decades later, is no longer present. The change is locally much more severe than could be expected from wide spread global climate change. This is most likely related to the effect of forests on rainfall on a local scale. For instance, the albedo over forested land is lower and clouds can move further land inward. Also after rainfall forests, through evapotranspiration, contribute to the formation of new clouds that can go further land inward. Also trees are known to produce mykists that contribute to the formation of raindrops. Therefore, with the reduction of the forest area the climate increasingly fast changes towards one with more, longer, drier and unpredictable dry seasons. Therefore, the initial fires lead to many more and a vicious circle of destruction has been set in motion.

So, basically the humans have contributed on a global scale as well as a local scale to changes in climate that have resulted in the more frequent occurrence of forest fires.

7.1.2. Dipterocarpaceae: Droughts and fires

Dipterocarpaceae suffer much from drought. There are many reports of drought leading to widespread death of many dipterocarp trees, for instance the dying of many Dipterocarpaceae in 1993 in the ITCI concession, and the dying of *Shorea curtisii* in Peninsular Malaysia in the nineteen eighties. Brünig (1969) described the death of stands of *Shorea albida* in swamps in Sarawak after heavy droughts. Although drought does have a big impact, the fires make the situation even more serious. Dipterocarpaceae contain resins, which are highly inflammable and which make that once a big fire is raging, virtually all Dipterocarpaceae disappear from the burned forest. In the present study it was also found that in the lightly burned forest almost all Dipterocarpaceae died (see Chapter 2). Smits (1994) also mentions the heavy impact of fires on the mycorrhizal fungi that survive in the soil. Important species may get lost as a consequence of the higher top soil temperatures experienced during the fires.

There are very few drought resistant Dipterocarpaceae. One species that can withstand the drought better than other Dipterocarpaceae is *Shorea laevis* (Bangkirai). This species has small leaves with a thick cuticula, adapted to drought. This species also has a wider range of ectomycorrhizal fungi, which include fungal species more commonly found on well aerating sandy soils. For instance, species like *Scleroderma sp.* with abundant rhizomorphs that are important in transporting water towards the roots of this tree species and which are crucial in times of extreme drought. So, *S. laevis* is well adapted to conditions of drought stress, but not fire. Actually, whenever we see clumps of *S. laevis* we can conclude that in this area there must be recurrent dry periods because other species cannot survive where *S. laevis* can. Therefore, this species can be used as an indicator of areas experiencing drought stress. This species grows on sandy soils on the tops of hills. The availability of water in these locations with sandy soils of a very low water retention

capacity, during drought periods is very limited. We typically see that in these sites *S. laevis* forms pure clumps of very slow growing, large trees that completely dominate these hilltops. In the lowland forest on the slopes and in the valleys, the soil textures are different with more clay content so that they have a higher water retention capacity and here the selection process is less severe with many more dipterocarp species surviving.

So, what are the short term and long term effects of fires on the Dipterocarpaceae? A short term effect is that much of the regeneration of the Dipterocarpaceae gets burned or dies later or dies as a direct consequence of the drought stress which can be worsened by the fires in the area or even region. Just in August 2002 it was announced on CNN that the smog of forest fires now covers almost all of South East Asia and that this smog layer contributes to the reduction in rain fall, thereby directly contributing to more deaths of dipterocarp plants. In the short term the conditions for regeneration of Dipterocarpaceae in the burned forest are very poor. The microclimate has changed and the stress of light, higher soil temperatures and loss of ectomycorrhizal inoculum all contribute to a reduced performance of dipterocarp regeneration in the burned forest. But after the fires, when they are not too widespread and intensive, we see that very quickly a layer of pioneer plant species occurs that within a relatively short period provide a new cover for the soil. Very quickly the microclimate gets restored and conditions for dipterocarp regeneration improve dramatically. The same is true for logged-over forests, except that there the soil compaction may present an additional problem for the regeneration. Although the thick layer of pioneer species will slow down the growth of the dipterocarp regeneration, thanks to their links with the mother trees many seedlings will survive and eventually take over this forest as dominant species.

But if the fires are very severe and widespread, or recurrent, then Dipterocarpaceae disappear completely from an area. Now their regeneration will fail completely. There is no longer a seed source available, and there are no longer suitable ectomycorrhizal fungi for growth of seedlings either. Eventually repeated fires lead to the formation of the infamous alang-alang (*Imperata cylindrica*) grasslands, which is a fire climax vegetation and easily burns again, thereby killing off any natural regeneration, while the grass itself quickly sprouts from its rhizomes. The presence of these alang-alang grasslands then severely impacts the water retention capacity of the soils, the fertility, the occurrence of erosion, causes a greater surface run off, thereby causing both floods and quicker droughts and repeated risks of fires. Another vicious circle has come to a dead end.

So, the local vicious circle combined with the global one of increasing CO₂ concentrations, the warming of the climate and more frequent El Niño events, lead to a very serious situation, especially for the Dipterocarpaceae. Since the late nineteenth century: 1887-88, 1903-04, 1914-15, 1941-42, 1972, 1982-83, 1992-93, 1997-98, 2002, Indonesia has experienced more and more severe droughts

(Leighton, 1984; Goldammer and Seibert, 1990). We cannot expect this development to stop or change direction now. On the contrary, the present political and social situations in Indonesia have only complicated matters further. Forest destruction because of greedy local governments, because of illegal logging and other reasons, has increased terribly. If no action is taken, Dipterocarpaceae, once the most abundant trees of South East Asia, may be doomed from the areas susceptible to droughts and fires.

The basic fact is that forest is not destroyed by fire, but it is set back to an earlier development phase where there are no more trees, and at the same time no (visible) trees as yet. Surface fires in 1982-83 and 1997-98, mainly killed small diameter trees, especially seedlings and saplings (Chapter 2). In general, fires reduce the number of small diameter trees more than logging does (Toma *et al.*, 2000b) and results in a lack of successful trees for the next generation. But the forest that results is a different one, no longer the dipterocarp forest for which the lowland forests of South East Asia are famous.

Mori (2000) observed that the frequency of forest fires decides the vegetation types. Places that are burned every 1 to 2 years become *I. cylindrica* grassland. Places that are burned every 4 to 5 years become bush land near agriculturally exploited areas and are dominated by fire-tolerant species such as *Nauclea orientalis*, *Piper aduncum* etc. Places that are burned every 10 to 20 years become *M. gigantea* and *M. triloba* forests or fallow lands associated with slash and burn agriculture. Places that are burned every few decades become intermediate phases of the rain forests. Places that are burned every several hundred years remain primary forests of dipterocarps as long as they still are connected to a patchwork of vegetation containing Dipterocarpaceae.

In Chapter 2 it was shown that the fires also had a dramatic effect on other groups of organisms, like in this case the butterfly population. The species diversity as well as their genetic variation was heavily impacted. Therefore the fate of the Dipterocarps represents the fate of many other organisms as well.

7.1.3. Dipterocarp regeneration

Natural dipterocarp forests until very recently recovered from drought impacts without needing assistance (see Mori, 2000, 2001; Toma *et al.*, 2000b). However, because of the needs and wishes of human societies this is no longer the case. Natural recovery is too slow for the management plans of the foresters. Foresters, therefore, try to restore the desired state of high forest, which is a development phase in forest dynamics also termed silvigenesis (Oldeman, 1974a, 1978, 1983, 1990), as soon as they can. This brings us to the next issue of how to tackle the fast degradation of dipterocarp forests through artificial regeneration and restoration of the burned forests.

First we need to consider why we should want to plant Dipterocarpaceae. After all we mentioned above that from the timber qualities, they are not particularly attractive. But when we look at the ecological role we should still consider Dipterocarpaceae for regeneration of degraded forests. The ectomycorrhizal Dipterocarpaceae can achieve larger biomass per hectare than other types of forests. This may be because of direct nutrient cycling, reducing the loss of nutrients. The stems of Dipterocarpaceae are taller and many plant and animal species are associated with the presence of Dipterocarpaceae in the forest. Dipterocarpaceae have resins with fungicides and insecticides in them so may be expected to be less risky to plant than other tree species. Dipterocarpaceae are naturally very homogeneous and still are not attacked by serious pests and diseases, even though their crowns high above the other trees and their clumps would make it easy for diseases to spread. So since their arrival in Malesiana since the tertiary, Dipterocarpaceae seem the ecologically best adapted trees to the conditions there. Therefore, we should still consider their application.

Assisted recovery of natural forest is mainly needed in areas with fire damage greater than 50% (Chapter 1, Table 1.1). Most of formerly well stocked areas with 25 to 50% fire damage is expected to recover naturally, especially in the absence of further damage by logging. Priadjati (in. prep.) states that the environmental condition in burned primary forest as far as the microclimate is considered, recovers within 2 years by pioneer species without any human influences. In this forest, where primary tree species such as Dipterocarps are still dominant, natural regeneration is the cheapest way to recover original forest, although it must be followed by assisted provision of additional light during their further development. Improvement of the light condition for seedlings and saplings by opening up the canopy is the most important treatment for the success of these plants. Ashton (1998) gives three stages of establishment and growth of successor trees: (1) seeds require partial shade protection for germination and early survival, (2) seedlings require an increase in light for satisfactory establishment and growth, (3) seedling survival and establishment is usually site specific, according to particular biotic, microclimatic and edaphic characteristics. Furthermore, Mori (2001) recommended less than 10% (relative light intensity) for seed germination, 30% for seedlings, 50% for saplings and 80% for pole-sized trees. The treatment stage (year) should change according to the species' light requirement level.

The stages in the natural and accelerated recovery of pure *Imperata cylindrica* after fires were described by MacKinnon *et al.* (1996). Tolkamp (2001) added that the acceleration of natural recovery is influenced by the frequency of fire, soil fertility, the distance to the closest forest, species composition of that forest, intensity (thickness) of the *Imperata* vegetation cover, and competition. He predicted that without any disturbance, the grassland would be replaced with shrubs and pioneer tree species within 5 to 10 years. Furthermore, Mori (2001) stated that it is very difficult for shrub forest to return to original forest without rehabilitation, because of a lack of mother trees of the primary species. Plantations of indigenous fast-growing pioneer tree species

are light demanding and able to survive in severe environmental conditions, and offer suitable conditions for the establishment of indigenous dipterocarp species. The silvicultural techniques of indigenous fast growing trees, such as *Peronema* species have already been determined (Tolkamp, 2001; Tolkamp and Priadjati, in prep.).

When Dipterocarps are used, the key to success for a dipterocarp planting is species choice and light control. Selection of species suited to the local soil and site conditions is essential. Appanah and Weinland (1996) gave criteria for the choice of planting species. They recommended *S. leprosula* for enrichment planting, and Otsumo *et al.* (1996b) proposed this species for combination planting on grassland. Kartawinata *et al.* (1980) reported that this species showed a high tolerance to water stress in areas of relatively low precipitation and a long dry season. Ito *et al.* (2000) found that *S. leprosula* is not suitable for sites affected by periods of severe drought. Light control should correspond to the light requirements of a species during its growing stages, so planting methods should reflect site conditions and growth characteristics of the species. Therefore, observation of shading effects on the initial growth of dipterocarp species is necessary in order to develop plans for the reforestation of degraded lands with indigenous species of Dipterocarpaceae. The results of this study confirmed that *S. leprosula* is a light demanding species at the early stage, 60 to 73% (relative light intensity) for seedlings and 74 to 100% for saplings (Chapter 5 and 6).

Important environmental factors for the growth of *S. leprosula* cuttings such as light intensity, soil properties and mycorrhizal inoculation were discussed in Chapters 5 and 6. In these experiments shading, soil type and mycorrhizal development affected the growth of *S. leprosula* cuttings. The leaf characteristics in the shaded plants such as a high chlorophyll concentration (in this study) and high chlorophyll-N ratio (Ishida *et al.*, 2000) increase the capacity of light capture, contributing to a high carbon gain within the whole-plant. This report is focused on the restoration of dipterocarp forest because this is important economically, biologically and also environmentally.

To give optimum support to the growth of *S. leprosula*, the colonisation by mycorrhizal fungi must change under different site conditions and development periods of *S. leprosula*. In this study, the initial inoculation in the greenhouse indeed helped *S. leprosula* to start to grow in the new environment. In the 15 months in the greenhouse, the mycorrhizal colonisation changed completely. Aggressive, pioneer and 'early stage' mycorrhizal fungi dominated the colonisation of *S. leprosula* roots. *Laccaria sp.* was the most common one, followed by *Thelephora sp.*, *Riessiella sp.* and *Inocybe sp.* Lee (1998) stated that results from pot experiments have a limited applicability to field conditions where competition from indigenous fungi are likely to determine the efficacy and persistence of the inoculant fungi. After 12 months in the field, the species composition of mycorrhizal fungi involved in root

colonisation also changed, even though the same pioneer and ‘early stage’ mycorrhizal fungi were still involved. *Inocybe sp.* was still there, with two new other species being most abundant, namely *Amanita sp.*, and *Scleroderma sp.*, but the number of mycorrhizal species decreased from 4 in the greenhouse to 3 in the field. The amount of mycorrhizas also decreased as the seedlings became bigger, so that the seedlings seemed to become less dependent on mycorrhizas. Vogt *et al.* (1982) reported that the percentages of mycorrhizas in the 23-year-old and 180-year-old *Abies amabilis* was about 1% and 0.3%, respectively. Smits (1994) stresses however that Dipterocarpaceae are obligate mycorrhizal. In his studies with perforons he noticed that although quantitatively mycorrhizae were not needed much, the presence of just a few was crucial for the survival and normal development of the plants.

