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NO. 13

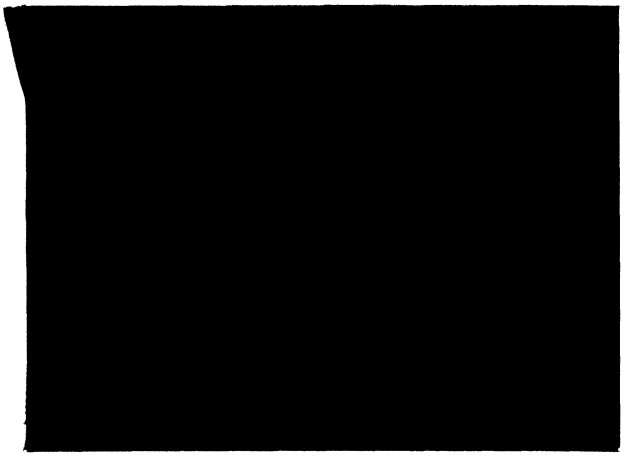
A SECOND LOOK AT AGATHIS

by

M.R. Bowen and T.C. Whitmore

1980

DEPARTMENT OF FORESTRY
COMMONWEALTH FORESTRY INSTITUTE
UNIVERSITY OF OXFORD



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Contents

INTRODUCTION

Since the publication of the 'First Look at Agathis' (Whitmore, 1977) more information has come to light on many of the topics covered there; several papers have been published and seed has been collected and distributed as an international species/provenance trial.

The Oxford-based investigation of Agathis is summarized in Bowen and Whitmore (1980), while in this paper we publish the new details not appropriated to that summary, and using the same category headings as in Whitmore (1977). These data in conjunction with those published previously provide an up-to-date statement of knowledge of the genus. We then go on to give details of the provenance trial and a note on a preliminary experiment on the response of seedlings of different species to three shade conditions.

TAXONOMY

Since the First Look was written a monographic revision of the genus has been undertaken and is published as Whitmore (1980). There are thirteen species of which two have two subspecies and one of these is the only new taxon discovered. An account of Agathis for Flora Malesiana, covering Sumatra to the Bismarck archipelago, is in the course of preparation by Dr. D. J. de Laubenfels. He is likely to take a narrower concept of species delimitation and make many or all of the montane populations of A. dammara in Borneo into different new species (including two of overlapping elevation on Mt. Kinabalu) and to split in two the lowland species of Celebes, Philippines and Moluccas. Foresters will have to judge for themselves whether this 'splitter's' view of the genus is justified.

FORESTS WITH AGATHIS AND THEIR EXPLOITATION

Additional notes on wild Agathis and its exploitation have come to hand. The overall picture on its ecology summarized in Whitmore and Page (1980) is not altered, especially the generalisations about population structure. Many Agathis forests are difficult to reach, or soon to be exploited, and data on them are recorded here.

Sabah. The montane stand of A. dammara near Keningau, Mt. Kinabalu has now been destroyed. It had poles but seedlings were rare (D. Chai, pers. comm.). Dense, accessible stands (which are probably of A. borneensis) have been discovered in the Crocker Range at over 600 m elevation on sedimentary rock. In the lowlands a further stand on ultrabasics has been found near Kalabakan.

Sarawak. Miscellaneous notes about A. borneensis in heath forest are to be found scattered through Brunig (1974).

Philippines (A. dammara). Additional general notes on range and ecology are given in Brown (1951) and by S.C. Halos and B. Tumaliuan (pers. comm.). Agathis occurs in a strongly seasonal climate not just on Palawan but

also in Abra province, northern Luzon, where it occupies upper slopes from 800 to 900 m interdigitating with Pinus kesiya forest on the lower slopes. In the intermediate zone Agathis is reported to extend upto 2000 m elevation on Mt. Balarit (2300 m), but is absent from the top 200 m of Mt. Balutitic (1800 m). The absence from ridge crests is general in northern Luzon in contrast to Palawan. The largest trees are found towards the upper slopes and on south facing slopes which are more densely populated than north facing slopes on a hill system that runs with spurs pointing eastwards. An area of 196 000 ha is estimated to contain 1.3 million m^3 of Agathis with up to 13 000 trees over 0.6 m dbh in a 1000 ha area.

Queensland. It seems probable that A. atropurpurea and A. microstachya were never common or widespread. Both are now very rare. D.I. Nicholson only knows of ten trees remaining of A. microstachya and A. Gardner suggests that probably 100 remain in total.

The original geographical range of A. atropurpurea and A. microstachya is not exactly known. The ranges of these two and A. robusta overlap and they do occur, but rarely, at the same place; for example A. atropurpurea and A. microstachya are both at Lake Barine on granite at 750 m, with A. robusta under 2 km away. Two large (c. 2 m) stems of A. microstachya have been 14C dated to 1050 and 450 years old.

In south Queensland A. robusta never occurs over 200 m elevation and most is at lower levels (pace Whitmore, 1977). It occurs on podzols as well as on more mesic soils.

Santa Cruz (Solomon) Solomon Islands (A. macrophylla). Exploitation of the Ndendö stands was completed in early 1979. Wildings and nursery-raised seedlings were line-planted with a high degree of survival. The species is not endangered, but seed can now only be obtained from scattered individual trees and small pockets which escaped logging until the new forest matures.

New Hebrides (A. macrophylla). The Aneityum forests were logged again from May 1978 to June 1979. Some 5000 m^3 of Agathis timber were exported during 1978 at c. £96 m^{-3} f.o.b. The species occurs as patches up to 1 ha in extent and 200-300 m distant from each other. It is concentrated on slopes protected from the prevailing southeast winds.

