Paraserianthes falcataria (L.) Nielsen

Ecology, silviculture and productivity

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Preface

Smallholders in Indonesia have long been actively planting trees on private or community land. Various actors have encouraged this activity with the aim of improving local livelihood security, environmental sustainability and industrial wood supply. Such tree-planting efforts are generally successful, but they are often undertaken without technical assistance. Farmers often lack the necessary technical capacity and knowledge regarding proper management. The most common management activity is harvesting products, with other management practices less frequently implemented. As a result, the quality and quantity of products may not be fulfilling their potential. The productivity of smallholder plantations can be improved by enhancing smallholders' management knowledge and skills including species selection (site matching), silvicultural management to produce high-quality products, and pest and disease management. There is thus a need for manuals on ecology and silvicultural management of the selected tree species planted by smallholders in Indonesia.

This manual, '*Paraserianthes falcataria* (L.) Nielsen: ecology, silviculture and productivity', is one of a series of five manuals produced as part of the research project 'Strengthening rural institutions to support livelihood security for smallholders involved in industrial tree-planting programmes in Vietnam and Indonesia' coordinated by CIFOR. This project was funded by Germany's Advisory Service on Agriculture Research for Development (BMZ/BEAF), through the Gesellschaft für Internationale Zusammenarbeit (GIZ) for a 3-year period (2008–2010).

This manual gathers as much information as possible on *Paraserianthes falcataria* (L.) Nielsen from available resources, with a focus on Indonesian sites. However, in terms of growth and yield (productivity), the availability of data for this species, particularly from smallholder plantations, is generally limited. Efforts have been made to collect inventory data from smallholder plantations in several villages in Ciamis District, West Java. In addition, we have used growth data for older stands collected by staff of the Forestry Research and Development Agency of the Indonesian Ministry of Forestry.

The manual has been translated into Indonesian and modified slightly to meet smallholders' needs. The authors believe this manual will benefit smallholders and organisations involved in implementing tree-planting programmes.

Haruni Krisnawati, Eveliina Varis, Maarit Kallio and Markku Kanninen

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1. Introduction

Paraserianthes falcataria (L.) Nielsen, also known as batay, is one of the most important pioneer multipurpose tree species in Indonesia. It is one of the tree species preferred for industrial forest plantations in Indonesia because of its very fast growth, its ability to grow on a variety of soils, its favourable silvicultural characteristics and its acceptable quality of wood for the panel and plywood industries. *Paraserianthes falcataria* plays an important role in both commercial and traditional farming systems in several sites in Indonesia.

This species, like other fast-growing tree species, is expected to become increasingly important for wood industries as supplies for plywood from natural forests decrease. The numbers of large-scale and smallholder *P. falcataria* plantations in Indonesia have increased steadily during recent years. The distribution is wide. The main *P. falcataria* cultivation areas are in Sumatra, Java, Bali, Flores and Maluku (Charomaini and Suhaendi 1997). According to a report by the Ministry of Forestry and the National Statistics Agency (2004), Central Java and West Java have the most *P. falcataria* trees grown by smallholders, with these 2 provinces accounting for more than 60% of the total number of *P. falcataria* trees planted by households in Indonesia.

2. Description of the species

2.1. Taxonomy

Botanical name: *Paraserianthes falcataria* (L.) Nielsen

Family: Fabaceae

Subfamily: Mimosoideae

Synonyms: *Adenanthera falcata* Linn., *Adenanthera falcataria* Linn., *Albizia falcata* (L.) Backer, *Albizia falcata* sensu Backer, *Albizia falcataria* (L.) Fosberg, *Albizia moluccana* Miq., and *Falcataria moluccana* (Miq.) Barneby and J.W. Grimes (Soerianegara and Lemmens 1993).

Vernacular and common names:

Common names in Indonesia: jeungjing, sengon laut (Java); tedehu pute (Sulawesi); rare, selawoku, selawaku merah, seka, sika, sika bot, sikas, tawa sela (Maluku); bae, bai, wahogon, wai, wikkie (Papua) (Martawijaya *et al.* 1989).

Common names in other countries: puah (Brunei); albizia, batai, Indonesian albizia, moluca, paraserianthes, peacock plume, white albizia (England); kayu machis (Malaysia); white albizia (Papua New Guinea); falcata, moluccan sau (Philippines) (Soerianegara and Lemmens 1993).

2.2. Botany

Paraserianthes falcataria is a large tree that can grow up to 40 m tall with the first branch at a height of up to 20 m (Figure 1). The tree can grow to 100 cm or sometimes more in diameter (Figure 2), with a spreading flat crown. When grown in the open, trees form a large umbrella-shaped canopy. The buttress is small or absent (Figure 3). The bark surface is white, grey or greenish, smooth or slightly warty, and is sometimes shallowly fissured with longitudinal rows of lenticels. The leaves are alternate, bipinnately compound and 23–30 cm in length (Figure 4). Leaflets are opposite and many, with 15–20 pairs on each axis; they are stalkless, small and oblong (6–12 mm long, 3–5 mm wide) and short-pointed at the tip. The topside of the leaf is a dull-green colour and hairless, and the underside is paler with fine hair (Soerianegara and Lemmens 1993, Arche *et al.* 1998).

