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Araucariaceae in Puerto Rico¹

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ABSTRACT

Araucariaceae is an ancient family of gymnosperms native to the southern hemisphere. The family consists of the genera *Araucaria* and *Agathis*. Although these two genera may appear similar in casual observation, the differences are significant. *Araucaria* has awl-shaped or lanceolate leaves, thorn-tipped in some species. The flowers are usually dioecious, the seed is joined to the ovuliferous scale, and the seeds are either wingless or with more or less equal wings. *Agathis* has, in contrast, broad, flat leaves, monoecious flowers, and free seeds with unequal wings (11). In many cases, species are isolated by physical or ecological barriers. For example, *Araucaria rulei* is native to only New Caledonia in the South Pacific. During the last five decades, five *Araucaria* and two *Agathis* species have been introduced into Puerto Rico for forestry and ornamental purposes (Fig. 1). More species might have been imported, but the native ranges of Araucariaceae are very isolated, and the seeds usually lose their viability quickly. Modern air transport could solve both problems. Local seed production from earlier plantings and vegetative propagation offer ways to rapidly multiply a species trials. Enough information now exists to begin establishing pilot plantations of two these species, *Agathis robusta* and *Araucaria heterophylla*, as soon as the economic and political climates favor it. This paper describes each of the seven species tried in Puerto Rico, surveys the known test plantings, and reports their performance. Sources of information include files of the Institute of Tropical Forestry (USDA Forest Service) and field measurements of available trees.

COMPENDIO

Araucariaceae pertenece a una familia antigua de gimnospermas nativa del hemisferio sur. Representantes de los géneros *Agathis* y *Araucaria* se han probado en plantaciones en Puerto Rico. El éxito obtenido en pruebas con *Agathis robusta*, *Araucaria heterophylla* y *A. cunninghamii* indican un uso forestal para estas especies. Los bosques del estado ya han plantado varias hectáreas de *Agathis* regenerado de las plantaciones originales en la isla. *A. heterophylla* se usa extensivamente como ornamento y se ha utilizado como árbol de navidad de primera clase. La ventaja en plantar esta especie probablemente será que ésta crece bien en diversos sitios. *A. cunninghamii* se encuentra en las áreas húmedas de la isla, posee muy buena forma y crece rápidamente una vez que se ha establecido. Recientemente una plantación de esta especie ha sido defoliada por un insecto, *Octaspidiotus araucariae*, introducido por accidente en los últimos años. El futuro de esta especie está en duda. Árboles plantados de las especies *A. hunsteinii* y *A. bidwillii* están creciendo vigorosamente pero el número de individuos son tan pequeños y su edad tan corta que no se debe recomendar en este momento. *Araucaria angustifolia* ha fallado en Puerto Rico.

INTRODUCTION

Agathis robusta (C. Moore) F.M. Bailey

Queensland kauri is a native of northeastern Australian, where it occupies altitude range from near sea level to nearly 900 m, in areas ranging in rainfall from 1 250 to 2 000 mm. In its native range, it attains a height of 30 to 55 m and a diameter of over a meter (16). The first planting in Puerto Rico was in Maricao in the western central mountains in 1937. At 48 years old, the remaining 18 trees near the forest headquarters averaged 20.5 m tall and 54.2 cm in diameter at breast height (dbh);

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on a nearby steep hill, 19 individuals averaged 18.7 m tall and 33.1 cm dbh (Table 1). A single tree, probably of the same group of seedlings and planted along a roadside in the Luquillo Mountains, is now 24.5 m high and 108 cm dbh (1986). Another six individuals of unknown age are scattered around the San Juan area, and another is growing in San German.

In 1958, a Queensland kauri seed lot was received from Australia. Seedlings raised from this lot were used to establish two small plantations in the Luquillo Mountains. For unrecorded reasons, one of the plantations failed completely; the other has done reasonably well. The 56 trees remaining averaged 14.1 m tall and 21.4 cm dbh in 1986. Another plantation was established at Maricao from wildlings originating from the 1937 planting at Maricao. These 104 trees are now 5.6 years old and average 5.9 m tall and 7.4 cm dbh. Another small plantation (31 trees originally planted) was established recently at Toro Negro in the Central Mountains. Average height at planting (precise date unknown) averaged 0.3 m. At about 16 months after planting, average height was 0.9 m and survival was 97%. In addition, about 2 000 containerized seedlings (former wildlings) have been dispatched for planting in Commonwealth forests in recent months; no data on survival are yet available.