Key issues for the management of plants bearing mycorrhizae in the nurseries include choice and preparation of appropriate potting mixes, nursery hygiene, and perhaps (Effendi *et al.*, 2001, Omon, 2002) the use of fertilisers. In Chapter 4 and 5, it was shown that physical soil properties influence the growth of *S. leprosula* cuttings. According to Ohta *et al.* (2000), the soils of degraded ecosystems had diverse textures with most chemical parameters tending to be influenced by the clay content. The cuttings in sandy loam showed a stronger and faster growth than the cuttings in sandy clay loam and loam. The high sand fraction in the soil provides a good aeration for mycorrhizae (Oldeman and Iriansyah, 1993; Omon, 2002). The aeration is not only apt to boost the development and survival of mycorrhizae, but does the same for the plants themselves, especially their roots. It is supposed that composition, acidity, moisture content and heat of the rooting media, heat treatment to reduce unwanted soil life, and the use of biocides including fungicides can be combined in a treatment optimising the conditions for both root colonisation and development, thus increasing the quality and quantity of seedling produced. However, both our results and those of Omon’s parallel project (2002) show, that the interactions between so many factors lead to a highly complex situation, far from easy to control.

Long-term survival of a species depends on its ability to adapt to environmental change, and the presence of genetic diversity in a population provides the basis for species adaptation (Rossignol *et al.*, 1998; Rimbawanto and Isoda, 2001). Adaptability is a two-sided process. It rests on the optimal match between a genotype (organism) and its direct environment (ecosystem patch or ‘eco-unit’; Oldeman, 1990, p. 512). The genotype of *S. leprosula* is taken to be variable, and its silvicultural environment is taken to be more or less constant and regular which is not true of its stressful and variable natural environment (see Chapter 3). This is the case in assisted recovery. The environment is here defined as a monospecific plantation on inhospitable sites, according to some variant of clear-cutting silviculture with intermediate to small-sized stands, or artificial eco-units, between 1 and 10 hectares per cut. The present study expressly does not concern other silvicultural systems. These would address the forest mosaic level, not the eco-unit, and so increase the natural variability of the

direct environment of the genotypes to be selected, e.g. by applying selective or mixed silvicultural systems. Therefore, they were left out of consideration in the present research project.

Transpiration and photosynthesis are important physiological processes in plant growth. According to Rossignol *et al.* (1998), these two processes are not only related to productivity but also to adaptation. Therefore, study of those two processes is very important in the given context. Information on transpiration and photosynthesis of tropical rain forest trees is still very limited as compared to that on temperate forest trees. Net photosynthetic rate (NPR) of *S. leprosula* is similar to a level of fast-growing species (Ishida *et al.*, 2000). It is important to know the reaction of the plants, so as to select genotypes adapted and adaptable to environmental stress in new habitats, in new environments, or in cultivation.

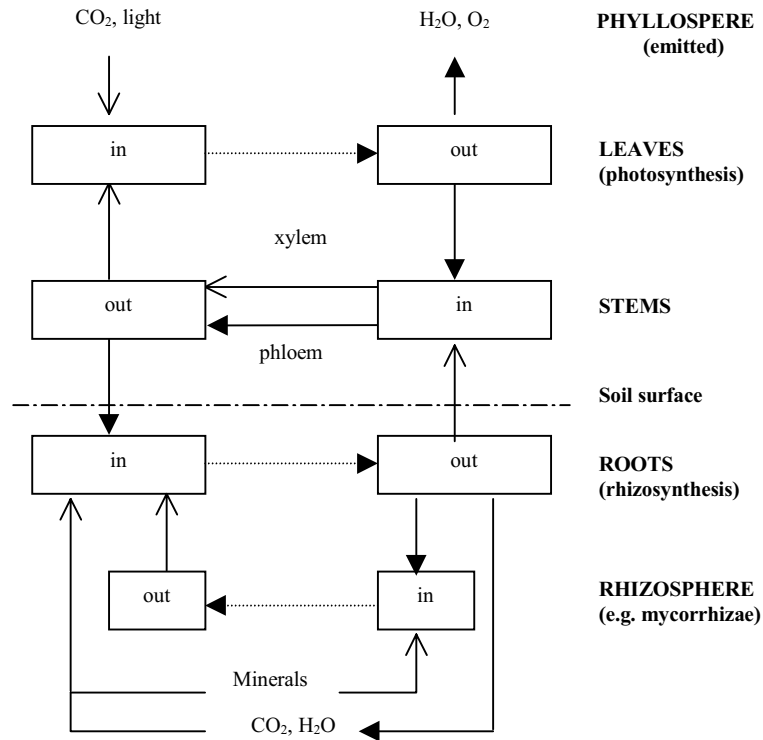


Figure 7.1 Diagram of the sap-stream of *S. leprosula* (inspired by Oldeman, 1990 and Omon, 2002). Thin-headed arrows indicate inputs, full-headed arrows show output flows, whereas dashed arrows explain the internal movement.

The diagram of the sap-stream (Fig. 7.1) shows the input-output relationships between roots in association with mycorrhizae, stem and leaves (also see Oldeman, 1974a; 1990). Photosynthesis receives inputs of light and carbon dioxide (CO₂) from the atmosphere and water plus organic nitrogen compounds from the roots by the sap-stream. The photosynthetic output is oxygen (O₂) and sugars. Production rates of these processes depend on different leaf properties such as leaf area, chlorophyll content and dry matter content. Phyllosphere organisms, such as epiphytes, are left out of the present study (Ruinen, 1974). Rhizosynthesis inputs are water and mineral nutrients from the environment and sugars from the crown. Rhizosphere organism, such as mycorrhizae produce vitamins for the higher plants (Smits, 1982). The output is composed of amino acids, vitamins and hormones that are distributed throughout the plant by the sap-stream.

From the above it is clear that we already have gained quite a bit of insight into the workings of Dipterocarpaceae and their regeneration. These insights and research results must now be translated into practical recommendations for management options or silvicultural practices, which will be discussed below.

7.2. SILVICULTURAL PRACTICES FOR SUSTAINABLE FOREST MANAGEMENT IN INDONESIA

7.2.1. Background

The environmental functions of forest have been reduced catastrophically in the last 50 years through interacting multiple and complicated factors and varying from place to place. The major accelerated forest and land degradation, and loss of biodiversity issues in South East Asia, especially in Indonesia are deforestation by clear-cutting and intensive forest practices (over exploitation of forests), illegal logging, conversion to agriculture by estates and smallholders, slash and burn agriculture or shifting cultivation, rapid population increases and urbanisation, lack of law enforcement and control, and enhanced large-scale forest fires (Mori *et al.*, 2000; Hillegers, 2001; Lee, 2001). Forest fires have become an increasing threat to sustainable forest management. Fragmentation of the landscape adds to further degradation of the biodiversity. Natural regeneration appears to be rare after deforestation. In order to counteract these processes, assisted forest recovery, using exotic and indigenous tree species is applied. Since the indigenous tree species are known to be the ecologically best adapted species, especially the Dipterocarps, they should receive priority in regenerating unproductive areas. Establishment of indigenous dipterocarps is not easy however, due to severe environmental conditions and poor soil conditions. Therefore, improvement of these severe environmental conditions is needed before reforestation can proceed.

7.2.2. Dipterocarp regeneration

Reforestation with dipterocarp species should aim at producing valuable timber with a low risk and be in line with valid criteria and indicators for sustainable forest management. The principles of biological automation, species site matching and stand management goals should be considered (von Gemmingen and Giono, 2001). Successful reforestation is only effective if it is ecologically and technically possible, economically feasible, socially acceptable and politically practicable (Smits, 1995; Garrity *et al.*, 1997). Schulte and Schöne (1996) and Appanah and Turnbull (1998) have made general reviews of silviculture and management of dipterocarps. Mori (2001) focused on dipterocarp forest restoration and based on composition and biomass in forests, he distinguished degraded forest into four categories: lightly, moderately and heavily degraded forest, and grassland or shrub forest. Lightly degraded forest is not considered for rehabilitation (see sub-chapter 7.1 above). Enrichment planting, patch (gap) planting or underplanting is needed in moderately degraded forest. Enrichment planting is often applied in the burned forest where there are few successor trees, whereas patch planting is preferred when sufficient planting stock of relatively light-demanding primary species, such as *S. leprosula* are available. Heavily degraded forest should be rehabilitated by underplanting, patch planting or line planting. Grassland or shrub forest should be reforested initially by fast-growing tree species or commercial timber species. Furthermore, Temmes (1992), Tjitrosoedirdjo (1993), Otsamo *et al.* (1995), Tolkamp (1999 and 2001) and Tolkamp *et al.* (2001) studied the role of silvicultural operations to reforesting *Imperata cylindrica* grasslands.

Reforestation with Dipterocarpaceae is hampered by the limited number and quality of planting stock and by the fact that these trees grow slowly (Leppe and Smits, 1994). Seeds, wildlings or cuttings availability, quality and the technical knowledge on their propagation influence the choice of species for planting. The technique for dipterocarp planting stock production has been extensively described in various publications (Smits *et al.*, 1990; Priadjati, 1996; Tolkamp and Priadjati, 1996; Kusdadi and Priadjati, 1998; Priadjati and Prayitno, 1998; Priadjati and Rayan, 1998; Priadjati *et al.*, 2001) and in manuals by Smits (1986), Yasman and Smits (1988), Leppe and Smits (1989). Whatever the source of the planting stock, its continuous supply is of the utmost importance to sustainable forest management. Furthermore, Priadjati *et al.* (2001) explained that in terms of economics of production, the choice between seeds, wildlings or cuttings production depends on the time lapse between the last dipterocarp mass flowering and the time the planting stock is needed. Concession holders expected natural regeneration to be sufficient because the forest is large enough. In fact, the natural forests are shrinking rapidly due mainly to conversion to other land-use forms inhospitable to dipterocarps (Indrabudi, 2002). Smits (1995) suggested that rehabilitation in the field should anticipate future needs that are identified with vision and are based on deep insight as to what is available and suitable, and should not follow trends.

Preparation of planting stock conditions in the nursery is an important step to achieve success in the reforestation with Dipterocarpaceae. The seedlings in the nursery usually do not well adapt to the new environmental conditions in the field. Therefore, the seedlings got a 'planting shock' when planted in the field and they required some time and energy to adjust to the new situation, i.e. by developing new leaves. The practical solution to a 'planting shock' condition of the seedlings is to introduce a transition phase in the nursery. In this phase, the seedlings are prepared for the new condition in the field, i.e. reducing the nursery shading so that the failure of plantation or 'planting shock' can be reduced.

Summarizing we can see that in order to rehabilitate the damaged forests using Dipterocarpaceae, we should use good quality planting stock, meaning the right sources, good quality, sufficient quantities, efficiently produced. Next the nursery management should be correct, meaning correct mycorrhizal fungi, good hardening off of the plants and in general good care of the plants during the nursery phase. Then in the next phase, the planting phase, we should ensure the right planting and shortly after that the right growing conditions for the newly planted trees. This means that after a correct selection of species and planting stock, light management is the most crucial aspect in silvicultural management. Finally, we need to ensure that the newly planted forests do not get burned again so we need to protect our areas accordingly.

7.2.3. Dipterocarp selection

We have just discussed the practical issues of dipterocarp regeneration. In order to make the prospect of planting Dipterocarpaceae more attractive we need to consider selection approaches to increase the productivity of our new plantations. In order to consider to what extent selection holds potential for Dipterocarpaceae we need to know more about the natural genetic variation amongst Dipterocarpaceae over geographically close and far away locations.

Considering genetic variability amongst *Shorea leprosula* from wide ranging origins we can see from the results of Chapter 3 that at least the phenotypic variation as indicated from the banding patterns is indeed very limited between the widespread populations. Still it can be seen that the geographically closer populations are also closer in their banding patterns and therefore may be expected to be genetically more similar. Some variation does indeed appear but is very limited. So, on the one hand again it would be disadvantageous to have more homogenous populations of *S. leprosula* but on the other hand it is a fact that the species is more homogenous and highly successful. In Chapter 3 it was already discussed that there may be various explanations for this apparent contradiction that on the one hand homogeneity should be disadvantageous, but on the other hand still proves to be a fact of life for *S. leprosula*. But, as mentioned above, there is some scope for selection amongst *S. leprosula*. For instance, the form factor of *S. leprosula* in East Kalimantan is slightly better than that of West Kalimantan. This slight difference may have a great impact

on the volume increment of usable material in the stem. Therefore, selection is still worthwhile pursuing.

A genetic conservation programme cannot be segregated functionally. It must consciously integrate socioeconomic realities. The increase in human population and the rise in demand for land and income from forest-related activities threaten the full range of genetic variability. A conservation programme can be effective if local rural people are involved in and also benefit from it. At the moment the dipterocarp forests are more under threat than ever before. Already the forest has become fragmented, and vast areas of the former range are now covered with alang-alang grasslands, which in fact are like biological deserts with only one shrub species dominating millions of hectares of land and excluding other species through the recurrence of fires and perhaps also through allelopathy.

So it is of paramount importance that we focus on trying to collect and safeguard as much of the genetic diversity there is left amongst the Dipterocarps of Borneo and that the most important species in this family, *Shorea leprosula*, should be given first priority.

7.3. CONCLUSIONS

If logging practices do not change and fire prevention measures are not implemented, future fires will follow the logging activities even deeper into the remaining forest. Hence, fires have become a major risk for the future of Indonesia's forests, especially of East Kalimantan's forests, and an obstacle to the necessary implementation of Sustainable Forest Management.

Dipterocarpaceae are species that adapted well under the conditions of a closed forest canopy, but the unnatural condition of opening the forest through logging and forest fires has made these forests less suitable for these species to grow well. It is very important to establish reforestation techniques for dipterocarp forests and to reforest degraded areas. Because of the important ecological and economical value of Dipterocarpaceae, it is important to save the total genetic resources in strictly protected areas. This is notwithstanding the fact that in this study an unusual high degree of homogeneity was encountered, which is very strange when compared with existing experiences for other plant species. *S. leprosula* shows very little morphological variation over their wide range in the Kalimantan region. It will be interesting and important to investigate this special aspect of dipterocarp genetic variation in subsequent studies.