Inflorescence is axillary, consisting of pedunculate spikes or racemes; the spikes are sometimes arranged in panicles. The flowers are bisexual, 12 mm long, regular pentamerous, subtended to bracts, and funnel or bell shaped; their colour is cream to yellowish. The fruit is a flat, straight pod, 10–13 cm long and 2 cm wide. It is not segmented, and is dehiscent along both sutures and winged along the ventral suture with many seeds (15–20). Seeds are subcircular to oblong, 6 mm long, flat to convex, without aril; their colour is a dull to dark brown and they are not winged (Soerianegara and Lemmens 1993).

2.3. Distribution

Paraserianthes falcataria is native to Indonesia, Papua New Guinea, Solomon Islands and Australia (Soerianegara and Lemmens 1993). Natural stands of *P. falcataria* are scattered around the eastern part of Indonesia (i.e. South Sulawesi, Maluku and Papua) (Martawijaya *et al.* 1989). In Maluku, *P. falcataria* is found in the islands of Taliabu, Mangolle, Sasan, Obi, Bacan, Halmahera, Seram and Buru. In Papua, it is found in Sorong, Manokwari, Kebar, Biak, Serui, Nabire and Wamena. In addition, it is planted in Java (Martawijaya *et al.* 1989) (Figure 5 and 6).

Figure 1. Straight bole of a *P. falcataria* tree

Figure 2. A *P. falcataria* tree, 60 cm in diameter on a smallholder farm in Ciamis, West Java

Figure 3. The small buttress of *P. falcataria*

Figure 4. The alternate leaves of *P. falcataria*

The species is also widely planted throughout the tropics including in Brunei, Cambodia, Cameroon, Cook Islands, Fiji, French Polynesia, Japan, Kiribati, Laos, Malaysia, Marshall Islands, Myanmar, New Caledonia, Norfolk Island, Philippines, Samoa, Thailand, Tonga, United States of America, Vanuatu and Vietnam (Orwa *et al.* 2009).

2.4. Ecological range

Paraserianthes falcataria can grow on a wide range of soils. It does not require fertile soil; it can grow well on dry soils, damp soils and even on salty to acid soils as long as drainage is sufficient (Soerianegara and Lemmens 1993). In plantations in Java, it has been reported to grow on various soil types with exception

Figure 5. One-year-old *P. falcataria* tree on a smallholder farm in Sukabumi, West Java

Figure 6. Two-year-old *P. falcataria* trees on a smallholder farm in Sukabumi, West Java

of grumusols (Charomaini and Suhaendi 1997). On latosols, andosols, luvial and red-yellow podzolic soils, its growth is very robust. On marginal sites, fertiliser may be needed to accelerate initial growth. However, growth will be faster thereafter as the ability to fix nitrogen increases.

Paraserianthes falcataria is categorised as a pioneer species that occurs in primary forest but more characteristically in secondary lowland rainforest and in light montane forest, grassy plains and along roadsides near the coast. In natural stands in Papua, *P. falcataria* is associated with species such as *Agathis labillardieri*, *Celtis* spp., *Diospyros* spp., *Pterocarpus indicus*, *Terminalia* spp. and *Toona sureni* (Soerianegara and Lemmens 1993).

In the species' natural habitat, annual rainfall ranges from 2000 to 2700 mm, and can be up to 4000 mm with a dry season of more than 4 months (Soerianegara and Lemmens 1993). The species is highly evapotranspiring, which requires a wet climate; therefore, an annual rainfall of 2000–3500 mm is considered optimal. Rainfall of less than 2000 mm/year will result in dry conditions, and rainfall of more than 3500 mm/year will create very high humidity, together with very low light intensity, which will possibly create fungal problems (Charomaini and Suhaendi 1997). The optimal temperature range is between 22 °C and 29 °C with a maximum of 30–34 °C and a minimum of 20–24 °C (Soerianegara and Lemmens 1993). Ideally, during the dry months, there will be rain for at least 15 days. On very dry sites, growth can be drastically reduced and the risk of stem borer attack may increase.

The altitudinal range of the species' natural habitat is up to 1600 m above sea level but may extend up to 3300 m above sea level (Soerianegara and Lemmens 1993). A study conducted by the Agricultural Polytechnics College in Kupang (East Nusa Tenggara) indicated that the species could survive at lower altitudes on rocky, reef or coral-derived soils, but its growth was somewhat low (Djogo 1997). In Papua, the species is found at an elevation of 55 m above sea level at the lowest site in Manokwari (Charomaini and Suhaendi 1997).

