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Styrax tonkinensis: Taxonomy, ecology, silviculture and uses

K. Pinyopusarerk
CSIRO Division of Forestry

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Preface

This report has been prepared as part of a forestry project supported by the Australian Centre for International Agricultural Research (ACIAR) and the Lao Department of Forestry. Much of the information is derived from Vietnamese and French literature, field notes, observations by the author and personal communications.

I have been generously assisted by many individuals and institutions during the preparation. In Vietnam, Prof Dr Le Dinh Kha and staff of the Forest Science Institute helped to locate and translate many Vietnamese references and provided information on natural distribution and utilisation in Vietnam; Messrs Nguyen Duong Tai and Hoang Son of the Forest Research Centre, Bai Bang, Vinh Phu, supplied research reports prepared by staff of the Centre.

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K. Pinyopusarerk
CSIRO Division of Forestry
Canberra ACT

Styrax tonkinensis: Taxonomy, ecology, silviculture and uses

Styrax tonkinensis (Pierre) Craib ex Hartwiss is an economically important tree species in Laos and Vietnam where it occurs naturally and is cultivated in plantations. It is fast growing and can be cut on a 10-year rotation. Other features include a high reproductive capacity and an absence of major pest and disease problems. The species is used as a commercial source of benzoin (French name is benjoin) resin in Laos, where collection and sale of the resin is an important cottage industry amongst the hill people of the north. The benzoin resin from Laos is of high quality and suitable for use by the perfumery industry. The resin is known as white shellac in Vietnam, and provided income for people in some northern provinces until 1954. Resin tapping is no longer widely practised in Vietnam due to a significant decline in the market value of the resin (Lam Cong Dinh 1964; Vu Dinh Phuong 1985).

Styrax tonkinensis was first cultivated in a reforestation program in Yen Bai, Vietnam, in 1960, but its pulpwood potential was not recognised until 1971 (Vu Dinh Phuong 1985). The species is currently an important pulpwood species, supplying short-fibred pulp to the pulp and paper mill in Vinh Phu Province (Williamson 1989). The annual planting in north Vietnam is 3000 ha of which 2500 ha are planted by the Vinh Phu Supply Unit (J.A. Keith 1994 pers. comm.).

Styrax tonkinensis was introduced to French Guinea in West Africa in 1913-14 (Chevalier 1947). The species has become naturalised in many areas owing to the early production of large quantities of seed, which germinate readily. From 1935, the Forestry Department took an interest in this tree and propagated it throughout the country, but not in plantations. Although *S. tonkinensis* is more successful at altitudes of 800 m and above, satisfactory growth is reported near sea level. The species was introduced into southern China in Guangxi and Yunnan provinces in the 1970s (Zhong Chonglu 1993 pers. comm.), and is cultivated for wood production and collection of the benzoin resin.

Most information available on *S. tonkinensis* is published in the Vietnamese and French languages. These publications are fragmented and difficult to access. This report aims to gather all the information available and draw attention to gaps where further research and development are needed.

Since 1992, the Australian Centre for International Agricultural Research (ACIAR) has assisted the Lao Department of Forestry to identify tree species and provenances suitable for the national reforestation program. Although emphasis has been on fast-growing exotic species, *S. tonkinensis* has been included as an example of a fast-growing indigenous species with significant potential for further development. One of the priorities in commencing work in Laos on this species was to review the species' biogeography, its silviculture and utilisation, and hence the preparation of this report.

Nomenclature

Styrax tonkinensis belongs to the family Styracaceae. The genus Styrax consists of more than 20 species, many of which are characterised by having some form of medicinal use. The botanical name is derived from the term 'Tonkinese', which means a native of northern Vietnam. *Styrax tonkinensis* has many synonyms, i.e. *S. tonkinense* Pierre, *Anthostyrax tonkinensis* Pierre, *S. macrothyrsus* Perkins, *S. hypoglaucus* and *S. subniveus* (Svengsuksa and Vidal 1992). The species is native to Laos and Vietnam. In Laos, it is known as *may nhan* (general); *nhan khan thung, nhan ngwa*, and *nhan mok* (Houa Phan); (kok) *phung* (Xiang Khouang); and *may tsi yong* (Meo). The local name in Vietnamese is *bo de* (Hoang Lien Son); *nhan* (Thanh Hoa); and *mu khoa deng*. The Chinese name is *an si siang*. It is called *kam yaan* in Thailand.

Botanical Description

The following botanical description of *S. tonkinensis* is largely based on that of Svengsuksa and Vidal (1992). Line drawings of flowering branchlet, fruit, seed and flower bud are illustrated in Figures 1 and 3.

Tree

Styrax tonkinensis is a tree up to 25 m tall and 30 cm in diameter, with a clear bole for about two-thirds of total tree height. Bark is grey, smooth, and 6–9 mm thick when young, but becoming brown and rough with longitudinal fissures with age. Trees are light branching, with branches more upright toward the top. Young trees have a dense crown which can occupy up to two-thirds of tree height.

Foliage

Leaves are simple, alternate, ovate to elliptical, light acuminate. They are round at the base, serrated near the end and are 4.5–10 cm long and 2.6–5 cm wide. Petioles are 6–10 mm long. The leaf lamina is tough and leathery appearing smooth on the upper surface and very rough and hairy on the lower surface. There are seven to nine pairs of secondary veins which are conspicuous on the upper and lower surfaces. A typical characteristic of *S. tonkinensis* leaves is the dark green colour on the upper surface and whitish green on the lower surface.

Inflorescence

Inflorescences, up to 18 cm long, are in double racemes in the upper axils of the leaves or at the terminal part of the shoot. They have a leafy base covered with yellowish stellate hair; the caducous bract and linear bracteoles are very hairy. The inflorescence is comprised of many small, white aromatic flowers, 12–15 mm long with 3–5 mm pedicels. The cup-shaped calyx is 3–4 mm long, densely covered with yellowish stellate hair on the outside and whitish hair on the inside, with five short lobes. The 8–12 mm long corolla has a 2.5–3 mm tube, five 6–8.5 mm × 2–3 mm overlapping lobes, felted with yellowish stellate hair on the outside, interspersed with simple hair on the inside. The stamens reach two-thirds of the corolla lobes; their flat filaments are covered with long stellate hair; the linear anthers are interspersed with long stellate hair. The superior ovary, slightly adherent to the base, is ovoidal and covered with stellate, hispid hair; the style is slender, bare, 10–13 mm long.

