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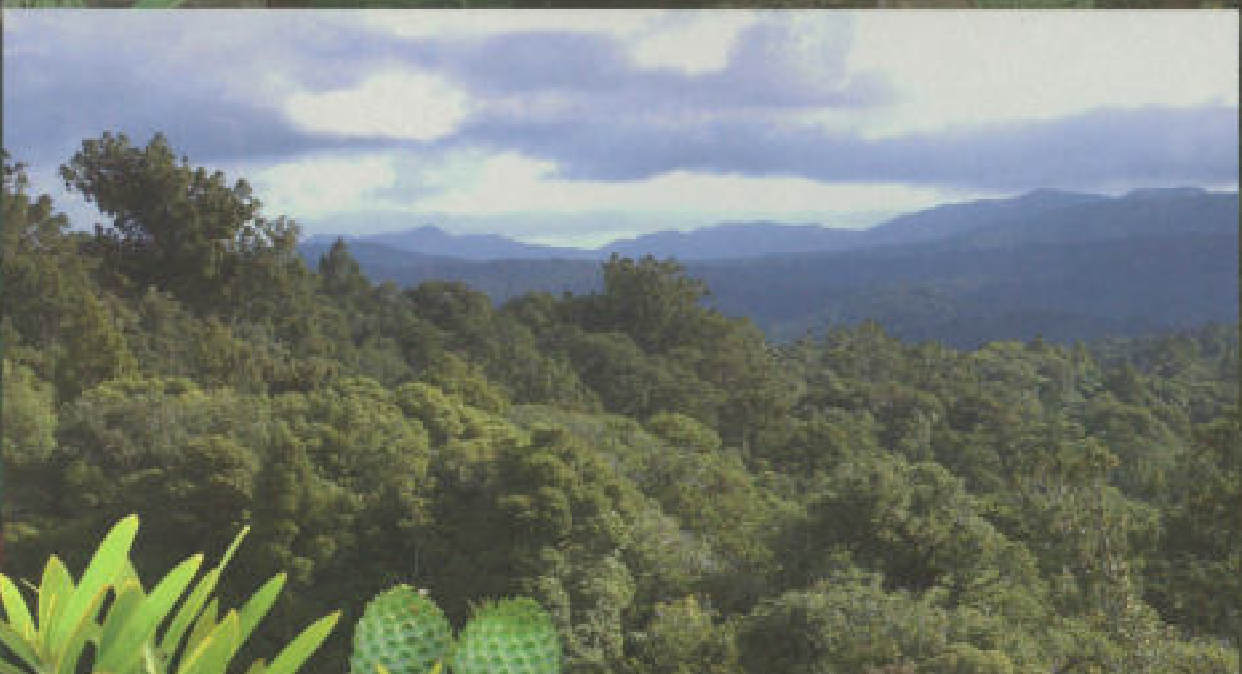

ECOLOGY, ESTABLISHMENT, GROWTH, and MANAGEMENT

David Bergin
and Greg Steward

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To obtain further copies of this publication, or for information about Forest Research publications, please contact:

Publications Officer
Forest Research
Private Bag 3020
Rotorua
New Zealand
telephone: +64 7 343 5899
facsimile: +64 7 348 0952
e-mail: publications@forestresearch.co.nz
website: www.forestresearch.co.nz

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Production Team

Jonathan Barran — photography
Teresa McConchie — layout design
Ruth Gadgil — technical editing
Judy Griffith — editing and layout

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Front cover insert: *Spreading large crowns of mature kauri, Waipoua Forest Sanctuary, Northland.*

Back cover: *Interior of St Andrews Church, Cambridge, built of kauri in 1881.*

KAURI
Ecology, establishment, growth, and management

David Bergin and Greg Steward

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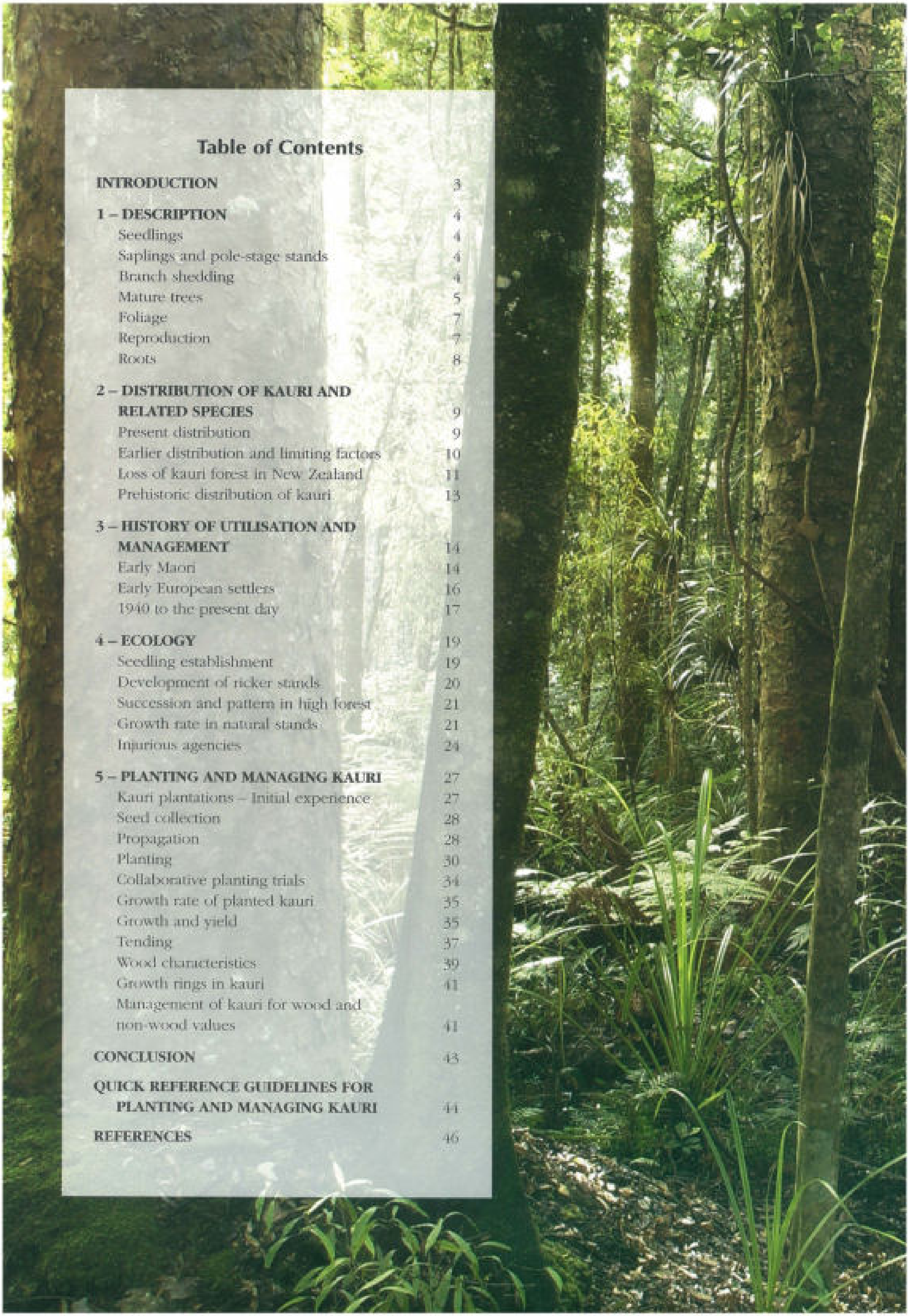


Table of Contents

Kauri (*Agathis australis* (D. Don) Lindl.) is a warm-temperate species that is dominant in the natural rain forests of the northern part of New Zealand. It can live for 1000 years or more and is probably New Zealand's best-known native tree. Massive individuals are regarded as national taonga (treasures). Kauri forest had cultural significance for early Maori who used the timber for making waka taua (seagoing canoes) and for the construction of whare (buildings). During the early period of European settlement most kauri forest was logged, cleared for farming, or destroyed by fires. From the mid-nineteenth to early twentieth centuries, kauri was an important component of the developing New Zealand economy, but the small remaining areas of mature forest are now reserves, most of them managed by the Department of Conservation. In many areas where native forest was cleared, young kauri stands are regenerating.

Kauri trees and the forests in which they grow are widely appreciated by New Zealanders and also by international visitors, and many excellent reviews of their habit, biology, ecology, and logging history have been published. This Bulletin does not set out to cover all aspects of the species; the intention is rather to provide up-to-date information for anyone wishing to plant individual trees or stands, and to manage kauri forest for timber production, conservation, and amenity value. The first four sections give an overview of the mode of growth, distribution, history, and ecology of kauri. The fifth section is a review of the latest information relating to establishment, management, productivity, and wood quality of plantations. Finally, a set of guidelines for planting and managing one of our best-known native tree species is offered to all those wishing to put this knowledge into practice.

Seedlings

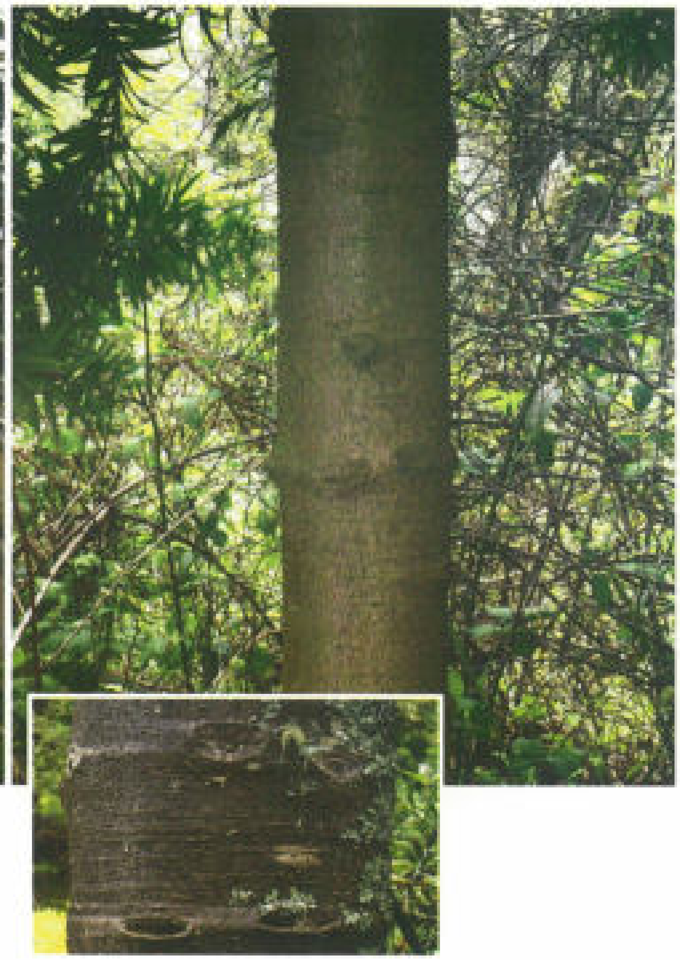
Kauri seedlings have single, apically dominant stems. Occasionally, when the tip of the growing shoot has been damaged, e.g., by frost, several stems develop to form a multi-leadered plant. Branches are borne almost at right angles to the stem and can be spindly.

Saplings and pole-stage stands

Most saplings have long, narrow, cone-shaped crowns and strong, single, leading shoots (monopodial habit). At the pole stage they are often referred to as "rickers". In natural forest this form persists until the stem reaches a diamter (at 1.4 m) of about 50 cm at age 150–200 years, after which the crown starts to spread (Ecroyd 1982). This process is sometimes referred to as "breaking out". Pole-stage kauri trees have a limited ability to coppice (develop new shoots) from cut stumps or from cut or damaged stems.

Seedlings and saplings usually have single, apically dominant stems. Branches are often long and spindly (below) *but the crown begins to taper as saplings develop.*

After the sapling stage, lower branches of kauri break away naturally, leaving a scar on the bark which subsequently flakes off. As a result the trunk is left free of knots.



Branch shedding

Branch abscission is a remarkable and valuable characteristic of kauri. From the sapling stage onwards, the lower branches break away cleanly from the trunk, leaving no lasting damage to the bark and no knots in the stemwood. The mechanism of abscission, described by Licitis-Lindbergs (1956), involves an increase in the proportion of cortex and pith tissue and a decrease in the formation of vascular tissue (wood) in the swollen base of the branch. Wilson *et al.* (1998) reported that branch shedding in mature trees leaves a rough-textured separation face on the bark of the trunk. As trees mature and bark starts flaking naturally, any sign of branch scars disappears.

Mature trees

Kauri trees reach a height of 30–50 m, rarely 60 m (Ecroyd 1982). When mature, they have straight, untapered, cylindrical stems that are free from branches and epiphytes to a height of 12–25 m or more. The massive crowns consist of upward-arching branches producing flat or slightly-rounded crowns. The stem diameter of trees aged 400–800 years is commonly 1–2 m and occasionally 3–5 m, although diameters greater than 6 m have been recorded. Ancient trees are often hollow, making the accurate determination of age from annual ring counts impossible. On Mt Tutamoe in Northland, a tree named Kairaru had a diameter of 6.4 m and a clear bole of over 30 m (Halkett and Sale 1986). Unfortunately, Kairaru was burnt before 1900. The largest existing individual (greatest wood volume) is Tane Mahuta in Waipoua Forest. This tree measured 4.4 m in diameter and 52 m in height in 1986 (Halkett and Sale 1986).