The results from this study confirm that *S. leprosula* is a light-demanding species at the early stage, 60 to 73% (relative light intensity) for seedlings and 74 to 100% for sapling. Even though *S. leprosula* can grow in open sites with a low mortality rate,

underplanting or line planting of this species after establishment of fast growing trees, like *P. canescens* is safer, more suitable and therefore recommended.

In summary we can state that the dipterocarp forests of Borneo face a very uncertain future. There is an urgent need to safeguard what is left. One of the key issues to safe what is left is the prevention of fire. This again can only be achieved through involving local people since fires are closely related to poverty issues and illegal activities by both small and large-scale trespassers. To deal with the people we need timely and accurate information of the right information content. New radar monitoring techniques can be helpful here. Finally, the information must be put to use by following up activities in the field. This will mean law enforcement, education and provision of alternatives for poor people living nearby forest areas. If conditions for safety and fire prevention can be created, *S. leprosula* holds the potential to benefit many people and all of Indonesia. Its reforestation can even contribute to reducing the impacts of global warming. Let us hope there still is a future for Dipterocarpaceae in Borneo.

SUMMARY

One of the serious problems Indonesia is facing today is deforestation. Forests have been playing a very important role in Indonesia as the main natural resources for the economic growth of the country. Large areas of tropical forests, worldwide considered to be among the richest in plant diversity, have been lost in recent years mainly due to inappropriate logging, illegal logging, shifting cultivation, and forest fires. The negative repercussions of these activities are felt from an economical as well as from an ecological point of view.

Time and again, Indonesia has experienced severe droughts often resulting in large forest fires. The fires used to occur only sporadically but now occur regularly every approx. 4 years in the area, with the largest and most destructive ones so far taking place in 1997-98. This climatic phenomenon was linked to a particularly pronounced El Niño Southern-Oscillation (ENSO), combined with numerous fires closely connected with human activities.

‘Dipterocarpaceae: Forest fires and forest recovery’ discusses a comprehensive ecological understanding of fires, an overview of forest dynamics after fires, and the restoration strategies of the forest. Planting materials are reviewed in terms of their genetic diversity and their growth in different soil substrates, with various mycorrhizal inoculations and levels of light. The present publication is the last in a series adding information to the earlier projects conducted by Smits (1994), Yasman (1995), Hatta (1999) and Omon (2002).

Microclimatic conditions change considerably after forest fires. The burned forest was characterized by elevated levels of light intensity and heat, and significantly reduced levels of humidity. After the fires, the natural dynamics of forest, in terms of regeneration of plants and butterfly communities, was set back to an earlier development phase where there were no more trees, only 2.5% of saplings survived and all saplings shorter than 5 m died. The butterfly community in the burned area had high densities of pioneer species associated with disturbed habitats. Burning caused a significant shift in the forest butterfly community. There was a highly significant variation in sapling and seedling density, diameter, and species richness between burned and unburned forest. Even though sapling height was significantly greater in burned than in unburned forest, there was no significant difference between their growth in both forests. The growth of both saplings and seedlings was completely unaffected by any edge effect in both forest types. The species richness, density and height of seedlings were significantly greater in unburned forest but their growth was significantly greater in burned forest. The diverse seedling community of unburned forest was replaced by a species-poor community of pioneers dominated by Euphorbiaceae.

Dipterocarp forests can recover from fire impact if the damage is not too extensive and the fires are not recurrent, but their natural recovery is too slow to make it economically interesting, and therefore foresters try to restore the desired state of high forest as soon as possible. Their measures are based on the fact that similar microclimatic conditions in both forest types were reached within two years, so assisted recovery can be implemented soon in the burned area by introducing valuable climax tree species i.e dipterocarp species, before they would arrive spontaneously.

Such operations require seedlings. Key issues for the management of dipterocarp stock plants in the nurseries included genetic diversity of the seedlings, choice and preparation of appropriate potting mixes, species-soil original matching, nursery hygiene and mycorrhizal inoculation. Cuttings grown in sandy loam showed a stronger and faster growth than the cuttings in sandy clay loam and loam. The higher sand fraction in the soil provided a good aeration for mycorrhizae and plants roots. Pasteurised soil media increased the growth of seedlings in the nursery. It is assumed that composition, acidity, moisture content and heat of the rooting media can be combined in a treatment optimising the conditions for both root development and root colonisation by fungi, thus increasing the quality and quantity of seedlings produced. It was found that interactions between so many factors lead to a highly complex situation, far from easy to control.

S. leprosula proved to be very homogeneous as expressed from the similarities in frequencies of the band patterns. The similarity was relatively high between eastern, central and western Kalimantan populations but the nearer the geographic distance the more similar the populations.

The initial inoculation supported *S. leprosula* to start growing in the greenhouse. In the established dipterocarp nursery, the spores of mycorrhizal fungi inoculated seedlings easily and freely. In 15 months in the greenhouse, all seedlings were colonised by these mycorrhizal weed fungi. *Laccaria sp.* was the most common one, followed by *Thelephora sp.*, *Riessiella sp.* and *Inocybe sp.* After 12 months in the field, the species composition of mycorrhizal fungi involved in root colonisation changed again. *Inocybe sp.* was still there, with two new other species being most abundant, namely *Amanita sp.* and *Scleroderma sp.* Even though the growth of *S. leprosula* seedlings in the nursery was supported by initial inoculation, in the field, no initial inoculation seedlings showed a stronger growth because they benefited more from the late stage fungi infecting the plants at the planting location.

When dipterocarps are used, the key to success for a dipterocarp planting is species choice and light control. Selecting species suited to the local soil and site conditions is essential. Light control should correspond to the light requirements of a species during its growing stages, so planting methods should reflect site conditions and growth characteristics of the species. *S. leprosula* is a light-demanding species at the

early stage, 60 to 73% (relative light intensity) for seedlings and 74 to 100% for saplings.

The assisted recovery of pure *Imperata cylindrica* areas after fires is accelerated using mixed plantations composed of indigenous fast-growing pioneer tree species, i.e. *Peronema canescens* that offer suitable conditions for the establishment of indigenous dipterocarp species. In circumstances without stress by fire, a young *P. canescens* tree has a well-developed monopodial trunk with a light canopy so that the light intensity under this species is very high or not much lower than in the open site. This shade condition (semi-closed) is not very suitable for *S. leprosula* seedlings when under-planted under this species. The capacity of *P. canescens* after fires to reiterate abundantly ('traumatic reiteration') and converge architecturally from *Scarrone's model* to a physiognomy resembling *Leeuwenberg's model* provided more favourable environmental conditions for *S. leprosula* to grow under the canopy of these trees (closed stand). Within almost three years, *S. leprosula* saplings in a closed stand and in a semi-open area reached a height of 281 to 283 cm and a diameter of 33 to 34 mm, whereas in the open area and under the semi-closed canopy of *P. canescens* they were only 165 to 193 cm high and 22 to 27 mm in diameter.

Long-term survival of a species depends on its ability to adapt to environmental change. Adaptability is a two-sided process. It rests on the optimal match between a genotype (organism) and its direct environment (ecosystem patch or 'eco-unit'). It is important to understand the reaction of the plants, so as to select genotypes adapted and adaptable to environmental stress in new environments. For this reason, next to the taxonomical data of *S. leprosula*, the architectural model and its reiteration are also described in this book.

In Chapter 7 an overview is provided of the fire and forest regeneration issues with special reference to the Dipterocarpaceae and *Shorea leprosula*. Much practical information is provided on conditions for a successful regeneration of Dipterocarpaceae. It is concluded that the Dipterocarpaceae have become a threatened plant family and that safeguarding the genetic diversity of *Shorea leprosula* is highly urgent. If Dipterocarpaceae are to survive, the issue of fires must be resolved and dealt with.

SAMENVATTING

Een belangrijk actueel probleem in Indonesië is ontbossing. Bossen hebben een hoofdrol als belangrijkste natuurlijke hulpbron voor de economische groei in Indonesië. Grote arealen bos, wereldwijd beschouwd als bijzonder rijk in plantaardige diversiteit, zijn verloren gegaan door onzorgvuldige kap, illegale kap, shifting cultivation en bosbranden. De negatieve gevolgen van deze activiteiten zijn zowel economisch als ecologisch voelbaar.

Regelmatig lijdt Indonesië onder extreem droge periodes die vaak resulteren in grote bosbranden. Deze branden kwamen sporadisch voor, maar tegenwoordig treden ze regelmatig (circa elke 4 jaar) op in het gebied, met de grootste en meest destructieve branden in 1997-98. Dit klimatologisch fenomeen is gekoppeld aan 'El Niño Southern Oscillation' (ENSO), gecombineerd met branden ontstaan door het handelen van de mens.

"Dipterocarpaceae: Forest fires and forest recovery" bespreekt een uitgebreide ecologische omschrijving van branden, een overzicht van bosdynamiek na brand, en herstelstrategieën van het bos. Plantmateriaal wordt gezien op genetische diversiteit en groei in verschillende bodemmonsters, geïnoculeerd met diverse mycorrhizae en onder diverse lichtomstandigheden. De huidige publicatie is de laatste in een serie die werd voorafgegaan door projecten van Smits (1994), Yasman (1998), Hatta (1999) en Omon (2002).

De omstandigheden in het microklimaat veranderen drastisch na een bosbrand. Het verbrande bos werd gekarakteriseerd door verschillende niveaus van lichtintensiteit en hitte, en een significant gereduceerd vochniveau. Na de branden is de natuurlijke bosdynamiek in termen van regeneratie van planten- en vlinderpopulaties teruggezet naar een eerder ontwikkelingsstadium zonder bomen; slechts 2,5 % van de jonge bomen heeft de brand overleefd, en alle jonge bomen onder de 5 meter zijn verdwenen. De vlinderpopulatie in het verbrande gebied had hoge aantallen pioniersoorten kenmerkend voor verstoorte habitats. Branden geven een verschuiving in de vlinder-populatie in het bos. Er was een hoge, significante variatie in dichtheid, diameter en soortenrijkdom van de jonge bomen en zaailingen tussen gebrand en ongebrand bos. Hoewel de jonge bomen in verbrand bos gemiddeld hoger zijn dan die in onverbrand bos is er geen verschil in groei in beide bossen. De groei van zowel zaailingen als jonge bomen was geheel niet beïnvloed door randeffecten in beide bostypen. De soortenrijkdom, dichtheid en hoogte van zaailingen waren significant groter in onverbrand bos dan in verbrand bos. De diverse zaailingpopulatie in onverbrand bos was vervangen door een soortenarme populatie gedomineerd door Euphorbiaceae.

Een dipterocarpenbos kan herstellen van brand als de schade beperkt is en de branden niet te frequent zijn, maar de natuurlijke regeneratie is te traag om economisch interessant te zijn. Daarom proberen bosbouwers de gewenste staat van bos zo snel mogelijk te herstellen. Hun maatregelen zijn gebaseerd op het feit dat een gelijk microklimaat in beide bostypen binnen twee jaar wordt bereikt, zodat het ondersteunde herstel snel kan worden gerealiseerd in het verbrande gebied met het introduceren van kostbare climax boomsoorten (dipterocarpen), voordat ze spontaan zouden opkomen.

Dergelijke operaties vereisen zaailingen. Sleutelementen voor het management van een dipterocarpenvoorraad in de kwekerij omvatten genetische diversiteit van de zaailingen, keuze en voorbereiden van een goede mix van de plantaarde, optimale bodem-condities, goede hygiëne en inoculatie met mycorrhizae. Stekken op zandig leem groeien sterker en sneller dan stekken op zandig kleileem en leem. De hogere zandfractie in de bodem zorgt voor een goede beluchting van de mycorrhizae en plantwortels. Gepasteuriseerde bodemmedia zorgen voor een grotere groei van de zaailingen in de kwekerij. Er wordt aangenomen dat de samenstelling, zuurgraad, vochtgehalte en temperatuur van het wortelmedium in een behandeling gecombineerd kunnen worden, zodat de condities voor wortelontwikkeling en wortelkolonisatie door de schimmels geoptimaliseerd worden en dus zowel kwaliteit als kwantiteit van de zaailingen toeneemt. De interactie tussen zoveel verschillende factoren leidt tot een complexe situatie, die moeilijk te controleren is.

S. leprosula bleek zeer homogeen, volgens de overeenkomsten in frequenties en bandpartonen. De overeenkomst was relatief hoog tussen oost, centraal en west Kalimantan populaties. Hoe kleiner de geografische afstand des te meer de populaties overeen kwamen.

De initiële inoculatie hielp *S. leprosula* te groeien in de kas. In de gevestigde Dipterocarpenkwekerij inoculeerden de sporen van de mycorrhizenschimmels de zaailingen makkelijk. Binnen 15 maanden waren alle zaailingen in de kas gekoloniseerd door mycorrhizenschimmels. *Laccaria* sp werd het meest gevonden, gevolgd door *Thelephora* sp., *Riessiella* sp. en *Inocybe* sp. Na 12 maanden veranderde de soortensamenstelling van de mycorrhizenschimmels, betrokken bij wortelkolonisatie in het veld nogmaals. *Inocybe* sp. was nog steeds aanwezig, met twee andere nieuwe soorten als meest voorkomend, namelijk *Amanita* sp. en *Scleroderma* sp. Hoewel de groei van *S. leprosula* zaailingen in de kwekerij gestimuleerd was door de initiële inoculatie, waren in het veld geen geïnoculeerde zaailingen met een sterkere groei, zodat ze meer profiteerden van schimmels uit latere successiestadia die de planten infecteerden op de plantlocatie.