New Caledonia. At Riviere Bleue some 2000-3000 m^3 are being cut per annum, mainly of A. lanceolata, for local use.

New Zealand. The Kauri Management Unit, Auckland Conservancy, published in 1978 a compendium of all measurements in second growth A. australis forests including volume increments. This very substantial body of data is important for future silviculture of the New Zealand Kauri.

PLANTED AGATHIS

Java. A study of mineral cycling in the central Javan plantations was conducted for 15 months to February 1978 by Drs. L.A. Bruynzeel. Publication is anticipated in 1980.

Costa Rica. Agathis robusta has done well in a trial conducted by Turrialba (Anon. 1976) on a site at 1220 m elevation on a leached recent volcanic soil in a rainfall of 3725 mm/year. At age 6.3 years the following measurements were obtained; $\bar{h}$ 7.55 m (m.a.i. 1.27 m), $\bar{d}$ 11.58 cm (1.96), vol. 15.66 m^3/ha and $\bar{h}$ 11.67 m (1.99), $\bar{d}$ 16.71 cm (2.88), vol. 88.76 m^3/ha. These should be compared with the results shown in Figs. 5.1 and 5.2 in Whitmore (1977).

PROPAGATION

Phenology

The months of the year at which ripe female cones are present varies from country to country. In many cases the available information is limited to the period at which 'mature' cones have been seen and little is known about the time scale of development, the peak collections period, or variations from year to year. Table 1 shows the revised data based on personal observations and the more reliable field reports, and replaces the similar table in Whitmore (1977).

The development of the female cone of Agathis robusta south Queensland provenance was described in detail by Nikles (1965), see Whitmore (1977). It takes 18 months from emergence to maturation, and it is now thought that other species differ.

In Fiji trees were examined in early January 1979 near Colo-i-Suva, in the Nausori Highlands and at Nadarivatu. A few, very young, female cones were seen, but none of intermediate size. The bulk of the seed crop was estimated to be mature by early to mid-February, with later cones maturing in March. It would thus appear that a 12-15 month growth period is required for this provenance of A. macrophylla.

At Gumi in Papua New Guinea material collected in mid-February 1979 from the crowns of mature trees of A. robusta subsp. nesophila showed large expanding buds which experienced tree climbers identified by eye as young female cones; dissection under a microscope confirmed this opinion. These cones are said to be fully mature by mid-November, suggesting a 9-11 month developmental period. Certainly no cones of intermediate age were seen on the large number of trees examined, lending support to the idea of a short development period.

In contrast to this relatively fast maturation period N. Q. Zabala (pers. comm.), has tagged developing cones on two trees of A. dammara of unknown (Philippines) origin planted at Los Banos, Luzon, and his results suggest that full development takes about two years.

On the Palawan Island, also in the Philippines, A. dammara occurs as patches separated by up to 2 km from each other. It is reported to produce mature seeds from mid-February to mid-April at the northern end, and from June to September in the south. The climate is less seasonal at the south tip of Palawan (Fig. 3.1 in Whitmore, 1977) which may explain this anomaly.

Table 1. The months when female cones mature (+ some, * most mature cones)

	O	N	D	J	F	M	A	M	J	J	A	S
Fiji, Viti Levu												
A. macrophylla	-	-	+	*	*	+	-	-	-	-	-	-
New Hebrides, Aneityum												
A. macrophylla	-	-	-	*	*	+	-	-	-	-	-	-
Solomon Islands, Santa Cruz												
A. macrophylla	-	-	*	*	+	-	-	-	-	-	-	-
Australia (*A. atropurpurea*,												
A. microstachya and												
A. robusta) all 3 spp.	-	-	*	*	-	-	-	-	-	-	-	-
New Caledonia												
A. corbassonii	-	-	-	*	*	-	-	-	-	-	-	-
A. lanceolata	-	-	-	-	+	*	+	-	-	-	-	-
A. moorei	-	-	-	*	*	-	-	-	-	-	-	-
A. ovata	-	-	-	-	-	*	+	-	-	-	-	-
Papua New Guinea												
Sirinumu												
A. robusta - nesophila	-	+	*	-	-	-	-	-	-	-	-	-
Gumi												
A. robusta - nesophila	+	*	-	-	-	-	-	-	-	-	-	-
Sepik												
A. labillardieri	-	*	+	-	-	-	-	-	-	-	-	-
Philippines (*A. dammara*)												
Zambales, Samar	-	-	-	-	-	-	-	-	-	-	-	*
Zamboanga; Cebu	-	-	-	-	-	-	-	-	-	-	-	?
Luzon, Los Banos	-	-	-	-	-	*	-	-	-	-	-	-
Palawan N	-	-	-	-	+	*	*	-	-	-	-	-
Palawan S	-	-	-	-	-	-	-	-	*	*	+	+
Luzon, Abra	+	*	+	+	-	-	-	-	-	-	-	-
Borneo, Balikpapan												
A. borneensis	-	-	+	*	+	-	-	-	-	-	-	-
Java (*A. dammara*)												
Pasir Hantap	-	-	-	-	-	+	*	+	-	-	-	-
Situgunung	-	+	*	+	+	+	*	+	-	-	-	-

At Pasir Hantap in west Java small plantations of three provenances of A. dammara (two Celebes, one Moluccas) and of A. borneensis (Brunei) were examined in mid-March 1979. Most trees bore female cones in all stages of development from very small to almost mature, suggesting a development period of 14-18 months and possibly a fairly extended fruiting season. Local foresters say that the peak of seeding is April and numbers of viable seed obtained per cone vary noticeably between provenances but is fairly constant from year to year. Viable seeds per cone are 60-70 for A. borneensis and the Moluccan provenance of A. dammara, and 15-20 and 5-10 for the two Celebes' provenances.