Fruit

The fruit is ovoid, 10–12 mm long and 5–7 mm wide, covered with greyish stellate hair, dehiscent through three valves. The pericarp is thin, about 1 mm; there is an upright, three-rowed fossulate single seed (very rarely two), with a verucousate, hard, thick, orange-coloured episperm.

In this report, for convenience the term 'seed' will be used instead of 'fruit'. The term 'fruit' will be used only where the distinction between fruit and seed is necessary.

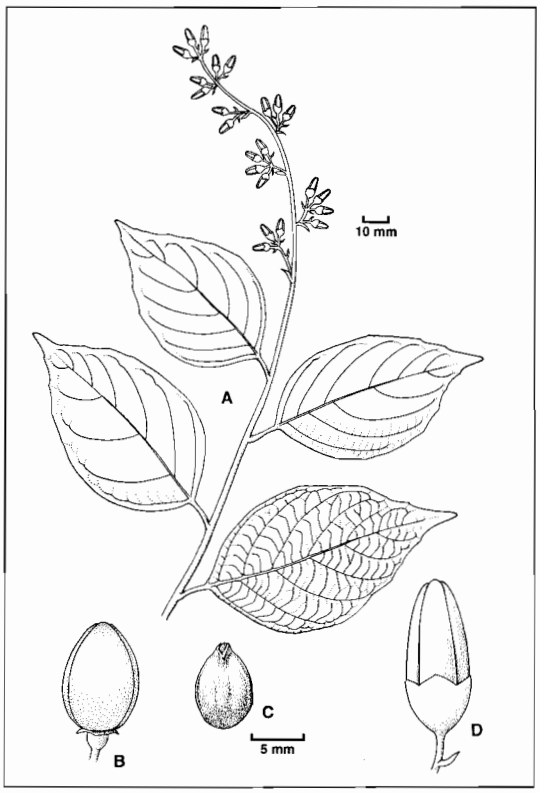

Figure 1 *Styrax tonkinensis*. A, flowering branchlet; B, fruit; C, seed; D, flower bud.

Natural Distribution

Styrax tonkinensis is found mainly in secondary rainforests in the northern parts of Laos and Vietnam (Figure 2). In Laos, it occurs in the five northern provinces of Phongsali, Louang Namtha, Oudomxai, Louang Phabang and Houa Phan (Anon 1923; S.

Ketphanh pers. comm. March 1993), between latitude 20° and 22°N and longitude 101° and 105°E. The distribution extends into Vietnam to the northern provinces of Son La, Hoa Binh, Yen Bai, Lao Cai, Vinh Phu, Tuyen Quang, Ha Giang, Bac Thai, Thanh Hoa and Nghe An (Anon 1923; Le Dinh Kha pers. comm. March 1994), between latitude 19° and 23°N and longitude 103° and 107°E.

The altitudinal range is mainly from 150 to 2100 m. In Laos, it is found predominantly at high altitude, 800–1600 m (Vidal 1960; Svengsuksa and Vidal 1992). In Vietnam, it is distributed at low to medium altitude, mostly below 1000 m (Vidal 1960). Trees growing naturally at altitudes as low as 60 m have been observed at Bavi and Cau Hai in Vinh Phu Province.

Ecology

Climatic Requirements

Rainfall

Over most of its distribution, *S. tonkinensis* occurs in areas with a mean annual rainfall of 1500–2200 mm with no distinct dry season, or only a few dry months. However, when cultivated, it will thrive in areas of harsher climate with a mean annual rainfall of 1300 mm and 3–6 dry months (Lam Cong Dinh 1964).

Temperature

In the natural range the mean annual temperature lies between 15° and 26°C. However, it can tolerate extreme temperatures of -4°C or +45°C, for brief periods (Lam Cong Dinh 1964).

Light

Styrax tonkinensis is a light-demanding species. In an open, burnt-over area the species often occurs in the upper storey. Wild seedlings cannot survive shade under dense forests.

Soil Requirements

The soils on which *S. tonkinensis* occur are yellow or red-yellow lateritic soils overlying mica schists, clay schists and sandstone. These soils are acidic, having 2–3% of humus in the surface layer with little P_2O_5 and K_2O, but with the ability to retain moisture. The species will grow well in non-eroded soils which are well drained, moist and fertile. It can also grow on brown-yellow lateritic soil overlying old alluvium, and humus lateritic soil on mountains overlying granite or schists. It does not grow well where hard pans underlay lateritic soils, or on sandy, limestone soils on barren hill slopes after laterisation.

Influence of Other Factors

The extension of the range of the species owes a great deal to activities of man and to its pioneer characteristics—the demand for light and its regular production of quantities of viable seed. Many stands of *S. tonkinensis* occupy sites previously used for slash-and-burn agriculture. Fire deliberately lit during the slash-and-burn process accelerates seed germination.

Phytosociology

Styrax tonkinensis is a gregarious species capable of invading gaps in the forest. Under favourable conditions, it may occupy many hectares as almost pure stands. Lam Cong Dinh (1964) reported a study in a *Styrax*-bamboo forest at Yen Bai Province in Vietnam on a steep slope (40–50°). *Styrax* trees dominated the upper storey where 800 stems (8–25 m in height) per ha were recorded; most trees were 15–20 m tall. No *Styrax* seedlings could be found under dense bamboos, but as many as 220 seedlings/m^2 grew where bamboos had been removed.

Bamboos, in particular *Dendrocalamus* sp., are one of the most common associates of *S. tonkinensis*. In natural regeneration following slash-and-burn agriculture, *Imperata cylindrica* and *Saccharum arundinaceum*, and occasionally *Miscanthus japonicus* are common undergrowth. Associated species in secondary rainforests include *Cinnamomum cassia*, *Quercus* sp. and *Toona ciliata*.

Qualitative Aspects of Development

Growth of seedlings and saplings

Seed germination is slow and sporadic. Although germination starts 10–15 days after sowing, it may last up to 5 months (Nguyen Ba Chat 1979). Temperatures favourable for germination are 20–25°C.