Agathis plantations probably should receive protection from weed competition until they reach 2 m in height. After growing a meter or so per year for 15 or 20 years, Queensland kauri in Puerto Rico tend to become round-topped and grow more slowly in height. Diameter growth, however, continues at 1 to 2 cm per year. The older trees have large, healthy crowns, so it is not unreasonable to expect this rate of diameter growth to continue for an extended period. Form is excellent and natural pruning is very rapid. An abscission layer appears to form at the base

of branches to be shed. The stem of one measured individual (Fig. 2) tapered more or less uniformly throughout its length. Volume equations developed for plantations in South Africa (4) should probably be applicable to trees in Puerto Rico.

Seed production and natural regeneration under the trees at Maricao have been abundant in recent years. Trees in San Juan and the Luquillo Mountains have produced cones, but no seedlings have resulted, and the cones examined during the investigation did not contain any developed seed. Once established, seedlings are shade-tolerant and able to endure for many years under a canopy casting moderate shade. They can grow up through a light overstory (personal observation).

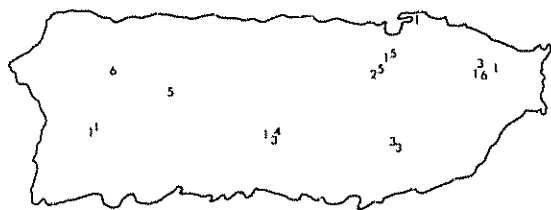
Queensland kauri is probably best adapted to the wetter areas of the island. All known individuals in Puerto Rico were planted within the 1 600 to 3 000 m mean annual precipitation (MAP) range. Puerto Rican plantations have shown tolerance to clay and serpentine soils, moderate compaction, and light salt spray. The death of the terminal leader has been noted in a few large trees on poor sites. Storm breakage of major canopy limbs in a few individuals has also been observed. Queensland kauri may not be windfirm when soil is shallow and wet. Five trees in the Luquillo Mountains plantation have been wind-thrown or now lean heavily.

The wood of one tree felled and sawn during the investigation was light tan, fine grained, uniform, and moderately soft, with a specific gravity of 0.47 g/cm³. Queensland kauri from Australia has a density of from 0.435 to 0.480 g/cm³ (2). Its module of rupture varies from 443-302 kg/cm² and a crushing strength of 250 to 239 g/cm² (13). Shrinkage is low, but collapse can occur under drying conditions (8). The wood is suitable for plywood, molding, doors, sashes, construction lumber, and pulp and paper (7, 13).

Table 1. Dimensions of *Agathis robusta* planted in Puerto Rico.

Plantation	Age (yr)	Number trees	dbh (cm)	Height (m)	Maximum dbh (cm)	Maximum height (m)
Maricao (headquarters)	48	18	54.2 ± 18.9*	20.4 ± 2.5	89.6	24.0
Maricao (steep slope)	48	19	33.1 ± 18.7	18.7 ± 4.5	59.4	25.5
Maricao (across creek)	5	104	7.4 ± 4.0	5.9 ± 3.2	18.6	13.0
Cienaga Alta (upper plot)	29	36	22.4 ± 10.5	14.6 ± 5.2	42.6	22.5
Cienaga Alta (lower plot)	29	20	19.7 ± 6.1	13.2 ± 3.4	32.2	17.5
Toro Negro	1	30	—	0.9 ± 0.3	—	1.6
Individual trees	29-48	7	64.5 ± 21.2	23.4 ± 3.0	108.2	26.5

* Mean ± standard deviation.



1. *Agathis robusta*, 2. *Agathis australis*, 3. *Araucaria cunninghamii*, 4. *Araucaria hunsteinii*, 5. *Araucaria bidwillii*, 6. *Araucaria angustifolia*; *Araucaria heterophylla* (found in all parts of the Island)

Fig. 1. Distribution of Araucariaceae planted in Puerto Rico.

Indications are that Queensland kauri could be an important timber producer in Puerto Rico. The time is ripe for the establishment of a number of pilot plantations of a hectare or more each. The supply of wildlings could accommodate this effort if all were not established the same year. Otherwise, a collection of seed from the Maricao seed-producing trees should be undertaken and seedlings raised in the nursery.

Agathis australis (D. Don) Salisbury

This species is represented by two known individuals growing as ornamentals in the San Juan area. Of unknown age, they are both about 5 m tall and 10 cm dbh. They are apparently healthy, but appear to be growing slowly. Because the natural range of *A. australis* lies 20° more poleward, it is unlikely that this species would be a good timber producer in Puerto Rico.