In other countries from which data are available, New Hebrides and Santa Cruz Islands (A. macrophylla) and New Caledonia (all five species), a development period of 15-18 months is indicated.

In a small plantation of A. moorei in New Caledonia, H. Gay (pers. comm.) reports that seed-set and the number of cones developing is better on the leeward side of the area, and that while trees on the windward side usually bear a moderate cone crop, almost all the seed is sterile. This variation is shown by the seed collected in February 1979 when the total cone crop was harvested from seven trees.

Table 2. Total cone and seed collections from seven plantation-grown trees of A. moorei

Tree No.	No. of cones collected	Weight of seed obtained (g)	Average weight of seed per cone (g)	
1	37	1935	52.3	leeward
2 or 5	15	1048	69.8	
4	18	907	50.4	
6	22	356	16.1	
10	12	313	27.1	
20	15	3	0.2	
25	7	35	5.0	windward

Considerably less information is available on the period of development and time of pollen shed in the male cone. Many of the cones continue to expand on the tree after the pollen has been released and fall over an extended period.

Grafting

In New Caledonia, a seed orchard (12 years from grafting) of some 28 trees, has produced a moderate number of mature cones containing fertile seeds. Scions 10-15 cm in length and 15 mm in diameter taken from mature forest trees were side-veneer or top-cleft grafted on to 1 m tall juvenile root stocks of A. moorei, the top-cleft grafts producing a firmer union. A. ovata and A. lanceolata grafted onto A. moorei rootstock have grown well but the biggest grafts are thought to be A. lanceolata on root stocks of the same species.

At Atherton, north Queensland, mature scions of A. robusta have been successfully grafted onto juvenile rootstocks of both A. robusta and

A. microstachya. The reciprocal grafts are also healthy.

Seed storage

Viability studies initiated in 1976 by R.D. Smith at the Royal Botanic Gardens, Kew, continue to confirm that Agathis australis, A. macrophylla Solomon provenances and A. robusta seed, when conditioned to moisture contents between 16 and 6 percent (wet weight basis) behave in an "orthodox" manner, i.e. reducing the moisture content of the seed, or lowering the temperature at which it is stored, prolongs longevity. It appears that A. macrophylla seed possesses a lower inherent longevity than that of A. robusta which in turn is lower than that of A. australis. One unexpected and unusual feature is found in the behaviour of A. macrophylla which wholly or partly accounts for its low viability. When seeds are stored at temperatures below $0^{o}C$ at moisture contents below 16 percent a proportion is killed immediately. The rest lose their viability in the manner which would be predicted from the behaviour of seed at temperatures above zero. The proportion of the seed which is killed on exposure to sub-zero temperatures increases with a decrease in either storage temperature or moisture content.

Measurements made on A. macrophylla Santa Cruz provenance showed that the moisture content of seeds from freshly shattered cones is c. 65 percent on a wet weight basis. Provided that the moisture content does not fall to or below 20 percent through natural drying, and the seeds are supported in a thin layer on wire mesh and sheltered from direct sun and rain, they remain completely viable for at least one week under ambient conditions. The rate of drying under natural conditions is roughly inversely proportional to daily rainfall. At moisture contents at or below 20 percent measurable losses of viability occur. These field measurements agree with extrapolations from earlier laboratory experiments at lower temperature and moisture contents. No immediate loss of seed viability was found if unripe cones were left in direct sunlight for up to four days to induce shattering.

Seeds which had been held at over 20 percent moisture content under ambient conditions for four days before being despatched by airmail arrived in Britain fourteen days later with 90 percent viability. When these seeds were then dried at $16^{o}C$ and 14 percent relative humidity for five days the moisture content decreased to 6 percent and viability dropped to 75 percent.

From these observations it was concluded that it should be possible successfully to transport fully viable seed to Britain (or elsewhere) where facilities are available to rapidly dry them and so prolong their longevity so long as moisture content is over 20 percent. On the basis of these conclusions the decision was made to collect seed for the international species and provenance trial described later. Unfortunately much lower viability than predicted was obtained in the seed collected for the trial.

Despite the inference which could be drawn from the previous viability studies, no correlation was found on arrival in Britain between the

germinability of the seed collected for the trial and its moisture content. It must therefore be deduced that at least one further factor must be controlled if Agathis seed is to be safely collected and transported. Two possible factors can be identified, the carbon dioxide/oxygen balance and chilling injury in transit.

Of the seed collected for the species and provenance trial the most viable was a small sample kept and transported in a substantially moistureproof, and therefore gas-tight, plastic container. The two batches of A. macrophylla seed previously successfully transported to Briain were both at lower moisture content and both very densely packed. This suggests that the CO_2/O_2 balance may be involved. It has not been possible to carry out the necessary experiments to confirm or deny this possibility.

Secondly, the seed might suffer 'chilling damage' in transit. The normal minimum temperature in the cargo hold of a jet airliner is 7°C but exceptionally it may fall to zero. Both early batches of A. macrophylla seed which reached Britain with high viability were in fact close-packed in insulated containers. The seed of various species which died were more loosely packed and poorly insulated. As this seed was also wetter it may have succumbed to 'chilling injury' at high moisture content. The solution to this problem would seem to be to transport seed in well insulated containers. Further experiments are planned.