Cheeseman (1913) made one of the earliest studies of age and growth of kauri, and refuted earlier claims that the largest trees were many thousands of years old. His conservative estimates of growth rate were based on measurements of annual rings in trees with stem diameters ranging from 60 cm to nearly 4 m. He calculated an age of 232 years for 1.2 m diameter trees.

Ahmed and Ogden (1987), using cores taken from trees of different diameter classes in numerous stands, concluded that typical longevity of trees in old-growth stands was over 600 years. They estimated that trees 2 m in diameter averaged 1100 years in age while a 3-m-diameter tree was probably 1680 years old (its seedling would have been established in AD 320, when the Romans were still occupying Britain!).

The largest living kauri tree, Tane Mahuta in the Waipoua Forest Sanctuary, Northland, showing the massive cylindrical branch-free trunk.
Inset: *The upper branches produce large rounded crowns.*

Foliage

Kauri leaves have no petioles and are arranged alternately. They are thick and leathery with parallel veins and are a dull olive-green colour. Juvenile leaves are 5–10 × 0.5–1.2 cm; adult leaves are 2.0–3.5 cm long. Most leaves remain on the tree for 3–6 years (Ogden and Ahmed 1989), some up to 15 years (Silvester and Orchard 1999).

The colour of seedling foliage varies from olive green to bronze to red. Reddening is noticeable in naturally regenerating seedlings and nursery-raised stock. It is caused by increased concentration of the red pigment rhodoxanthin and is thought to be a response to high light intensity (Peterson 1963).

Roots

Root growth in kauri seedlings is slow. The newly germinated seedling has a strong taproot and a fibrous lateral root system that often develops on only one side (R.Lloyd, Kauri Management Unit, New Zealand Forest Service, unpubl. data). The taproot of small seedlings can be as much as three times longer than the shoot. A single taproot, or sometimes multiple taproots, continues to develop in young trees, reaching a depth of 2 m or more unless impeded by rock or a hard soil pan.

Mature kauri trees have well-developed root systems (Yeates 1924; Cranwell and Moore 1936), the large lateral roots often extending beyond the width of the crown. Deep "peg" roots or "sinkers" descend from the laterals and provide firm anchorage. Observations of large wind-thrown trees in several Northland forests indicated a tendency for three to four large surface roots to radiate up to 6 m from the base (R.Lloyd unpubl. data). There was no sign of a taproot but numerous peg roots were 4 m in length and terminated in a network of smaller roots.

Mature trees form an extensive network or mat of fine feeding roots extending from the lateral roots into the interface between decomposing litter and the mineral soil (Yeates 1924; Cranwell and Moore 1936). These have a beaded appearance due to modification of their structure, but any resemblance to legume nodules is superficial. Claims that they are the sites of symbiotic nitrogen fixation have not been substantiated (Silvester and Bennett 1973).

The influence of mycorrhizal fungi on growth of kauri has been the subject of several investigations (e.g., Baylis *et al.* 1963). These fungi are found naturally in forest soils and often form specific symbiotic associations with roots that enhance the absorption of moisture and nutrients. While Bieleski (1959) found no difference in growth rate between kauri seedlings grown in sterile soil and those exposed to mycorrhizal infection, Morrison and English (1967) reported that mycorrhizal infection stimulated phosphate absorption by the nodule-like roots.

Fusion of major lateral roots has been observed in mature trees (R.Lloyd unpubl. data). Roots occasionally become grafted with those of neighbouring kauri trees and the stumps of felled trees may therefore remain alive for considerable periods.

Above: *Variation in foliage colour is a feature of naturally regenerated and nursery-raised seedlings. Reddening may be a response to high light intensity.*

Reproduction

Kauri is monoecious, i.e., male and female cones are borne on the same tree. The long male cones (2.5 × 0.8–1.2 cm) are borne in leaf axils, usually on branches above the female cones but sometimes on the same branch. Kauri has a 2-year reproductive cycle, with pollen sac and ovule formation beginning in October. Pollen is shed and fertilisation occurs during the following September-October period (Owens *et al.* 1995). Seeds mature in March of the second year in cones that are 5.0–7.5 cm in diameter when ripe. Seed-bearing cones break up on the tree and release seeds with small wings. These are dispersed by wind and gravity, and seedfall may continue for 3 weeks.

Although trees do not usually produce viable seed until they are 25–40 years of age (Halkett 1983), female cones have been observed on planted trees as young as 6 years old and seed has been reported on 15-year-old trees. Seed is produced annually but quantity and viability are variable.

Seeds are not dispersed over great distances. They have single small membranous wings, approximately 10 mm in width, and do not travel further than 20–100 m from the tree crowns in normal weather conditions. Most fall within 50 m of the parent tree (Enright *et al.* 1999). Ecroyd (1982) reported dispersal distances of 1.5 km, but these are very rare.

Small male cones are usually located on branches above the female cones, but sometimes on the same branch. They produce pollen in spring. Seed matures approximately 6 months later in autumn.

Kauri seed is released from cones when they disintegrate in late summer and early autumn. A small wing causes the relatively heavy seed to spiral to the ground for distances up to 100 m from the parent in average weather conditions.

PART 2 – DISTRIBUTION OF KAURI AND RELATED SPECIES

Present distribution

Kauri is a characteristic emergent canopy tree in natural forests lying north of a line between Kawhia and a point just south of Tauranga. This line corresponds approximately to latitude 38°S (Ecroyd 1982) and marks the separation of a northern and a southern element in the flora of New Zealand. Some species in the northern location, including kauri, are related to tropical plant families (Ogden *et al.* 1992). Before human settlement extensive forests in this region included groves of kauri, or scattered trees emerging over a broadleaved canopy of other species such as taraire (*Beilschmiedia tarairi*). They were often associated with other native conifers such as tanekaha (*Phyllocladus trichomanoides*), rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), and totara (*Podocarpus totara*).

Near to its southern limit, kauri occurs as scattered trees and small stands. It increases in abundance further north to become common just south of Auckland (Ecroyd 1982). Scattered pockets of mature trees remain on the Coromandel Peninsula where stands of saplings and pole-stage kauri are more common. The largest remaining stands of mature trees are found in Northland. Younger kauri are most common in eastern Northland, on Great Barrier Island (Aotea), Little Barrier Island (Hauturu), and a number of other islands in the Hauraki Gulf and off the eastern coast of the Coromandel Peninsula.

In Northland, Auckland, and Waikato, kauri is a lowland species, common only between sea level and 300 m (Ecroyd 1982). It occurs up to 700 m in several parts of the Coromandel Peninsula. On Te Moehau, a rugged mountain system at the northern end of the peninsula, Cranwell and Moore (1936) described an area of more than 30 ha where stunted and gnarled trees were frequent between 600 and 800 m and where active regeneration was taking place.

Kauri in a plantation established in 1955 on the Taieri Plain south of Dunedin are on average 20 m high. Viable seed has been collected from this stand.

Kauri planted 15 years ago in a Dunedin city park are producing cones.

Earlier distribution and limiting factors

Factors that control the current natural limit of kauri distribution have been the subject of debate for many years (Ogden *et al.* 1992). Bieleski (1959) considered that where the average daily temperature maximum falls below 17°C, kauri growth rate decreases to the point of dormancy, thus reducing the duration of the annual growth period. In latitudes south of the current natural range, slow growth combined with a short growing season results in suppression by species that are better adapted to cool conditions. This would account for the ability of kauri to grow in more southerly locations and at higher altitudes when it is not in competition with other species.

It has been suggested that scattered groves of kauri near to the natural distribution limit are relict stands and that growth further south is restricted by lack of suitable soils and terrain rather than by climatic conditions (Clayton-Greene 1978). When an ecological disturbance provides an opportunity for recolonisation, plant species that are more competitive on fertile soils may suppress any kauri seedlings that are present.

There is no doubt that kauri can grow much further south if competition from other species is reduced and warm frost-free sites are available. Plantations in Taranaki approaching 70 years of age are 120 km south of the limit of the present natural range (Herbert *et al.* 1996). In the lower North Island and the South Island numerous plantings in amenity parks and gardens have been successful. Kauri has also established at Invercargill and on Stewart Island, although an extended period of severe frosts has recently killed kauri in an Invercargill park (G.Morgan, Southland Regional Council, pers. comm.). Longevity of some stands on sites prone to severe frosts may therefore be at risk.

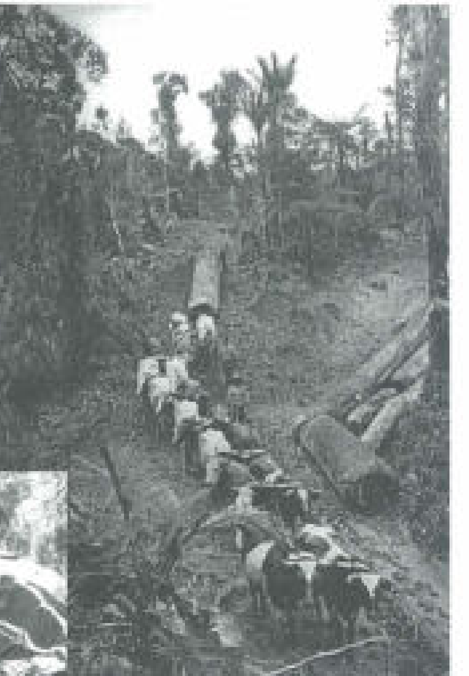
Although cones are produced on trees planted in many places south of the natural limit, few instances of successful seedling establishment have been formally recorded (Steward *et al.* 2003). These included New Plymouth, on the edge of a 60-year-old kauri plantation in a city park, and Wellington, in gardens near semi-mature trees growing in sheltered suburban sites.

Two seedlings have been found 5–6 m from a 30-year-old tree at Woodend, near Christchurch, where this tree and a 44-year-old kauri have been producing cones for a number of years (I.Platt, Ministry of Agriculture and Forestry Senior Forestry Adviser, pers. comm.). Viable seed has been collected from a plantation near Dunedin (Ecroyd 1982) but no seedlings were found.

Loss of kauri forest in New Zealand

Before human colonisation of New Zealand took place, kauri forest is thought to have covered 1.0–1.5 million hectares (Halkett 1983; Halkett and Sale 1986). Approximately 7000 ha of old-growth kauri forest remained by the 1980s. The accuracy of estimates and definitions of "kauri forest" is debatable, but there is no doubt that the amount of old-growth forest with kauri as a significant component is currently little more than 1% of that which existed before human settlement. Halkett (1983) reported that in the 1980s, second-generation kauri comprising dense stands and scattered trees covered an area of some 60 000 ha. Shrubland containing kauri in Northland and the Coromandel Peninsula may have been cleared over the past 20 years (Beveridge *et al.* in press).

Felling a large kauri tree in Omahuta Forest, Northland, in 1910.



Oxen teams extracting kauri logs from a Northland forest in the late 1800s

Jacks were essential for moving large kauri logs in preparation for transporting to the mill.

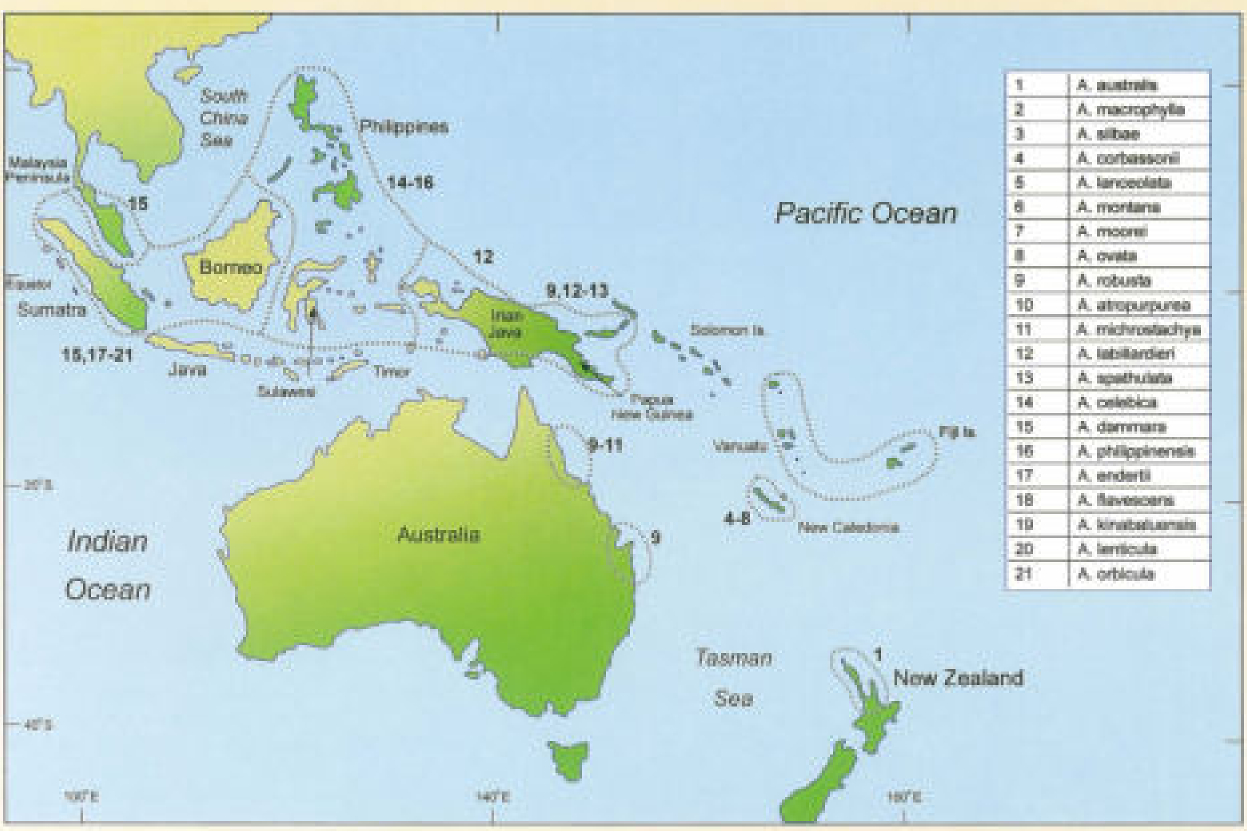
CLOSE RELATIVES OF KAURI AND THEIR DISTRIBUTION

Agathis is one of the three genera of the Araucariaceae, a family of coniferous trees found almost exclusively in the Southern Hemisphere. The 21 species of *Agathis* occur in the forests of Australia, Papua New Guinea, New Caledonia, New Zealand, and other parts of the south-west Pacific.