Germination is epigeal. The leafy cotyledons, <1 cm in diameter, begin to unfold but then extend and become somewhat round, 2 × 2.5 cm. The first and subsequent leaves are alternate. The root develops clearly as a tap root. Seedlings develop axillary shoots

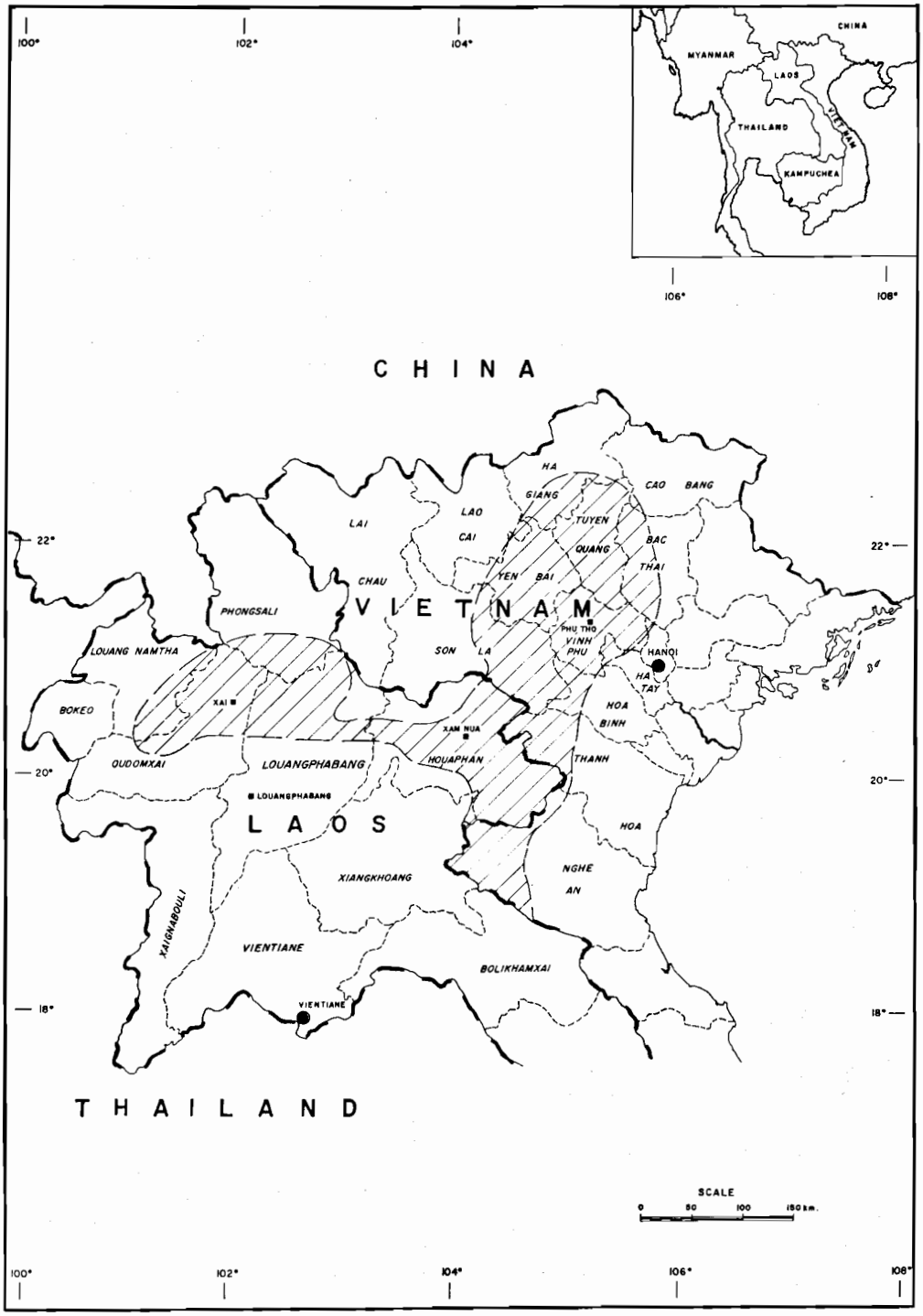

Figure 2. Natural distribution of *Styrax tonkinensis* in Laos and Vietnam.

in the early stage, but these never outgrow the leading shoot, indicating strong apical dominance. A line drawing of a three-month-old seedling is illustrated in Figure 3.

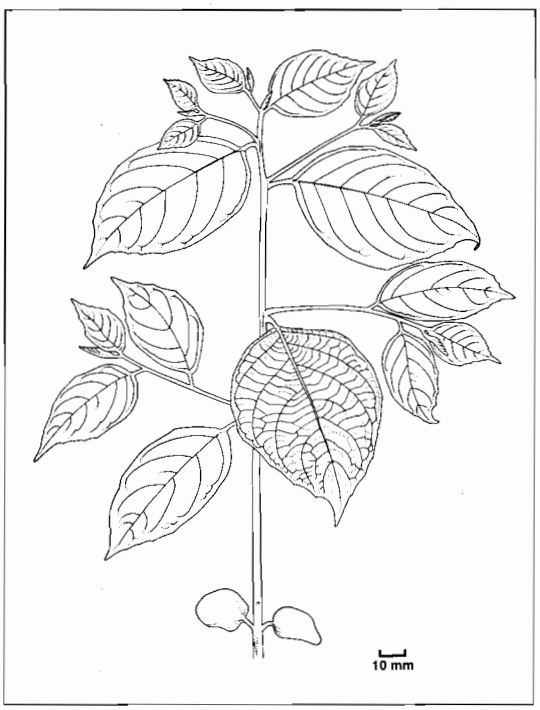

Figure 3. Line drawing of a three-month-old seedling of *Styrax tonkinesis.*

Development of the tree

Young trees tend to develop a deep and moderately dense crown, with an upright (35–55°) branching characteristic (Lam Cong Dinh 1964). The branches become progressively more horizontal and the foliage becomes less with age. The development of a clear bole as a result of natural pruning denotes the change from juvenile to mature tree. The root system is shallow and as the tree ages, the tap root disappears (Vu Dinh Phuong 1985).

Deciduous habit

Styrax tonkinensis is a partly deciduous tree and sheds its leaves during the cool, dry season between November and February or March (Lam Cong Dinh 1964). Old trees shed more leaves than young trees. New flushes generally start in March, but young trees tend to sprout earlier. Defoliation is irregular in young trees in particular, partial loss often being followed by regrowth in response to light rain.