Many other foresters report difficulties in storing Agathis seed for more than a few weeks (e.g. Suriamihardja, 1979) and experimental results are rarely published. However, between 1958 and 1962 Queensland State Forest Service stored air dried seeds (12-15 percent moisture content) of 'A. robusta' (possibly in fact A. microstachya or A. atropurpurea) at -15°F in airtight containers with no loss of the viability of c. 64 percent. In non-airtight containers viability fell to 17.5 percent, while at room temperature all seeds died. These results are in broad agreement with those of R.D. Smith.

Early results from New Zealand on the storage of seed of A. australis, the least 'tropical' of the genus, indicated that the seeds of this species also posed long term storage problems (Hocking, 1935; McKinnon, 1936; Sand, 1936). Hutchin's (1918) assertion that A. australis seed will remain dormant in the ground for many years before germinating remains unproven but would not in any case appear to hold true for the Agathis species of tropical rain forest, where numerous pests are likely soon to destroy non-germinating seeds. By 1946 MacMorran (1946) had shown that seed of A. australis stored at c. -10°C remained 64 percent viable after two years, while seed held at room temperature died. And in 1957 Mirams demonstrated that seed moisture content during storage is also of great importance. Recently Preest (1980), in a comprehensive experiment lasting almost twelve years, studied the combined effects of both temperature and seed moisture content on longevity. Preest's (1980) results are based on only one experiment and one seed lot but they agree with and extend those of R.D. Smith and from Queensland, and are by far the most comprehensive data available. Seed batches of A. australis were stored in air-tight containers at moisture contents of 6, 10, 15 and 20 percent, and at temperatures of -10°, 5°, 10°, 15° and 20°C. Longevity was dependent on both factors although moisture content was the more critical. Preest concluded that 'the

optimum moisture content appeared to be around 6 percent. For short- and medium-term storage (upto 6 years) the optimum temperature was about 5°C. For larger storage, or higher moisture content (10 percent), the results suggested that the optimum temperature is below freezing point' with viability little impaired, and probably in excess of 12 years.

All the available data thus indicate that satisfactory seed storage techniques are now being worked out for some species. However, further work is needed to extend these results to tropical species and to develop better means of transporting seeds from country to country.

Vegetative propagation

Work on the vegetative propagation of Agathis has continued, at the Institute of Terrestrial Ecology, Edinburgh (Leakey and Longman, 1978), to examine the variation in rooting due to cutting origin. Cuttings were taken from the main stem and lateral shoots of seedlings, and from previously rooted cuttings of A. macrophylla. All cuttings were treated with a 'quick dip' in 0.22 NAA/IBA in methanol, and set under mist.

Cuttings of main stem origin rooted better than those from lateral shoots, the most pronounced differences being in the rate of rooting during the first five weeks. Subsequent growth of these rooted cuttings confirmed observations that lateral shoot cuttings tend to grow plagiotropically whereas main stem cuttings are orthotropic.

Cuttings of the indigenous Agathis of Peninsular Malaysia (A. borneensis) have been successfully rooted at Kepong (Momose, 1978). Cuttings 150-200 mm long including several nodes and with leaves left attached on the upper part were successful from coppice shoots but not from the branches of mature trees. Short cuttings of one leaf and bud, similar to those used at Edinburgh, successfully rooted after six months (these two were presumably from coppice shoots). It should be noted that Agathis has not previously been known to coppice.

A mist propagation unit has recently been built at Oxford and further investigations on the rooting of cuttings, using a number of Agathis species, have been started.

Rooted cuttings c. 0.2 m tall of A. dammara Java provenance, A. macrophylla Fiji provenance and A. robusta raised at Edinburgh as described in Whitmore (1977) were successfully introduced to Peninsular Malaysia by air in October 1977 and, after a period in a nursery, planted out in the open at the timber concession of Perkayuan Tenggara at Bukit Ibam. Initially A. macrophylla Fiji provenance grew best. In mid 1979 all were reported to be growing vigorously (P.F. Burgess pers. comm.) though some still remained plagiotropic.

PESTS AND DISEASES

Pests

Seed eating moth, Agathiphaga (Lepidoptera: Aglossata; Agathiphagoidea)

New information has now been gathered on this serious pest.

Fiji (A. macrophylla). In general, local foresters report that the level of infestation by Agathiphaga vitiensis is low, from 0.15 percent and varying between areas. However, at Nadarivatu, several cones, estimated to be a month from maturity, were split open and all contained larvae. The infestation involved from 20-30-(70) percent of the seed. About one third of the infested seed had two holes drilled in the corners, while one tenth had three holes - the third being centrally placed (and perhaps not Agathiphaga). A few seeds had four holes but the remaining infested seeds differed little in external appearance from unattacked seeds. A very small number of the seeds were found with one or two holes in the wing but with no apparent damage to the enclosing cone scales. None of the cones opened at Nausori Highlands contained attacked seed.

New Hebrides (A. macrophylla). Cones collected on Aneityum island were mature and contained 110-180 seeds, but up to 95 percent of these were empty. In all cases two or three of the remaining seeds were infested. The numbers were proportionally higher in cones with more developing seed. Usually four holes were found, but more rarely two, at the corners of attacked seed. Where only two holes were present they were invariably adjacent on one of the short sides of the seed, and never situated diagonally. In fact no diagonally placed holes were found throughout the distribution range. The holes were sometimes drilled only through one coat of the testa, and sometimes completely through the seed.