Araucaria cunninghamii Ait Ex D. Don

The native range of hoop-pine extends from northern New South Wales, Australia, along the coast of Queensland into several isolated areas in New Guinea, including Fergusson Island off its coast. The species occurs from 90 to 2 800 m in elevation (15). Mean annual precipitation ranges from less than 900 to over 2 500 mm (3).

Seeds of hoop-pine were first brought to Puerto Rico in 1959. Seedlings were grown in a USDA Forest Service nursery and outplanted at the Carite Commonwealth Forest. The plantation was between 1.5 and 2 ha in size. At age 26, the 331 trees of the plantation averaged 24.1 m tall and 30.8 cm dbh (Table 2); the tallest tree measured 32.5 m in height. Basal area of the plantation at Carite was 23.8 m²/ha, 85% of which was *Araucaria*. Part of the plantation was measured at age 24. Sixty-seven individuals represented in both measurements had grown an average of 1.8 m in height and 2.0 cm in diameter during the two-year period. In their native range, hoop-pines may reach 60 m tall and attain a girth of

3 m (15). An 18.5-year-old hoop-pine plantation in New South Wales, with 889 stems/ha, had a basal area of 22.7 m²/ha (1). The mean diameter was 18 cm, and mean dominant height was 14.6 m.

Another importation of seeds (from New Guinea) took place in 1980. The seeds were germinated, grown in containers, and outplanted at three locations. At five years, these trees averaged 2.2 to 3.3 m in height (Table 2); the tallest was 5.5 m. *Pinus caribaea* Morelet, sometimes used as a growth benchmark in Puerto Rico, might be expected to reach 7.6 m by that age (9). The height growth of hoop-pine is slow at first but speeds up eventually, at about five years of age.

A few one- or two-year-old seedlings were observed in the older Carite plantation. Hence, seed production has begun for at least one tree. Hoop-pine is sufficiently shade-tolerant to persist in the understory for many years after being planted or overtopped, but it makes little growth there. Several suppressed trees from the planting 26 years ago still survive around the edges of the plantation.

Our trees exhibit remarkably small and even taper throughout their height (Fig. 1). Pruning in hoop-pine is slower than in *Agathis robusta* or *Pinus caribaea*.

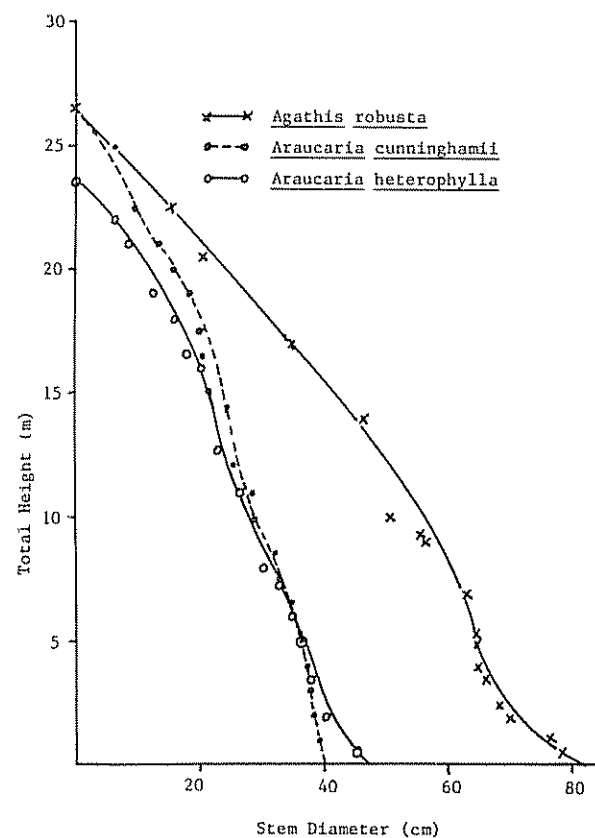


Fig. 2. Taper curves for one tree each of three Araucariaceae species planted in Puerto Rico.

The wood from one tree sawn locally was light tan, fine grained, and had a density of 0.58 g/cm³. It should be suitable for molding, construction lumber, and plywood.

A. cunninghamii will probably do best in areas of abundant rainfall, as in the north and central parts of Puerto Rico. All our plantations are in areas exceeding 2 000 mm MAP. The species, however, suffers in poorly drained soils, as evidenced by poor growth and increased mortality in seasonally swampy areas within the older Carite plantation. The soils in our plantations range in texture from loams to silty clay loams to clays and range in pH from 4.4 to 5.1. Ntima (11) reports that hoop-pine grows on a large variety of soils, provided they are moist but well-drained.