Agathis australis (kauri), the most southerly representative of the genus, is endemic to New Zealand (Ecroyd 1982). The other species are found as far west as the islands of Sumatra and the Malay Peninsula, as far north as the Philippines, and as far east as Fiji (Halkett 1983). They are all commonly known by the New Zealand Maori name "kauri", sometimes as "kauri pine", and are all highly prized for their fine-grained uniform timber (Whitmore 1977). Best-known are Queensland kauri (*A. robusta*) and Fijian kauri (*A. macrophylla* var. *vitiensis*). The greatest concentration of the genus (a group of five species) is found in New Caledonia (Whitmore 1977). Many species are geographically isolated or have a limited range. No hybridisation within the genus has been recorded (Ecroyd 1982).

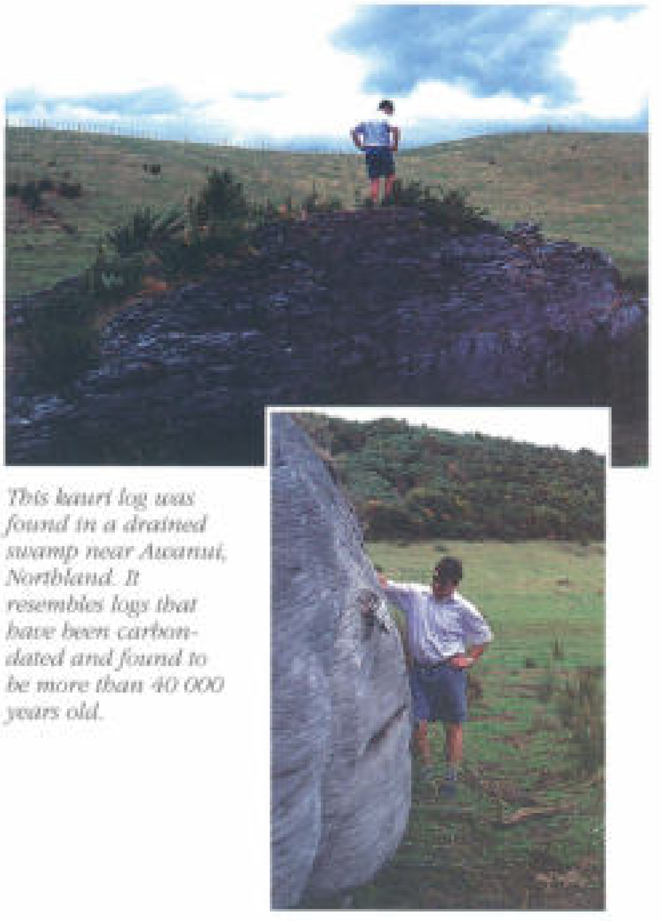
The two other genera of the Araucariaceae are *Araucaria* (19 species) and *Wollemia* which has a single species, *W. nobilis*. Wollemi pine was not identified until 1994 when it was found in a wet sheltered gorge in the Wollemi National Park, north-west of Sydney, Australia.

Distribution of the 21 *Agathis* species in the south-west Pacific (modified from Halkett 1983; Farjon 1998).



Prehistoric distribution of kauri

Kauri pollen preserved in layers of sediment which can be dated is an excellent indicator of the former presence of the species. Fossil wood found in bogs has also been used widely to investigate the prehistoric distribution of kauri (Ogden *et al.* 1992). Pollen records indicate that the area covered by kauri has varied over hundreds of thousands of years in response to climate and sea level changes (Ecroyd 1982; Kershaw and McGlone 1995). The species was present well south of its current distribution limit as late as 300 000 years ago. It was scarce during the warmest and coldest periods, maximum abundance being achieved when the climate was cool and moist. Kershaw and McGlone (1995) considered that once kauri regenerates under milder conditions, its longevity and vast size permit it to compete successfully with other species, especially on nutrient-limited sites. In colder and drier periods, beech (*Nothofagus* spp.) and the podocarps become dominant and kauri is confined to microsites scattered throughout the range. Kauri trees have been more numerous during the last 7000 years in the north and during the last 3000 years in the southernmost part of the present range (Kershaw and McGlone 1995). Ogden *et al.* (1992) argued that regeneration of kauri is dependent on large-scale ecological disturbance, and that the more recent population increase is due to disturbance by wind or fire rather than to changes in temperature or rainfall.



This kauri log was found in a drained swamp near Awanui, Northland. It resembles logs that have been carbon-dated and found to be more than 40 000 years old.

Kauri wood has been preserved in swamps throughout lowland parts of Northland and as far south as the Waikato where carbon dating has provided age estimates of more than 40 000 years. In reviewing the history of kauri distribution, Ogden *et al.* (1992) regarded the presence of kauri wood in bogs as a mystery because the present-day habitat is mainly ridge-tops or relatively dry north-facing slopes. They observed that kauri is occasionally found growing on waterlogged sites, and suggested that "swamp kauri" forest may have been destroyed by early logging or that trees were established before the bogs developed. They acknowledged that changes in climate or tectonic movements could have accounted for site changes since forest establishment.

Kauri forests once present in the Waikato lowlands were destroyed by flooding after the Taupo eruption about 1800 years ago. Draining of swamps has revealed the stumps of former kauri giants.

The Taupo eruption 1800 years ago felled and buried the central North Island podocarp forest with layers of volcanic ash and pumice which often became wetlands (Clarkson *et al.* 1988). During conversion to agricultural land, one such bog site was found to contain well-preserved kauri wood, leaves, and cone scales, as well as plant material of a number of associated species (A.E.Beveridge, New Zealand Forest Research Institute, unpubl. data). Draining, burning, and shrinkage of peat revealed extensive root systems and massive stumps of kauri. Carbon dating and a thin covering layer of Taupo Pumice linked burial with the last Taupo eruption. The site appears to have been flooded by the Waikato River after the eruption. Pollen analysis of lake deposits and bogs in the lower Waikato (Ohinewai and Hamilton) shows that kauri grew at the margins of swamps which reached a maximum level approximately 1000 years ago. Bog vegetation was prone to fire and adjacent kauri trees were probably destroyed by burning after Polynesian settlement (McGlone *et al.* 1984; Newnham *et al.* 1989).

PART 3 – HISTORY OF UTILISATION AND MANAGEMENT

Early Maori

Although totara was the tree most revered by Maori throughout New Zealand, kauri was highly regarded in the north. Its straight branch-free stems growing beside harbours or near rivers were favoured for making waka taua (seagoing canoes) and the wood was used for carving (Clifton 1990). Major Richard Cruise of H.M.S. Dromedary described a canoe seen in the Bay of Islands in 1820: "It was 84 feet long, 6 feet wide and 5 feet deep ... It was made of a single cowry-tree, hollowed out, and raised about two feet, with planks firmly tied together and to the main trunk, with pieces of flax plant inserted through them ... A post fifteen feet high rose from the stem and stern, which, together with the sides, was carved in open work, painted red, and with a profusion of black feathers ..." (from Clifton 1990).

The giant trees of the kauri forest have always had cultural significance for Maori people. Many myths and legends record divine properties attributed to the species. Today's largest surviving specimens are known as Tane Mahuta (Lord of the Forest) and Te Matua Ngahere (Father of the Forest).

Exuded resin (kauri gum) was called "kapia" by early Maori (Hayward 1982). Fresh gum was used for chewing, as was older gum when softened by water. Gum bound in flax was ignited and used as a torch for fire-lighting and night-fishing. Gum was also used for tattooing when burnt and pounded, the fine soot being mixed with oil and animal fat to make blue-black or greenish pigments.

"RANGATIRA OF LAND AND SEA"

Northern Maori believed the kauri to be the father of the sperm whale. Because of their huge size, both were regarded as the rangatira (chiefs) of their respective realms. Their bark and skin show similarities of texture, while kauri gum is like the ambergris found in the intestines of the whale.

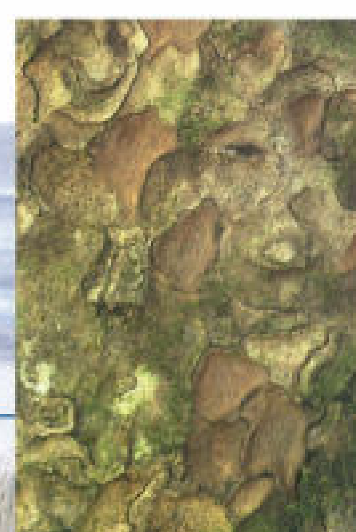
In times long past, a sperm whale came ashore and spoke thus to the kauri: "Kauri! Come with me to the sea which is fresh and cool."

"No!" said the kauri. "You may like the sea but I prefer to stand here with my feet in the soil."

"All right" said the whale "then let us agree to exchange our skins."

That is why the bark of kauri is thin and full of resinous oil.

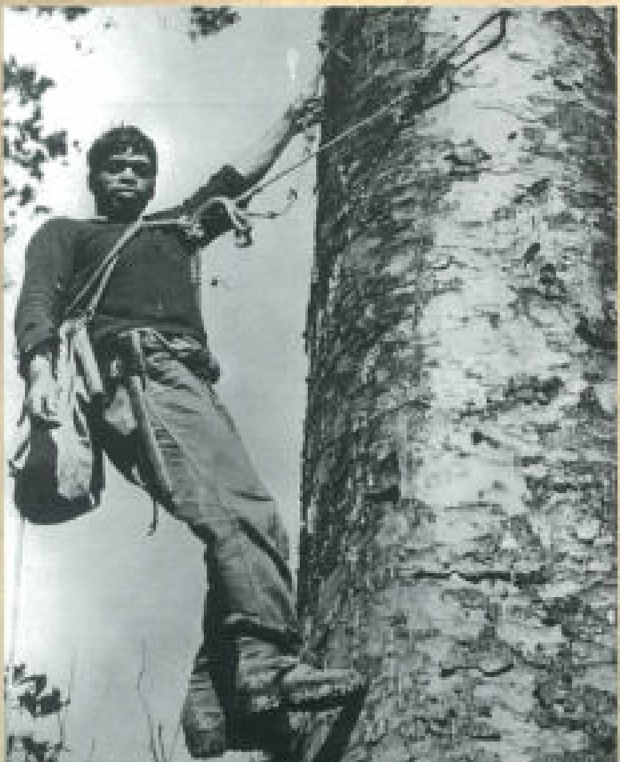
Acknowledgement – Auckland Museum



THE KAURI GUM INDUSTRY

Kauri gum is the solidified resin of kauri trees. Resinous sap oozes from fractures or wounds to the bark of the tree, along splits where branches fork, and where branches have broken. It deters the entry of fungi and insects. Congealed lumps of gum eventually fall to the ground and are covered by layers of forest debris. Large deposits of buried gum were built up over thousands of years. In areas of Northland known as "gumlands" the soil has been systematically excavated in the search for gum deposited by the trees that once grew there.

Gum was found to have properties that made it valuable in the manufacture of linoleum, paint, and varnishes. Top grade nuggets were made into fashionable beads and used for carving. Gum deposits dug from the soil of cutover or burnt forests were the source of a thriving local export industry between 1840 and 1940, peaking around 1900 when 10 000 tons were exported. The gum collectors of this period first gathered surface deposits and later drained swamps and bogs to reach fossil layers. Immigrant Dalmatians and Croatians dominated gum production in the Northland gumfields from the mid-1880s (Reed 1948).