2.5. Wood characteristics

Paraserianthes falcataria wood is generally lightweight and soft to moderately soft. The colour of the heartwood ranges from whitish to a pale pinkish-brown or a light-yellowish- to reddish-brown; the heartwood of the younger trees is not clearly demarcated from the sapwood (pale coloured), but it is more distinct in older trees (Soerianegara and Lemmens 1993). The wood density is between 230 and 500 kg/m^3 at 12–15% moisture content (Table 1). The grain of the wood is straight or interlocked, and the texture is moderately coarse but even. The wood is not durable when used outside; it is often highly vulnerable to various kinds of insects and fungal attacks. Graveyard tests in Indonesia showed an average service life in contact with the ground of 0.5–2.1 years. However, the wood treated with preservatives can have an average life in contact with the ground of 15 years in tropical conditions (Soerianegara and Lemmens 1993).

2.6. Uses

In West Java, where growing conditions are optimal, *P. falcataria* is one of the important commercial timber species used for both the pulp and paper industry and furniture. The wood is also suitable for general purposes such as light construction (e.g. rafters, panelling, interior trim, furniture and cabinetwork), lightweight packing materials (e.g. packages, boxes, cigar and cigarette boxes, crates, tea chests and pallets), matches, wooden shoes, musical instruments, toys, novelties and general turnery (Figure 7). The wood is an important source of lightweight veneer and plywood and is very suitable for the manufacture of light- and medium-density particleboard, wood–wool board and hardboard as well as block-board. The wood is extensively used for the manufacture of rayon and for supplying pulp for the manufacture of paper (Soerianegara and Lemmens 1993).

As a nitrogen-fixing species, *P. falcataria* is also commonly planted for reforestation and afforestation to improve soil fertility (Heyne 1987). The natural drop of leaves and small branches contributes nitrogen, organic matter and minerals to the upper layers of soil (Orwa *et al.* 2009). The trees are sometimes interplanted with agricultural crops such as corn and cassava and fruit trees (Charomaini and Suhaendi 1997). They are often planted in home gardens for fuelwood (charcoal), and the leaves can be used as fodder for chickens and goats. The bark is reported to serve as tannin nets in Ambon (Maluku), and is sometimes used locally as a substitute for soap (Soerianegara and Lemmens 1993). The trees are also planted as windbreaks and firebreaks. They have been used as ornamental and shade trees planted along the sides of the highway from the Indonesian capital Jakarta to the West Java city of Bogor.

Table 1. Wood density of *P. falcataria*

Wood density (kg/m^3)			Moisture content	References
Low	Medium	High	(%)	
240	330	490	15	Martawijaya *et al.* (1989)
230	300	500	12	Soerianegara and Lemmens (1993)

Photo: E. Varis Photo: E. Varis Photo: H. Krisnawati

Figure 7. Some products made from *P. falcataria* wood: (a) finger-jointed laminated panel, (b) three-play plywood and (c) packing material

3. Seed production

3.1. Seed collection

Paraserianthes falcataria trees start to flower as early as 3 years after planting. The flowering and fruiting seasons differ according to geographical location. Soerianegara and Lemmens (1993) reported 2 flowering periods per year for *P. falcataria* grown in Peninsula Malaysia and Sabah. Djogo (1997) reported the flowering time in Indonesia is between October to January and the best time to collect seeds is in July–August. In Hawaii, *P. falcataria* is reported to flower in April and May, with pods maturing in June to August, and in India, pods mature in May and June (Parrotta 1990). In general, ripe pods appear approximately 2 months after flowering.

The pods start to open when ripe, often when they are still attached to the tree, scattering the seeds on the ground. The seeds can be picked from the tree after they change colour from green to straw-coloured or from the ground by shaking the branches. The seeds are sometimes easily collected by cutting down branches bearing ripe brown pods or from felled trees if the fruits are in the right condition. A healthy 5–8-year-old plantation of *P. falcataria* can produce 12 000 viable seeds per ha. The weight of 1000 seeds is approximately 16–26 g (Soerianegara and Lemmens 1993).

3.2. Seed preparation

The pods of *P. falcataria* should be processed as soon as possible after collection. The pods can be dried in the sun, after which they can be processed through a macerator or flailed by hand to extract the seeds. Debris may be removed with aspirators or air-screen cleaners or by simple winnowing. Immature, empty or broken seeds can be removed by water flotation or by careful blowing in seed aspirators. There are approximately 38 000–44 000 cleaned seeds per kg (Parrotta 1990, Soerianegara and Lemmens 1993).

3.3. Seed storage and viability

The seeds can be easily dried to about 8–10% moisture content. Dried seeds can be stored for at least 1.5 years at 4–8 °C with no loss of viability. The germination rate may be still high (70–90%) after 18 months of storage (Soerianegara and Lemmens 1993). For longer storage, Parrotta (1990) recommends storing *P. falcataria* seeds in sealed containers and placing them in the refrigerator at 3–5 °C.

Before sowing, seeds should be soaked in boiling water for 1–3 minutes or dipped in concentrated sulphuric acid for 10–15 minutes followed by washing and then 15 minutes of soaking in cool water to accelerate and ensure uniform germination (Soerianegara and Lemmens 1993). Another method is to dip the seeds in boiling water, remove them from the heat source and allow them to cool at room temperature, leaving the seeds in the water for 24 hours (Parrotta 1990). Proper treatment with any of these methods should produce germination rates as high as 80% to almost 100% within 10 days (Parrotta 1990, Soerianegara and Lemmens 1993).