Considerable leaning from the base and two or three windthrows occurred in one of the youngest plantations (Toro Negro) after a recent severe rain-storm. The cause appeared to be a weakly developed lateral root system. No windthrow of large trees has been observed. Except in young plantations at high elevations, hoop-pine is reputed to be windfirm (11). A plantation of hoop-pine in Mauritius withstood cyclonic winds up to 250 km/hr with little damage.

A few months after measurements were made, the older Carite plantation was attacked by a coccoid sucking insect, *Octaspidiotus araucariae*. The twigs soon blackened and fell off, leaving the plantation nearly defoliated. New growth is emerging on nearly all trees, but it in turn is being attacked. The young plantations have not yet shown any signs of attack. The insect was originally known from New Caledonia and the Carolina Islands, but apparently arrived here on potted plants imported from Hawaii (14). The common ornamental, Norfolk Island-pine (*A. heterophylla*), which is not seriously affected, was the only host until recently. If hoop-pine is susceptible to attack in all parts of the island, it will be impractical to grow this timber species in Puerto Rico.

Araucaria heterophylla (Salisb.) Franco

The most common *Araucaria* on the island is the Norfolk Island-pine. Many thousands of them are planted as ornamentals in all parts of the island. The native range of this magnificent tree is restricted to Norfolk Island in the South Pacific, where it may attain heights of 61 m or more (11). However, the species has been successfully grown in most warm subtropical and tropical areas of the world.

Table 2. Dimensions of *Araucaria cunninghamii* planted in Puerto Rico.

Plantation	Age (yr)	Number trees	dbh (cm)	Height (m)	Maximum dbh (cm)	Maximum height (m)
Carite (old planting)	26	311	30.8 ± 10.5*	24.1 ± 5.8	53.7	32.5
Carite (new planting)	5	227	3.0 ± 1.2	2.5 ± 0.8	6.5	5.0
Toro Negro	5	147	2.2 ± 1.1	2.2 ± 0.7	5.7	4.4
Cienaga Alta	5	39	3.6 ± 2.1	3.3 ± 1.3	7.5	5.5

* Mean ± standard deviation

Table 3. Dimensions of *Araucaria heterophylla* sampled in Puerto Rico.

Location	Age range (yr)	Number trees	Annual diameter growth (cm)	Annual height growth (m)	dbh range (cm)	Height range (m)
San Juan	13-30	10	2.0 ± 0.4*	1.0 ± 0.2	30-45	15-23
Caguas	15-28	10	1.9 ± 0.4	1.0 ± 0.2	29-48	15-26
Cayey	7-20	10	2.0 ± 0.4	1.0 ± 0.2	15-40	8-23
Ponce	15-30	10	2.1 ± 0.3	1.0 ± 0.1	35-54	16-28
Corozal**	15	29	1.2 ± 0.3	1.0 ± 0.2	10-25	8-20

* Mean ± standard deviation.

** Former Christmas tree experiment.

A sampling of Norfolk Island-pine was conducted on a transect across the middle of Puerto Rico. In all, 40 trees were measured, 10 each in four cities: San Juan, near sea level and a MAP of 1 650 mm; Caguas, at 50 m elevation and a MAP of 2 030 mm; Cayey, at 400 m elevation and a MAP of 1 525 mm; and Ponce, at near sea level and a MAP of 915 mm. The age of each tree was determined by asking the property owners; height and diameter were measured. Ages of the trees sampled ranged from seven to 30 years (Table 3). Height of the oldest tree was 27.5 m and dbh was 54 cm. Mean annual height growth (ht/age) by city ranged from 0.99 to 1.01 m. Mean annual height growth of the four locations was compared by one-way analysis of variance; no significant difference between sites was determined. Height (H) of the 40 trees sampled was predictable from dbh (D) by the formula $H = -4.0657 + 0.6206 D$, with $R^2 = 0.76$ and $S_{x,y} = 0.60$.

Ornamental Norfolk Island-pines used in Puerto Rico are propagated from seeds and cuttings (10). The stems are slender, with little taper (Fig. 1). Form can be excellent except that most trees are pistol-butted (mild basal crook), and a few grow in a spiral form. The pistol butt may be caused by the weight of the tree at a meter or two in height before the stem is stiff enough to fully support the weight of the rapidly growing top. Form problems could probably be overcome by selecting a resistant clonal source or by staking the young trees. Norfolk Island-pines do not commonly produce seed in Puerto Rico. This could limit nursery production of the species, but may change as the local trees get older.