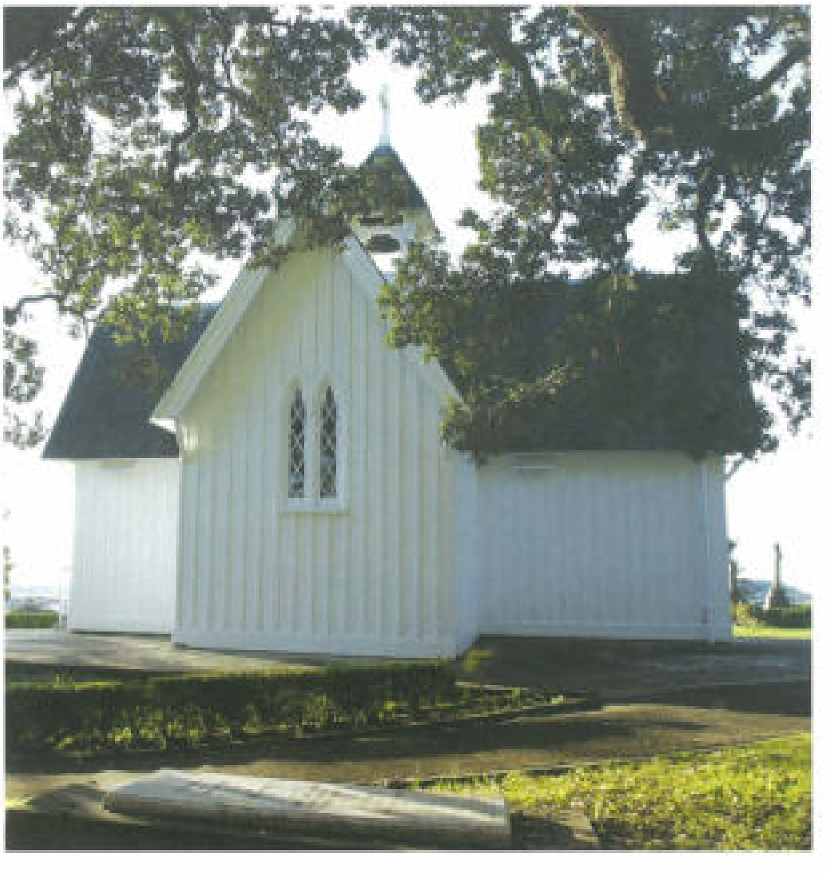
Gum was also collected from forks in the largest trees and from notches cut in the stems by a process known as "bleeding". Gum collectors and farmers often lit fires to clear land, and large areas of standing forest were burnt. Gum bleeding was found to have a harmful effect on tree health and was made illegal in 1905. Even so the practice continued for some years, especially on the larger stems.

Gum bleeding involved climbing kauri trees and notching the trunk to stimulate the production of resin, which was later collected.

Many early buildings were constructed of kauri as the timber had excellent qualities. The romantic timber building known as Alberton in Auckland began as a farm house in 1863 and was later expanded with decorative verandahs and towers. Lower right: *St Stephen's Chapel in Judges Bay, Auckland, built in 1856.*

Early European settlers

French sailors in the late 1700s were the first Europeans to record the presence of kauri and to identify the potential for masts and spars. Exploitation of the forests began at the start of the nineteenth century. Spars were exported to Sydney or London during the late 1820s and a decade later sawmills and boat-building yards were established, using kauri as the main timber. Demand increased for the straight even-grained wood which had excellent strength, workability, and finishing properties. The peak production year was 1906 (443 000 m^3 cut in 36 mills) after which the industry began to decline until the late 1940s when annual production dropped to below 5000 m^3/year. The forests were devastated by over-logging and fire, even though the damage was recognised as it was occurring. As early as 1840 the "waste and destruction of the kauri resource" was documented, calls being made for reservation of suitable stands before settlement (Roche 1990).



Stumps testify to the clearance of former kauri forest that yielded hundreds of thousands of cubic metres of high-grade wood for boat building, furniture manufacturing, and house construction.

Emphasis today is on protecting our old-growth kauri forests, including this stand known as "The Seven Sisters" in Waipoua Forest. Boardwalks protect the root systems of these giant trees from the effects of trampling by thousands of visitors each year.

1940 to the present day

Destruction of the national kauri resource became a public issue during the 1940s. A conservation movement was led by Professor W.R.McGregor who had a long association with early research in Waipoua Forest. In 1952, an area of 9000 ha of forest at Waipoua containing a significant kauri component was recognised as a Forest Sanctuary. This area has become an important visitor attraction. Several of the giant trees are close to a road built through the forest in 1927.

Small-scale partial-logging operations were permitted in several kauri forests until 1979, but by 1980 all kauri logging in State Forests had ceased. Today, protected natural areas, most of them administered by the Department of Conservation, ensure the survival of both old-growth forest and modified stands containing mature and developing kauri trees.

Kauri forest produced large quantities of high-grade timber for nearly 100 years, up to the early twentieth century. Timber was exported or used locally for many purposes including furniture-making and house-building. Wood and resin products contributed greatly to the general economy and to employment in the northern districts during the late nineteenth and early twentieth centuries.

Huge kauri felled in a Northland forest. Note figure standing at end of log.

The KAURI Museum
MATAKOHE

The Kauri Museum is located at Matakohe, south of Dargaville, on the western side of Northland. Settlers first came to Matakohe and nearby Paparoa in 1862. The museum was established to celebrate their centennial and pay tribute to those early pioneers. It is administered by a charitable trust with wide local community support, with the mission to record aspects of the kauri industry and local pioneers and to provide displays and information for the public.

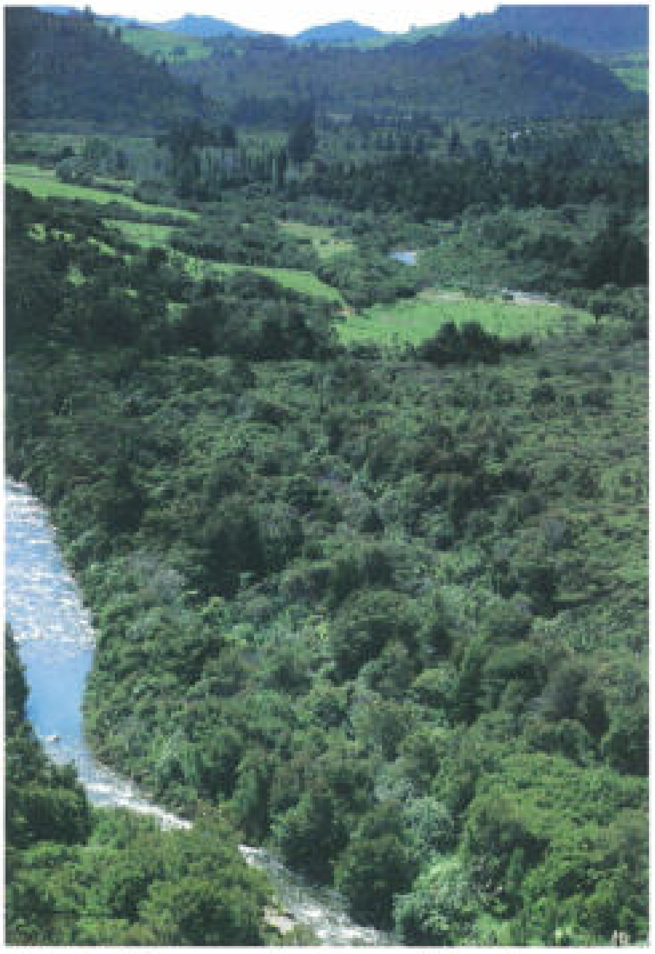
The museum provides an insight into the history of exploitation of kauri forests for timber and gum from early settler days until conservation measures were taken over the last century to preserve remaining kauri forest. A wide range of static and working model displays depict the kauri industry throughout Northland; they include felling equipment, a steam sawmill, and end-uses of wood and gum.

Natural establishment

Under natural conditions, the immediate post-germination stage is critical for successful kauri establishment. If the autumn is moist and warm, seed germinates within a few weeks of seedfall. Bieleski (1959) suggested that failure of seedlings to establish under a cover of mature trees might be due to the inability of young trees to reach soil through the thick layers of litter and raw humus. He considered that high mortality rates were the result of desiccation. Seedlings frequently become established on rotting logs, on root mounds of fallen trees, or on disturbed soil where moisture and nutrients are locally available.

Bieleski (1959) considered that the cessation of growth in winter may be a factor that limits natural kauri establishment. By early June, seedlings have usually developed two cotyledons or seedleaves, two true leaves, and a 2- to 5-cm unbranched taproot. At this stage they are susceptible to drought, especially on ridge-tops in late autumn. When finally established, on the other hand, they become drought-tolerant and dry periods may even stimulate root development. Older kauri seedlings can tolerate a wider range of conditions than many other species (Bieleski 1959).

Light and temperature conditions and the thinner litter layer in secondary forest are more favourable for establishment of kauri seedlings than conditions in old-growth forests (Mirams 1957; Bieleski 1959). Seedlings are also common on burnt sites colonised by shrubs, or on reverting pasture that has been invaded by small-leaved vegetation (Ecroyd 1982).



Kauri seedlings grow well under a small-leaved canopy of manuka or kanuka that has colonised land cleared by fire or other disturbance.

Development of ricker stands

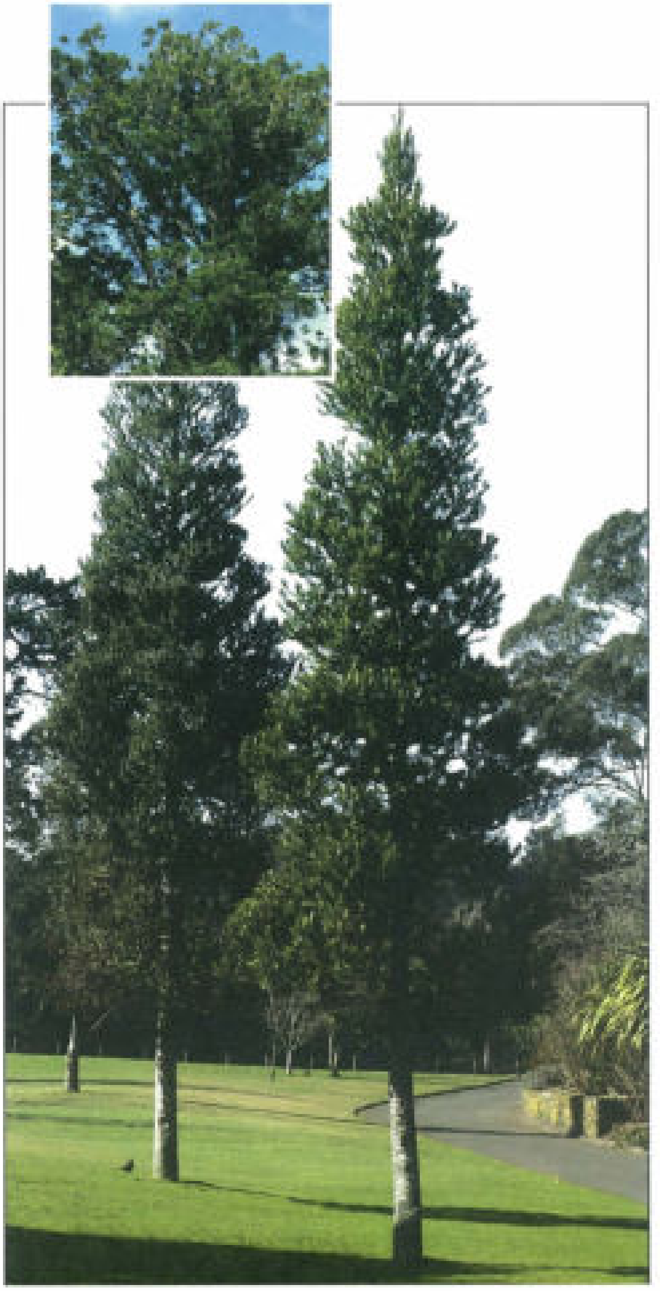
Optimum growth rates are associated with sheltered sites and friable, freely draining soils of moderate fertility. Often only scattered trees develop in fertile sheltered valleys and on lower slopes because broadleaved trees, shrubs, and ferns are able to grow more rapidly and suppress most of the young kauri plants (Beveridge *et al.* in press). In contrast, dense stands or groves of kauri frequently occupy drought-prone and less fertile ridgetops, spurs, and upper slopes where, although growth is slow, there is less competition from other species. For example, Burns & Leathwick (1996) found the predominant distribution at Waipoua Forest of most conifers, including kauri, was on the most infertile sites, generally on upper slopes and ridges. In contrast, most dominant broadleaved species tend to reach their greatest importance at mid to lower slopes.

The vegetation succession from burned forest through associations dominated by manuka (*Leptospermum scoparium*), kanuka (*Kunzea ericoides*), and tanekaha to kauri ricker stands, has been described by several authors. Ogden (1983) found that ricker stands that had developed after burning in the late 1800s contained more than 4000 pole and sapling stems per hectare.

Stands of most tree species undergo self-thinning as height and biomass increase. Light-demanding early successional species are usually suppressed by hardwoods such as taraire and kohekohe (*Dysoxylum spectabile*). Where kauri is present, the tallest poles eventually emerge above neighbouring trees, usually when their stem diameter reaches about 50 cm. At this stage, the lower branches of the conical ricker crown are shed and an open, spreading crown develops above the canopy of hardwood species (Ogden and Stewart 1995).

A number of small kauri forests composed of dense saplings and submature trees developed after fire in pre-European times. One of the best examples is Pukekaroro Forest, 100 km north of Auckland. Kauri in such discrete stands tends to be even-aged and some trees are up to 250 years old (Beveridge *et al.* in press).

The conical crown of pole-stage kauri (below) changes into an open spreading crown (inset) when the trees begin to emerge above the hardwood canopy about 100 years after establishment.