4. Propagation and planting

4.1. Sowing

Paraserianthes falcataria seeds are usually sown by broadcasting in the seedbed. Before sowing, the soil should be sterilised to avoid damping-off. The seeds are pressed gently into the soil and then covered with a layer of fine sand up to 1.5 cm thick (Soerianegara and Lemmens 1993). The soil in the seedbed must be loose and well drained. Application of a surface layer of mulch is recommended, and excessive shading should be avoided. Germination usually takes places 5–10 days after sowing. Untreated seeds germinate irregularly; germination may start after 5–10 days but can be delayed for up to 4 weeks.

4.2. Preparation for planting out

Paraserianthes falcataria can be raised by planting out nursery-raised seedlings (Figure 8), container seedlings or stump cuttings (Parrotta 1990, Soerianegara and Lemmens 1993). Wildings of *P. falcataria* are sometimes collected and potted for planting but they are delicate and must be handled carefully. In the nursery, seedlings are usually retained until they are about 2–2.5 months old before planting out (Figure 9). The seedlings can be transplanted when they have reached a height of 20–25 cm with a woody stem and a good fibrous root system. For stump cuttings, the suggested size is 5–20 cm in length and 0.5–2.5 cm in diameter with a root length of 20 cm (Martawijaya *et al.* 1989).

Figure 8. *P. falcataria* nursery in Ciamis, West Java

Figure 9. *P. falcataria* seedlings ready for planting out

Container seedlings are often transplanted into the field when they have reached the age of 4–5 months (Soerianegara and Lemmens 1993).

4.3. Planting

Paraserianthes falcataria seedlings should be planted at the beginning of the rainy season. Before planting, all weeds that could hinder seedling growth and survival should be removed. The seedlings are usually planted in fields at a spacing of 2×2 m to 6×6 m (Soerianegara and Lemmens 1993, Bhat *et al.* 1998). The recommended spacing depends on the management objectives. A common spacing for pulpwood production is 3×3 m. For saw-log production, the trees are spaced at 6×6 m on fertile sites. For premium log production, trees may be planted in rows 10 m apart, with 1 m spacing between trees. For farm woodlots, trees may be planted in blocks at a spacing of 2×2 m. Sometimes trees are planted along fence lines or boundaries to grow for timber. On farms where trees are grown at scattered, irregular spacings, the trees sometimes generate naturally (Bhat *et al.* 1998).

5. Plantation maintenance

5.1. Weeding

Paraserianthes falcataria plantations should be kept weed-free during the first 2 years. Weeding should be conducted after the first 2 months, and then at 3-month intervals. According to Anino (1997), lines 2 m wide should be totally cleared of weeds for about a year; thereafter, periodic vine-cutting ensures the saplings are free from noxious weeds. Prajadinata and Masano (1998) reported that, in Indonesia, weeding on *P. falcataria* is usually done 2–3 times in the first and second years after planting.

5.2. Fertilising

To improve the growth of *P. falcataria*, 100 g of NPK fertiliser (14:14:14) should be applied to each seedling, either during or immediately after planting. Fertiliser may be placed in the planting hole or applied in a ring around the seedling. Depending on soil fertility, it is often recommended to fertilise plantations again 5 years after planting (Bhat *et al.* 1998).

5.3. Replanting

Replanting is strongly recommended. Dead seedlings should be replaced with new seedlings within the first year after planting (Prajadinata and Masano 1998).

5.4. Pruning

As *P. falcataria* trees have a tendency to fork, pruning is recommended at an early stage of stand development, if the aim is to produce high-quality timber with long single boles and full growth potential. Pruning is usually carried out starting at the age of 6 months, and then at 6-month intervals until 2 years of age (Soerianegara and Lemmens 1993).

5.5. Thinning

The principal objective of thinning is to improve the growth of remaining trees to obtain an acceptable form for the final crop. Trees selected for thinning should consist of diseased or pest-infested trees, deformed or poorly shaped trees and suppressed trees. Prajadinata and Masano (1998) reported that regular thinning should start 2 years after planting and then every year up to 10 years. When the stand for timber production is 4–5 years old, the stand can be thinned to a density of 250 trees per ha and then reduced progressively to 150 trees per ha after 10 years.