Als dipterocarpen gebruikt worden zijn soortenkeuze en lichtcontrole de sleutel tot succes. Keuze van soorten die passen bij de lokale bodem en omgevingscondities is essentieel. Lichtcontrole moet passen bij de lichtbehoefte van de soort tijdens de

groeistadia, dus plantmethoden moeten omgevingsomstandigheden en groeikarakteristieken van de soort reflecteren. *S. leprosula* is een lichteisende soort in het beginstadium, 60 tot 73% relatieve lichtintensiteit voor zaailingen en 74 tot 100% voor jonge bomen.

Het geassisteerde herstel van *Imperata cylindrica*-land na brand wordt versneld door gebruik van gemengde plantages, samengesteld uit inheemse snelgroeiende pionierboomsoorten zoals *Peronema canescens* die een stabiele omgeving creëren voor de vestiging van inheemse dipterocarpensoorten. In omstandigheden zonder stress door brand heeft een jonge *P. canescens* een goed ontwikkelde monopodiale stam met een licht kronendak zodat de lichtintensiteit onder deze soort hoog is, niet veel lager dan in het open veld. De schaduwconditie (half gesloten) is niet erg geschikt voor *S. leprosula* zaailingen geplant onder deze soort. De capaciteit van *P. canescens* om na branden uitbundig uit te groeien (traumatische uitgroei) en de architectonische verandering van Scarrone's model tot een vorm die lijkt op Leeuwenberg's model, gaven betere omstandigheden voor *S. leprosula* om onder het kronendak van deze soort te groeien (gesloten stand). Na bijna drie jaar hadden de jonge bomen in gesloten of half-open gebied een hoogte van 281 tot 283 cm en een diameter van 33 tot 34 mm, terwijl in de open gebieden onder het half-gesloten kronendak van *P. canescens* hoogtes van 165 tot 193 cm en diameters van 22 tot 27 mm werden bereikt.

Het voortbestaan op lange termijn van de soorten hangt af van hun vermogen om zich aan te passen aan veranderingen in de omgeving. Aanpassing is een tweezijdig proces. Het is gebaseerd op de optimale inpassing van een genotype (organisme) in zijn directe omgeving (deel van ecosysteem, verjongingseenheid of 'eco-unit'). Het is belangrijk de reactie van planten te begrijpen, om de soorten of genotypen te kiezen die zijn aangepast of zich kunnen aanpassen aan stress in de nieuwe omgeving. Daarom worden naast de taxonomische gegevens ook het architectuurmodel en de reïteratie ervan beschreven in dit boek.

In hoofdstuk 7 wordt een overzicht gegeven van aspecten van brand en bosregeneratie, met speciale aandacht voor *Dipterocarpaceae* en *Shorea leprosula*. Veel praktische aandacht is gegeven aan de omstandigheden voor een succesvolle regeneratie van *Dipterocarpaceae*. Er wordt geconcludeerd dat de *Dipterocarpaceae* een bedreigde plantenfamilie zijn geworden en dat het behoud van de genetische diversiteit binnen de soort *Shorea leprosula* zeer urgent is. Als we *Dipterocarpaceae* willen behouden moet het probleem van bosbranden worden aangepakt.

RINGKASAN

Salah satu masalah serius yang dihadapi Indonesia saat ini adalah deforestasi. Hutan sangat berperan sebagai sumber daya alam yang utama dalam pertumbuhan ekonomi negara. Besarnya wilayah hutan tropis di Indonesia, dianggap sebagai salah satu yang mempunyai keanekaragaman hayati yang terkaya di seluruh dunia, telah hilang dalam beberapa tahun terakhir terutama karena pembalakan yang tidak tepat, pembalakan liar, sistem peladangan berpindah, dan kebakaran hutan. Ditinjau baik dari sudut pandang ekonomis maupun ekologis, berbagai kegiatan tersebut hanya memberikan efek negatif.

Indonesia telah mengalami beberapa kali kekeringan yang hebat dan sering mengakibatkan kebakaran hutan yang besar. Kebakaran dulunya hanya terjadi sporadis, namun sekarang menjadi rutin sekitar 4 tahun sekali, dan yang terbesar dan paling merusak terjadi pada tahun 1997-98. Fenomena iklim ini berkaitan erat dengan El Niño Southern-Oscillation (ENSO), yang dikombinasikan dengan api yang berhubungan erat dengan kegiatan manusia.

‘Dipterocarpaceae: Kebakaran hutan dan pemulihan hutan’ menjabarkan suatu pemahaman ekologis yang menyeluruh tentang kebakaran hutan, pandangan tentang dinamika hutan pasca kebakaran, dan strategi tentang pemulihan hutan. Keanekaragaman genetika dan pertumbuhan anakan sebagai bahan pertanaman di berbagai jenis tanah, mikorisa dan cahaya dipelajari secara menyeluruh di buku ini. Publikasi ini merupakan seri terakhir yang melengkapi informasi terdahulu yang dilakukan oleh Smits (1994), Yasman (1995), Hatta (1999) dan Omon (2002).

Kondisi iklim mikro berubah banyak setelah kebakaran hutan. Hutan yang terbakar dicirikan dengan tingginya tingkat intensitas cahaya dan suhu, dan pengurangan tingkat kelembaban udara secara signifikan. Setelah hutan terbakar, dinamika alami dari hutan yang berkaitan dengan regenerasi tanaman dan komunitas kupu-kupu kembali ke tahap perkembangan awal, dimana tidak ada pohon lagi dan hanya 2.5% dari tanaman tingkat pancang yang bertahan hidup dan semua pancang dengan tinggi kurang dari 5 m mati. Komunitas kupu-kupu di areal bekas terbakar mempunyai kerapatan yang tinggi akan jenis pioner yang berkaitan dengan habitat yang rusak. Kebakaran mengakibatkan perpindahan yang signifikan terhadap komunitas kupu-kupu di hutan. Ada variasi yang sangat nyata pada kerapatan, diameter dan keanekaragaman jenis pada tingkat pertumbuhan pancang dan anakan antara hutan yang terbakar dan yang tidak terbakar. Meskipun rata-rata tinggi tingkat pancang di hutan yang terbakar secara nyata lebih dibandingkan di hutan yang tidak terbakar, namun tidak ada perbedaan pertumbuhan tinggi yang nyata antar kedua kondisi hutan. Pertumbuhan, baik tingkat pancang maupun anakan sama sekali tidak dipengaruhi oleh adanya efek tepi di kedua tipe hutan. Keanekaragaman jenis, kerapatan dan tinggi anakan secara nyata lebih tinggi di hutan tidak terbakar, namun

pertumbuhannya secara nyata lebih tinggi di hutan terbakar. Keragaman komunitas anakan di hutan tidak terbakar digantikan oleh jenis pioner yang kurang beragam, yang didominasi oleh Euphorbiaceae.

Hutan *Dipterocarpa* dapat pulih dari pengaruh kebakaran jika kerusakan yang ditimbulkan tidak terlalu luas dan api tidak berulang. Namun demikian, pemulihan secara alami berjalan sangat lambat sebelum dapat menghasilkan, sehingga para rimbawan berusaha untuk memulihkan keadaan hutan seperti yang diharapkan sesegera mungkin. Ukuran yang digunakan berdasarkan kenyataan bahwa kemiripan kondisi iklim mikro di kedua tipe hutan dapat dicapai dalam waktu dua tahun, sehingga percepatan pemulihan dapat dilaksanakan segera di lokasi yang terbakar dengan mengintroduksi jenis pohon klimaks yang komersial seperti jenis dipterokarpa, sebelum dapat tumbuh secara spontan.

Kegiatan penanaman dalam rangka percepatan pemulihan memerlukan anakan. Isu kunci dalam pengelolaan stok tanaman dipterokarpa di persemaian meliputi keanekaragaman genetik dari anakan, pilihan dan persiapan campuran media yang sesuai, kesesuaian jenis dan asal tanah, kebersihan persemaian dan inokulasi mikorisa. Anakan tumbuh lebih kuat dan cepat di tanah yang lempung berpasir dibandingkan dengan anakan yang tumbuh di lempung liat berpasir dan lempung. Semakin tinggi kandungan pasir di tanah memberikan aerasi yang baik untuk mikorisa dan akar tanaman. Media tanah yang dipasteurisasi meningkatkan pertumbuhan anakan di persemaian. Diasumsikan bahwa komposisi, keasaman, kelembaban dan suhu dari media perakaran dapat dikombinasikan dalam suatu perlakuan untuk mengoptimasi kondisi, baik untuk perkembangan akar maupun kolonisasi akar oleh jamur, yang selanjutnya meningkatkan kualitas dan kuantitas dari anakan yang dihasilkan. Interaksi antar banyak faktor mengakibatkan situasi yang cukup kompleks, jauh dari mudah untuk dikontrol.

S. leprosula terbukti sangat seragam seperti yang terlihat dari kemiripan di frekuensi fenotip pada pola pita. Kemiripan relatif tinggi antara populasi di timur, tengah dan barat Kalimantan, namun jarak geografi yang lebih dekat memberikan kemiripan yang lebih antar populasi tersebut.

Inokulasi awal membantu *S. leprosula* untuk mulai tumbuh di rumah kaca. Di persemaian dipterokarpa yang telah berkembang, spora jamur mikorisa sangat mudah dan dengan bebas menginokulasi anakan. Selama 15 bulan di rumah kaca, semua anakan telah terkolonisasi oleh jamur mikorisa. *Laccaria* sp. merupakan jenis yang paling sering dijumpai, diikuti oleh jenis *Thelephora* sp., *Reissiera* sp. dan *Inocybe* sp. Setelah 12 bulan di lapangan, komposisi jenis jamur mikorisa yang tergabung dalam kolonisasi akar berubah lagi. *Inocybe* sp., dengan dua jenis baru lainnya, seperti *Amanita* sp. dan *Scleroderma* sp. menjadi yang terbanyak. Meskipun pertumbuhan anakan *S. leprosula* di persemaian didukung dengan adanya menginokulasian awal, namun setelah di lapangan, tanpa adanya inokulasi awal

menunjukkan pertumbuhan anakan yang lebih kuat karena mendapat keuntungan yang lebih banyak dengan adanya jamur 'tahap akhir' yang menginfeksi tanaman di lokasi penanaman.

Jika dipterokarpa digunakan, kunci sukses dalam penanaman jenis dipterokarpa adalah pemilihan jenis dan pengaturan cahaya. Seleksi jenis yang sesuai dengan status tanah dan kondisi lingkungan adalah hal yang mendasar. Penyesuaian cahaya harus berhubungan dengan cahaya yang dibutuhkan oleh jenis tanaman selama tahap pertumbuhan, sehingga metoda penanaman harus mencerminkan kondisi lahan dan karakter pertumbuhan jenis tanaman. *S. leprosula* merupakan jenis yang memerlukan cahaya pada tahap awal pertumbuhan, 60 sampai 73% (intensitas cahaya relatif) untuk anakan dan 74 sampai 100% untuk tingkat pancang.

Pemulihan terkendali di padang alang-alang, *Imperata cylindrica* setelah kebakaran dapat dipercepat dengan menanam campuran yang terdiri dari jenis pohon pioner yang cepat tumbuh, seperti *Peronema canescens* yang memberikan kondisi yang memadai untuk perkembangan jenis lokal dipterokarpa. Pada kondisi tanpa stres oleh api, tanaman muda *P. canescens* mempunyai batang tunggal dengan tajuk ringan sehingga cahaya di bawah jenis ini intensitasnya sangat tinggi dan tidak cukup rendah dibanding di tempat terbuka. Kondisi naungan ini (semi-tertutup) tidak sesuai bagi anakan *S. leprosula*. Kemampuan *P. canescens* setelah kebakaran untuk bertunas kembali dengan banyak ('reiterasi traumatik') dan berubah dari model arsitektur Scarrone menjadi model Leeuwenberg yang memberikan kondisi lingkungan yang lebih sesuai bagi *S. leprosula* untuk tumbuh di bawah tajuk dari pohon tersebut (tegakan tertutup). Dalam waktu hampir tiga tahun, pancang *S. leprosula* di bawah tegakan tertutup dan di lahan semi-terbuka tingginya bisa mencapai 281 sampai 283 cm dan diameter dari 33 sampai 34 mm, sedangkan di tempat terbuka dan di bawah semi-tertutup tajuk *P. canescens*, tingginya hanya 165 sampai 193 cm dengan diameter 22 sampai 27 mm.

Kemampuan hidup yang panjang dari suatu jenis tergantung pada kemampuannya untuk beradaptasi dengan perubahan lingkungan. Kemampuan beradaptasi terdiri dari dua-sisi proses yang berujung pada gabungan yang optimal antara genotip (organisme) dan lingkungannya (ekosistem atau 'eko-unit'). Adalah penting untuk memahami reaksi tanaman, sehingga dapat untuk menseleksi genotip yang dapat beradaptasi dan yang dapat beradaptasi dengan stres lingkungan di lingkungan baru. Untuk alasan tersebut, di samping data taksonomi dari *S. leprosula*, model arsitektur dan reiterasinya juga dibahas di buku ini.

Gambaran menyeluruh mengenai isu kebakaran dan regenerasi hutan dengan bahasan utama Dipterocarpaceae dan *Shorea leprosula* menjadi topik pada Bab 7. Banyak informasi praktis mengenai kondisi untuk keberhasilan regenerasi pada Dipterocarpaceae. Disimpulkan bahwa Dipterocarpaceae telah menjadi kelompok jenis yang terancam dan penyelamatan keanekaragaman genetik dari *S. leprosula*

adalah hal yang sangat mendesak. Jika Dipterocarpaceae tetap dipertahankan, isu mengenai kebakaran hutan harus dihadapi dan dipecahkan.

GLOSSARY

Acuminate (Bodegom *et al.*, 1999); having a sharp point, less than 45°.

Acute (Bodegom *et al.*, 1999); a sharp point, between 45° and 90°.