Flowering and fruiting

Flowering and fruiting time varies with location. Flowering usually occurs during April to June (sometimes until July), and fruit matures from July to November (Legris 1949; Lam Cong Dinh 1964; Svengsuksa and Vidal 1992). The first flowering takes place at 4–5 years of age. When fully mature, i.e. 10 years old, each tree produces up to 40 kg of fruit per year. Each 2–3 kg of fruit contain 1 kg of seed. There are about 8000–9000 seeds per kg. Fresh seed has high germinative capacity; 80–90% is obtainable.

Natural pruning

Natural pruning is excellent, and thus pruning is not necessary in *Styrax* plantations. Mature trees usually have clear boles for two-thirds of total tree height.

Silvicultural Systems

Natural Regeneration

Styrax tonkinensis regenerates well in gaps, provided that undergrowth is not too heavy, as saplings are sensitive to competition in their early years. After this phase, the young trees grow very rapidly to dominate the site. An inventory in Vietnam reported by Lam Cong Dinh (1964) found that there were as many as 37 000 seedlings (2–6 leaves) under 430 mature trees in 1 ha—an average of 86 seedlings per mature tree. However, due to high mortality and competition, only one of the 86 seedlings reached maturity.

When harvesting *S. tonkinensis* forest in Vietnam, 50–100 *S. tonkinensis* trees/ha are left to provide seed. Some ground work (e.g. clearing undergrowth) may be done to assist seed germination and seedling growth. Additional seed is sometimes sown. Local people provide tending during the first few years to help the young trees to establish and to restrict invasion by bamboo.

In northern Laos, villagers have a different practice to assist natural regeneration of *S. tonkinensis*. A 14–15-year-old regrowth forest will be clear-felled and the area burnt during the dry season. The fruit, which falls during clear felling, germinates in the following rainy season. The dense seedling population will be heavily thinned to 600–800 stems/ha at 3–4 years. Cash crops, especially upland

rice, are interplanted for a few years before the crown canopy becomes too dense. Resin tapping starts at year 7 and continues for 6–7 years, at which age resin production of the trees is poor. The whole stand will then be cleared and another cycle of regeneration begun.

Styrax tonkinensis in Plantations

To date, Vietnam is the only country known to carry out large-scale planting of *S. tonkinensis*, with over 50 000 ha having been established. Hence the silvicultural practices discussed here are based largely on Vietnamese experience, especially that described by Lam Cong Dinh (1964) and Anon (1983).

Seed collection

Seed of *S. tonkinensis* is collected between September and November in Vietnam (Lam Cong Dinh 1964; Le Quang Dang 1966) and October and November in Laos (Legris 1949). Collection is made from trees with the following characteristics:

- About 10 years of age
- Free from diseases
- Well-proportioned canopy
- Not located on the edge of a stand
- No top die-back
- A minimum distance of 30 m between trees

Ripe fruit only is collected from the middle of the canopy. Collection should not be made from the ground because fallen fruit does not germinate (Lam Cong Dinh 1964). Ripe fruit is characterised by:

- A silvery colour with pale white spots of the outermost coat
- Splits at the top of the fruit
- An outer seed coat which is dark black or cow-skin yellow
- An inner seed coat (between testa and endosperm) which is clear and thin
- An endosperm which is translucent with a greenish outer cover

Seed storage

Styrax tonkinensis seed loses viability within short time of collection unless it is properly stored. Moisture content is the most critical factor determining seed viability. Doan Van Nhung et al. (1978) stored seed for up to 11 months at moisture contents at or below 17%; they found that germination during the first 8 months was 0–18% and that none of the seed germinated after 8 months. In contrast, when the moisture content was maintained around 30% over a 14-month period, germination remained high at 65–70%.

Hoang Chuong (1974) noted that when the seed was kept under dry storage the moisture content dropped very rapidly from 30% to 2–3%, and that the seed then failed to germinate. However, the moisture content of seed could be restored by simply soaking in water. The highest moisture content attained was 35–36% even when seed was soaked in water for months. The seed germinated well after its moisture content was brought back to 30%, suggesting that when its moisture content was low the seed was simply dormant and that it retained the ability to germinate under favourable conditions.

The required high moisture content of seed can be achieved by putting the seed in either still or running water (Hoang Chuong 1974). Storing the seed in mixture with wet sand has also been found to yield very satisfactory results. The latter storage method is now a standard practice in Vietnam (Anon 1983). The process comprises two stages. The first is pre-storage to bring the moisture content to the safe level, i.e. 30%, since newly-collected seed is often at a moisture content much lower than the safe level. This first stage is also used as a pre-germination treatment, during which the seed will be separated from the fruit. The second stage is for storage of up to 1 year.

Pre-storage

- Mix fruit thoroughly in wet sand until it is coated with the sand
- Place the mixture in a 10 m × 1.5 m bed to a depth of 15 cm and spray with 40–50 litres of water every 3rd day
- Remix the fruit-sand beds gently twice a day
- The process is considered to have been satisfactorily concluded if the outermost coat of fruit has turned from hard with silvery whitish spots to soft and grey
- The pre-storage process can extend to 30–40 days

Short-term storage

- Separate seed from sand by sieving with mesh screen
- Mix seed with fresh wet sand in a ratio of 1:1
- Place the mixture of seed and sand in beds of 10 m × 1.5 m to a depth of 60 cm, and cover with 3 cm wet sand

On a specified day of each month the seed-sand beds are tended as follows:

- Gently turn the mixture

- Spray 40–60 litres of water over each bed
- Ensúre the bed surface is even and porous
- Maintain a top layer of 3 cm of moist sand

Such storage should be under shade with good ventilation and at an ambient temperature of around 16–17°C. Seeds stored under this condition for 1 year will maintain high germinative capacity (Lam Cong Dinh 1964). Storage procedures are carried out only when seeds are not to be sown in the first spring following collection in autumn.