5.6. Control of pests and diseases

Surveys to evaluate insect pests in *P. falcataria* plantations have recorded that stem borer (*Xystrocera festiva*), small bagworm (*Pteroma plagiophleps*) and yellow butterfly (*Eurema* spp.) are the main threats (Nair and Sumardi 2000). The borer is present in most *P. falcataria* plantations in Java and Sumatra. The severity of incidence appears to be higher in Java where *P. falcataria* has been cultivated for a long period (Hardi *et al*. 1996). Severe infestation reduces the yield and quality of the wood, and often leads to the death of the trees. Infestation usually begins when the trees are 2–3 years old and the percentage of trees infested increases with age (Matsumoto 1994). Notoatmodjo (1963) reported that the estimated yield loss in *P. falcataria* plantations in East Java was about 12% if the trees were harvested at the age of 4 years, and about 74% if they were harvested after 8 years. A common method to control *X. festiva* is cutting or removing infested trees to prevent the spread of the borer population. In state-owned plantations, this operation is usually carried out together with regular thinning operations by removing infested trees instead of systematic thinning. According to Kasno and Husaeni (1998), this method reduced the infestation rate to 4–10% of trees, although this may not be sufficient. They further recommend an integrated control strategy:

1. a 3-monthly inspection, during which early infestations are detected and the bark removed from the infested portion of the trunk to expose and kill the early larvae;
2. annual thinning to remove infested trees; and
3. release of the egg parasitoid (*Anagyrus* sp).

Attacks by small bagworms cause defoliation. Small bagworm is a sporadic pest, but some companies in Sumatra have reported severe infestations (Nair and Sumardi 2000). Our recent surveys in *P. falcataria* smallholder plantations in Sukabumi (West Java) also detected this incidence (Figure 10). Repeated heavy infestations may result in tree dieback. This usually occurs repeatedly in endemic patches. Another pest, yellow butterfly larvae, occasionally defoliate nursery seedlings in Sumatra and Java (Irianto *et al.* 1997), but the infestation is not economically important. The pest can be controlled by hand picking them and destroying them.

Some diseases have been reported to infect *P. falcataria.* In the nursery, seedlings are occasionally damaged by damping-off fungi of Pythium, Phytophthora and Rhizoctonia (Nair and Sumardi 2000). High incidence usually occurs during the rainy season in November–January. Cultural methods such as providing seedbeds with a roof and reduction of watering frequency and intensity may prevent infection (Anino 1997). Root rot caused by *Botryodiplodia* sp. occurs in young plantations in South Kalimantan and Jambi (Anggraeni and Suharti 1997). Widyastuti *et al.* (1999) reported the incidence of root rot (infected by *Ganoderma* fungi) in older *P. falcataria* trees. In general, *P. falcataria* trees do not suffer from these diseases, except for trees older than 10 years (Nair and Sumardi 2000).

The disease most recently reported to affect *P. falcataria* trees is gall rust (*Uromycladium tepperianum*), which has damaged some *P. falcataria* plantations in some parts of Java (Rahayu 2008). Our recent surveys in *P. falcataria* smallholder plantations of Ciamis (West Java) also detected this disease, particularly amongst trees growing at higher elevations (Figure 11). The disease can result in dieback or death of trees. Anino (1997) indicated that the disease was successfully managed by not planting trees at elevations above 250 m, where the disease has been very severe. Pruning and burning of infected parts, conversion of cleared areas to other suitable tree species and use of bio-control agents such as *Penicillium italicum*, *Acremonium recifei* and *Tuberculina* spp. may be effective in preventing the disease.

Figure 10. ***P. falcataria*** **trees in Sukabumi (West Java) defoliated by bagworm attacks**

Figure 11. Gall rust-infected ***P. falcataria*** **trees in Ciamis (West Java)**

6. Growth and yield

6.1. Growth rates

Paraserianthes falcataria can grow rapidly, particularly the young stands. Bhat *et al.* (1998) reported that, under favourable conditions, the trees can reach a height of 7 m in 1 year, 16 m in 3 years and 33 m in 9 years. Kurinobu *et al.* (2007a) reported that *P. falcataria* trees in 3–5-year-old stands growing in state-owned plantations in Kediri (East Java) have a mean diameter of 11.3–18.7 cm (maximum diameter 25.8 cm) with a mean height of 11.7–20.5 m (maximum height 23.5 m).

In our recent study of smallholder plantations in Ciamis (West Java), we recorded that the mean diameter of *P. falcataria* trees ranges from 3.4 to 16.7 cm with a maximum diameter of 36.0 cm for trees younger than 4 years old. The mean height of the corresponding stands ranges from 3.9 to 19.6 m with a maximum value of 27.0 m. The mean diameter for trees older than 5 years (but less than 10 years) growing on the same sites is between 8.7 and 40.1 cm and the mean height is between 9.9 and 27.9 m. For older stands, the trees in 12-year stands are recorded to have a diameter of 24.6–74 cm and a height of 15.3–36.2 m. The wide variations in mean diameter and height as recorded in our study are probably due to differences in growing conditions, including site quality, altitude, slope and silvicultural management.

Sumarna (1961) made predictions of the growth of *P. falcataria* based on 134 sample plots located in several sites in Kediri (East Java) and Bogor (West Java). He noted that, to the age of 5 years, the mean annual increment (MAI) in height of *P. falcataria* trees growing on sites of average quality is about 4 m; growth then slows as the trees age (Figure 12b). At the age of 8–9 years the height increment is about 1–1.5 m, and at 10 years of age it is only about 1 m. A similar trend was observed for the diameter increment; however, the MAI in diameter fluctuates around 4–5 cm until the age of 6 years (Figure 12a). At the age of 8–9 years, the diameter increment is still high, about 3–4 cm; it then decreases slowly thereafter.

