Paraserianthes falcataria (L.) Nielsen — Batai, Moluccan sau

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Leguminosae (Mimosoideae) — Legume family

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Paraserianthes falcataria, known as batai or Moluccan sau, is a medium-sized, fast-growing tree found in wet forests of Southeast Asia. Under favorable plantation conditions, tree heights of 13 to 16 m at 5 years and 19 m at 9 years have been reported (*14, 20*). Open-grown trees form a large, umbrella-shaped crown of light foliage. Batai is a promising and versatile species for use in forestry development programs in the humid tropics because of its rapid growth, vigorous coppicing, capability to compete with weeds, and utility in agroforestry and silvopastoral systems.

HABITAT

Native Range

The native range of batai extends from latitudes 10° S. to 5° N. and includes the eastern islands of the Indonesian archipelago, the Moluccas, West Irian Jaya, Papau New Guinea, and the Solomon Islands (*28*, fig. 1). It is commonly found in wet forests at elevations up to 1,200 m in its native Southeast Asia range (*23*).

In the 1870's, batai was introduced and cultivated throughout Southeast Asia from Burma to the Philippines (*25*). Batai is grown in plantations in the Hawaiian Islands, Fiji, Bangladesh (fig 2.), the Philippines, and elsewhere in Southeast Asia and has been used in adaptability trials in Western Samoa, Australia, Taiwan, India, Sri Lanka, Zaire, Guatemala, Honduras, Nicaragua, Costa Rica, and Panama (*9, 16*). In Java it is widely planted in home gardens and in a variety of agroforestry systems (*28*). It has become naturalized in many areas where it has been introduced, such as in abandoned sugar cane fields in Hawaii. Batai trees have a life span of about 25 years (*23*).

Climate

Batai grows well in wet tropical regions where annual precipitation ranges from 2000 to 4000 mm, with at least 15 days of rain during each of the driest 4 months (*27, 36*). In the Philippines, the best plantation growth has been achieved on sites with no dry periods and an annual rainfall of 4500 mm (*28*). The species requires a temperature range of 22 to 29 °C (*28*).

Soils and Topography

Batai growth is favored on deep, well-drained alluvial soils with reasonably high fertility, although it will survive on infertile sites (*27, 31*). Like many other leguminous species, it is likely to perform better on slightly alkaline than on acid soils and is not suited to dry sands (*23*). It readily forms an association with *Rhizobium* spp., and the resultant nitrogen-fixing capacity enables it to thrive in nitrogen deficient soils (*1*). The species has been successfully established on tailings left after tin mining (*25, 28*).

Associated Forest Cover

In its native range, batai is most commonly found on disturbed sites and in early successional forests (*35*). In Indonesia, it is found on disturbed sites within lowland rain forests dominated by the Dipterocarpaceae, *Eusideroxylon zwageri* T. et B., *Agathis* spp., *Intsia* spp., *Pometila* spp., *Octomeles sumatrana* Miq., *Ochanstachys amentacea* Mart., *Diopyros celebica* Bakh., *Pericopsis mooniana* Thw., *Santiria* sp., *Madhuca* sp., *Elmerillia* sp., *Eucalyptus deglupta* Blume, and *Anthocephalus chinensis* (Lamk.) Rich. ex Walp. (*30*). On the island of Ceram (Indonesia), it is associated with *Eugenia* spp., *Diospyros pilosanthera* Blanco, *Vitex cofassus* Reinw., *Pterocarpus indicus* Willd., *Aleurites moluccana* Willd., *Koordersiodendron pinnatum* Merr., *Octomeles sumatrana* Miq., and *Myristica* sp. (*33*). Batai has become naturalized on open grasslands in many parts of Southeast Asia where it has been introduced (*8*).