Planting stock

Until the mid-1970s, direct sowing of pre-treated seeds into prepared holes was used routinely for *S. tonkinensis* plantings in Vietnam (Nguyen Ba Chat 1979). Five to seven seeds were sown in each hole in which one to five seeds might germinate. Subsequently, the seedlings were thinned to leave only one plant per hole. This method was uneconomical because many seeds were wasted. With the advent of government policy to increase planting of *S. tonkinensis* to supply material for the pulpwood industry, the Forest Research Institute was commissioned to improve techniques of plantation establishment. New planting methods using nursery-raised tubed seedlings and stumps were introduced.

In the nursery, treated seeds are sown onto germination beds, which are kept continually moist during the germination period. The germination mix should be free draining; a mixture of one part river sand and one part loamy forest soil is suitable. Germinated seeds are transplanted into tubes containing forest top soil when the cotyledons have fully expanded. They are protected from full sunlight until the first two seedling leaves appear. The seedlings are kept in the nursery for 2 months by which time they should reach 15 cm in height with five to seven leaves, and are ready for outplanting.

Stumps are prepared from seedlings which are raised in nursery beds for 10–12 months, at which time the seedlings are 1–1.5 m tall and 1–2 cm in diameter at the root collar. The seedlings are lifted from nursery beds at planting time. The stem is cut off 3–5 cm above the root collar and some of the lateral roots are trimmed from the tap root.

The planting methods using nursery-raised seedlings or stumps, however, did not reduce the amount of seed used compared to that used by direct sowing, because of poor recovery and damage by crickets in the nursery (Nguyen Ba Chat 1979). For each kilogram of seed only 530 plantable seedlings were produced. Therefore, to establish 1 ha of plantation with a density of 3300 trees, 6 kgs of seeds were needed. The same amount of seed would be required to raise seedlings for stumping. If direct sowing was used, only 3 kgs of seeds were needed. Tubed seedlings might be seen to have an advantage over direct sowing in that they could be used to replace the dead ones after planting. This was not necessarily true since, in the direct sowing method, holes without germinated seeds were rare. Nguyen Ba Chat (1979) concluded that nursery techniques of *S. tonkinensis* needed to be improved if increased use of tubed seedlings or stumps was anticipated.

Planting density

Various initial planting densities are currently used in Vietnam. The planting density chosen depends on the site quality, planting method and, to a lesser extent, demand for fuelwood and small wood in the area.

Three initial densities have been recommended by the government for all plantings, regardless of the planting material (Anon 1983). These are:

(1) 1600–2000 stems/ha (approx. 2.2 × 2.2 m spacing). This density is used where the soil is fertile, well drained and not subject to erosion. Associated vegetation is dominated by tall trees in mixture with bamboo or a pure stand of bamboo.

(2) 2000–2500 stems/ha (approx. 2 × 2 m spacing). This is used where the soil is relatively fertile and well-drained but may be subject to erosion. Associated vegetation is dominated by small trees or shrubs in mixture with bamboo.

(3) 2500–3300 stems/ha (approx. 1.8 × 1.8 m spacing). This spacing is suitable where soil fertility is low and there is poor drainage or erosion anticipated. Associated vegetation consists of small shrubs and/or pure bamboo, or a well developed grassland. This density is also recommended where demand for fuelwood and small wood is high.

Establishment techniques

Direct sowing, nursery-raised stock (tubed seedlings) and stumps can be used individually or in combination depending on various circumstances e.g. soil fertility, time of planting and availability of resources. Regardless of the stock used site preparation follows the same routine. Ground vegetation is cleared, left to dry and burnt. A strip of vegetation 10 m wide will be maintained around mountain tops if the slope is 25–30°. Furthermore, if

the slope is more than 100 m in length, additional 5–10 m wide strips of vegetation with spacing of 50–100 m following the contours will be kept. The following establishment prescription is followed:

Direct sowing

- Burn the debris 10–15 days before digging holes
- Dig planting holes to 20 cm × 20 cm × 25 cm deep
- Five to six seeds, spaced at 5 cm, are placed in each hole and covered with a 2 cm layer of porous soil
- Supplementary planting with tubed seedlings will be carried out if survival is <80%

The sowing time is from October to January. Seed is sown in February only in exceptional circumstances, i.e. if the soil is fertile, continuous rain is anticipated and maximum temperature does not exceed 25°C at time of sowing.

Tubed stock planting

- Dig planting pits of 25–30 cm × 25–30 cm × 20–25 cm
- Remove tubes (if not degradable) before putting the seedling in the hole
- Replant after one month if survival is <80%

Planting time is normally from January to March, or April if weather permits. Planting can also be carried out in September or October if seedlings have reached plantable size and sites are prepared.

Stump planting

- Dig planting pits of 35–40 cm × 35–40 cm × 25–30 cm
- Carefully place the stump into the hole so that at least 2–3 cm of stem protudes above the soil
- Sprouting should take place 7–10 days after planting otherwise replant within 1 month
- Stumps should be planted during January–February
- When sprouts attain 20–30 cm, trim to the single best shoot

Mixed planting

Mixed planting with *Manglietia glauca* (a fast-growing species suitable for planting for pulpwood production) has been recommended to reduce the problem of insect attack (Thai Van Trung 1975). *Manglietia glauca* should be planted first in spring at a spacing of 6 m between rows and 1.5 m within rows. *Styrax tonkinensis* seedlings are planted in autumn between the rows of *M. glauca*. Initial stocking of the combination of the two species is 2050 trees/ha. To lessen the impact of leaving exposed soil between the rows of *M. glauca* for some months, it is suggested that a legume ground cover, *Tephrosia candida,* be sown to control the weeds, reduce erosion and to improve the soil fertility. Rice or maize can also be planted between the rows, but cassava or tuber-root plants must not be inter-planted. After *S. tonkinensis* is inter-planted with *M. glauca*, cereal crops should not be cultivated on the site. Apart from *M. glauca*, other species such as *Cinnamomum cassia, Ormosia tonkinensis, Quercus hagiangensis* and *Rhamnoneuron halansae* may be suitable for the mixed planting.

Maintenance and tending

Weeding

In the first 2 years, *S. tonkinensis* plants should be kept free of weed competition by regular removal of ground vegetation and cultivation of soil in a 50–60 cm radius around each plant. For older plantations, tending is generally by clearing climbers and unwanted ground vegetation on an as-needed basis.

Fertilizer

The main objective of fertilizer application is to produce uniform, fast-growing plantations. Uniformity makes it easier to prescribe thinning operations.