6.2. Height–diameter relationship

Height and diameter are essential inventory measures for estimating tree volume. However, measurement of tree height is difficult and costly. Consequently, height is measured for only a subset of trees. Quantifying the relationship between tree height and diameter is therefore necessary to predict heights of the remaining trees. Despite this importance, relatively little information is available on the height–diameter relationship for *P. falcataria* plantations.

Using measurement data on 1467 *P. falcataria* trees of 1–12 years of age collected from smallholder plantations in Ciamis District, West Java, the relationship between total tree height (H) and diameter at breast height (D) of *P. falcataria* was investigated. Six non-linear models were tested: Chapman–Richards, Curtis, exponential, Gompertz, Korf and Weibull. Of these, the Chapman–Richards

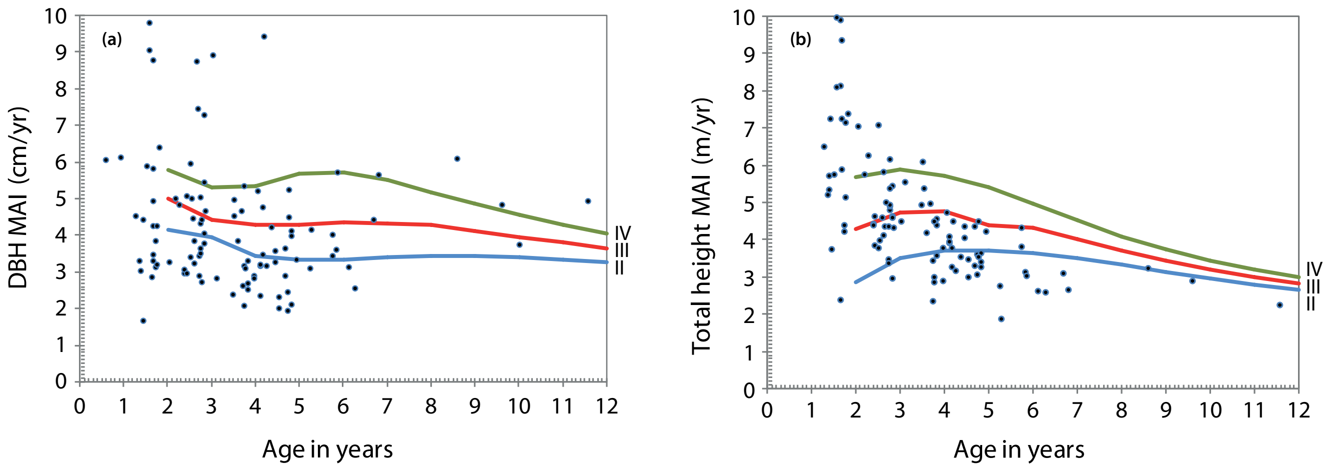

Figure 12. Mean annual increment (MAI) in diameter (a) and height (b) of *P. falcataria* trees taken from measurements of smallholder plantations in Ciamis (West Java) overlaid with increment curves taken from a preliminary stand yield table of *P. falcataria* (Sumarna 1961) (*points*: average values of measured data in Ciamis, *lines*: values from the yield table). Roman numerals indicate site quality class with a low class number indicating poor site quality.

model best fits the data. The functional form of the selected model was:

$$H = 1.3 + b_0 \left(1 - \exp\left(-b_1 D\right)\right)^{b_2}$$

The results of fitting the selected model, including non-linear least squares estimates of the parameters, the standard error, t-statistic, p-value, the root mean squared error (RMSE) and the adjusted coefficient of determination, are presented in Table 2. The model explains a relatively high proportion of the total variation in observed values of tree height, accounting for about 80%, although the RMSE value produced was quite high (about 2.7 m). This result may not be surprising as the height–diameter relationships found in the data were highly variable (Figure 13). This is likely to be due to data having come from plots with a wide range of stand densities, ages and sites. Predictions may be improved by incorporating into the model any additional stand variables that are expected to affect the height–diameter relationship.

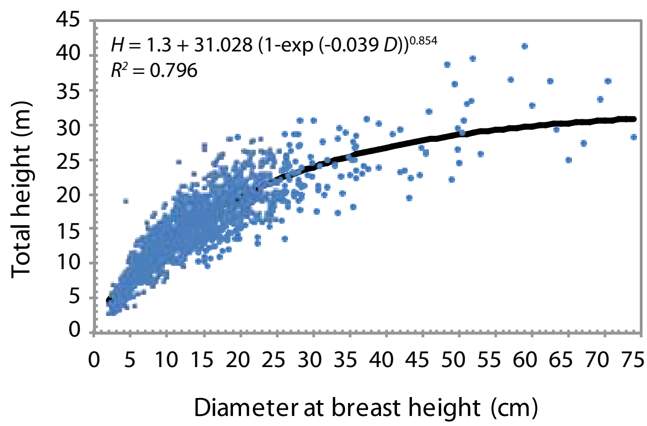

Figure 13. The height–diameter relationship of *P. falcataria* trees developed using measurement data from smallholder plantations in Ciamis, West Java (*points*: measured values; *line*: model).