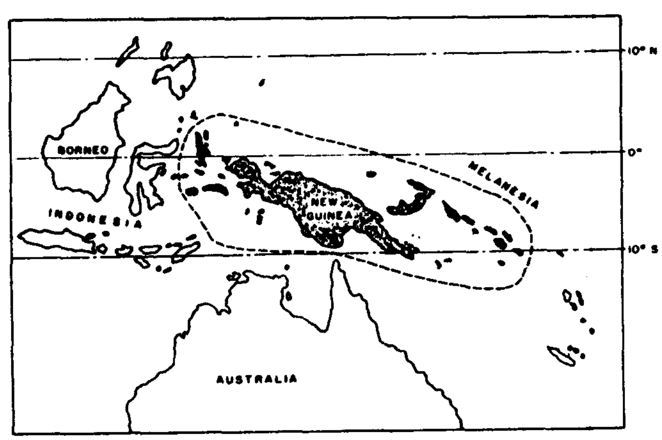

Figure 1.—*Native range of batai* (Paraserianthes falcataria) *delineated by dashed line.*

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Figure 2.—*Batai* (Paraserianthes falcataria) *plantation in Sylhet, Bangladesh. The stand to the right in the photo is 3.5 years old; the one on the left is 18 months old.*

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting.—Batai first produces flowers when trees are approximately 3 to 6 years of age (*16, 24, 31*). In its native range in Southeast Asia, batai has been reported to flower for a period of about 2 weeks between March and June and again from August to December (*8, 11*). The sessile flowers are borne in the upper crown on the branches of axillary panicles up to 15 cm long (*11, 23*). Individual flowers are greenish yellow to creamy white in color, with a broadly campanulate-turbinate, seriaceous, toothed calyx 1 to 2 mm long and stamens 3 to 5 mm long (*11, 13*).

The fruits are pale brown, pointed, thin-walled, flattened pods 10 to 15 cm long and 1.8 to 2.5 cm broad, and they ripen approximately 2 months after flowering (*11, 40*). The pods, which open while attached to the tree, each contain between 15 and 20 seeds (*23*).

Seed Production and Dissemination.—Batai seeds are small (6 mm long; 38,000 to 44,000 per kilogram), flat, and obvate and have a hard, smooth testa with a distinct circular marking on each surface (*32, 36, 40*). Seeds are produced in great abundance and are released from the open pods while attached to the tree and dispersed short distances by wind. Ripe pods may be collected prior to dehiscence and air-dried to release the seeds (*40*).

Seedling Development.—Batai seeds germinate on the soil surface. Germination is slow without scarification and is facilitated if seeds are immersed in boiling water for 3 minutes and then soaked for 24 hours in water at room temperature prior to sowing (*40*). Alternatively, seeds may be scarified mechanically or treated with sulfuric acid for 12 minutes followed by a water soaking for 18 hours (*28*). Under natural conditions, seeds may remain on the soil surface for months or years prior to germination; fire appears to be a natural scarifying agent (*6*).

Seeds germinate readily in 2 to 10 days, provided there is sufficient soil moisture (*40*). Germination rates for undamaged, freshly extracted seeds range from 65 to 98 percent (*40*). Air-dried seeds stored at 4 to 8 °C in airtight containers retain their viability for up to 2 years (*36, 40*).

Seedlings respond well to fertilization; phosphorus and nitrogen applications at the rate of 12.5 and 100 kg/ha were reported to maximize seedling growth rates during the first 4 months after germination (*26*). Root nodules contain the nitrogen-fixing bacteria *Rhizobium* spp. These nodules, which may be elliptical or branched, were found to be larger and more abundant on seedlings grown in nitrogen-deficient than in nitrogen-enriched soils (*26*).

The natural regeneration of batai is generally good on burned or otherwise cleared ground in the vicinity of mature trees. Once established, seedlings grow rapidly and generally are not greatly affected by competing vegetation (*8*).

Wild seedlings can be successfully collected and potted for planting (*40*). For nursery production, scarified seeds may be sown directly into seedling containers (*31*). It is recommended that seedlings be hardened by progressive exposure for 2 weeks before outplanting (*16*).

Plantations may be established using containerized seedlings (10 cm or greater in height) or bare-root seedlings with the tops removed (*16, 36*). Seedings whose tops have been clipped off (30-90 cm stem and 20-25 cm root) reportedly show good survival and rapid recovery even when planted in dense grasslands dominated by *Imperata cylindrica* Beauv. (*4*). Newly established plantations usually require weeding two or three times during the first year, with occasional elimination of vines thereafter, as needed (*28*). In Malaysia, where plantations are established at an initial spacing of 3 by 3 m, it is recommended that low branches and extra leaders be pruned at the end of the first year or when canopy closure is nearly complete (*31*).

Vegetative Reproduction.—Vegetative regrowth after cutting is vigorous and is an effective means of regeneration in plantations (*24, 39*); coppiced trees are commonly harvested on an 8-year cycle (*23*). Tissue culture plantlets have been produced using seed tissue (*27*).