Succession and pattern in high forest

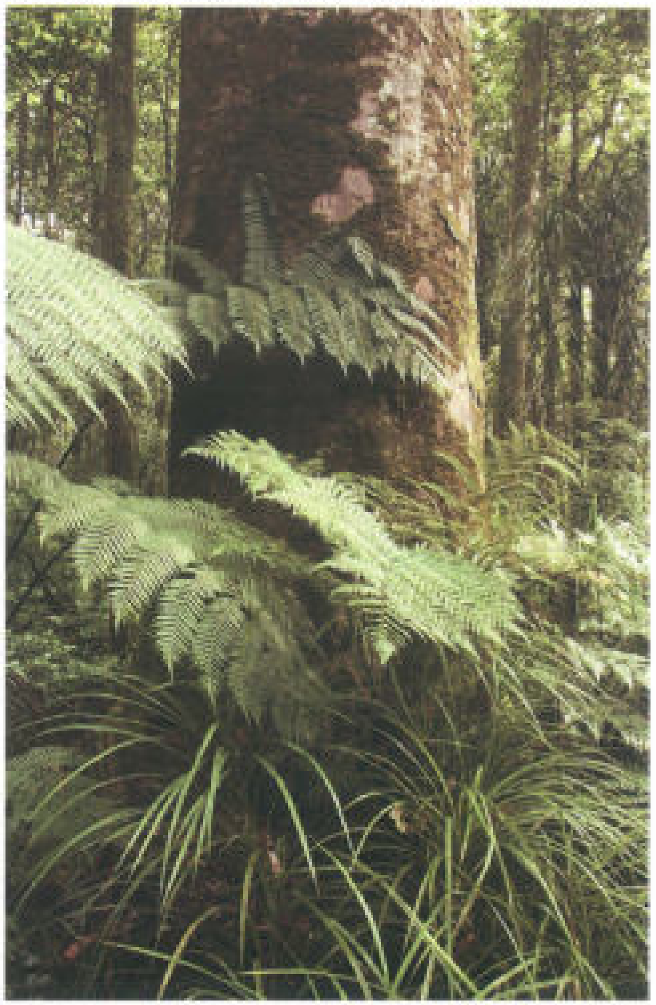
Ogden and Stewart (1995) reviewed several successional models that could explain the mosaic pattern typical of mature forest where kauri occurs in patches surrounded by a mixture of other broadleaved trees and conifers. At Waipoua, mature kauri comprises only 7% of the total forest, occupying areas of about 3 ha on ridges and north-facing upper slopes (Burns and Leathwick 1996). Ogden and Stewart (1995) suggested that, while this may be due in part to tolerance of drought, it is also possible that the sites were once open areas resulting from storm damage or fire and that colonisation by manuka and kanuka could have allowed a new cohort of kauri to develop. Replacement by a second generation would have been patchy because tree-fall gaps are rapidly colonised by broadleaved species. Only large gaps are likely to have been reoccupied by kauri. These sites are often susceptible to wind and storm damage. Over time kauri would have been restricted to low-fertility, high-disturbance-prone, ridge crests where broadleaved species are unable to compete. Kauri has potential for colonising a wider range of sites if large-scale disturbance occurs. Past climate change as well as more recent logging and burning has probably been responsible for the formation of sites where kauri could establish (Ogden and Stewart 1995).

Growth rate in natural stands

Under natural conditions the growth rate of kauri is variable, particularly at the seedling and sapling stage. Height growth of kauri seedlings in full light is usually 10–25 cm/year, increasing through sapling and pole stages to 30–40 cm/year (Ecroyd 1982). At low light levels under a dense forest canopy, kauri may grow very slowly for 50 years or more. A stand of suppressed kauri saplings on the Coromandel Peninsula had an average height of 1.4 m at a mean age of 40 years (Burns and Smale 1990). Saplings and poles grow most rapidly with full overhead light. Diameter growth rate ranges from less than 2 mm/year on poor sites to over 6 mm/year (Barton 1999). At the site studied by Burns and Smale, the mean annual diameter increment of sub-mature trees 100–200 years old was 4.3 mm. Most had the conical ricker form but the crowns of larger trees were starting to spread. Cheeseman (1913) recorded a mean diameter growth rate of 2.5 mm/year in 20 trees of approximately 1 m diameter. In a study of 25 sites over the species range, Ahmed and Ogden (1987) concluded that trees 10–140 cm diameter had a mean annual diameter growth increment of 2.3 mm/year. This rate was similar to that recorded by Steward and Kimberley (2002) in four natural stands 120 to 220 years old. Ahmed and Ogden (1987) found that the correlation between age and diameter was weak, i.e., the largest tree at a particular site is often not the oldest one.

Above: *A dense kauri stand on a ridge site at Pukekaroro, Northland. Kauri tolerates infertile drought-prone ridge sites where there is less competition from broadleaved species.*

Below: *A forest of mature kauri with spreading crowns emerging from a canopy of broadleaved trees.* Astelia trinervia, *sometimes referred to as "kauri grass", can dominate the forest floor of some Northland kauri forests.*



Did you know…

Biomass

Kauri forests, due to their great longevity and slow organic decomposition, accumulate larger amounts of biomass than forests of most other species throughout the world. Silvester and Orchard (1999) estimated that a mature stand with basal area up to 100 m^2/ha in Trounson Park, Northland, had accumulated 2200 tonnes dry matter/ha: 1500 tonnes/ha above ground, and 750 tonnes/ha in roots and litter.

Litter accumulation

The build-up of organic matter on the floor of kauri forests is evident to any visitor. This litter layer contains a high proportion of woody material and reproductive structures (Silvester and Orchard 1999), and may be 2 m or more in depth near the base of large trees. The accumulation of litter is the result of remarkably slow decomposition, especially in slow-growing stands on nutrient-poor sites where it can last for nearly 80 years. Silvester and Orchard (1999) estimated that 73–546 tonnes litter/ha were present at four sites ranging from pole-stage stands to mature forest. These amounts are substantially greater than the 4–50 tonnes/ha found in warm temperate conifer forests overseas. Large amounts of litter accumulate in forests of other New Zealand tree species, but the highest values recorded for kauri exceed those found in either beech (380 tonnes/ha) or podocarp (464 tonnes/ha) forest (Goh and Heng 1987).

Podsolisation

Slow decomposition of large amounts of litter with a strongly acid reaction and a high content of phenolic compounds leads to a process of soil podsolisation under kauri forest (Silvester and Orchard 1999). On all soil types, especially sedimentary soils, acidic or mor humus is formed. This promotes leaching from the upper soil layers, leaving a white sandy horizon. The deposition of minerals at a lower level in the soil profile leads to the formation of an impervious iron pan (Gibbs 1980). Under the warm humid climate of the upper North Island the potential for podsolisation is strong. In strongly weathered sandy soils the influence of individual kauri trees can sometimes be seen in "egg cup"-shaped bleached areas within the soil profile (Ecroyd 1982). On soils derived from basaltic parent material, the effects of kauri litter decomposition on clay minerals may alter hydrological characteristics.

Nitrogen cycling

In mature kauri forests, large amounts of plant nutrient elements, especially nitrogen, accumulate in the litter and humus layers (Silvester 2000). In spite of this, there is good evidence that the growth of kauri is often limited by nitrogen availability. Studies of trees in pole-stage stands have shown that levels of available nitrogen and phosphate are often low and that application of nitrogen fertiliser results in a significant increase in growth rate, especially if this is done at time of thinning (Madgwick *et al.* 1982; Barton and Madgwick 1987).

Silvester (2000) recorded extremely high levels of nitrogen immobilisation and storage at two sites dominated by pole-stage kauri and two dominated by mature kauri trees. He considered that these were the consequence of a slow build-up of nitrogen fixed by free-living bacteria over a long period of time. Most of this nitrogen appeared to be unavailable to the trees, which showed evidence of nitrogen deficiency. Only 0.3–0.7% of the ecosystem nitrogen was mobilised in any year, and the nitrogen-use efficiency of kauri (155 g dry matter/g nitrogen) was found to be twice as great as that reported for other forest species.

Temperature

As the genus *Agathis* has a distribution centred in the subtropics with kauri being the southernmost, it is not surprising that kauri grows in the northern third of the North Island and requires a high temperature for optimum growth. Two distinct temperature effects have been observed: growth rate decreases when the temperature falls below about 24°C; and apical dormancy sets in when the average daily temperature maximum falls below 17°C (Bieleski 1959). Barton (1978) reported moderate growth rates when the mean monthly temperature was higher than 15°C between November and April.

Kauri seed germination rates are highest between 19°C and 27°C. The most rapid seedling growth occurs at day/night temperatures of 22°/16°C (Barton 1978). Kauri seedlings will tolerate temperatures down to –2°C at the cotyledonary stage, and down to –4°C when older (Barton 1985). Tree twigs and foliage can withstand temperatures of –7°C (Sakai and Wardle 1978). Frosts within the current natural distribution range are few and mild near the coast but more frequent and severe at inland sites. This is confirmed by the shape of the current southern natural distribution limit. The more severe frosts further south may be a major factor limiting the natural spread of kauri southwards. In older trees the period of annual growth is shorter at more southern latitudes (Bieleski 1959), optimum temperatures being reached only in the north of the North Island.

Light tolerance

Kauri seedling establishment takes place under the relatively high light conditions found in early successional forests, e.g., those dominated by manuka or kanuka (Mirams 1957). Enright *et al.* (1993) found that seedlings grew very slowly when the degree of canopy openness was less than 10%. Growth rate increased rapidly as openness increased to 20%, but there was little change at higher levels. Barton (1999) suggested that optimum seedling growth occurs at about 54% of full sunlight.

The work of Mirams (1957) and others indicates that kauri acts as an early secondary species, colonising large tree-fall gaps after the establishment of a nurse canopy of manuka and kanuka. In contrast to the shade tolerance of seedlings, foliage of mature trees is strongly light-demanding.

Water use

Bieleski (1959) first showed that kauri seedlings growing at what was near wilting point for other plant species grew as fast as those in moist conditions. Subsequent studies confirmed that kauri has an extremely high water-use efficiency. This is consistent with many observations of kauri's ability to grow on dry skeletal ridges where many other species cannot survive (W.B.Silvester pers. comm).

Human activity

Direct damage to trees has been caused by gum and seed collectors through tree climbing with boot spikes. The cutting of bark for gum bleeding has resulted in embedded wood damage and the introduction of pathogens. Many old trees in Waipoua Forest were damaged by gum collectors who notched the trunks along their full length (Reed 1964).

Roading activities close to large kauri in Waipoua Forest in the mid-1920s resulted in significant crown dieback in larger trees, a number of them sustaining stem injuries at the base. Recent roading alignment in the area involved construction of road bridges to protect root systems of larger trees (A.E.Beveridge pers. comm).

Several giant kauri trees stand close to State Highway 12 which passes through the Waipoua Forest Sanctuary. To protect their feeding roots, raised platforms supported by pillars were constructed when the road was widened.

Injurious agencies

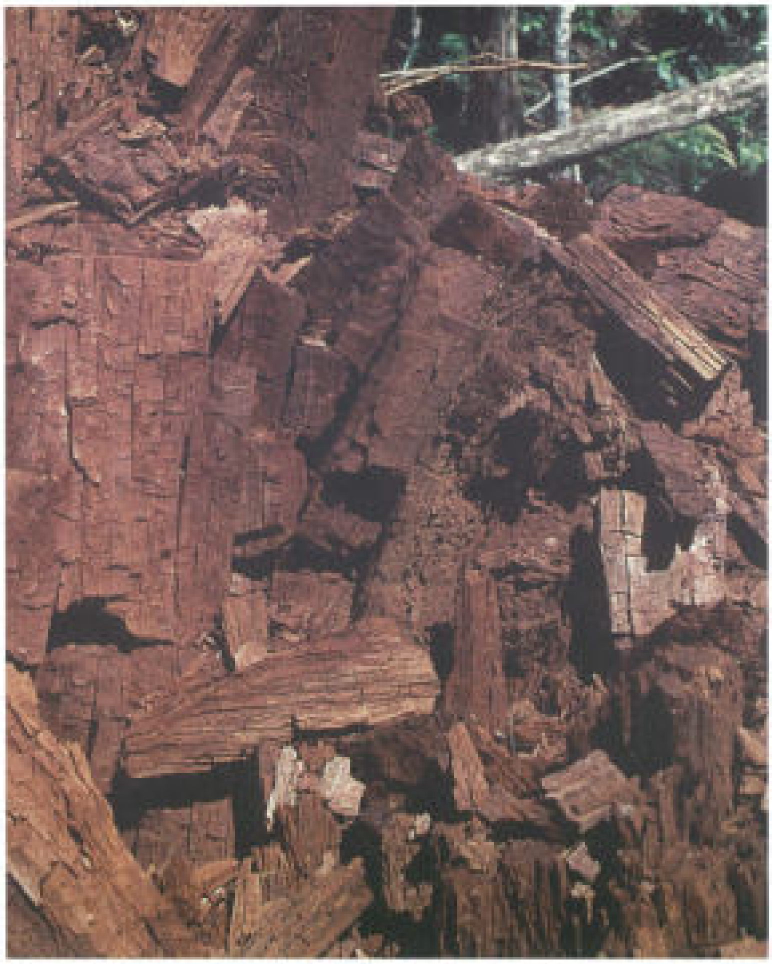
Fungi

Four fungi (*Phytophthora cryptogea*, *Phytophthora cinnamomi*, *Pythium irregulare*, and *Pythium ultimum*) have been recorded as the cause of rootlet rot in kauri seedlings, mainly in nurseries established on heavy, poorly drained soils (Newhook 1959; Robertson 1973).