Nitrogen fertilizer is to be applied immediately after planting to help the newly-planted seedlings to establish themselves within the shortest possible time. The recommended rate is 60 g N fertilizer per tree, which is divided into 3 applications of 20 g each within a 1 month period. Fertilizer should be dug in, approximately 40 cm from the plant (Anon 1983).

Hoang Son (1989) reported fertilizer trials in 6–8-month-old *S. tonkinensis* plantations at Ham Yen, Tuyen Quang Province. The soils were strongly acidic (pH 3.4–4.5) and low in N (0.07–017%) and P (2–5%). NPK and superphosphate fertilizers were found to improve height and diameter growth, but the responses were short lived, i.e. no effect after 6 months. Another trial of various combinations of N and P (in the form of urea and superphosphate) showed that all N and P mixtures significantly improved height and diameter growth compared to the control treatment. There were, however, no clear-cut results as to the most effective combination although low P and high N tended to be more favourable. There is a need for more systematic studies on fertilizer requirements of *S. tonkinensis*.

Table 1. Thinning regimes for *Styrax tonkinensis* plantations of different initial densities(derived from Anon 1983).

	Initial density (stems/ha)								
	2000			2500			3300		
	Thinning intensity	Remaining trees		Thinning intensity	Remaining trees		Thinning intensity	Remaining trees	
	(%)	No. of trees (stem/ha)	Mean dbh (cm)	(%)	No. of trees (stem/ha)	Mean dbh (cm)	(%)	No. of trees (stem/ha)	Mean dbh (cm)
First thinning	50–55	900–1000	6.5–7.5	50–55	1100–1250	5.5–6.5	50–55	1500–1650	5.0–6.0
Second thinning	25–35	650–750	9.5–10.5	35–40	700–750	8.5–9.5	50	750–850	7.0–8.5

Thinning

Thinning forms part of routine management in *S. tonkinensis* plantations, as a result of high stocking at establishment. In general, two thinnings are required before the plantations reach the rotation age of 10 years; the first (50–55% intensity) at about 2 years old and the second (25–35% intensity) at about 3 years. This results in a final stocking of about 600–800 stems/ha. Table 1 shows thinning regimes for *S. tonkinensis* plantations of different initial densities.

It is recommended that thinning be done during the dry season. At the first thinning, if the survival rate is >80%, systematic thinning in combination with selective thinning can be applied.

Thinning schedules based on mean diameter at breast height (dbh) of the plantation have been developed. The dbh has been shown to be highly correlated (r = 0.9) with crown diameter (Pham Minh Nguyet 1976). Since the mean crown diameter of the plantation (D) reflects the current spacing of the plantation itself, the desirable number of trees per ha (N) at a given time can be estimated by $N = 10\,000/D^2$.

The following thinning program based on mean dbh of the plantation has been proposed for *S. tonkinensis* plantations established on average soils in Vietnam.

Growth and Yield

Styrax tonkinensis is considered to be a fast growing species. Under favourable conditions annual height increment of 3 m can be attained during the first 3 years. A mean height of 18–25 m and dbh of 20–24 cm with underbark volume of 0.20 m^3/tree are obtainable at 10 years (Thai Van Trung 1975). Such growth would give a yield of about 150 m^3/ha where final stand stocking is 600–800 stems/ha.

However, growth varies considerably depending on site quality, planting method and stand density. Nguyen Ba Chat (1979) compared growth of *S. tonkinensis* established (spacing not reported) with potted seedlings, stumps and direct sowing at Cau

Table 2. Thinning guidelines based on the mean dbh of *Styrax tonkinensis* plantations established on average soils in Huu Lung, Lang Son, Vietnam (after Pham Minh Nguyet 1976)

Mean dbh (cm)	Initial stocking (stems/ha)	Trees to be thinned (stems/ha)	Trees remaining (stems/ha)
2	5 690	1 979	3 711
4	3 711	1 101	2 610
6	2 610	675	1 935
8	1 935	443	1 492
10	1 492	307	1 185
12	1 185	221	964
14	964	165	799
16	799	125	674
18	674	99	575
20	575	78	497
22	497	63	434
24	434	52	382
26	382		

Note: The mean dbh is an indication of the maximum number of trees per ha. Thus for the mean dbh of 10 cm the number of standing trees in the plantation should not be more than 1500 stems/ha.

Hai, Vinh Phu Province. At 2 years, mean height was 8.4, 8.3 and 7.7 m for potted seedlings, stumps and direct sowing respectively.

Initial density has been found to affect tree growth (Table 3). Observations in 2.5-year-old stands of different densities in Yen Bai, northern Vietnam, showed that under very high densities (8300–10 600 stems/ha), trees grew rapidly in the first year. At 2.5 years, however, diameter growth decreased considerably, due probably to competition among the trees. Under initial density of 4400 stems/ha, height and diameter growth in the first year was slower than that obtained for the higher density plantings, but the reverse was true at 2.5 years due to less competition. The results suggest that early thinning (at 2 years) is necessary for high density plantings.

Table 3. Height and diameter at breast height of *Styrax tonkinensis* planted at different densities in Yen Bai, northern Vietnam (derived from Lam Cong Dinh 1964)

Initial stocking (stems/ha)	1-year growth Height (m)	1-year growth dbh (cm)	2.5-year growth Height (m)	2.5-year growth dbh (cm)
10 600	3.0	1.7	9.3	6.2
8 300	3.0	1.9	8.5	5.4
4 400	2.4	1.6	9.9	7.2

Pests and Diseases

A defoliator, *Fentonia* sp. (Lepidoptera: Notodontidae), is reported to damage thousands of hectares of *S. tonkinensis* plantations in Vietnam each year (Le Nam Hung 1990a). The larval stage has four instars, but the third and fourth instars are most damaging; each larva consumes 6–7 g of leaves during the larval stage. Prior to entering the pupal stage, the larvae dig into the ground. Some 91% of the cocoons in the ground lie within the crown projecting area. Observation during an outbreak in Yen Bai in 1980 recorded up to 169 larvae/m^2. Adult moths are active at night, with peak activity between 8 and 9 pm. Female moths each lay about 190 eggs on the lower side of leaves.