A small number of cones were found with 1.5 mm diameter holes in the scales; in these instances the central 'candle' often showed frass damage and the cone was distorted. A Nitidulid beetle was found in one of these cones.

Solomon Islands (A. macrophylla). High levels of Agathiphaga damage are reported each season in collections made on Ndendö (K.D. Marten and T. Nolan, pers. comm.) and these severely limit the quantity of seed available for replanting.

New Caledonia (A. moorei, A. corbassonii). Several hundred cones of A. moorei were examined, containing many thousand mature seeds; of these only 20 seeds were found to be destroyed by the larva of Agathiphaga. All had four holes per seed. Similarly, only three seeds from 85 cones of A. corbassonii were attacked. This appears to be the first record of Agathiphaga in New Caledonia, although H. Gay (pers. comm.) has noticed a small number of damaged seeds in previous years. No seed damage was seen in the small number of A. lanceolata cones examined, although there is no reason to suppose that this and the two other sympatric species (A. montana and A. ovata) are immune to attack.

Papua New Guinea. Although pests appear to attack the cones and seed of Agathis in Papua New Guinea (see below) there is, as yet, no evidence for the presence of Agathiphaga.

Australia. The original description of Agathiphaga queenslandensis was made by Dumbleton (1952). Since then, however, no one from the Queensland State Forestry Department has reported infested seed but B.P.M. Hyland (pers. comm.) reports that larvae can be found in most years in seeds of A. robusta growing in north Queensland. There are never any holes in the seeds. It seems reasonable to suggest that seeds of A. microstachya and A. atropurpurea could also be attacked.

Other insect pests

Borneo. One recently fallen female cone was found to be heavily attacked by pin hole borers. Damage was mostly confined to the seeds and central 'candle' and there were few holes through the scales. G.S. Robinson identified the larvae as a member of the Gelechiidae.

Java. A study has been made of the termites associated with A. dammara plantations in Java by Z.B. Kiman (BIOTROP Annual Report 1976/7). 'About 15 termite species of 3 families were recorded. Two species belong to the family Rhinotermitidae, i.e. Schedorhinotermes longirostris (Bauer), and S. javanicus (Holmgren). More than 12 species belong to the family Termitidae, namely: Microtermes insperatus Kemner, Macrotermes gilvus (Hagen), Nasutitermes sp., N. acutus (Holmgren), Odontotermes sp., O. sundaicus Kemner, O. malaccensis Holmgren, O. sarawakensis (Holmgren), O. javanicus Holmgren, Capritermes buitenzorgi Holmgren, C. sp., and C. ceylonicus Holmgren. Only one species belongs to the family Kolotermitidae, i.e. Kalotermes pintoi Kemner. Schedorhinotermes longirostris and S. javanicus were the most prevalent species within plantations in Baturraden, Situ Gunung and Gunung Walat. The percentage of occurrence of S. longirostris was 81.25, 48.14, and 54.55 percent in Baturraden, Situ Gunung and Gunung Walat respectively; whereas that of S. javanicus was 12.50, 25.92, and 13.64 percent respectively in the same areas. Severity of damage, age of trees attacked and the altitude of each plantation were also recorded.'

Papua New Guinea. Two species of moth have been raised by H. Roberts (pers. comm.) from cones of Agathis robusta subsp. nesophila and A. labillardieri collected in Papua New Guinea. The most common has a wingspan of 18 mm, with white fore- and grey hind-wings. At rest the wings are held at an acute angle; the body is yellowish with paired black spots. This has been identified by J.D. Bradley as possibly Tarphyscelis sp. (Yponeumetidae) and is widespread from Port Moresby to the east Sepik and New Britain. The second moth, found only at Gumi near Bulolo, is smaller, with a 12 mm wingspan, of the same colouration with the wings held flatter. It has been identified by J.D. Bradley as an un-named genus near Proselena (Tortricidae).

A damaged cone collected by J. Zieck at Sirinumu, Papua, was examined by H. Roberts. Its external appearance coincided with green cones previously seen from other parts of the range. Lepidopterous larvae had moved through the scales as well as in the central 'candle'. Many larvae appear to pupate just inside the outer surface of a scale prior

to emergence through a 1.5 mm diameter hole, in or between, scales. In cases previously examined by H. Roberts a number of larva have pupated in a white silk cocoon on the cone surface or stalk. Moths emerge around mid-February from green cones collected in mid-November, i.e. at a time when the mature cones would be expected to have fallen.

Bud material collected from the Gumi area was also examined. The larger buds, identified by climbers as potential female cones, all showed signs of damage by lepidopterous larvae and two contained living specimens. All the buds were more or less completely destroyed so an attack at this stage is potentially serious. Frass and damage was also noted on fresh young stems and in slightly older, though still green, wood, suggesting the larvae could move freely to surrounding buds. In young cones pupation probably takes place outside the cone on nearby stems. H. Roberts suggests that these larvae are very probably of the same species as those attacking the adult cone, i.e. ?Tarphyscelis.

The frass damage seen in the central 'candle' and the holes bored through the cone scales look somewhat alike in cones collected in the New Hebrides, Atherton, Australia, at Balikpapan, Borneo and in Papua New Guinea although it is probable that the larvae causing the damage are different in each place.

No large borers in standing timber have been reported in Papua New Guinea (H. Roberts, pers. comm.) although Ambrosia beetles and bark beetles peculiar to Agathis rapidly invade felled logs. Roberts considers that Agathis is likely to have many species not previously described.