In natural or planted kauri stands that have developed beyond the seedling stage, pathogens and pests are considered to be of low or only local importance (Ecroyd 1982; McKenzie *et al.* 2002). *Phytophthora cinnamomi* and *Phytophthora nicotianae* have been associated with stem lesions on older kauri trees, causing minor damage (Newhook 1959; Brien and Dingley 1959). Gadgil (1974) isolated *Phytophthora heveae* from roots and sapwood of dying kauri rickers (about 20 cm dbh) and from soil in a small area of diseased trees on Great Barrier Island. Although the fungus was shown to be pathogenic to kauri seedlings, it was also isolated from soil associated with healthy looking kauri. Gadgil suggested that pathogenic activity could be related to the effect of environmental factors that place trees under stress.

Rootlet rot (arrow) in nursery-raised kauri seedlings. The roots are fragile and the bark can be easily stripped off. It is likely that poorly drained soils contribute to the development of root rot in kauri.

The cause of dieback in mature kauri trees such as this giant at Waipoua Forest is difficult to identify. It has been linked to a number of factors including unusually wet seasons, presence of root-rot fungi, rot in the trunk, fire, lightning strike, and roading close to trunks.

Old kauri trees often have rot in the trunk and root system. The brown cubical heartrot in living kauri trees can contribute to windfall of giants.

Large, dead, standing trees are a prominent feature of some kauri groves. Podger and Newhook (1971) described death and dieback of kauri and associated species in two small areas of 80- to 100-year-old kauri regrowth in the Waitakere Ranges near Auckland. *Phytophthora cinnamomi* was isolated from roots of kauri and other species. The authors discussed the possibility of a link between the fungus and damage to the vegetation, particularly after periods of heavy rainfall. There is an unpublished suggestion that death or dieback of old kauri trees on flat ridge tops in the Waipoua Forest Sanctuary is associated with unusually wet summers and the presence of *Phytophthora* species including *P. cinnamomi* (F.J.Newhook pers. comm.). Johnston *et al.* (in press) consider that the introduced fungus, *P. cinnamomi*, may affect regeneration patterns and could have a greater impact after any climate change to warmer wetter conditions.

Old trees (usually those with signs of crown dieback if aged 600 years or more) often have bole and root rot. Several kauri giants that have fallen within the last 50–100 years have been hollow or contained extensive rot. Among the wood-rot fungi, *Heterobasidion araucariae* causes a minor sapwood decay of living kauri trees but is not of great significance (Hood 1992). A number of fungi cause heartrot of living kauri trees; these include *H. araucariae* and an unnamed native fungus (until recently known incorrectly as *Phaeolus schweinitzii*) which colonises mature and over-mature living trees in old-growth kauri forest, producing a brown cubical rot (Hood 1992).

Insects

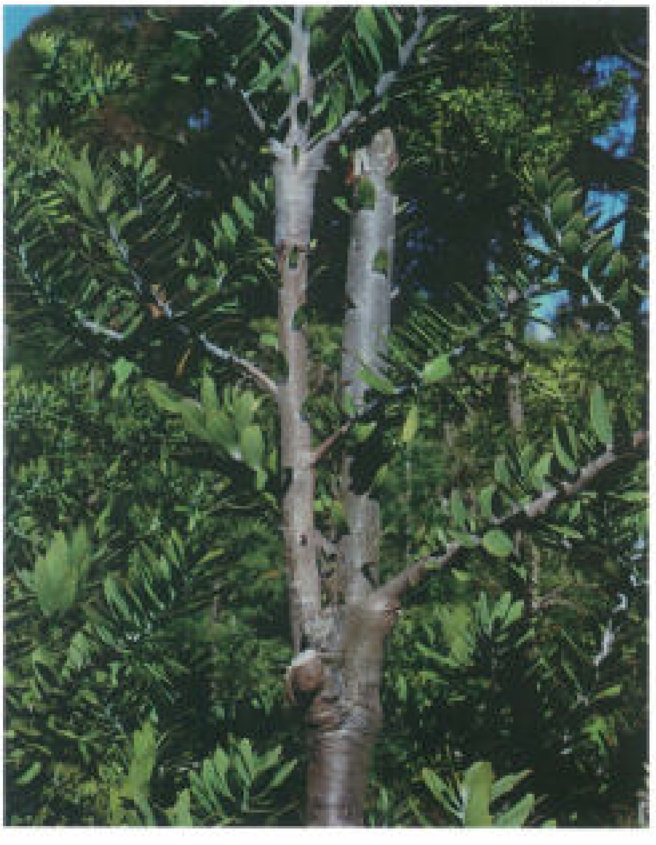
Kauri has few problems with insects, although anecdotal evidence suggests insect damage to growing tips of seedlings may lead to development of double leaders. Two species that are encountered are the kauri leaf miner (*Acrocerops leucomya*) and the greenheaded leafroller (*Planotortrix excessana*) but neither is a significant pest of kauri (J. Bain, Forest Research, pers. comm.)

Windthrow

There are no well-documented records of windthrow involving sound kauri trees in otherwise-undisturbed forest. Anecdotal accounts of windthrow after fire or partial logging seem to relate mainly to forest margins or roadsides during severe storms (Conway 1959). Species of *Agathis* are considered to be windfirm throughout their range (e.g., Neil and Barrance 1987). Even so, hundreds of mature kauri trees in Puketi, Omahuta, Herekino,

Above: *Damage to new top growth of a kauri seedling caused by late frost that can lead to development of two or more leaders.*

Below: *Frost damage on seedling leads to double leadering*



Warawara, and Waipoua Forests were uprooted by a cyclone in Northland on 14 March 1959 (R.Lloyd unpubl. data).

Animal browsing

Until recently, forests in the northern part of New Zealand suffered less damage from introduced browsing animals than forests further south. Deer (*Cervus* spp.) were either absent or restricted to small populations and the brush-tailed possum (*Trichosurus vulpecula*) has spread into Northland only during the last 20–30 years, although some smaller forest areas have been grazed by domestic stock. However, damage to kauri seedlings and saplings by feral goats (*Capra hircus*) and possums has been observed at a number of sites (e.g., Johnston *et al.* in press). On Great Barrier Island, which is possum-free, seedling establishment in a 137-year-old second-growth kauri stand has been prolific.

Seed predation

The common weta (*Hemideina thoracica*) feeds on fallen kauri seed (Mirams 1957) and the kaka or bush parrot (*Nestor meridionalis*) can break open ripening cones to obtain the seed. The introduced eastern rosella (*Platycercus eximius*), mice (*Mus musculus*), and ship rats (*Rattus rattus*), now widespread in kauri forests, all eat kauri seed. Barton (1983) suggested that mice could be an important cause of kauri seed loss, and cited records of large mouse populations at the time of seedfall in forests near Auckland.

Frost

Frost can damage the shoots of young kauri plants where there is insufficient shelter, especially if the low temperatures are unseasonal. Frost damage during the first 2 years can lead to the development of more than one leading shoot. Kauri saplings and young trees planted in sheltered localities near Dunedin (latitude 46°S) have not been damaged in spite of heavy frosts. On the other hand, the tops of saplings and young trees planted further south in Invercargill were killed during a particularly cold winter in 2002 (G.Morgan pers. comm.).

These spots are relatively common damage on leaves of kauri but do not appear to affect growth. There have not been any fungal or insect pathogens consistently associated with spotting on kauri leaves.

Kauri plantations – Initial experience

Between the 1930s and the 1960s the New Zealand Forest Service carried out sporadic planting of nursery-raised seedlings and wildling kauri over an area of about 200 ha (Halkett 1983). Subsequent tending was usually inadequate and plant survival and growth were very variable. More than half of the plantings appear to have failed either partially or completely.

In the mid-1970s and early 1980s up to 50 000 kauri seedlings/year were planted by the Forest Service in Northland, Great Barrier Island, and the Coromandel Peninsula. Most of these were raised at Sweetwater Nursery, north of Kaitaia. Planting focused on the supplementing or enriching of approximately 400 ha of tall scrub and partially logged forest where natural kauri regeneration was considered to be inadequate (Halkett 1983). Once again there was little systematic assessment of survival or early growth rate, and lack of adequate releasing from other species often resulted in poor performance.

Local authorities planted kauri in urban areas and the Auckland Regional Authority established several research trials in the Hunua Ranges (Barton 1995). Some trees among the older plantings had high survival and growth rates. These were usually in small stands on fertile, sheltered, and accessible sites such as Victoria Valley, Glenbervie Forest, and Great Barrier Island. Many successfully managed plantations in parks and reserves are now more than 50 years old — e.g., those in Mair Park, Whangarei; Cornwall Park and Kirk's Bush, Auckland; the Hunua Ranges; Gudex Memorial Reserve, Cambridge; and Brooklands Park and Fred Cowling Reserve, New Plymouth. These stands currently provide useful information about growth rate and management requirements on a variety of sites.

Seed collection

Kauri seed can be collected during February and March in Northland; later in southern areas. Cones usually break up on the tree and collection of large quantities of seed involves climbing and selection of intact cones. The first scattering of cone scales beneath mature trees indicates that seed is ready for collection (Lloyd 1978). Tree-climbing is hazardous and requires professional training and special equipment. Trees with poor form are avoided; young trees branching to low levels are frequently used. Lightweight extendable ladders and rope climbing techniques are employed by arboriculturalists. Where climbing is not practicable, some of the seed shed from disintegrating cones is caught on a raised sheet of hessian or plastic spread beneath the tree (Barton 1994).

Individual trees bear both male and female cones, and self-pollination is possible. This leads to inbreeding and is likely to increase the incidence of undesirable characteristics, such as retarded growth in the progeny (L.Gea, Forest Research, pers. comm.). For this reason seed should only be collected where the presence of many kauri trees increases the probability of cross-pollination.

Seed treatment

Cones left to dry in warm well-ventilated conditions disintegrate within 5–10 days, and seed is separated from cone debris and scales by sieving and hand picking. Not all seeds are viable and only those which are firm and swollen at the base of the wing are retained (Barton 1994).

Unless it is to be sown immediately after collection, seed is stored dry in airtight containers in a refrigerator to prolong viability (Lloyd 1978). Preest (1979) found that at normal ambient temperatures, viability is lost within a few months. Seed keeps well for 2 years at 20°C if the moisture content of the surrounding air is low. It can be stored for 5–6 years at a moisture content of 6%. For longer-term storage, temperatures below freezing point may be required (Preest 1979).

Propagation

Sowing and germination

Seed sowing takes place as soon as possible after collection to ensure maximum viability and also to take advantage of warm conditions. In most nurseries kauri seed is scattered over standard seed-raising compost in trays which are then kept in glass- or plastic-houses. The optimum mean temperature for germination is 25°C and under moist conditions a range of 19–27°C stimulates germination within 8 days (Barton 1994). Below 15°C germination is slow and the mortality rate higher. Soaking of seed in water for 18–24 hours before sowing shortens the period required for emergence to 4–6 days (Lloyd 1978).

Seed collected from northern localities may have higher germination rates (P.Smith, Taupo Native Plant Nursery, pers. comm.; S.King, Waipoua Forest Restoration Trust, pers. comm.). Germination rates are highly variable when seed is collected from different trees in different years.

Transplanting 4-week-old kauri seedlings from trays into containers.

Seedling growth

Within 4 weeks of emergence, seedlings approximately 5 cm tall with two fully extended cotyledons are transferred to small (less than 5-cm-diameter) containers filled with standard potting mix, and placed in a shade house. Growth rate is dependent on time of sowing, local climate, and availability of artificial heating. Under sheltered warm conditions, seedlings 15–20 cm high can be transferred to a final container within a year.

Most kauri plants are raised in PB2 or PB3 polythene bags 10–15 cm in diameter and 15 cm high. Development

Above: *Tinus Rootrainers accommodate the strong taproot of kauri seedlings but restrict shoot development as seedlings have less space.*

Left: *In commercial nurseries, most kauri plants are raised in containers, often PB2 or PB3 polythene bags.*

of a dense fibrous feeding root system in nursery-raised kauri seedlings can be difficult. Because seedlings develop a strong taproot, deeper containers such as Tinus Rootrainers are sometimes used but the smaller container diameter can restrict development of tops and fibrous roots.

While kauri can be raised as bare-rooted seedlings, the vertical taproots are damaged by mechanical undercutting. There is a need to ensure that adequate proliferation of lateral feeding roots occurs within a viable nursery regime.

In most nurseries a plant height of 40 cm is achieved within 2 years.

Kauri seedlings sown 4 weeks previously in a heated house at the Taupo Native Plant Nursery. Seed collected from trees in Waipoua Forest (background tray) had a higher germination rate than seed collected further south on the Coromandel Peninsula (foreground).

Obtaining high-quality nursery-raised seedlings is essential for successful planting programmes. This includes an adequately developed fibrous feeding root system that can be achieved for both container-raised (a) *and bare-rooted seedlings* (b). *However, roots of kauri seedlings can be highly variable and need to be inspected to ensure seedlings with poor quality roots are rejected —* (c) *deformed tap root in container-raised seedlings,* (d) *few fibrous roots in bare-rooted seedling.*

Cuttings

Kauri plants have been raised from cuttings but this method is considered to be too expensive to be adopted on a large scale (Barton 1994). Cloning techniques involving vegetative reproduction have been used in limited tree breeding trials and in the development of seed orchards.