Sapling and Pole Stage to Maturity

Growth and Yield.—Growth of batai is very rapid. In saplings the main stem grows vigorously, producing a straight to somewhat irregular bole and ascending branches, which form an open, conical crown. Mature trees, characterized by a smooth grayish-white bole and a high, broadly spreading crown, may attain a maximum height of 25 to 45 m and stem diameters at breast height (d.b.h.) of 50 to 90 cm (*11, 36*). Leaves are bipinnate, 15 to 40 cm long (including rachis), with 8 to 10 pairs of pinnae up to 10 cm long. Each pinna is comprised of 15 to 25 pairs of leaflets 3 to 13 mm long and 3 to 8 mm wide (*11, 23*).

In adaptability trials conducted in Costa Rica at a premontane wet tropical site, mean tree heights of 5.5, 10.7, and 13.5 m were recorded at 2, 3, and 4 years, respectively. Corresponding mean stem d.b.h.'s in this study were 5.8, 10.7, and 13.9 cm (7). Additional adaptability trials have been established at dry tropical sites in Panama and Nicaragua (*9*). In these latter trials, average tree heights ranged from 1.0 to 2.8 m at 12 months, 1.7 to 3.5 m at 24 months, and 3.4 to 3.7 m at 3 years. In trials conducted in Trinidad at a low-elevation site characterized by well-drained, nutrient-poor, acidic soils and a mean annual rainfall of 2100 mm, a mean tree height of 3.4 m and a mean stem d.b.h. of 3.7 cm were reported for 2-year-old stands (*21*).

In adaptability trials conducted in northeast Thailand, the average height of 6-month-old seedlings was reportedly 2.1 m; average leaf biomass at 6 months was 189 g per seedling (oven-dry weight) (*18*). Average tree heights of 2.1 and 3.0 m were reported in separate 12-month-old plantation trials in Thailand established at a 1- by 1-m spacing; corresponding average stem d.b.h.'s were reported as 1.7 and 2.5 cm. At 2 years, average height and d.b.h. in the latter trial were 5.6 m and 4.2 cm, respectively (*39*).

In 4-year-old plantations in Assam and the Andaman Islands of India, average tree heights and stem d.b.h.'s reportedly ranged from 9.2 to 14.2 m and 60 to 90 cm, respectively (*32*). In Sabah, Malaysia, mean annual height and d.b.h. increments at 5 years were reportedly as high as 5.0 m and 3.7 cm, respectively (*31*). In 6-year-old plantations in the Philippines, average height and stem d.b.h.'s were reported as 12.8 m and 18.4 cm, respectively (*24*).

Mean annual wood volume increments of 20 to 40 m^3/ha over a rotation of 8 to 12 years are common on good sites (*27*). Mean annual volume increments of 45 to 66 m^3/ha have been reported for 5-year-old plantations with an average stocking of 800 trees per hectare in Sabah, Malaysia, where the optimal rotation age for plantations raised for fiberboard, veneer, and sawlog production ranges from 8 to 12 years (*31*).

Total aboveground biomass was estimated in 5- and 9-year old plantations on a wet tropical site in northeast Mindanao in the Philippines to be 76 and 102 t/ha (ovendry weight), including 7.5 and 12.3 t/ha of branch biomass and 1.7 and 1.6 t/ha of leaf biomass, respectively. In this study, average tree heights of 12.9 and 18.8 m, average stem diameters of 13.9 and 30.3 cm, basal areas of 19.0 and 25.3 m^2/ha, and stem volumes of 209 and 278 m^3/ha were recorded for the 5- and 9-year old stands, respectively (*20*).

In Java, batai has been grown in mixed plantations on infertile sites as an early cover crop of the more valuable shade-tolerant timber species such as *Altinga excelsa, Castanopsis tungurrut, C. javanica, Podocarpus imbricata, Quercus* spp., *Nyssa javanica, Schima noronhae, Fagraea fragrans, Swietenia macrophylla, Gordonia excelsa,* and Diptocarpaceae species (*2, 12, 19*).