Norfolk Island-pine was tested as a Christmas tree in Puerto Rico and was the most highly recommended of six evergreen trees tested (12). A marketable tree can be produced in three to four years after outplanting. After the Christmas tree study was terminated, 29 trees remained undisturbed on the site. This is the only planting of this species in a "stand" on the island. At age 15, they measured 15.7 m high and 17.7 cm dbh. These trees originated from seed and form was excellent. Natural pruning is proceeding slowly, as it is for Norfolk Island-pine all over Puerto Rico.

Norfolk Island-pine grows well in a remarkable range of site conditions. It is seen growing as an ornamental in yards in areas with rainfall as low as 750 mm MAP (irrigation in the early years and runoff from house roofs may be involved). The species also grows in areas exceeding 2 500 mm MAP. Both acid and alkaline soil pH's (4.4 to 8.3) are tolerated, as are textures ranging from clay to loamy sand. Salt spray

near the seashore is not a problem. Although no data are available, the species is probably not tolerant of waterlogged soils. No serious pests or disease have been observed. Norfolk Island-pine is very windfirm (10).

The wood of a tree cut during this investigation was light tan, fine grained, with numerous small, red knots; density was 0.62 g/cm³. Samples of 20 trees in Hawaii averaged 0.42 g/cm³, a radial shrinkage of 2.6%, a tangential shrinkage of 4.1%, modulus of elasticity of 99 559 kg/cm² and a modulus of rupture of 500 kg/cm² (5). The appearance is reminiscent of spruce (*Picea*). This wood should be suitable for general construction and as "knotty pine" specialty wood for paneling and medium quality furniture.

Norfolk Island-pine seems to have potential as a timber tree in Puerto Rico. Small trial plantations for yield estimation are needed. It will probably be necessary to order seed from international suppliers and grow the seedlings in local forest nurseries.

Araucaria hunsteinii K. Sch.

Klinki-pine is a native of Papua New Guinea, where trees of this species have attained heights of 85 m and girths of 6 m. The species occurs at elevations of 600 to 1 500 m and where MAP exceeds 1 600 mm (11).

Seeds (Papua New Guinea source) were obtained from the Food and Agriculture Organization in 1979. These were sown in containers and outplanted at Toro Negro in the Central Mountains in 1980. At five years old, 20 trees remained. They averaged 1.8 m in height and 1.54 cm dbh; the tallest was 2.6 m. The trees were vigorous, with no apparent disease or insect problems. The same leaning, partially uprooted condition occurred in one of the klinki-pines, as was observed in *A. cunninghamii* on this site.

Early growth of klinki-pine is a little slower than that of hoop-pine planted on the same site at the same time. According to Ntima (11), klinki-pine in New Guinea eventually catches up with hoop-pine and is favored for its better form. The species will need some protection from competition. The plantation has been given an annual weeding. It is too early to predict the future of this interesting species, but early indications are not discouraging.

Araucaria bidwillii Hook.

The bunya-bunya is native to coastal areas of southeastern Queensland, Australia. It occurs at eleva-

tions of 150 to 1 050 m, with a MAP of 890 to 1 270 mm. In its native habitat, it reaches a maximum height of 43 m (11).

The author has observed two individuals growing as ornamentals in the San Juan area (elevations of about 20 and 50 m and MAP's about 1 775 and 2 030 mm). At perhaps 10 to 15 years old, one is 11.5 m high, with a dbh of 29 cm, and the other is 9.6 m high, with a dbh of 29 cm. Two other, even larger individuals are growing on private property at Rio Abajo (elevation 300 m and MAP of 2 000 mm). All are apparently healthy and growing well. The species should be tested systematically in a plantation environment in Puerto Rico.

Araucaria angustifolia (Bert) O. Kuntze

Parana-pine, a native of southern Brazil, was planted at a number of sites representing diverse soil types in Puerto Rico. In one site in the Luquillo Mountains, multiple seed sources from across the range of Parana-pine were used. The results have been consistent — poor survival and slow growth. Currently at 25 years (1986), the few surviving trees are flat-topped, stagnated, and very unthrifty. Few trees have exceeded 6 m in height. Parana-pine is not adapted to winter drought (6) such as that in Puerto Rico and prefers somewhat cooler temperatures. Apparently, Parana-pine should not be planted in Puerto Rico.

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