Planting container-grown kauri seedlings along a cut line in 4- to 5-m-high scrub. Additional cultivation around the planting hole, particularly in heavy soils, is likely to improve early performance.

Most kauri plantings fail due to poor maintenance after planting. Keeping recently planted kauri seedlings free of competing weed growth is essential and may need to be carried out for 3–5 years after planting. Regrowth of shrubby species can be cut back with a slasher. Vigorous grass sites can be carefully sprayed with herbicide using a knapsack.

Planting

Site selection

As kauri seedlings tend to have poorly developed root systems that can be susceptible to drought, particularly within the first 1–2 years after planting, additional care in site slection and preparation is likely to improve establishment. Heavy compacted soils may impede root growth which is usually more rapid in soils of light texture (Ecroyd 1982). Excavation of a soil pit 30 cm in diameter and 30 cm deep for each plant has a beneficial effect in compacted clays (Lloyd 1977).

Early growth is favoured by a combination of moist fertile soil and absence of competing plants. Nursery-raised kauri seedlings exhibit low survival rates and slow growth on infertile drought-prone ridges, even where few plants of other species are present. Saplings grow most rapidly in full overhead light, but small seedlings require shelter. The most favourable sites for planting are those where secondary forest or scrub has developed after burning, or where pastoral farmland has been invaded by small-leaved vegetation such as manuka or kanuka. In both cases releasing may be required.

Weed control

A major requirement of successful estabishment is a commitment to keeping planted kauri seedlings free of regrowth of other species. Releasing, or cutting back vegetation that potentially will overtop planted kauri, may be required annually for up to 5 years until kauri are 1.5–2 m high.

Fertiliser treatment

Application of fertiliser can improve the growth rate of planted kauri on nutrient-poor sites (Barton 1995). Lloyd (1977) suggested that a slow-release NPK fertiliser applied during the early stages of establishment would improve plant vigour but not necessarily height growth. Bergin and Kimberley (1987) found that height and diameter of kauri planted 5 years previously in gaps in 3- to 4-m-high scrub had been increased by the application of slow-release Magamp (50 g per seedling) at time of planting, but doubling the rate of Magamp appeared to be detrimental to growth and survival. Fertiliser application 12 months after planting did not stimulate growth.

MANAGEMENT OF ARAUCARIACEAE IN OTHER COUNTRIES

The highly-regarded timber properties of New Zealand kauri are characteristic of related species overseas. In their natural setting, members of the Araucariaceae usually occur as scattered individuals in a mixed forest. This type of natural forest was often managed for timber production, with plantations established after logging. In Australia, guidelines for managing Queensland kauri (*Agathis robusta*, see foliage centre right) were developed in the early 1900s (Department of Public Lands 1917). These were extended to include plantation management in the 1930s, but insect attack in south-east Queensland put an end to planting in 1960 (Nikles in press). On sites outside its natural distribution range (e.g., South Africa) *A. robusta* grows well and still holds promise for timber production (Bredenkamp 1981). *Agathis moorei* (see foliage top left) and *A. lanceolata* are managed successfully for timber in plantations in New Caledonia (Wilcox and Platt 2002). *Agathis macrophylla* var. *vitiensis*, a native of Fiji, has been established as a timber resource, and in Vanuatu *A. macrophylla* has been managed in both natural and planted stands. *Agathis* is known for its resistance to cyclone damage in plantations (Neil and Barrance 1987).

A natural mixed age stand of Araucaria bidwillii *in the Mary Valley, south-east Queensland. The large seed from these bunya trees was an important food source for aboriginal people, while the timber became exploited from natural forest from the 1860s to the 1930s. Plantations of bunya now total about 1000 ha.*

In central Java, where *Agathis* is not found naturally, *A. dammara* has been introduced from the Philippines. It is grown in plantations on upland volcanic soils where it is highly productive (25–30 m^3/ha/year). This species is managed for its resin (copal) as well as for timber, and the planted area in Java exceeds 10 000 ha (A.E.Beveridge pers. comm.). In Sabah, Malaysia, *A. dammara* has been included in a suite of species designed to rehabilitate 25 000 ha of logged forest and to sequester atmospheric carbon dioxide (Moura-Costing *et al.* 1994).

Araucaria species, which are closely related to *Agathis*, have also been managed for high-quality timber in plantations. Hoop pine (*Araucaria cunninghamii*), a native of Queensland Australia and Papua New Guinea, has been planted since the 1930s and the 45 000-ha production estate now consists of second-rotation stands of genetically improved stock. Hoop pine has been established in plantations in Malaysia (Chew Theng Kok 1975) together with *Araucaria hunsteinii*, which is also a native of Papua New Guinea. Parana pine (*Araucaria angustifolia*) is grown in plantations in Brazil and northern Argentina.

Left: *A plantation of hoop pine* (Araucaria cunninghamii) *in south-east Queensland, established at >1000 stems/ha. Initial plantings have been felled at around age 60 years but estimates from tree breeding trials suggest that new stands will be less than 40 years old at felling.* Inset: *Clearfelling of hoop pine from the Imbil region in Queensland. The timber is a high-class softwood on which the Australian plywood industry was founded.*

COMMUNITY INITIATIVES FOR KAURI FOREST RESTORATION

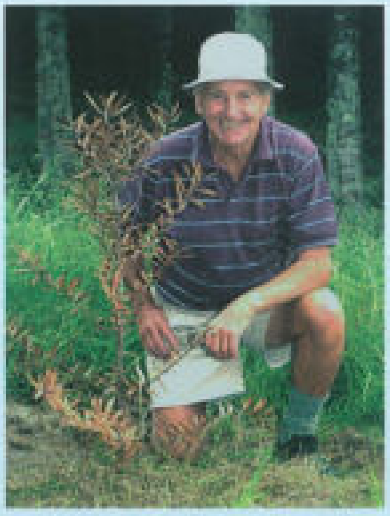
Community programmes for planting kauri on land once occupied by kauri forest are currently under way on the Coromandel Peninsula and in Northland. Each of these projects takes a different approach to the restoration of kauri forest on relatively fertile sites previously cleared for farming. Early success has depended on careful consideration of the ecological requirements of kauri. One group undertook the establishment of a nurse species (manuka) and the other used existing shrubs to provide shelter for planted kauri.

The Kauri 2000 Trust

KAURI 2000

This Trust, formed in 1999, began with a vision of restoration of kauri forest in the Coromandel Peninsula. Inspired and chaired by local enthusiast Cliff Heraud, it evolved from the desire of local communities to celebrate the New Millennium in a tangible, enduring way. It is now a long-term project which invites families, individuals, communities, businesses, schools, and visitors to support the planting and maintenance of kauri seedlings on planting sites designated by Kauri 2000, mainly on Department of Conservation land or on suitably covenanted private property.

During the first 5 years, the Trust will have planted close to 20 000 kauri plants on around 33 sites in 12 localities throughout the Peninsula. Planted areas had been cleared and burnt some time previously and most had a 4-m-high cover of regenerating manuka and shrub hardwoods. Narrow lines are cut through the vegetation at 4-m spacing by contractors, and volunteers plant kauri seedlings, grown from local seed, at 4-m intervals along these lines. Some sheltered sites on ex-pasture land free from shrub growth have also been planted. Survival rates have been high, particularly in areas of low scrub and within stands of kanuka and manuka. This reflects the care taken in planning, site selection, and maintenance. With good after-planting care, ricker or pole-stage stands can be expected to develop within 50 years.



Cliff Heraud, founding chair of the Kauri 2000 Trust, beside a kauri established 2 years earlier on a grassy sheltered site. Cliff was recently awarded the Queen's Service Medal for his role in initiating and building the Trust and inspiring many to help in the re-creation of the kauri forests of the Coromandel Peninsula.

Cherry Ladd, a Kauri 2000 Trust co-ordinator, releasing a kauri plant from shrub regrowth on the Coromandel Peninsula. Most of the Trust's kauri are planted in lines cut through 4-m-high scrub dominated by manuka and shrub hardwoods.

Millennium Kauri Forest (Waipoua Forest Trust)

Large-scale conversion of retired pasture to manuka shrubland has been undertaken by the Waipoua Forest Trust, south of the Waipoua Sanctuary in Northland. Dense rows of manuka have grown from seed sown by volunteers after mechanical discing has overturned the turf.

This project, undertaken by the Waipoua Forest Trust and managed by one of the founding trustees Stephen King, was established as a bicultural partnership in 1998 to "protect, restore, interpret and promote the internationally significant natural heritage at Waipoua for the scientific, educational and spiritual benefit of New Zealand". A major undertaking of the Trust is to extend kauri forest cover to the south of the Waipoua Forest Sanctuary. Since the early 1990s, the programme has involved establishment of manuka cover on previously farmed land, using a direct-seeding technique. Locally sourced manuka seed has been scattered by hand along furrows made at 5–6 m spacing by tractor-drawn discs. Developing shrub growth will provide shelter for interplanted kauri seedlings. The project is funded by donations to the Trust and uses volunteer labour.

Dense rows of manuka are developing. Kauri raised at an on-site nursery from locally collected seed will be planted 2–3 years after establishment of manuka. Pilot-scale plantings have demonstrated that the nurse stands of manuka improve kauri survival and growth. Patches of kikuyu grass (*Pennisetum clandestinum*), a vigorous species detrimental to establishment of both manuka and kauri, is removed by spraying with a selective herbicide. Planting of nursery-raised manuka directly into grass has proved to be more labour-intensive than direct seeding and involves more effort in keeping plants free from grass regrowth during the early years.

Stephen King (inset), *one of the founding trustees and Project Manager of the Waipoua Forest Trust, inspects 3-year-old manuka grown from direct-sowing of seed* (left). *It will be used to nurse future kauri plantings.*

Collaborative planting trials

A number of kauri planting trials have been set up by Forest Research in collaboration with community groups and local authorities. These are currently providing information about early growth rates and silvicultural requirements.

Whitecliffs Reserve, South Auckland — kauri planting trial

In collaboration with the Franklin District Council and local landowners, kauri was planted in a stand of manuka established 5 years earlier on a fertile lowland site recently retired from pastoral farming. Now 5 years old, the kauri trees are 1.5 m high. They have grown at a rate similar to that of other indigenous conifers planted at the same site.

Hikuai, Coromandel — fertiliser trial

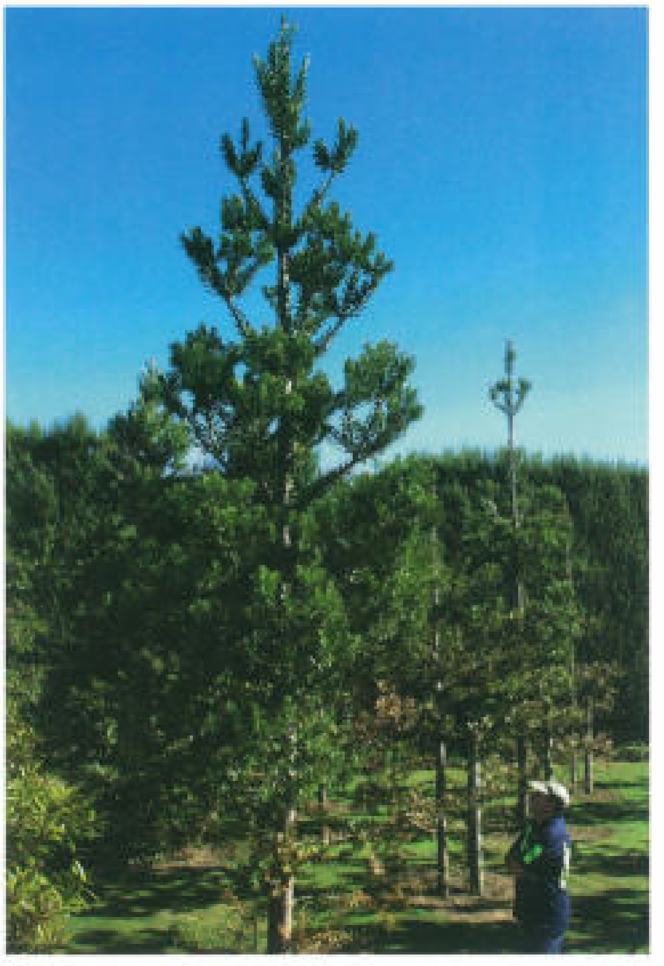
The effect of a slow-release NPK fertiliser is being tested on sites managed by the Kauri 2000 Trust. Early results indicate an increase in the growth rate of seedlings receiving 30 g fertiliser at time of planting.

Growth measurement plots in existing plantations

Since the mid-1980s, Permanent Sample Plots (PSPs) have been marked out in kauri plantations located in a wide range of urban and rural sites. Growth data from frequent remeasurements are fed into the PSP database at Forest Research and are used to provide input into growth models. Further PSPs are demarcated when new stands are established.

Fred Cowling Reserve and Brooklands Park, New Plymouth

Two kauri plantations, now approaching 70 years of age, are being managed through collaboration between the New Plymouth District Council, Friends of Pukekura Park, and Tane's Tree Trust. Growth of these dense stands (approximately 1200 stems/ha) is slowing down, and thinning to less than 1000 stems/ha is expected to halt the decline. Growth rates of the remaining trees will be monitored and the wood properties of timber from felled trees will be investigated.