Australia. D.I. Bevege (pers. comm.) reports the presence of the larva of a small moth (adult wingspan 9 mm) in seeds of A. robusta. So far the species is unidentified, but may be related to the Hoop Seed Moth Hieromantis (Stathmopodidae) of Araucaria cunninghamii. Damage is difficult to see except as tiny punctures in the seed wing, and as pin-head holes in the seed scale, made as the larva works its way through 10-12 seeds.

A new undescribed species of weevil, similar to the weevils of Araucaria found throughout its range, has also been found in the cones of A. robusta. It is possibly a member of the Nemonychidae but has no known effects (D.I. Bevege, pers. comm.).

In Atherton public park one A. robusta tree with many mature cones was examined. One mature cone, still on the tree, had a 1.5 mm shot hole, the outer edges of three scales were eaten and an active 10 mm white larva found (see Papua New Guinea).

Diseases

Halos and Quinones are examining the correlation between diameter class and the presence of wood decay in Philippines Agathis. The rot is thought to be caused by a species of Fomes and fruiting bodies have been observed on apparently healthy as well as dying and dead trees. Similar fruiting bodies are also found on neighbouring Pinus kesiya. These workers say that there is a strong correlation between diameter and wood

rot, especially in trees over 1.6 m diameter. They have classified the decay into three types:-

Type A - rot extending from the bark into the cambium.
B - rot starting from the root and extending upwards into the stem to form a hollow heart.
C - rot also originating in the root but decayed regions appearing only as scattered spots across a section.

The type of rot occurring varies from region to region and may be correlated with climate. Type A is found in northern Luzon and the Apayao-Kalinga region of central Luzon, where rainfall is compressed into a six month period. Type B (with some type C) is found in northern Samar with a heavy, evenly distributed rainfall; while Type C rot has been found at Zamboanga (Mindanao), with an evenly distributed though light rainfall. The majority of trees examined in the Abra area of northern Luzon were between 1.2-1.7 m dbh, although very occasional trees were estimated to be 2.2 m dbh. Quite large numbers of trees above 1.8 m dbh were dead, although still standing. Large dead trees were also noted on Palawan and resin tappers report that frequently tapped trees develop a rot in the older cuts. Termites also enter tapping wounds and ultimately lead to death.

PRODUCTS

Timber

In general, New Zealand Agathis has a better reputation in the trade for durability. Timber of A. macrophylla Vanikoro provenance is said to have a higher resistance to soft rots than most other species (CSIRO Forest Forest Products Newsletter 374, July 1976). The more 'tropical' species of Agathis, especially Indonesian, show a tendency to possess growth rings whereas Australian species have none (W. Smith, pers. comm.). There are no significant timber differences between the three Australian species except probably in the amount and extent of spiral grain. Sprial grain is also more prevalent at high altitudes.

Some provenances or species may have a heritable tendency to spiral grain. This is of special importance in such a low strength wood, and is clearly an important character to avoid in selecting trees for a provenance trial or seed orchard. As far as possible any trees with a spirality greater than 5-6°, in a 1.2 m length should be rejected (W. Smith, pers. comm.). Smith believes A. macrophylla from the New Hebrides and A. ovata have higher degrees of twisting than other species, with A. ovata the worst.

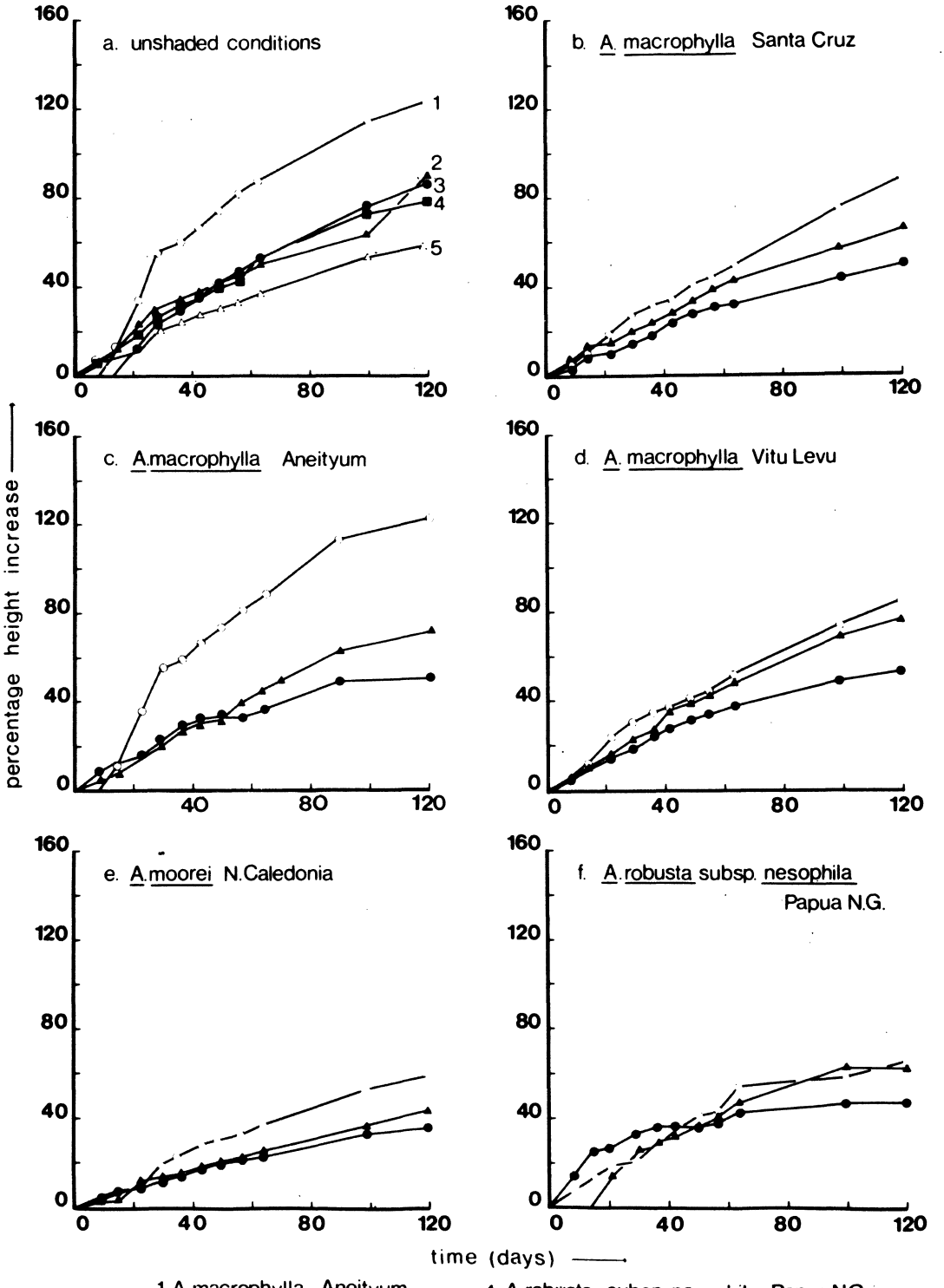
Within the Philippines, trees from Abra (N. Luzon) are of very twisted form with the spiral anticlockwise and branching is much 'heavier' than normal. Elsewhere in the Philippines form is excellent (S.C. Halos and A. Quinones, pers. comm.).