Alternate (Bodegom *et al.*, 1999); an arrangement of one leaf per node along the stem.

Anodic (Pasteur *et al.*, 1988); jargon for the band closest to the anode (+ pole) in individuals showing two or more isozymes after a given stain.

Apex (Bodegom *et al.*, 1999); the top of an organ (usually used for leaves).

Apposition (Hallé *et al.*, 1978); resulting in branching by displacement of a continued active terminal meristem by a more vigorous lateral, i.e., no meristem abortion involved.

Architecture; the visible, morphological, expression of the blueprint of organic growth and development (Hallé *et al.*, 1978). In the definition by Edelin (1984) the influence of both endogenous and exogenous processes is better expressed, but morphology is less accentuated: “the architecture of a plan resides in the nature and relative arrangement of each of its parts; it is, at every moment the expression of an equilibrium between endogenous growth processes and external constraints of the environment”. Both definitions basically express the same concept.

Architecture diagram (Edelin, 1977), the specific expression of the model, including the minor architectural details. The term was later replaced by architectural unit (Barthélémy *et al.*, 1989). Architectural diagram as used in the present study, means a sequence of drawings representing the architectural development of a tree species.

Architectural model (Hallé and Oldeman, 1975); method of characterisation of different architectures. The definition of a model concerns only the major architectural characters; many minor architectural variations may find a place within the limits of such a definition (also see architectural diagram, reiteration).

Architectural unit; see architectural diagram.

Automatic reiteration (Edelin, 1984); automatic reiteration is the direct result of metamorphosis. Metamorphosis is the process in which along the main, least differentiated axis during development, first the highest differentiated type of axis occurs, followed sequentially by lower differentiated types of axis. The continuation of this process results in the reproduction of types of axis with the lowest degree of differentiation, i.e. axes similar to the main axis. These axes are by definition reiterations of the main axis and therefore called automatic reiterations.

Axis (Hallé *et al.*, 1978); supporting part of an organ or complex, e.g., leaf axis, stem.

Axillary (Rossignol *et al.*, 1998); placed in leaf axil

- Biodiversity** (Rossignol *et al.*, 1998); epiphenomenon of biocomplexity expressed as diversity of biological instruction carriers at one moment in biological time and at one biological scale level.
- Branch differentiation** (Hallé *et al.*, 1978); morphological specialization either as sequential expression of meristematic specialization or growth correlation (e.g. from orthotropic to plagiotropic shoots).
- Branching pattern**; regularity in branching sequence and morphological characteristics of branches.
- Cathodic** (Pasteur *et al.*, 1988); jargon for the band closest to the cathode (- pole) in individuals showing two or more isozymes after a given stain.
- Chablis** (Hallé *et al.*, 1978); a gap in the forest produced by the fall of a tree; the fall of the tree itself and the resulting forest damage (from the French).
- Competition** (Leersnijder, 1992); interaction between living systems, by which one system profits at the cost of the other (also see tree competition).
- Continuous growth** (Hallé *et al.*, 1978); growth without visible rhythm producing shoots without distinct articulations.
- Cotyledon** (Bodegom *et al.*, 1999); the first leaf or leaves of a plant, already present in the seed and usually differing in shape from the later leaves.
- Deforestation** (Arunarwati and Hussin, 2001); the rate of change of forest cover area caused by the change of use of forest land from forest to non-forest.
- Development**; process in which irreversible changes take place.
- Distichous (leaf) arrangement** (Hallé *et al.*, 1978); alternate, but restricted to a single plane.
- Domatia** (Bodegom *et al.*, 1999); small holes, tufts of hairs or scale-like structures usually in the axis of veins, usually on the lower leaf surface.
- Eco-unit** (Oldeman, 1990); every surface on which at one moment in time a vegetation development has begun, the architecture of which, eco-physiological functioning and species composition are ordained by the same set of trees until the end (also see zero-event).
- Ectomycorrhizae** (Oldeman, 1990); mycorrhizae that grow on the outside of roots (also see mycorrhizae, endomycorrhizae).
- Elliptic** (Bodegom *et al.*, 1999); a shape broadest in the middle with smoothly and equally curving sides.
- Endomycorrhizae** (Oldeman, 1990); mycorrhizae that grow inside the tree root and its cells (also see mycorrhizae, ectomycorrhizae).
- Epicotyledonary seedling axis**; first aboveground axis that a seed produces. The extension of the hypocotyl until it branches.
- Epigeal germination** (Hallé *et al.*, 1978; Bodegom *et al.*, 1999); in which the cotyledon(s) escape from the seed coat and usually appear above ground as photosynthetic organs.
- Flexibility**; the ability to adjust growth and development under the influence of external factors (see also plasticity).

- Forest degradation (Mori, 2001);** a kind of canopy gap forming process and/or retrogressive actions against plant succession process caused by natural disasters and human activities.
- Forest rehabilitation (Mori, 2001);** human intervention to counter forest degradation processes, e.g. promotion of the recovery process in large gaps of dipterocarp forest or conversion of shrub forest to high storey plantation forest.
- Genotype;** complete set of inherited genes of an organism.
- Glabrous (Bodegom *et al.*, 1999);** without hairs.
- Growing space;** the space available to a tree, in which it is more competitive than its neighbours (also see tree competition).
- Habitat (Whittaker *et al.*, 1973);** the community (or communities) in which a species lives (also see ecotope, niche).
- Hierarchy (Edelin, 1991);** organization in a tree which results in the formation of only one trunk, either by a monopodium or sympodium (also see organization pattern, polyarchy).
- Indument(um) (Bodegom *et al.*, 1999);** the hairy covering as a whole.
- Life cycle strategy (Harper and Ogden, 1970);** the whole complex time and space pattern of energy allocation by an organism (see also reproductive strategy).
- Life history;** the position of a tree in relation to other trees in the forest during its development.
- Locus (Pasteur *et al.*, 1988);** part of a chromosome which corresponds to a gene
- Metamorphosis (Oldeman, 1990);** a programmed period of tree development, in which the repetition of the patterns displayed in early branching can be found back in each of the sub-crowns that are building the whole crown of the tree.
- Midrib (Bodegom *et al.*, 1999);** the central and usually largest vein of the leaf.
- Model (botanical)(Hallé *et al.*, 1978);** short for *architectural tree model*, generalized growth programme, which determines the successive architectural phases of a tree.
- Monomorphic (Pasteur *et al.*, 1988);** a gene or a character which does not differ in the individuals analysed.
- Monopodium (Hallé *et al.*, 1978);** an axis established by a single indeterminate meristem, i.e., branches remain subordinate; hence *monopodial growth*, growth by continued activity of a single meristem (also see *sympodium*).
- Mycorrhizae (Oldeman, 1990);** fungi living in symbiosis with plant roots (also see *ectomycorrhizae*, *endomycorrhizae*).
- Niche (Whittaker *et al.*, 1973);** the place of a species within the community (also see ecotope, habitat).
- Node (Bodegom *et al.*, 1999);** a point on the stem where one or more leaves are or were attached.
- Obtuse (Bodegom *et al.*, 1999);** blunt, an angle more than 45°.

- Organization pattern (Edelin, 1991);** organization at tree level, coordinating, by hierarchy or polyarchy, the suppression or appearance of reiteration units in the tree.
- Orthotropy (Hallé *et al.*, 1978);** gravitational response which produces a vertical axis, hence *orthotropic shoot* with the complex of characters resulting from this response, i.e., radial symmetry and vertical orientation (also see *plagiortropy*).
- Ovate (Bodegom *et al.*, 1999);** flat shape with the outline of an egg, the broadest part below the middle.
- PAR;** Photosynthetically Active Radiation. This is the radiation with wavelengths between approx. 400 and 700 nm (also see *PPFD*).
- Petiole (Bodegom *et al.*, 1999);** the stalk of the leaf.
- Pasteurisation;** partial sterilisation of a substance at a temperature that destroys objectionable organisms without major chemical alteration of the substance.
- Phenotype;** all aspects of morphology, physiology, behaviour and ecological relations of an organism, which can be visually observed, resulting from its genotype-environment interaction.
- Photosynthesis** refers to the conversion process of carbon dioxide and water to carbohydrates by green plant cells in the presence of light, whereby oxygen is liberated as a by-product.
- Phyllotaxis;** leaf arrangement. The disposition of leaves around or along an axis.
- Plagiortropy (Hallé *et al.*, 1978);** gravitational response which produces an oblique or horizontal axis, hence *plagiortropic shoot* with the complex of characters resulting from this response i.e., dorsiventral symmetry and horizontal orientation (also see *orthotropy*).
- Plasticity;** the ability to adjust growth and development under the influence of external factors (also see flexibility).
- Polyarchy (Edelin, 1991);** organisation in a tree which results in the formation of more than one trunk-like structure, either by monopodia or sympodia (also see hierarchy, organization pattern).
- PPFD;** Photosynthetic Photon Flux Density. This is the density of photons in the wavelengths between approx. 400 and 700 nm that reach a certain point (also see PAR).
- Prolepsis (Hallé *et al.*, 1978);** development of a lateral branch after a period of dormancy (also see syllepsis).
- Reiteration (Oldeman, 1974a; Hallé *et al.*, 1978);** development of shoots outside the normal expression of the architectural model of a tree, as a specialized environmental response (also see *architectural model* and *model*).
- Reiteration unit;** the branch or branch complex resulting from reiteration.
- Reproductive strategy (Harper and Ogden, 1970);** “the strategy allocation particularly associated with reproduction”.
- Rhythmic growth (Hallé *et al.*, 1978);** growth of an axis determined by a rhythm which results in periodic shoot.

- Spiral (leaf) arrangement** (Hallé *et al.*, 1978); alternate, but radially arranged, i.e., forming a helix.
- Stellate** (Bodegom *et al.*, 1999); star-shaped, often of hairs.
- Stipule** (Bodegom *et al.*, 1999); a scale-like or leaf-like appendage usually at the base of the petiole, sometimes adnate to it, often paired.
- Suppressed trees**; trees with reduced growth due to their position beneath other trees.
- Syllepsis** (Hallé *et al.*, 1978); development of a lateral shoot without a period of dormancy, i.e. contemporaneous with its parent axis; hence *sylleptic branch*, a branch developed by syllepsis (also see *prolepsis*).
- Sylvigenesis** (Oldeman, 1978); the process by which the forest develops and includes many partial processes continuing through successive phases in shorter or longer cycles,
- Sympodium**; trunk or branch formed by a sequence of meristems relaying each other (also see monopodium).
- Terete** (Bodegom *et al.*, 1999); smoothly rounded in cross-section.
- Tier** (Hallé *et al.*, 1978); a group of closely inserted branches or branch complexes (whorled or pseudo-whorled) widely separated from other groups of branches.
- Tree competition**; interaction between adjacent trees for the allocation of available growing space (competition for the available resources of light, water and nutrients)(also see competition, growing space).
- (tree) temperament** (Oldeman and van Dijk, 1991); the set of growth and development reactions shown by a tree towards its environment during its life cycle.
- Truncate** (Bodegom *et al.*, 1999); more or less squarely at the end.
- Vein** (Bodegom *et al.*, 1999); one of the lines which form the structural and vascular strands of the leaf.

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CURRICULUM VITAE

Aldrianto Priadjati was born on July 31, 1969 in Yogyakarta, Indonesia. He studied forestry at the Faculty of Forestry, Gadjah Mada University in Yogyakarta. He obtained the degree of Forest Engineer (Ir) with silviculture as his major in 1993. He was the fastest and the best graduate with the predicate **Cum Laude**. He has been working as a technical member of staff at the Association of Indonesian Forest Concession Holders (APHI) since September 1993. He has also been working as a forest rehabilitation researcher at the International Ministry of Forestry (MoF)-Tropenbos Kalimantan Programme, in the Wanariset Samboja Forestry Research Station, East Kalimantan since October 1993. From January 1994 to October 1998 he was head of the Forest Rehabilitation Group at the International MoF-Tropenbos Kalimantan Programme. He completed several training courses, attended some national and international seminars, congresses, workshops as well as conferences and published some papers in proceedings and bulletins. Some publications are:

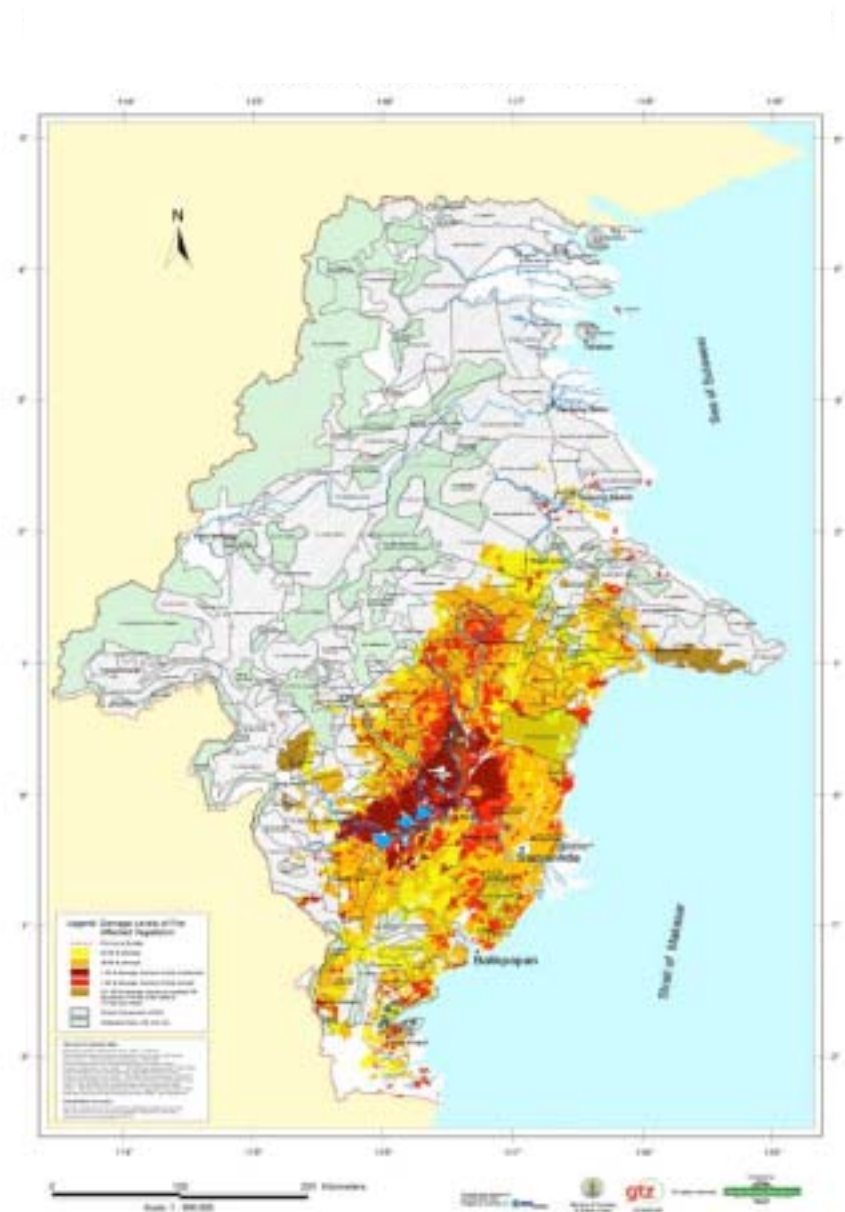
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APPENDIX 1

Fire damage classification in East Kalimantan 1997-98 based on ERS-SAR images (after Hoffmann *et al.*, 1999 and von Gemmingen, 2001)



APPENDIX 2

All butterfly species ($n > 5$) used in the correspondence analysis.