The *Fentonia* defoliator has numerous natural enemies including two ant species (*Oecophylla smaragdina* and *Cremastogaster* sp.) and two bees (*Anastatus* sp.) (Le Nam Hung 1990a). A colony of *Oecophylla smaragdina* ants can eat up to 200 larvae in 48 hours, and that of *Cremastogaster* sp. consume 800 eggs in 48 hours. Of the *Anastatus* bees, one is a parasite of eggs and another (a black bee) is a parasite of larvae. It is therefore necessary to protect ants as well as bees in the *S. tonkinensis* forests.

Control measures by chemical sprays have also been recommended during the outbreak (Anon. 1983; Le Nam Hung 1990b). Any use of chemicals must follow strict state regulations imposed by the Vietnamese Ministry of Forestry. Soil cultivation around the trees in young plantations during the dry season (October to December) not only reduces weeds but also kills up to 90% of *Fentonia* pupae (Le Nam Hung 1990b).

Seedlings in the nurseries are sometimes damaged by crickets. No control measures have been suggested.

Products and Utilisation

Wood Products

The wood of *S. tonkinensis* is white, soft and light, with air-dry density (15% moisture) between 413–450 kg/m^3 (Lam Cong Dinh 1964; Vu Dinh Phuong 1985). It is used to make wooden shoes, pencils, chopsticks and matches. It is not suitable for use in construction because the wood is not durable and is easily broken, bent or buckled. As much as 6000 m^3 of round wood was reported to have been utilised for 180 million match boxes during the 1960s in Vietnam (Lam Cong Dinh 1964). Wood from thinning is generally used as firewood or poles. *Styrax tonkinensis* is also used in laminates because it peels well and makes good stable veneer.

Styrax tonkinensis is an important pulpwood species in Vietnam although its wood to pulp ratio appears to be high (8.6 m^3/tonne). The wood fibre for the pulp and paper mill located at Bai Bang, Vinh Phu Province consists of *S. tonkinensis* of which 112 000 tonnes are needed for annual production, and bamboos from natural forests at 48 000 tonnes (Williamson 1989). Laboratory pulping tests of *S. tonkinensis* in comparison with some hardwoods species have been reported by Giertz (1974). The results are shown in Tables 4 and 5.

Non-wood Products

Benzoin resin

An important non-wood product from *S. tonkinensis* is benzoin resin, a balsamic resin widely used in the perfumery industry. The balsamic latex flows from

Table 4. Bisulphite Chemimechanical pulping of different hardwoods

Species	Origin	Cooking conditions Temp (°C)	Time (min)	pH	Consumption of chemicals (%S on wood)	Yield (%)	Brightness (SCAN)
Poplar	Norway	150	65	4.2	3.5	81	76
Eucalyptus	Brazil	150	60	5.0	3.6	85	44
saligna			90	5.0	4.2	81	45
Styrax	Vietam	170	40	6.3	3.0	88	61
tonkinensis			60	6.3	3.2	84	58
		155	20	4.5	6.0	75	
Manglietia	Vietnam	170	25	4.9	3.4	89	60
glauca		155	40	4.5	4.0	85	

Table 5. Physical properties of laboratory sheets. Unbleached chemimechanical pulps; single stage refining.

Species	Yield (%)	Density (g cm^3)	Breaking strength (km)	Tear factor
Birch	85	.48	4.8	54
		.56	6.4	45
Eucalyptus	85	.29	1.9	17
saligna		.41	3.2	20
Styrax	88	.33	3.5	37
tonkinensis		.42	3.8	35
Manglietia	89	.36	3.7	37
glauca		.43	4.0	28
Comercial chemical pulp				
Bleached pine sulfate		.69	7.2	123
		.79	8.6	103

wounds in the bark and outer wood where incisions are deliberately made. It is thus a pathological product (it does not occur in healthy, unwounded trees). The resin is yellow-orange or yellow-brown with an almost white or creamy fracture. The odour is pleasant, sweet-balsamic with a distinct note of vanillin. When chewed, the resin becomes plastic. Its taste is aromatic but somewhat acrid-bitter and biting (Arctander 1960). The benzoin resin of *S. tonkinensis* is characterised by its content of benzoic acid (10–12%), while the major constituent is benzyl benzoate (65–70%). Analysis of a resin sample collected from Laos using combined gas chromatography/mass spectrometry reveals that apart from benzoic acid and benzyl benzoate there are a significant number (>20) of aromatic esters present (J. Brophy 1993 pers. comm.).

The benzoin resin from *S. tonkinensis* is commercially known as 'Siam Benzoin' because at one stage it was marketed through Siam (former name of Thailand) (Adamson 1971). The name could also have been adopted because highland Laos was, for some time, under Siamese domination (Drouet 1924). The important market during the 1960s was in London, where annual trade was as high as 60–70 tonnes. Extractives from Siam Benzoin—benzoin tincture and benzoin resinoid—are used in high quality perfumery work where they have excellent fixative qualities. However, the demand for benzoin resin has declined due to the increased use of synthetic flavour material. There is also 'Sumatra Benzoin', a balsamic resin exuded from *Styrax benzoin* trees growing naturally in Sumatra and the Malay Peninsula. Siam Benzoin is recognised as a far superior product to the Sumatra Benzoin.

Resin tapping is an important cottage industry and widely practised by highland people (Lao Thung) in northern Laos despite the decreasing demand. Resin is also tapped in Vietnam but only on a small scale (Le Dinh Kha 1993 pers. comm.). The method is primitive. The tapper makes a notch 8–10 cm wide and 5–6 cm long into the cambium. The bark which is still attached to the trunk by its lower part is loosened. These incisions are staggered at intervals of 20–30 cm along the trunk. The lower incisions are made at 30 cm from the ground; the higher ones at the level of the first branches. In some villages, the incisions are made up to 2 m only; the following year a new 2 m section is tapped above the first one, and so on until the first branch is reached.