The resin industry

In the Sepik region of Papua New Guinea, a good tree will produce 20 kg of gum per year, at a world market price for top grade resin of £300 per tonne.

Percentage increase in height growth of three species and five provenances of Agathis grown in a glasshouse under three light régimes. a. **unshaded conditions;** b–f **differing light conditions.**

○—○ unshaded ▲—▲ light shade ●—● heavy shade



1 A.macrophylla Aneityum
2 ·· ·· ·· ·· ·· ·· ·· Santa Cruz
3 ·· ·· ·· ·· ·· ·· ·· Vitu Levu
4 A.robusta subsp. nesophila Papua N.G.
5 A.moorei N.Caledonia

On Palawan a good tree is said to produce 16 kg of resin per year, but this could be appreciably increased with more frequent visits and the average is only 2 kg. Maximum yield comes from trees of 0.4-0.8 m diameter. Prices quoted locally are 1.5 peso/kg in Palawan and 2.0 peso in Manila; but 3.0 peso if smuggled to Borneo (£88, £118 and £176 per tonne respectively). Hence much resin goes to Borneo and official figures for Palawan resin production are believed to be 50-100 percent too low (£1 = 17 peso). The quality of resin and its value are said to vary throughout the Philippines (S.C. Halos), and typical buying prices are quoted by her as, Palawan 0.96 peso/kg, Zambales 0.90, Quezon 0.65, Samar 0.30 - the quality is said to differ.

A detailed study has been commenced by S.C. Halos at the new Philippines Forest Research Institute to investigate difference in resin yield between trees and localities and to link this with morphological traits.

Consideration to tapping methods has been given in Indonesia. Sumantri and Sastrodimodjo (1977) discovered that traditional tapping methods were cheaper and just as high in yield and quality as others. Malinka (no date) has published simple advice on tapping methods for Irian Jaya.

SEEDLING RESPONSE TO LIGHT

The accumulated information on the ecology of Agathis and its performance under different silvicultural regimes clearly shows that seedlings of some species and provenances can grow in open, brightly lit sites and others need some degree of shading from direct sunlight, and concomitant higher aerial humidity, lower soil surface temperature and leaf temperature. It is easier and cheaper to establish seedlings in the open and if they can tolerate these conditions they are likely to grow faster than in shade. The two extreme responses are exemplified by Malayan (and perhaps all) A. borneensis which requires shade and grows slowly and A. macrophylla, especially the southern New Hebrides provenance, which grows fast in the open.

A start has been made to analyse these responses with the end in view of making recommendations for silviculture of small Agathis.

An exploratory experiment was conducted in a glasshouse at Wytham near Oxford during the summer and autumn months of 1979 when insolation approximates tropical intensity although day length is greater and both temperature (20-32(-38)^{o}C) and relative humidity ((20-)40-85 percent) fluctuate more than within the humid tropics. Conditions at this time of year are a very rough approximation to those in the open in the humid tropics.

Seedlings of three provenances of A. macrophylla (Santa Cruz, Vitu Levu and Aneityum), A. moorei (New Caledonia) and A. robusta subsp. nesophila (Papua New Guinea), were grown in pots in unshaded, lightly shaded (c. 60 percent of unshaded light) and heavily shaded (c. 35 percent) conditions, from August through to the end of November. Owing to a shortage of strictly comparable material no attempt was made at a comprehensive analysis of growth, which was assessed simply as stem height and on a subsample as total axis length. All species and provenances grew

fastest without shade. Agathis macrophylla Aneityum provenance seedlings initially grew fastest, possibly because they were initially the smallest, but later the growth rate was comparable to the other provenances of A. macrophylla and A. robusta subsp. nesophila. A. moorei consistently made less height growth, Fig. 1a. Similar results were obtained for total shoot growth.