Table 2. Parameter estimates, standard errors and related fit statistics of the height–diameter model for *P. falcataria* plantations

Parameter	Estimate	SE	t	Pr ≥|t|	RMSE	R^2adj
b_0	31.027720	1.0155	30.56	< 0.0001	2.6698	0.7958
b_1	0.034125	0.0036	10.87	< 0.0001		
b_2	0.853808	0.0318	26.85	< 0.0001		

6.3. Stem volume equation

The estimation of the volume of an individual tree is a necessary step for the estimation of the stand volume. Several stem volume equations have been produced for *P. falcataria* in Indonesia (e.g. Bustomi *et al.* 1995, Kurinobu *et al.* 2007b). Bustomi *et al.* (1995) developed a single stem volume equation for *P. falcataria* using 93 sample trees from plantations in Jonggol, West Java (Table 3). The models were estimated from diameter at breast height (D) alone or in combination with total tree height (H), or from the length of bole measured to a specified minimum top diameter, i.e. to predict stem volume up to 5 cm in upper diameter (V_5) and clear bole volume (V_c). These models were used to construct stem volume tables (V_5 and V_c), either one-way tables in which volumes were given for a particular DBH, or 2-way tables that provide estimates for a DBH for a range of height measurements.

Kurinobu *et al.* (2007b) developed a total stem volume equation that is compatible with a stem taper equation using a sample of 172 *P. falcataria* trees from plantations in Pare, East Java (Table 3). The stem taper equation was based on a logarithmic volume equation with the addition of 1 free parameter that minimised the standard errors of estimate to the observed diameter of stems at 1-m intervals. The derived taper equation, according to Kurinobu *et al.* (2007b), is able to predict the stem taper of *P. falcataria* with reasonable accuracy, although it is not flexible enough to describe changes in the upper portion of the stem. They stated that the volume equation is able to predict the volume up to 20 cm in diameter reasonably well.

6.4. Biomass estimation

Biomass estimation for *P. falcataria* has been reported by Siringoringo and Siregar (2006) and Siregar (2007). Siringoringo and Siregar (2006) developed allometric equations to provide a means to estimate biomass using 34 sample trees of *P. falcataria* grown in state-owned plantations in Sukabumi, West Java. The range of the DBH of the sample trees was 2–30 cm. The 34 trees were felled, and after felling, each tree was divided into sections and weighed; roots were also destructively sampled and weighed. Two models were developed to predict aboveground biomass, root (belowground) biomass and total biomass: one using diameter alone and the other using a combination of diameter and height as independent variables (Table 4). Siregar (2007) developed similar equations for *P. falcataria* growing in state-owned plantations in Kediri (East Java) using 35 sample trees with a diameter range of 16.6–31.2 cm. Two models, one

Table 3. Stem volume models developed for *P. falcataria* in Indonesia

Location (site)	Age sample	N sample	Equation form	Reference
Jonggol (West Java)	7–8	93	$\log V_c = -3.859 + 2.4798 \log D$	Bustomi *et al.* (1995)[a]
			$\log V_5 = -3.590 + 2.3528 \log D$	
			$\log V_c = -4.1143 + 2.137 \log D + 0.6269 \log H$	
			$\log V_5 = -3.7948 + 2.078 \log D + 0.5028 \log H$	
Pare (East Java)	8	172	$\log V_t = -4.294 + 1.838 \log D + 0.987 \log H$	Kurinobu *et al.* (2007b)[b]
			$\log d_L = 0.331 + 0.919 \log D + 0.495 \log H - 0.44 \log L$	

a Model developed for under-bark volume

b Model developed for over-bark volume

Table 4. Allometric equations developed for *P. falcataria*

Site	Component	Model	R^2	Reference
Sukabumi (West Java)	Aboveground	$B_{above} = 0.1126\ D^{2.3445}$	0.94	Siringoringo and Siregar (2006)
		$B_{above} = 0.0742\ D^2H^{0.831}$	0.94	
	Belowground	$B_{below} = 0.0281\ D^{2.697}$	0.93	
		$B_{below} = 0.0195\ D^2H^{0.766}$	0.93	
	Total	$B_{total} = 0.1479\ D^{2.2989}$	0.94	
		$B_{total} = 0.0986\ D^2H^{0.8144}$	0.95	
Kediri (East Java)	Aboveground	$B_{above} = 0.3196\ D^{1.9834}$	0.87	Siregar (2007)
	Belowground	$B_{below} = 0.0069\ D^{2.5651}$	0.94	
	Total	$B_{total} = 0.2831\ D^{2.063}$	0.91	

Table 5. Biomass estimates (t/ha) of *P. falcataria* stands at different locations

Location (site)	Aboveground	Belowground	Total	Reference
Sukabumi (West Java)	50.00	7.80	57.80	Siringoringo and
	48.44	7.56	56.01	Siregar (2006)
Kediri (East Java)	73.33	10.64	83.97	Siregar (2007)

using DBH alone and the other using a combination of DBH and height as independent variables, were developed, but only the DBH model was finally selected for practical reasons (Table 4).