In Hawaii, growth, yield, and foliar nutrient concentrations were compared for mixed plantations of batai and *Eucalyptus* spp. (1:1 mixture) and pure eucalyptus plantings established at 2- by 2-m spacings. At 65 months, eucalyptus grown with batai were 63 percent taller and 55 percent larger in diameter than eucalyptus grown in pure plantings. Total aboveground biomass at 65 months was estimated as 58.2 and 37.1 t/ha (ovendry weight) for eucalyptus and batai, respectively, in the mixed planting and 37.6 t/ha in the eucalyptus monoculture. Foliar concentrations of N, P, K, Ca, and S were significantly higher for eucalyptus grown with batai than those in pure plantings. Soil nutrients, with the exception of K in the surface soil, did not vary significantly between plantations (*14*).

Rooting Habit.—Batai generally forms a shallow, widespreading lateral root system extending over an area greater than the extent of the crown, with numerous vertical secondary roots and a poorly developed taproot (*11, 15*). As noted earlier, batai readily forms an association with *Rhizobium* spp. (*1, 26*). The resultant nitrogen-fixing capacity contributes to its ability to grow on marginal sites and its popularity in agroforestry systems (*27*).

Reaction to Competition.—Batai is a light-demanding species and cannot tolerate suppression. It can, however, stand moderate shade during the seedling, sapling, and small pole stage (*8*). It has been successfully established through stump and seedling plantings in grasslands dominated by *Imperata cylindrica* in Southeast Asia (*34*). With occasional weeding during the first year, batai quickly overtops and eventually shades out this otherwise persistent grass and provides perches for birds that disperse the seeds of other forest tree species, which may then develop in the understory (*11*).

In spacing trials conducted in Thailand, average heights and stem d.b.h.'s in 2-year-old stands ranged from 5 to 7 m and 3 to 7 cm, respectively (*39*). In this study, in which plantation stocking rates ranged from 2,500 to 20,000 trees per hectare, average tree growth rates were generally greater in the less dense stands.

Damaging Agents.—Several hemipteran, lepidopteran, and coleopteran insect pests have been reported to feed on young shoots, leaves, sap, and dead wood of batai in South and Southeast Asia (*5*). These include the sap-sucking hemipterans *Lecanium longulum* Douglas and *Pseudococcus virgatus* Cockerell (Coccidae); the defoliating larvae of *Polydesma inangulata* Guenee (Noctuidae), *Eurema blanda* Boisduval (Pieridae), and *Catopsilia pomona* (Fabricus); the bagworm *Pteroma plagiophleps* Hampson; the wood-borer and shoot-pruner beetles *Xystrocera festiva* and *Callimetopus* sp. (Carambicydae); and the bark-eating larvae of *Indarbela quadrinotata* Walker (Indarbelidae) (*3, 5, 7, 17, 29, 31*).

A large number of fungal pathogens have been reported as the cause of leaf, stem, and root diseases in batai (*17, 29*). In Java, Sumatra, and Sri Lanka, *Pleiochaeta albiziae* (Petch) Hughes causes yellow-brown leaf spots with dark-green margins and may lead to complete defoliation and death of nursery stock and young transplants (*29*). The powdery mildew *Oidium* spp. reported in Java causes severe defoliation and death of infected seedlings. Leaf necrosis caused by *Camptomeris albizziae* (Petch) Mason has been reported in south and northeast India (*29*). Leaf spotting and leaf cast caused by *Cercosporella theae* Petch have been reported in India and Sri Lanka. The alga *Cephaleuros virescens* Kunze, widely distributed in tropical regions, has been reported as causing leaf spots on batai in Malaysia. *Rhizoconia solani* Kuhn (in northeast and south India) and *Thanatephorus cucumeris* (Frank.) Donk (in Sri Lanka) have been reported as the cause of web blight (*29*).

Corticium salmonicolor Berk. & Br., the cause of "pink disease," has been recorded in the Philippines, India, and Sri Lanka (*17, 29, 31*). Stem cankers have also been reported to be caused by *Fomes* spp. (in south India) and *Nectria pulcherrima* Berk & Br. (in Sri Lanka) (*29*). *Botryodiplodia theobromae* Pat., a weak-wound pathogen, *Phomopsis mendax* (Sacc.) Trav. and *Phoma* spp. have been noted as the cause of dieback in Indonesia and India (*17, 29*). Other pathogens reported to cause stem dieback are *Physalospora rhodina* (Berk. and Curt.) Cke. (in Sumatra) and *Thyridaria tarda* Bancroft (in Madagascar) (*29*). Stem infection caused by *Macrophoma theicola* Petch. (in northeast India) and charcoal stump rot caused by *Ustulina zonata* (Lev.) Sacc. (in northeast India) and *U. deusta* (Fr.) Petrak. (in Java) have been reported (*29*). *Fusarium solani* (Mart.) Sacc., a highly virulent bark and stem disease causing the formation of stem cankers in other *Albizia* species, is reported in south India as the cause of seedling wilt (*29*). The bacterial wilt *Pseudomonas solanacearum* E.F. Smith has been reported in plantations in south India (*29*).