Butterfly species	Family	1997	1998	1999	Func.Group	CA-1	TVE-1	Cos ²
<i>Arhopala pseudomuta</i>	Lycaenidae	Yes	No	No	Tree-Und	2,420	0,056	0,236
<i>Arhopala norda</i>	Lycaenidae	Yes	No	No	Tree-Und	2,088	0,050	0,440
<i>Arhopala denta</i>	Lycaenidae	Yes	No	No	Tree-Und	1,397	0,019	0,132
<i>Thamala marciana</i>	Lycaenidae	Yes	No	No	Tree-Und	1,261	0,017	0,152
<i>Coelites eupythychioides</i>	Satyridae	Yes	No	No	Mix-Und	1,190	0,019	0,253
<i>Arhopala epimuta</i>	Lycaenidae	Yes	No	No	Tree-Und	1,189	0,059	0,583
<i>Hidari irava</i>	Hesperiidae	Yes	No	Yes	Herb-Edge	1,126	0,012	0,082
<i>Arhopala anthelus</i>	Lycaenidae	Yes	No	No	Tree-Und	1,079	0,024	0,189
<i>Mycalesis anapita</i>	Satyridae	Yes	No	No	Mix-Gap	1,020	0,017	0,146
<i>Allotinus nivalis</i>	Lycaenidae	No	No	No	Predator	0,971	0,011	0,088
<i>Mycalesis patiana</i>	Satyridae	Yes	No	No	Mix-Gap	0,840	0,026	0,267
<i>Allotinus horsfieldi</i>	Lycaenidae	Yes	No	No	Predator	0,830	0,007	0,069
<i>Faunis stomphax</i>	Satyridae	Yes	No	No	Mix-Und	0,747	0,028	0,353
<i>Zeuxidia doubledayi</i>	Satyridae	Yes	No	No	Mix-Und	0,604	0,006	0,066
<i>Euthalia godartii</i>	Nymphalidae	No	No	Yes	Shrub-Und	0,580	0,022	0,589
<i>Euthalia alpheda</i>	Nymphalidae	No	No	No	Shrub-Gap	0,507	0,005	0,050
<i>Erites elegans</i>	Satyridae	Yes	No	No	Mix-Und	0,490	0,018	0,231
<i>Drupadia parva</i>	Lycaenidae	Yes	No	No	Mix-Gap	0,431	0,002	0,019
<i>Coelites epiminthia</i>	Satyridae	Yes	No	No	Mix-Und	0,414	0,002	0,033
<i>Drupadia theda</i>	Lycaenidae	Yes	Yes	Yes	Mix-Gap	0,379	0,009	0,167
<i>Lexias pardalis</i>	Nymphalidae	Yes	No	No	Shrub-Und	0,351	0,001	0,016
<i>Euthalia iapis</i>	Nymphalidae	Yes	No	No	Shrub-Und	0,330	0,008	0,177
<i>Dolpha evelina</i>	Nymphalidae	Yes	No	No	Shrub-Gap	0,292	0,002	0,019
<i>Tanaecia aruna</i>	Nymphalidae	Yes	No	No	Shrub-Gap	0,264	0,007	0,202
<i>Tanaecia munda</i>	Nymphalidae	Yes	No	Yes	Shrub-Gap	0,248	0,007	0,208
<i>Euploea eynhovi</i>	Danaidae	No	Yes	No	Mix-Gap	0,246	0,001	0,007
<i>Athyma pravara</i>	Nymphalidae	Yes	No	Yes	Shrub-Gap	0,229	0,001	0,007
<i>Koruthaialos rubecula</i>	Hesperiidae	Yes	No	Yes	Herb-gap	0,209	0,002	0,026
<i>Jamides pura</i>	Lycaenidae	Yes	Yes	Yes	Mix-Gap	0,177	0,005	0,089
VeryRare	Diverse				Diverse	0,167	0,002	0,036
<i>Euploea mulciber</i>	Danaidae	Yes	Yes	Yes	Mix-Edge	0,109	0,000	0,005
Rare	Diverse				Diverse	0,063	0,000	0,024
<i>Neptis leucoporus</i>	Nymphalidae	Yes	No	Yes	Mix-Gap	0,050	0,000	0,018
<i>Tanaecia clathrata</i>	Nymphalidae	No	No	Yes	Shrub-Gap	0,016	0,000	0,003
<i>Terinos terpander</i>	Nymphalidae	No	No	No	Shrub-Edge	0,016	0,000	0,000
<i>Eulaceura osteria</i>	Nymphalidae	Yes	No	No	Tree-Und	0,000	0,000	0,000
<i>Eurema sari</i>	Pieridae	Yes	Yes	Yes	Mix-Gap	-0,033	0,000	0,007
<i>Lebadea martha</i>	Nymphalidae	Yes	No	No	Mix-Edge	-0,042	0,000	0,001
<i>Eurema nicevillei</i>	Pieridae	No	No	No	Mix-Gap	-0,052	0,000	0,011
<i>Abisara geza</i>	Riodinidae	Yes	No	No	Mix-Edge	-0,063	0,000	0,001
<i>Eurema tominia</i>	Pieridae	No	No	No	Mix-Gap	-0,229	0,003	0,077
<i>Cirrochroa satellita</i>	Nymphalidae	No	No	Yes	Mix-Gap	-0,278	0,002	0,011
<i>Elymnias penanga</i>	Satyridae	No	No	No	Mix-Edge	-0,297	0,001	0,013
<i>Lasippa tiga</i>	Nymphalidae	No	No	No	Mix-Edge	-0,298	0,006	0,205
<i>Euploea modesta</i>	Danaidae	No	Yes	No	Mix-Gap	-0,309	0,001	0,008

APPENDIX 2 (Continued)

Butterfly species	Family	1997	1998	1999	Func.Group	CA-1	TVE-1	Cos ²
<i>Pantoporia paraka</i>	Nymphalidae	Yes	No	Yes	Mix-Edge	-0,451	0,005	0,039
<i>Graphium agamemnon</i>	Papilionidae	Yes	No	Yes	Mix-Edge	-0,453	0,005	0,082
<i>Jamides celeno</i>	Lycaenidae	Yes	Yes	Yes	Mix-Edge	-0,546	0,012	0,139
<i>Charaxes bernardus</i>	Nymphalidae	Yes	Yes	Yes	Mix-Gap	-0,616	0,027	0,285
<i>Athyma kanwa</i>	Nymphalidae	Yes	No	Yes	Shrub-Gap	-0,711	0,021	0,138
<i>Elymnias panthera</i>	Satyridae	No	Yes	Yes	Mix-Gap	-0,720	0,006	0,076
<i>Moduza procris</i>	Nymphalidae	Yes	No	Yes	Mix-Edge	-0,796	0,020	0,264
<i>Saletara panda</i>	Pieridae	Yes	Yes	No	Mix-Edge	-0,914	0,036	0,341
<i>Ypthima fasciata</i>	Satyridae	Yes	No	No	Mix-Edge	-0,920	0,009	0,077
<i>Neptis hylas</i>	Nymphalidae	Yes	No	Yes	Mix-Edge	-1,040	0,023	0,154
<i>Euthalia monina</i>	Nymphalidae	No	No	No	Shrub-Gap	-1,045	0,015	0,157
<i>Orsotriaena medus</i>	Satyridae	Yes	No	Yes	Mix-Edge	-1,215	0,135	0,521
<i>Appias nero</i>	Pieridae	Yes	Yes	No	Mix-Edge	-1,338	0,040	0,355
<i>Appias albina</i>	Pieridae	No	Yes	Yes	Mix-Edge	-1,379	0,072	0,440
<i>Mycalesis horsfieldi</i>	Satyridae	Yes	Yes	Yes	Mix-Edge	-1,381	0,020	0,171
<i>Graphium antiphates</i>	Papilionidae	Yes	Yes	No	Mix-Edge	-1,398	0,034	0,259
<i>Eurema lacteola</i>	Pieridae	No	No	Yes	Mix-Edge	-1,483	0,026	0,184
<i>Appias paulina</i>	Pieridae	No	Yes	No	Mix-Edge	-1,806	0,034	0,304

The value of each species along the first dimension (CA-1), proportion of total variation explained on the first dimension (TVE-1) and the correlation with CA-1 (Cosine²) are given. In addition the presence or absence of each species recorded here is shown for the proximate Wanariset research forest which was very severely burned in the 1997-98 forest fires and now consists of small unburned patches surrounded by a large matrix of burned forest.

APPENDIX 3

All seedling species (n > 5) used in the correspondence analysis. The value of each species along the first dimension (CA-1), proportion of total variation explained on the first dimension (TVE-1) and the correlation with CA-1 (Cosine²) are given.

<i>Seedling species</i>	<i>Family</i>	<i>CA-1</i>	<i>TVE-1</i>	<i>Cos²</i>
<i>Aglia simplicifolia</i>	<i>Meliaceae</i>	1,173	0,019	0,095
<i>Aporusa dioica</i>	<i>Euphorbiaceae</i>	1,031	0,021	0,174
<i>Saurauia</i> sp	<i>Actinidiaceae</i>	0,994	0,019	0,065
<i>Lauraceae</i>	<i>Lauraceae</i>	0,912	0,011	0,095
<i>Vatica umfonata</i>	<i>Dipterocarpaceae</i>	0,890	0,025	0,515
<i>Dipterocarpus confertus</i>	<i>Dipterocarpaceae</i>	0,885	0,014	0,178
<i>Diospyros</i> sp	<i>Ebenaceae</i>	0,869	0,018	0,301
<i>Dacryodes rostrata</i>	<i>Burseraceae</i>	0,869	0,025	0,384
<i>Urophyllum</i> sp	<i>Rubiaceae</i>	0,841	0,017	0,420
<i>Xanthophyllum</i> sp	<i>Polygalaceae</i>	0,807	0,012	0,215
<i>Shorea laevis</i>	<i>Dipterocarpaceae</i>	0,729	0,037	0,374
<i>Macaranga lowii</i>	<i>Euphorbiaceae</i>	0,620	0,034	0,467
<i>Syzygium</i> sp	<i>Myrtaceae</i>	0,602	0,011	0,086
<i>Knema</i> sp	<i>Myristicaceae</i>	0,578	0,014	0,387
<i>Drypetes kikir</i>	<i>Euphorbiaceae</i>	0,547	0,010	0,135
<i>Aglia</i> sp	<i>Meliaceae</i>	0,491	0,007	0,065
<i>Ixora</i> sp	<i>Rubiaceae</i>	0,463	0,004	0,043
<i>Rubiaceae</i>	<i>Rubiaceae</i>	0,454	0,005	0,035
<i>Ardisia</i> sp	<i>Myrsinaceae</i>	0,408	0,005	0,058
<i>Aporusa lucida</i>	<i>Euphorbiaceae</i>	0,402	0,002	0,027
<i>Pternandra</i> sp	<i>Melastomataceae</i>	0,373	0,004	0,074
<i>Very Rare</i>	<i>Diverse</i>	0,248	0,007	0,177
<i>Eugenia</i> sp	<i>Myrtaceae</i>	0,236	0,003	0,021
<i>Rare</i>	<i>Diverse</i>	-0,027	0,000	0,005
<i>Gironniera nervosa</i>	<i>Ulmaceae</i>	-0,063	0,000	0,003
<i>Fordia splendidissima</i>	<i>Leguminosae (P)</i>	-0,145	0,003	0,058
<i>Artocarpus</i> sp	<i>Moraceae</i>	-0,388	0,003	0,032
<i>Vernonia arborea</i>	<i>Compositae</i>	-1,267	0,038	0,233
<i>Macaranga trichocarpa</i>	<i>Euphorbiaceae</i>	-1,342	0,058	0,195
<i>Macaranga</i> sp2	<i>Euphorbiaceae</i>	-1,351	0,030	0,166
<i>Macaranga</i> sp1	<i>Euphorbiaceae</i>	-1,503	0,106	0,395
<i>Macaranga hypoleuca</i>	<i>Euphorbiaceae</i>	-1,549	0,138	0,688
<i>Macaranga gigantea</i>	<i>Euphorbiaceae</i>	-1,593	0,163	0,470
<i>Dillenia</i> sp	<i>Dilleniaceae</i>	-1,965	0,140	0,377

APPENDIX 4

Site characteristics of each population

1. Laham (Kutai) population

In this region, wildlings were collected from PT Tunggal Yudi Hutani (Barito Pacific Timber Group) in the village of Laham, Long Iram sub-district, Kutai district, East Kalimantan. Laham is located at 0°14' to 0°31' latitude North and at 115°18' to 115°39' longitude East. The topography is undulating (10 to 15%) and the altitude is between 100 and 500 meter above sea level (asl). The Kutai district lies in the perhumid tropical climate region. The soils in the area are latosols and red-yellow podzols on a matrix of alluvial and igneous rocks of volcanic origin. They show comparatively low nutrient levels. The vegetation of the site consists of climax forest. The mass fruiting season of dipterocarp species was in 1998. Wildlings of *S. leprosula* were collected on 11 to 25 November 1999 from two areas, namely Laham and Long Merah. The collection in Laham was from 2 to 18 km (2, 4, 4.5, 5, 7, 8, 12, 13, 16 and 17.5 km) while in Long Merah the collection focused on Seed Stand area at 30 km, temporary camp at 31 km, Permanent Sampling Plot (PSP) area and logyard.