According to Siringoringo and Siregar (2006) and Siregar (2007), the proportion of aboveground biomass is about 86.5–87.3%, and that of the belowground biomass is about 12.7–13.5%. The total aboveground biomass estimated for *P. falcataria* is significantly higher in Kediri than in Sukabumi (Table 5).

6.5. Productivity

Paraserianthes falcataria is a fast-growing tree species and the yield is often high. Lemmens and Soerianegara (1993) reported that a volume MAI of 10–25 to 30–40 m^3/ha can be attained in an 8–12-year rotation. Bhat *et al.* (1998) reported that, under favourable conditions, the trees can reach a volume MAI of 39–50 m^3/ha in a 10-year rotation.

In good-quality sites in Indonesia, *P. falcataria* has been reported to reach a maximum volume MAI of 67 m^3/ha/year by the age of 6 years, producing up to 403 m^3/ha over the rotation (Sumarna 1961). In medium-quality sites, volume MAI of 50 m^3/ha/year can be attained in 7–8 years (with 185 trees/ha when 8 years old and 150 trees/ha when 7 years old) producing up to 350–400 m^3/ha including yields from thinning. In poor-quality sites, total volume production in 8 years old stands is about 313 m^3/ha and a maximum volume MAI of 40 m^3/ha/year may not be achieved for 12 years (Sumarna 1961).

6.6. Rotation

For pulpwood production, harvesting of trees can take place around 8 years after planting; for timber production, harvesting can start when trees are 12–15 years of age. For *P. falcataria* planted in agroforestry systems, harvesting usually takes place around the age of 10–15 years; trees are planted in combination with annual crops in the first year and with grazing animals in subsequent years (Soerianegara and Lemmens 1993). Bhat *et al.* (1998) stated that, in the Philippines, a common rotation for pulpwood production is 6–8 years and for saw-log production is 15–17 years.

The rotation length may be guided by the time taken for stands to reach their maximum volume MAI. In Indonesia, Sumarna (1961) predicted that *P. falcataria* plantations will reach their maximum volume MAI, i.e. the volume of thickwood with a diameter of 7 cm or more, sometime between 6 and 10 years after planting, depending on site quality (Figure 14). In state-owned plantations in Java, economic rotations for *P. falcataria* have been set at around 8 years, according to a decree by the director of Perum Perhutani (Decree No. 378/Kpts/Dir/1992; Perum Perhutani 1995).

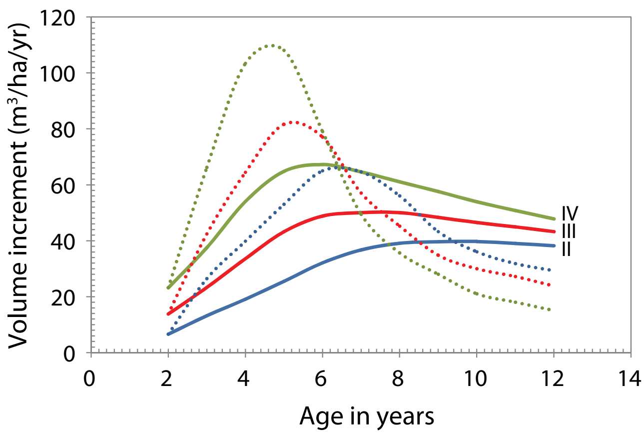

Figure 14. Volume MAI (*solid lines*) and Current Annual Increment (CAI) (*dashed lines*) against age by site quality for *P. falcataria* plantations. Graphs are drawn from preliminary yield tables (Sumarna 1961), which presented only 3 site classes, II, III, and IV, with a low class number indicating poor site quality.

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This manual gathers information on the ecology and silviculture of *Paraserianthes falcataria* (L.) Nielsen, with a focus on Indonesia. It also includes growth and yield data from published sources, collected from smallholders' farms in the research sites in South Kalimantan province, and collected previously by the Forestry Research and Development Agency of Indonesia. This manual is one of five manuals that guide smallholder tree planting of five selected tree species in Indonesia. The other four species are: A*cacia mangium* Willd.; *Aleurites moluccana* (L.) Willd.; *Anthocephalus cadamba* Miq.; and *Swietenia macrophylla* King. Smallholders in Indonesia have planted trees on private or community land for a long time. Various actors have encouraged this activity with the aim of improving local livelihoods, environmental sustainability and industrial wood supply. Since farmers often lack technical capacity and management know-how, the quality and quantity of products may not be optimal. Productivity of smallholder plantations can be improved by enhancing smallholders' management knowledge and skills, including species selection based on site matching, silvicultural management to produce high-quality products, and pest and disease management.

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