The growth of all the plants decreased with shade (Fig. 1 b-f), though there are indications of a differential response between species and provenances. A form factor relating leaf area to length and maximum width was calculated (D. Alder). This only ranged from 0.64 to 0.68 despite the markedly different leaf shape between species. It is planned to conduct further glasshouse and growth chamber experiments on seedlings to elucidate some of the basic characteristics of growth and then to extrapolate to studies in shade houses and the forest at a suitable location in the tropics. Thus we plan to link observations in closely controlled, relatively uniform environments with others in semi-natural and natural ones. There are too many variables to make it easy to interpret growth in the forest without such back-up analyses for simpler environments.

At Bogor experiments on A. dammara seedlings showed that leaf production increased considerably with increasing light up to 53 percent full light and decreased as illumination was increased further. It was also stimulated by foliar application of nitrogenous fertiliser (Biotrop, 1976a). Work was also begun on competition with Imperata cylindrica, and different shade intensities on transplanted seedlings of the same species (Biotrop, 1976b).

INTERNATIONAL SPECIES/PROVENANCE TRIAL

An international species/provenance trial was established in 1979. During January-March nine countries were visited and seed was either collected at the time or arrangements made to have later collections sent to the U.K. for distribution. In all six collections were received, most from the humid tropics, rather than more strongly seasonal climates. These seeds were sent out in June and July 1979 to seventeen countries (see Table 3) chosen to include a whole variety of site types over a large geographic range, with the objective of obtaining as much data as possible on the potential of Agathis as a plantation tree. Table 3 also includes details of direct country to country seed exchanges made during 1979.

In many countries through its natural range a heavy and increasing exploitation of rain forests is endangering the wild populations, and equally important consideration in selecting the trial recipients was given to choosing locations for the ex situ conservation of provenances and species.

The limited size of the collections (largely resulting from attacks by the seed-eating larva of Agathiphaga) and continuing problems of seed transport and storage necessitated unequal distribution among the participant countries.

As the young trees of many provenances are intolerant of full sunlight it has been suggested that the trial be planted with a 'nurse' crop of Leucaena leucocephala (Philippines, giant variety, or in one case ex Nicaragua) for the first few years of life. Experience in Java and the Philippines suggests that the association of the two genera is satisfactory and initial growth of the Agathis is promoted. A unit block of 49 plants (7 x 7) is suggested at 4 x 4 m spacing, interspersed with a similar number of pre-established Leucaena, also at 4 x 4 m, to give a formal plant espacement of 2 x 2 m, and a block size of 28 x 28 m. Seed viability was calculated prior to despatch and seed was sent in unit lots to contain approximately 100 germinable seeds, i.e. sufficient to plant one unit block, with adequate reserves.

After germination it was recommended that the seedlings be pricked out into 75-120 mm polythene pots and gradually hardened off under light shade over the next 9-18 months. After this time they should have obtained a height around 0.3 m and be ready for field planting.

The period in the nursery is not critical, and a varying time scale can be used to fit in with site preparation and suitable planting weather. Planting into bare ground at a freely draining site, on a soil of good physical structure is recommended. Frequent weeding is required in the early years. Grasses are known to be particularly inhibiting. The Leucaena nurse should be removed after some five years, by which time the Agathis is likely to have overtopped it.

Agathis international species/provenance trial, 1979

	A. macrophylla Fiji	A. macrophylla Aneityum	A. macrophylla Santa Cruz	A. robusta subsp. nesophila Papua New Guinea	A. dammara Palawan	A. moorei New Caledonia	A. australis New Zealand	A. microstachya	A. atropurpurea	L. leucocephala (nurse) ex Philippines	L. leucocephala (nurse) ex Nicaragua
Australia	1	-	1	1	1	-	-	-	-	6	-
Brunei	1	-	-	1	-	-	-	-	-	6	-
Cameroon	1	-	-	-	-	-	-	-	-	6	-
Colombia	1	-	-	-	-	-	-	-	-	6	-
Costa Rica	1	1	1	1	1	-	-	-	-	6	-
Fiji	-	-	4	-	-	-	-	-	-	-	-
Ghana	1	-	-	-	-	-	-	-	-	6	-
Indonesia	1	-	-	-	-	-	-	-	-	6	-
Ivory Coast	1	-	1	1	-	-	-	-	-	6	-
New Caledonia	1	-	4	-	-	-	3	-	-	6	-
New Hebrides	-	-	-	-	-	2	-	-	-	-	-
New Zealand	-	-	-	-	-	2	-	-	-	-	-
Nigeria	1	-	-	-	-	-	-	-	-	-	7
Papua New Guinea	-	-	-	-	-	2	-	-	-	-	-
Philippines	1	-	-	1	-	-	-	-	-	6	-
Puerto Rico	1	-	1	1	-	-	-	-	-	6	-
Reunion	-	-	-	-	-	2	-	-	-	-	-
West Malaysia	1	1	1	1	1	-	-	-	-	6	-
Sabah	1	-	-	-	-	-	-	-	-	6	-
Sarawak	1	-	-	-	-	-	-	-	-	6	-
Sierra Leone	1	-	-	-	-	-	-	-	-	-	-
Solomon Islands	-	-	-	-	-	2	-	-	-	-	-
South Africa	1	-	-	1	-	-	-	5	5	6	-

1. Seed despatched via Oxford 1979
2. Seed sent directly from New Caledonia
3. Seed sent directly from New Zealand
4. Seed sent directly from Solomon Islands
5. Seed sent directly from Australia
6. + 7. Leucaena leucocephala seed to be used as a nurse crop

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