2. Tarakan (Bulungan) population

Wildlings were collected from the Bulungan Research Forest (BRF) which lies administratively within the Malinau district, East Kalimantan and is about 18 km from the Malinau municipality. The western site of the BRF lies at 2°45'12.38 latitude North and 115°48'7.87 longitude East and the eastern site lies at 3°21'3.76 latitude North and 116°34'2.79 longitude East. The topography of BRF is rugged throughout, with its most strongly dissected terrain located in the southwest and west sides. Of BRF 84% is mountainous with a relief amplitude of more than 300 meter, 11% is hilly and the rest is flat. About 40% of the BRF area is dominated by 25 to 40% slopes. The altitude is around 100 meter above sea level (asl). The BRF geology consists of sedimentary rocks and intrusional rocks from the pre-tertiary and quarter eras. The BRF geology is dominated by rocks associated with the plate margins especially mélange. The soils in the area are Podsolik Ortoksik (PPT, 1983) or Orthic Tropodults (USDA, 1975) or Orthic Acrisols (FAO/UNESCO, 1974). The soils at Langap in the Malinau concession are mostly clay loam (Machfudh and Kartawinata, 2001).

The highest temperature is 27.5°C and the lowest temperature is 23.5°C. The relative humidity is high, ranging from 75 to 98%. According to the Schmidt and Fergusson (1951) system, the BRF area has an A rainfall type, where the dry period is less than 2 months and the wet season is more than 9 months. The average is 10 to 20 rainy days per month (CIFOR, 2002).

APPENDIX 4 (Continued)

Lowland dipterocarp forest is the most extensive forest type (98% of the total area) in the BRF. Wildlings were collected on 9 to 18 February 2000 from PT Inhutani II, a subunit of Malinau which belongs to the CIFOR Research Site.

3. *Kalbar population*

a. *Sanggau district*

In this region, wildlings were collected from PT Batasan Timber, the village of Tanjung Ilai, in the Balai Karangan subdistrict. This region is located at 0°30' to 0°50' latitude North and at 110°10' to 110°45' longitude East. The topography is undulating. The Sanggau lies in the perhumid tropical climate region. The soils in the area are latosols and red-yellow podzols on a matrix of alluvial and igneous rocks of volcanic origin. The vegetation of the site consists of climax forest. There were only a few wildlings found without the mother trees. Wildlings were collected on 5 to 10 October 2000 from four locations, namely Seed Orchard, nursery area, production forest and logged-over forest.

b. *Sintang district,*

In this region, wildlings were collected from PT Halisa Bintang, around 138 km from the village of Nanga Sepauk, in the Sintang district. This village is located at 0°15' to 0°50' latitude North and at 111°00' to 111°30' longitude East. The Sintang lies in the perhumid tropical climate region. The soils in the area are latosols and red-yellow podzols. They show comparatively low nutrient levels. The vegetation of the site consists of climax forest. The fruiting season of dipterocarp was around three years before the collection period. The trees of *S. leprosula* with a diameter of more than 50 cm were rare and could be found in seed orchards at 114 km. Wildlings were collected for a week after 10 October 2000 from four areas, namely the natural forest at 75 km, logged-over area, Sungai Putik natural forest at 96 km and in Seed Orchard at 114 km.

c. *Kaburai region,*

In this region, wildlings were collected from PT Sari Bumi Kusuma (SBK) at the village of Kaburai. This village is located at 0°20' to 0°30' latitude South and at 112°20' to 112°40' longitude East. The topography is undulating. The Kaburai lies in the perhumid tropical climate region. The vegetation of the site consists of climax forest. The last fruiting season for *S. leprosula* was in March 2000. Wildlings were collected on 17 to 23 October 2000 from two areas, namely around the nursery at 54 km to the Jami area, and at 76 km to the nursery area at 93 km.

APPENDIX 5

Effect of mycorrhizal inoculation on various growth parameters of *S. leprosula* cuttings 15 months after treatment. a: length of axes, h: height, Δh : height increment, d: diameter, b: length of branches, Σa : number of axes, Σl : number of leaves

Soil type	Pasteurisation	Mycorrhizal inoculation	a (cm)	h (cm)	Δh (cm)	d (cm)	b (cm)	Σa	Σl
Sandy loam	Non pasteurised		50.7	30.1	18.1	0.48	26.2	3.1	18.5
	Pasteurised		38.6	31.9	18.1	0.48	14.6	1.7	15.5
Sandy clay loam	Non pasteurised		33.5	22.9	11.7	0.38	15.8	2.1	10.6
	Pasteurised		45.7	30.3	16.8	0.48	22.2	2.6	17.5
Loam	Non pasteurised		39.8	28.5	15.3	0.39	15.4	2.2	14.3
	Pasteurised		44.0	33.1	20.9	0.52	13.8	2.2	17.8
Sandy loam		No inoculation	41.3	26.1	11.7	0.43	25.3	2.2	16.6
		<i>Amanita</i> sp	50.6	38.8	22.8	0.54	19.7	2.6	18.0
		<i>Russula</i> sp	41.9	33.5	19.4	0.49	21.0	2.6	16.5
		<i>Scleroderma</i> sp	46.5	28.4	18.3	0.49	27.1	2.5	18.0
		Cocktail	44.0	29.0	18.3	0.45	18.0	2.3	16.2
Sandy clay loam		No inoculation	18.6	16.6	7.4	0.30	10.0	1.2	6.5
		<i>Amanita</i> sp	38.1	28.7	14.8	0.43	11.3	2.2	11.4
		<i>Russula</i> sp	38.0	25.4	16.2	0.41	18.9	2.3	15.3
		<i>Scleroderma</i> sp	46.4	30.3	15.3	0.55	20.1	2.6	15.2
		Cocktail	52.4	29.9	17.7	0.45	27.0	3.2	19.6
Loam		No inoculation	45.2	30.5	16.6	0.49	14.7	2.3	16.7
		<i>Amanita</i> sp	43.2	31.9	15.5	0.42	11.3	2.4	16.3
		<i>Russula</i> sp	56.2	40.2	27.4	0.51	19.2	2.7	21.3
		<i>Scleroderma</i> sp	33.6	30.0	19.7	0.46	7.2	1.8	13.7
		Cocktail	31.3	21.3	11.3	0.40	19.8	1.8	11.9
	Non pasteurised	No inoculation	34.4	21.7	8.3	0.38	20.4	2.1	12.2
		<i>Amanita</i> sp	45.9	31.8	17.7	0.43	18.1	2.7	14.6
		<i>Russula</i> sp	41.0	31.3	19.9	0.43	14.6	2.6	14.2
		<i>Scleroderma</i> sp	45.4	25.5	15.1	0.44	25.6	2.7	16.2
		Cocktail	38.1	24.7	14.2	0.40	17.2	2.2	14.6
	Pasteurised	No inoculation	36.9	27.9	15.5	0.44	14.4	1.8	14.8
		<i>Amanita</i> sp	40.6	34.1	17.7	0.50	7.6	2.0	15.6
		<i>Russula</i> sp	50.6	34.9	22.2	0.52	25.2	2.5	21.8
		<i>Scleroderma</i> sp	38.0	34.1	20.4	0.56	7.9	1.9	15.1
		Cocktail	47.1	28.8	17.3	0.46	27.3	2.7	17.2

APPENDIX 5 (Continued)

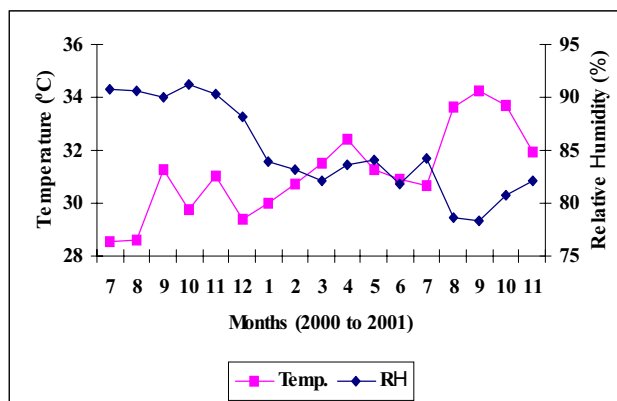
Soil type	Pasteurisation	Mycorrhizal inoculation	<i>a</i> (cm)	<i>h</i> (cm)	<i>Dh</i> (cm)	<i>d</i> (cm)	<i>b</i> (cm)	Σa	Σl
Sandy loam	Non pasteurised	No inoculation	46.0	25.5	8.8	0.41	41.0	2.5	17.8
		Amanita sp	52.2	40.2	27.8	0.55	18.0	3.0	18.0
		Russula sp	49.5	35.5	24.2	0.53	21.0	3.7	16.3
		Scleroderma sp	57.3	24.5	15.3	0.44	32.8	3.7	22.5
		Cocktail	47.0	23.5	14.2	0.45	23.5	2.7	17.8
	Pasteurised	No inoculation	38.2	26.5	14.5	0.44	17.5	2.0	15.8
		Amanita sp	48.3	36.8	17.7	0.52	23.0	2.0	18.0
		Russula sp	30.5	30.5	14.7	0.44	0.0	1.0	16.8
		Scleroderma sp	35.7	32.3	21.2	0.54	10.0	1.3	13.5
		Cocktail	41.0	34.5	22.5	0.45	9.8	2.0	14.5
	Non pasteurised	No inoculation	19.3	16.0	6.8	0.30	10.0	1.3	6.8
		Amanita sp	35.8	22.3	8.5	0.35	20.3	2.3	8.3
		Russula sp	25.1	18.8	8.8	0.33	9.5	2.0	8.7
		Scleroderma sp	49.8	26.7	14.5	0.54	23.2	3.0	14.3
		Cocktail	37.2	30.8	19.8	0.39	9.5	1.7	14.7
	Pasteurised	No inoculation	17.5	17.5	8.0	0.30	0.0	1.0	6.0
		Amanita sp	40.3	35.0	21.0	0.52	5.3	2.0	14.5
		Russula sp	50.8	32.0	23.7	0.50	28.3	2.7	21.8
		Scleroderma sp	41.3	35.8	16.0	0.57	11.0	2.0	16.5
		Cocktail	67.7	29.0	15.5	0.51	38.7	4.7	24.5
Loam	Non pasteurised	No inoculation	41.8	24.8	9.2	0.43	17.0	2.7	13.8
		Amanita sp	49.7	33.0	16.7	0.39	16.7	2.7	17.3
		Russula sp	48.5	39.7	26.7	0.43	13.3	2.0	17.5
		Scleroderma sp	29.0	25.3	15.3	0.35	11.0	1.3	11.7
		Cocktail	30.0	19.7	8.5	0.37	15.5	2.3	11.2
	Pasteurised	No inoculation	48.5	36.2	24.0	0.54	12.3	2.0	19.5
		Amanita sp	33.5	30.3	14.3	0.47	3.3	2.0	14.8
		Russula sp	63.8	40.7	28.2	0.59	23.2	3.3	25.2
		Scleroderma sp	38.2	34.7	24.0	0.57	5.3	2.3	15.7
		Cocktail	32.5	23.0	14.0	0.42	28.5	1.3	12.7

APPENDIX 6

Average monthly temperature and relative humidity of the air in the greenhouse in 2000 (Chapter 5) and 2001 (Chapter 4, exp.1)

Months	Atmospheric temperature (°C)		Relative humidity (%)	
Year	2000	2001	2000	2001
January		30		82
February		31		83
March		32		82
April	28	32	91	84
May	30	31	89	84
June	28	31	90	82
July	29	31	91	84
August	29	34	91	79
September	31	34	90	78
October	30	34	91	81
November	31	32	90	82
December	29		88	
Average	29	32	90	82

Atmospheric temperature and relative humidity in the greenhouse from July 2000 to Nov 2001 (Chapter 4, exp. 2)



APPENDIX 7

Descriptions of selected and representative soil profiles (after Iriansyah *et al.*, 1998)

General site information and derived values

<i>Profile number</i>	:	<i>P3</i>
<i>Mapping unit</i>	:	Fmc 110
<i>Location</i>	:	<i>Experiment plot Km 42</i>
<i>Pedon classification</i>	:	<i>Humic Trofaquents (USDA, 1987)</i> <i>Gleic-humic Fluvisol (FAO, 1988)</i>
<i>Elevation (m asl.)</i>	:	<i>-</i>
<i>Physiography/Landform</i>	:	<i>Flat</i>
<i>Slope gradient (%)</i>	:	<i>0</i>
<i>Slope aspect, shape</i>	:	<i>Flat, West to East</i>
<i>Stoniness (%)</i>	:	<i>None</i>
<i>Rock out crop (%)</i>	:	<i>None</i>
<i>Parent material</i>	:	<i>Alluvium</i>
<i>Effective soil depth (cm)</i>	:	<i>15</i>
<i>Water table</i>	:	<i>50 cm from surface on dry season</i>
<i>Flooding frequency</i>	:	<i>Permanent</i>
<i>Soil drainage</i>	:	<i>poor</i>
<i>Erosion</i>	:	<i>sheet erosion (barely)</i>
<i>Land use/vegetation</i>	:	<i>swamp forest</i>

Profile Description

Horizon	Depth (cm)	Description
A0	0-70	10 YR 3/3 (dark brown) moist; clay; fine subangular blocky; slightly sticky and non plastic (wet); loose (moist) consistence; 10 R 4/8 (red) many, coarse distinct oxidation mottles; many micro to macro pores; many very fine to fine, and many medium coarse roots; clear, wavy boundary to
H	70-110	10 YR 3/3 (dark brown) wet; sapric material; non sticky and no plastic (wet); few micro to macro pores; few very fine to fine, and few medium to coarse roots; clear, smooth boundary to
AC	110-150	10 YR 7/1 (light gray) wet, sandy clay; angular blocky; few micro to macro pores; few very fine to fine, and few medium coarse roots.