Tapping is done on 3- to 5-year-old trees in natural forests, and on 6- to 8-year-old trees in regenerated forests (Svengsuksa and Vidal 1992). The tapping

continues for 3–4 years in natural forests and 6–7 years in regenerated forests until the tree dies. When tapping is conducted with greater moderation, production from a single tree may continue for up to 6–8 years. It is suspected that intensive tapping contributes to the early demise of productive trees. Tapping time varies with locality. In Xam Nua, Houa Phan Province, incisions are made in July/August, and resin harvested in December/January. In Louang Phabang, incisions are made at the end of the wet season in October/November, and resin collected in March. A few weeks after the incisions, the sap grows thicker but remains soft and viscous until the first cold days in winter, which make it hard and brittle, and ready for collection. It has been noted that incisions made during dry years remain clear allowing a good flow of resin. On the contrary, in a very wet year, the bark partly closes up on the cut, preventing the secretion. There is, however, no information on the relationship between size of incision and secretion of resin. On average, 1–3 kg of resin is produced by each tree in each year.

The production of benzoin resin varies with tree and altitude (Drouet 1924; Lam Cong Dinh 1964). More resin is obtained from trees having dark brown, thick bark with deep fissures and obvious parenchyma cells. Trees yielding less resin have light-coloured, thin, smooth bark, with shallow fissures and obscure parenchyma cells. The trees in Laos are more resin-productive than those in Vietnam (Svengsuksa and Vidal 1992). This may be due to the fact that the trees in Laos are mainly distributed or cultivated at high altitude.

Raw benzoin contains many impurities such as particles of bark and leaves. The market value of the benzoin not only depends on the purity but also the size of tears; the larger the tears the higher the value. Therefore, care is exercised during the harvest not to break the large tears. After the harvest, villagers carry out an initial sorting of good quality tears from the bark, i.e. clean and large tears. High quality tears represent less than one-third of the original harvest. This is tedious work normally done by women.

During the 1940s, the benzoin sold on the world market (mainly America and France for perfumery) under the name 'Siam Benzoin' came mostly from Laos. In 1948 alone, 30 tonnes were produced from Xam Nua, Houa Phan Province, and another 20 tonnes from the basin of Nam Ou, Louang Phabang Province (Legris 1949). This production almost entirely satisfied the world demand. Purchase price as at village was around $US15/kg. At the end of 1993, the purchase price had declined to $US1.50–$US2/kg. This is due to the decrease in demand for the resin perfumery. The current annual production of the benzoin is not known, but is believed to be significantly less than 50 tonnes.

Recent developments in Laos suggests that the demand for benzoin resin may rise. The French are believed to have been negotiating with Lao authorities for an annual supply of 40 tonne (K. Kingsada 1994 pers. comm.). Furthermore, investors from Malaysia have shown interest in a wide range of non-wood forest products from Laos including essential oils and benzoin resin (C. Inthavong 1993 pers. comm.). The benzoin resin from *S. tonkinensis* will, no doubt, remain an important source of income for the highland Lao people.

The benzoin resin is used in traditional medicine in China. The products are claimed to cure rheumatism, coughs, colds, stomach ache and heart burn (Zhong Chonglu 1993 pers. comm.).

Erosion Control and Amenity

Styrax tonkinensis is used to restore eroded soils, and planted to provide green fire breaks in the French Guinea in West Africa (Chevalier 1947). It is sometimes planted as an ornamental tree.

Genetic Variation

There have been no systematic studies of the genetic variation within *S. tonkinensis*. The only evidence of such an attempt appears to be a report on a small provenance trial by Nguyen Thai Ngoc (1989). His study, however, compared only three sources from a narrow range in Vietnam and did not show significant provenance differences.

Other information suggests that substantial genetic variability may exist:

(1) Extensive altitudinal range. The species is distributed from 60 m to 2100 m above sea level. Such a distribution raises questions as to whether patterns of genetic variation have developed relating to adaptation to changing climate. Such a range of habitats commonly results in clinal variation in a variety of attributes.

(2) Morphological variation. Two distinct characteristic bark types have been observed in the species, i.e. dark brown, thick and cracking bark, and white, thin and smooth bark. It is not known

whether this difference is related to altitudinal distribution. In Louang Phabang, Laos, *S. tonkinensis* is thought to consist of two forms, locally called 'red' and 'white' nhan (B. Thongmalaivong pers. comm. March 1993).

(3) Variation in resin yield. Resin yield has been observed to vary with altitude. Higher-resin-yielding trees are reported to be distributed at altitudes above 600 m (Lam Cong Dinh 1964; S. Ketphanh pers. comm. March 1993). Furthermore, trees having thick dark brown or red bark are claimed to produce more resin than those having thinner and lighter bark (Lam Cong Dinh 1964; B. Thongmalaivong pers. comm. March 1993).

Summary and Conclusions

Styrax tonkinensis is a fast-growing tropical species occurring naturally in secondary forests in northern Laos and Vietnam. The species is easy to establish and has a wide variety of uses, making it an economically important tree in these countries.

For more than 30 years, *S. tonkinensis* has been a major plantation species in northern Vietnam to supply raw material to the country's only pulp and paper mill in Vinh Phu Province. At present, however, there appears to be no genetic improvement program for the species. Only recently has seed from different provenances been collected in Laos and Vietnam, but this has not been done in any systematic, range-wide fashion. Although study of provenance variation may now be possible, there is a need for a more extensive sampling of populations to secure genetic material for tree improvement programs.

Plantation establishment is either by direct sowing, tubed stock or stumps. The use of tubed stock has been adopted in Vietnam to reduce the large amount of seed necessary for direct sowing. Seedling losses in the nurseries, however, are high. As a result, the actual amount of seed used to produce seedlings to establish each hectare of plantation is sometimes greater than that needed for direct sowing. It appears that nursery techniques for *S. tonkinensis* need to be improved, and the slow and sporadic germination of seed investigated. The possibility of using vegetative propagation to multiply superior planting stock should be determined.

The major use of this species in Laos is for benzoin resin production. There are indications that intensive tapping may cause the early death of productive trees. It is apt to explore alternative or less intensive tapping methods which might sustain high resin yields from individual trees for an extended period.

The benzoin resin produced from Xam Nua is reported to be of high quality and suitable for use in perfumery industry. However, there is insufficient information to conclude that trees occurring in other regions are inferior in this regard. This can only be confirmed by a systematic assessment of variation in the yield and quality of resin of trees throughout the natural range of the species.

Given the availability now of effective and rapid methods of chemical analysis, and relevant precedents provided by research on other species, there is a real possibility that varieties of *S. tonkinensis* with high yields of high quality resin could be quickly developed through modest investment in a cooperative research program.

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