Macrophomina phaseolina (Tassi) Goid., the cause of black root rot, has been reported in Sri Lanka, Java, Uganda, and North Africa, and *Armillariella mellea* (Fr.) Karst. has been reported in Java, Tanzania, and Zaire. Other reported root pathogens include *Phellinus noxius* (Corner) G.H. Cunn. (in Sri Lanka), *Ganoderma pseudoferreum* (Wakef.) Overeem & Steinm. (in Java, Malaysia and Sri Lanka), *Ganoderma lucidum* ((W. Curt.) Fr.) Karst. (in Sumatra and Sri Lanka), *Ustulina deusta* (Hoffm. ex Fr.) Lind. (in Java), *Botryodiplodia* Pat. (in south India), and *Aglaospora* sp. (in northeast India). The brown root rot *Fomes noxius* Corner (in Sri Lanka), purple root rot *Helicobasidium compactum* Boedijn. (in Indonesia), and violet root rot *Sphaerostilbe repens* Berk. & Br have also been reported. The fungus *Irpex subvinosus* (Berk. & Br.) Petch has been recorded both as a root pathogen and the cause of butt rot in batai (*17, 29*).

The foliage of this species is subject to browsing by livestock, deer, and monkeys (*8, 27*). Squirrels browsing on the bark of young branches have been reported to cause serious damage to plantations in Malaysia (*16*).

Branches of mature trees break readily in heavy winds, and the shallow rooting habit make them susceptible to windthrow (*11, 16, 27*). The massive surficial root system of batai is known to contribute to soil erosion on steep hillsides and is therefore not recommended for such sites (*28*). Plantations are reported to be highly susceptible to fire damage (*16, 36*).

SPECIAL USES

Batai is used as a shade tree for tea, coffee, and other crops in Java. In Sri Lanka, trees grown for this purpose are usually pollarded when reaching a 30-cm stem diameter (*11, 13, 38*). It is the primary species used in farm forestry in western Java and is used in the Philippines for streambank stabilization and catchment protection following timber harvests (*16*).

The light-brown to slightly yellowish or pinkish heartwood is soft and light (specific gravity: 0.3-0.5 g/cm^3), with a strongly interlocked or spiral coarse-textured grain. The heartwood is not clearly demarcated from the sapwood. Large logs are not difficult to saw although they are often hollow or affected by heart rot. The wood seasons satisfactorily, and although it is not durable, it absorbs preservatives well (*8, 10, 16*). In the 1970's batai logs were rotary-peeled and processed for core stock in Hawaii (*27*).

Parasenanthes falcataria is not recommended as a structural timber, but may be used for matches, packing cases, tea chests, lightweight pallets, shelving, and light construction (*11, 13*). The wood is reasonably good for veneer, fiberboard, particleboard, linings, and moulding (*16, 31*). As a fuel it has a number of unfavorable characteristics; it burns rapidly, has a low calorific value (2.0-3.4 kcal/g) and a high ash content, and is difficult to split (*11, 36*).

This species is considered a promising source of pulpwood for production of certain grades of paper such as white wrapping and printing paper (fiber length: 1.15 mm). Papers made from batai sulphate pulp are reported to compare favorably with those made from softwood kraft pulp in terms of flexibility and bonding characteristics; pulp yields are satisfactory, although some difficulties in bleaching are reported (*11, 16, 27, 31, 39*).

Batai is currently being evaluated as a short-rotation coppice crop for fodder production in Southeast Asia (*18*). Coppice regrowth rates and foliar nutrient levels (3.2 percent nitrogen) compare favorably with other leguminous tree species currently used for fodder production (*39*).

GENETICS

Paraserianthes falcataria is easily confused with *Enterolobium cyclocarpum* Griseb. in Southeast Asia (*37*). The species was formerly known as *Albizia falcata* (L.) Backer, *A. moluccana* Miq., and, more recently, as *A. falcataria* (L.) Fosberg (*21, 28*).

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