APPENDIX 7 (Continued)

General site information and derived values

<i>Profile number</i>	:	<i>P6</i>
<i>Mapping unit</i>	:	Ff 110
<i>Location</i>	:	<i>Experiment plot Km 42</i>
<i>Pedon classification</i>	:	<i>Typic Tropaquents (USDA, 1987)</i> <i>Aquic Cambisol (FAO, 1988)</i>
<i>Physiography/Landform</i>	:	<i>Flat</i>
<i>Slope gradient (%)</i>	:	<i>0</i>
<i>Slope aspect, shape</i>	:	<i>level, North to South</i>
<i>Stoniness (%)</i>	:	<i>None</i>
<i>Rock out crop (%)</i>	:	<i>None</i>
<i>Parent material</i>	:	<i>Clay stone</i>
<i>Effective soil depth (cm)</i>	:	<i>50</i>
<i>Water table</i>	:	<i>> 50 cm</i>
<i>Flooding frequency</i>	:	<i>temporary</i>
<i>Soil drainage</i>	:	<i>poor</i>
<i>Erosion</i>	:	<i>sheet erosion (barely)</i>
<i>Land use/vegetation</i>	:	<i>secondary forest</i>

Profile Description

Horizon	Depth (cm)	Description
Ah	0-20	7.5 YR 5/2 (brown) moist; clay; few subangular blocky; sticky and plastic (wet) firm; (moist) consistence; 5 YR 5/8 (yellowish red) common few distinct oxidation mottles; 5 YR 5/1 (grey) common few irregular reduction mottles; many to common micro to medium coarse roots; clear, wavy boundary to
B1wg	20-60	10 YR 6/1 (grey) moist; Clay, coarse angular blocky, very sticky to very plastic (wet) firm (moist) consistence; 10 YR 3/2 (very dark brown) many medium distinct oxidation; few to few micro to medium pores; few very fine to fine and common medium to coarse roots; clear, wavy boundary to
B2w	60-90	7.5 YR 5/8 (strong brown) wet; Clay, coarse angular blocky, very sticky to very plastic (wet) consistence; 2.5 YR 3/4 (dark reddish brown) many common distinct oxidation mottles; few micro and macro pores; few very fine to fine and common medium coarse roots; clear, wavy boundary to
BC	90-120	7.5 YR 7/0 wet, Clay; coarse angular blocky; very sticky to very plastic (wet) consistence; 2.5 YR 4/4 many, common distinct oxidation mottles; few micro and macro pores; few very fine to fine, and few medium coarse roots.

APPENDIX 7 (Continued)

Fmc-110

The mapping unit is dominated by Humic tropaquents, and distributed over flat land with a slope average of 2% or less. On the surface, the soil texture consists of silty clay to clay, and in the subsoil of sandy loam to sandy clay loam. The soil depth is generally shallow, less than 25 cm due to water saturation. As a result, internal drainage is very poor to poor. There are many grey mottles throughout the profile. The surface soil is very acid and is low to very low in nutrients of available phosphates, nitrogen, and an effective cation exchange capacity (ECEC). The area is permanently inundated.

Ff-110

The mapping unit is dominated by Typic tropaquults, and distributed over flat to almost flat land with a slope average of less than 3%. On the surface, the soil texture consists of silty clay to fine clay, and in the subsoil of fine clay. The soil depth is generally shallow, less than 25 cm due to a high water table fluctuation. As a result, internal drainage is very poor to poor. There are many grey mottles throughout the profile. The surface soil is very acid and has a high level of nutrients of available phosphates, potassium, nitrogen, and base cations. This area is inundated occasionally by heavy rains.

Umc-330

The mapping unit is distributed over undulating land with a slope gradient of 5 to 8%. On surface, the soil texture consists of loam to sandy loam, and in the subsoil of sandy clay loam to sandy clay. The soil depth is deep with moderate to good internal drainage. There are very few to few mottles throughout the profile. The surface soil is acid, and has a low in nutrients of available phosphates, nitrogen, and effective cation exchange capacity (ECEC).

APPENDIX 8

Combination of soil type and shading level against various mineral contents of *S. leprosula* cuttings after 12 months in the field. SL: sandy loam, SCL: sandy clay loam, L: loam, D₀: without shading, D₁: light shading, D₂: moderate shading, C: carbon, K: potassium, N: nitrogen, P: phosphorus.

Soil type	Shade level	C (%)			K (%)			N (%)			P (%)		
		Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf
SL		30.6	33.2	34.6	0.43	0.51	1.07	0.45	0.26	0.96	0.05	0.05	0.10
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
SCL		30.8	33.7	35.0	0.45	0.49	1.16	0.45	0.28	0.98	0.07	0.06	0.11
		<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>
L		30.8	33.7	35.1	0.57	0.65	1.05	0.45	0.28	1.07	0.06	0.06	0.11
		<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>
	D ₀	30.7	33.5	34.9	0.55	0.49	1.05	0.45	0.27	0.10	0.06	0.05	0.11
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
	D ₁	30.8	33.5	34.7	0.46	0.58	1.05	0.45	0.29	1.02	0.07	0.06	0.10
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
	D ₂	30.8	33.6	35.0	0.44	0.58	1.17	0.47	0.26	0.98	0.06	0.06	0.12
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
SL	D ₀	30.6	33.2	33.9	0.52	0.48	0.98	0.46	0.25	0.95	0.05	0.05	0.10
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>
	D ₁	30.8	32.8	34.8	0.43	0.49	0.97	0.42	0.27	0.95	0.05	0.05	0.10
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>
	D ₂	30.3	33.7	35.0	0.34	0.56	1.25	0.49	0.26	0.99	0.06	0.04	0.11
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>	<i>a</i>
SCL	D ₀	30.4	33.7	35.1	0.43	0.44	1.11	0.43	0.28	0.92	0.07	0.05	0.11
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
	D ₁	30.7	33.8	34.8	0.42	0.49	1.13	0.45	0.30	0.99	0.09	0.06	0.10
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>	<i>a</i>
	D ₂	31.4	33.5	35.1	0.48	0.56	1.23	0.49	0.25	1.03	0.05	0.08	0.13
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>
L	D ₀	31.0	33.6	35.8	0.69	0.55	1.08	0.46	0.27	1.14	0.06	0.06	0.11
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>
	D ₁	30.8	33.8	34.6	0.53	0.78	1.06	0.47	0.30	1.14	0.08	0.06	0.10
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>	<i>a</i>
	D ₂	30.8	33.6	35.0	0.49	0.60	1.02	0.43	0.28	0.93	0.06	0.06	0.11
		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
Grand mean		30.8	33.5	34.9	0.48	0.55	1.09	0.45	0.27	1.00	0.06	0.06	0.11

Note: Values followed by the letters *a*, *b*, or *c* in the same column indicate the significant differences at a 5% level according to Duncan's Multiple Range Test

APPENDIX 9

Combination of soil type (S), mycorrhizal inoculation (M) and shading (N) against various growth parameters of *S. leprosula* cuttings after 12 months in the field. S: soil type, N: shading level, M: mycorrhizal inoculation, a: length of axes, Δa : axes increment, h: height, Δh : height increment, d: diameter, Δd : diameter increment, b: length of branches, Σb : number of branches, Σa : number of axes, Σl : number of leaves, Σl_b : number of leaves at the branches, Σl_s : number of leaves at the stem

Treat. Comb.	a	Δa	h	Δh	d	Δd	b	Σb	Σa	Σl	Σl_b	Σl_s
S & N	Ns	0.001	0.04	Ns	0.001	0.001	0.01	Ns	Ns	Ns	0.02	Ns
S & M	0.04	Ns	Ns	Ns	0.002	Ns	Ns	Ns	Ns	0.05	Ns	Ns
N & M	Ns	Ns	Ns	Ns	0.031	Ns	Ns	Ns	Ns	Ns	Ns	Ns
S,N&M	0.01	Ns	0.04	Ns	0.014	Ns	0.02	Ns	Ns	0.01	0.02	Ns

Note: values are the level of significant differences
Ns is not significantly different at a 5% level (Duncan's Multiple Range Test)

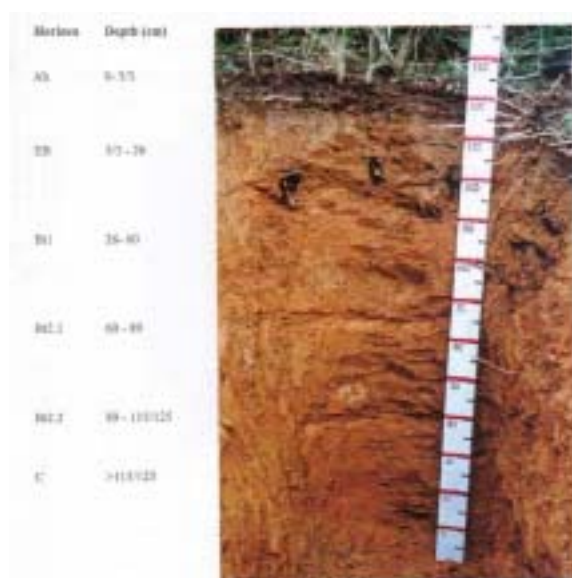
APPENDIX 10

Descriptions of selected and representative soil profiles in the experiment plot 35 km (after Tolkamp, 1999)

General site information and derived values

<i>Profile number</i>	:	W1
<i>Location</i>	:	Experiment plot 35 km
<i>Pedon classification</i>	:	Typical Paleudults (USDA, 1987) Chromic Haplic Alisol (FAO, 1988)
<i>Diagnostic horizons/features</i>	:	ochric, argillic
<i>Greenwich coordinates</i>	:	Latitude: 1°1' S; Longitude: 116°57' E
<i>Elevation (m asl.)</i>	:	50
<i>Geomorphic component</i>	:	Upper slope
<i>Slope gradient (%)</i>	:	10
<i>Slope shape, aspect</i>	:	straight, East – West
<i>Micro relief</i>	:	Chablis (Koop, 1981, 1989; Oldeman, 1974b, 1990), Tree throw features, no pattern
<i>Stoniness</i>	:	None
<i>Parent material</i>	:	Claystone
<i>Effective soil depth (cm)</i>	:	115
<i>Obstructive layer</i>	:	none
<i>Water table</i>	:	not observed
<i>Flooding frequency</i>	:	none
<i>Soil drainage</i>	:	moderate
<i>Erosion</i>	:	sheet erosion (barely)
<i>Land use/vegetation</i>	:	abandoned land/ Imperata cylindrica badland

APPENDIX 10 (Continued)



Profile Description

Ah Horizon: 7.5 YR 5/4 (Brown), interior large peds, moist; Loam, fine weak sub angular blocky, slightly sticky and slightly plastic wet, very friable; no mottles, many fine to medium roots, no coarse roots; many fine to medium pores, no coarse pores; clear smooth boundary to

EB Horizon: 10 YR 6/6 (Brownish yellow), interior large peds, moist; Clay loam to Clay, fine to medium weak sub angular blocky, slightly sticky and slightly plastic wet, very

friable moist; no mottles, many fine and few medium roots, many coarse roots; many fine and medium moderate pores, no coarse pores; gradually wavy boundary to

Bt1 Horizon: 10 YR 6/6 (Brownish yellow), interior large peds, moist; Clay, medium moderate sub angular blocky, slightly sticky and slightly plastic wet, friable moist; faint irregular reduction (10 YR 7/4), mottles interior large peds, few fine to medium roots, no coarse roots; many fine pores, no medium and coarse pores; gradually wavy boundary to

Bt2.1 Horizon: 7.5 YR 6/8 (Reddish yellow), interior large peds, moist; Clay, medium to coarse moderate sub angular blocky, sticky and plastic wet, friable moist; few faint irregular reduction (10 YR 7/4), mottles interior large peds, few fine roots, no medium to coarse roots; many fine pores, no medium and coarse pores; gradually wavy boundary to

Bt2.2 Horizon: 7.5 YR 5/8 (Strong brown), interior large peds, moist; Clay, medium to coarse moderate sub angular blocky, sticky and plastic wet, friable moist; many faint distinct irregular reduction (10 YR 7/4), mottles interior large peds; much fine faint irregular oxidation (2.5 YR 5/8) mottles interior large peds; few fine roots, no medium to coarse roots; moderate fine pores, no medium and coarse pores; irregular, wavy boundary to

C Horizon: Ironstone, very coarse, very strong, extremely firm; boundary not reached.