A young kauri plantation at Te Puna, north of Tauranga. This stand is measured regularly through collaboration between Tane's Tree Trust and the local landowner. Six years after planting on this fertile lowland site the trees are more than 6 m high.

Right: *Thinning of two New Plymouth kauri plantations, nearly 70 years old, in order to improve growth rates. The quality of the wood in the felled trees will be evaluated.*

Growth rate of planted kauri

In some plantations, kauri diameter increment averages more than 10 mm/yr for periods up to 40 years. Individual trees may grow as much as 1 m in height in 1 year (Ecroyd *et al.* 1993). Annual growth rates of 7 mm diameter and 36 cm height are more common (Pardy *et al.* 1992). In a survey of indigenous tree plantations on a wide range of sites, Pardy *et al.* (1992) found that the predicted mean annual height increment for planted kauri was comparable with that of the fastest-growing of the major indigenous conifers (44 cm at 20 years, reducing to 26 cm at 80 years). Predicted annual diameter increment was 6.9 mm. All the stands measured were less than 100 years of age.

A 44-year-old kauri plantation on Great Barrier Island with an average diameter of 33 cm and height of 19 m.

Kauri planted as single trees or in small groves in Rotorua, near the natural southern distribution limit, have grown as well as those within the natural range further north. Individuals growing on the freely draining pumice soils have reached 40 cm in diameter and 20 m in height within 50 years. In one exceptional stand on a lowland Bay of Plenty site, annual increments of 95 cm in height and 17 mm in diameter have been recorded.

The best-performing stands of planted kauri are in fertile sheltered areas. They include small well-managed plantations established by the New Zealand Forest Service in Northland and Great Barrier Island (Halkett 1983), plantations in urban parks in Whangarei, Auckland, and New Plymouth, and many small stands established by private landowners (Pardy *et al.* 1992). Some of these are now approaching 70 years of age. Many of them are dense stands with stocking rates greater than 1000 stems/ha. Growth rates have slowed down and mortality of individual trees is noticeable as competition increases (e.g., Herbert *et al.* 1996). Thinning will be appropriate in stands where many of the trees have multiple leaders. Form pruning to remove all but one leader and also the occasional large steep-angled branch may be advisable.

Growth and yield

Growth of well-managed planted kauri can be four times faster than that in natural stands (*see* Table). The stem volume of New Plymouth kauri plantations is as great as that of planted totara at age 60 years (Bergin 2003). Although diameters are similar in both species (approximately 30 cm), the greater timber productivity potential of kauri is determined by the height differential (kauri 21 m, totara 15 m). The New Plymouth stands are current examples of best practice since trees were established on fertile sheltered sites and have been managed carefully.

Growth rates of kauri are much lower than those of exotic conifers commonly planted in New Zealand (*see* Table). Rotation lengths for native tree species are commonly twice as great as those for radiata pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*), and cypress (*Cupressus macrocarpa, C. lusitanica*). Volumes of 600–800 m^3/ha estimated for kauri at age 60 years or more are clearly lower than those obtained from 30-year-old radiata pine (Maclaren 1993), 50-year-old Douglas fir (Miller and Knowles 1994), and 40-year-old cypresses (Miller and Knowles 1996).

This 50-year-old plantation of kauri in Fred Cowling Reserve, New Plymouth, has a very high growth rate even though it is located 120 km south of the limit of the natural range of the species.

Species	Stand age (years)	Stand density (trees/ha)	Mean height (m)	Mean dbh (cm)	Volume (m^3/ha)	MAI (m^3/ha)
Fred Cowling kauri plantation	69	1300	20	28	588	9
Brooklands Park kauri plantation	60	1375	21	30	804	13
Kauri (natural stands)	60	1000	13	18	200	2
Totara (planted stands)	60	1000	15	33	470	8
Totara (natural stands)	60	1000	11	17	110	2
Radiata pine	30	350	40	45	400–900	13–30
Douglas fir	50	350	40	45	900	18
Macrocarpa	40	350	35	40	240–600	6–15

Comparison of growth rates in two New Plymouth kauri plantations with growth rates in other forest stands in New Zealand. Volumes for kauri and totara are based on total stem height.

Above: *60-year-old stand with only 1000 stems/ha.* Inset: *Large branches tend to form on edge trees.*

Effect of stocking rate on timber yield

Herbert *et al.* (1996) estimated the timber productivity of the two New Plymouth kauri plantations at age 60 years. Initial planting rates were 1680 and 2240 trees/ha but a combination of natural mortality and an early light thinning in the denser stand had reduced stocking to an average of 1375 trees/ha. Total stand timber volume was 804 m^3/ha and this is predicted to increase to 1103 m^3/ha at age 80 years. Average height was 21 m and average diameter 30 cm. Mean annual increment was 13 m^3/ha, having declined from a peak value of 20 m^3/ha at age 40 (Herbert *et al.* 1996).

Steward and Kimberley (2002) found that the most rapid diameter growth of natural kauri aged ≥120 years occurred in densely stocked stands (>1000 stems/ha. Greatest diameter increments for planted kauri (8 mm/yr) were recorded in a recent study of three stands with stocking rates of 500–550 stems/ha. It is unlikely that this growth rate would be maintained, since within-stand competition is likely to develop even in these moderately stocked stands. Hutchins (1919) suggested that natural stands assume stocking rates of 150–200 stems/ha, but Halkett (1983) reported a mean of 85 stems/ha in an old-growth forest. At stocking rates exceeding 1000 stems/ha, Herbert *et al.* (1996) also observed a negative effect of tree density on diameter increment in 60-year-old planted stands at New Plymouth.



Pruning of the lower branches of kauri saplings stimulates the abscission of the remaining stub. Cutting too close to the trunk may result in damage and gum bleeding. Right: Abscission of branch stubs takes place within a few weeks of pruning sapling kauri but may take longer on larger trees.

Tending

Pruning and removing multiple leaders

Kauri trees lose their lower branches naturally, and metabolic resources are then allocated to other parts of the tree. Abscission occurs earlier in stands maintained at a high density. Artificial branch removal (pruning) may be required to improve stem form of young trees if they are widely spaced or located at the stand edge. The cut is usually made to leave a 5 cm stub which falls off within a year, leaving a knot-free stem. Large steep-angled branches and multiple leaders are sawn off close to the stem. Research is required to determine the maximum diameter of branches and stems at which pruning will have a beneficial effect.

Wilson *et al.* (1998) found that when branches of saplings were cut back to 5 cm, most of the stubs abscised within 6 weeks irrespective of the time of year. Comparable uncut branches showed no evidence of abscission at the end of the 6-week period.

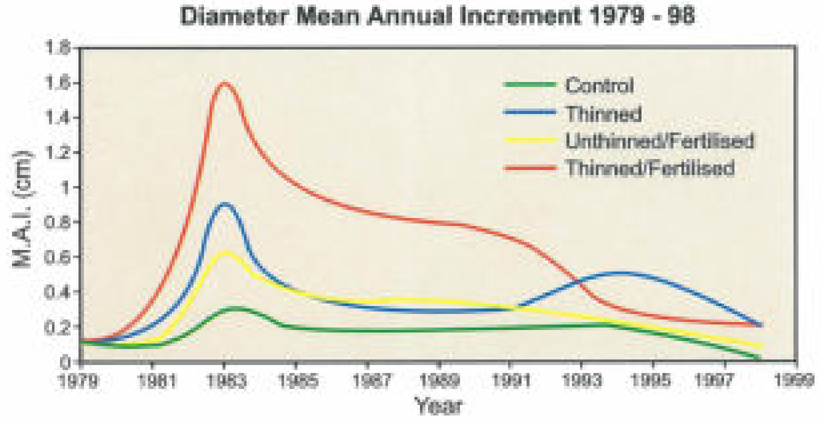
Thinning and fertiliser treatment in pole-stage stands

The New Zealand Forest Service undertook thinning trials in kauri stands between the late 1950s and 1970s (Halkett 1983). The aim was to increase growth rate and quality in pole-stage stands that had developed after logging, land clearance, or fires by reduction of within-stand competition. Trials assessed 19–40 years after thinning showed increases in diameter growth of 3.1–3.3 mm/yr. Unthinned controls had mean annual diameter increments of 1.2–1.4 mm (Steward and Kimberley in press).

Barton and Madgwick (1987) found a substantial growth response to thinning and application of nitrogenous fertiliser in a naturally regenerated pole-stage stand in the Hunua Ranges, south of Auckland. The stand was known to be deficient in nitrogen and phosphate. Within 6 weeks of treatment, foliage colour changed from olive-green to bright green, but the effects on growth were not


Extra leaders that have arisen, probably from damage to the growing tip (left), should be removed as soon as possible at the seedling stage in the nursery or when saplings have established after planting. Depending on size of stems, secateurs (right) or pruning shears can be used to remove codominant leaders as close to the main stem as possible.

Stem diameter growth responses to thinning and application of nitrogenous fertiliser. Treatments were applied to a natural second-growth kauri stand in 1979 (from Barton 1999).



seen for some time. Mean annual diameter increment increased from 1 to nearly 16 mm within 2 years (*see* Figure). Thinning alone produced an eight-fold and fertiliser treatment alone a six-fold increase in diameter increment (Barton 1999). The mean annual increase in volume over 19 years in dominant trees was 5.8 m^3/ha (4.4%) in control plots and 13.3 m^3/ha (11.6%) in plots where trees had been thinned and fertiliser applied. Almost 50% of standing stems in a 66-year-old plantation of kauri located at Brooklands Park, New Plymouth, were felled to reduce stocking from 1300 stems/ha to around 700 stems/ha (Gould 2002). Mean diameter in this stand before thinning was 31 cm and mean height was 19 m. A decline in current annual increment (Herbert *et al.* 1996) and a high incidence of unstable multi-leadered stems were considered to justify intervention. Selected trees were carefully felled by sequential removal of crowns, upper bole lengths, and remaining timber in order to prevent damage to the remaining trees

This 66-year-old kauri plantation in Brooklands Park, New Plymouth, was thinned from 1300 stems/ha (left) *to 700 stems/ha* (right) *after consultation with the local community. The work was carried out by highly skilled arborists who were able to thin without damage to the residual trees.*

WOOD CHARACTERISTICS

"Whenever standards of excellence are quoted for timbers, kauri, Burma teak, Honduras mahogany, and hickory are names that spring to mind. Kauri headed that group of timbers which was suitable for all but the most specialised needs"

(Hinds and Reid 1957)

The heartwood of mature kauri trees has a well-deserved reputation as one of the finest softwood timbers in the world. At one time, the flawless wide planks obtained from large trees were in great demand. Very little heartwood is currently available from tree harvesting, but wood of good quality can be salvaged from stumps, fallen trees and recycled timber.

Dry heartwood is buff brown in colour with variations ranging from yellow to reddish brown. It has excellent working qualities and the straight, fine, even grain with a characteristic minute speckle allows a high quality finish. It is moderately durable when in contact with the ground, very durable when continuously wet, and excellent for use in hot humid conditions (Hinds and Reid 1957). Wood recovered from ancient logs preserved in swamps has a colour and lustre that is highly valued for craft work, even where its mechanical properties have deteriorated (Clifton 1990).

Formation of heartwood

In the late 1970s, the New Zealand Forest Service thinned and milled kauri from a 120-year-old "ricker" stand in Northland (Ecroyd *et al.* 1993; L.J.Gibson unpubl. data). Fewer than 1% of the boards were classified as heartwood and the recovery of clear timber at 37% was only half of that usually expected from mature kauri logs.

A comparison of planted and natural second-growth kauri stands indicated that stem diameter is a major predictor of the presence and amount of heartwood (Steward and Kimberley 2002). Age is a secondary predictor. Heartwood was found in stems with diameters as small as 10 cm in natural trees and 16 cm in planted trees, but it represented less than 4% of the total stem volume. All stems greater than 35 cm in diameter contained some heartwood but usable quantities were present only when diameters reached 60 cm. Trees with stem diameters greater than 90 cm can be expected to contain a minimum of 2 m^3 heartwood per tree in the lowest 6 m log. Diameter increments in the best-performing plantations in this study suggested that an average diameter over bark of 90 cm would be achieved in 120–150 years.

Sapwood quality

Smaller logs from regenerating kauri forest yield good-grade narrow piece-sizes which are mainly sapwood (Hinds and Reid 1957). Although sapwood has many of the properties of heartwood, it lacks durability, is not resistant to *Anobium* borer, and is less dimensionally stable.

Logs thinned from a 66-year-old planted stand in New Plymouth were used to investigate wood properties of plantation-grown kauri. Twenty stems representing the largest trees in the stand (mean diameter 39.4 cm; mean height 20.5 m) were found to contain mainly sapwood. Basic density was lower than that of mature kauri heartwood, but higher than that of radiata pine timber. Wood shrinkage values resembled those of old-growth kauri heartwood but stiffness scores were higher than those recorded for old-growth kauri or commonly used exotic forestry species. Wood quality did not vary significantly across the width of the log (pith to bark). The results suggest that relatively young kauri plantations have potential as a valuable solid wood resource, and are not necessarily inferior in this respect to natural second-growth stands containing heartwood.

Control of wood properties

After studying the wood properties of members of the family Araucariaceae and the genus *Pinus*, Harding (1990) concluded that, in general, wood properties are under a higher degree of genetic control than growth traits. Heartwood formation in kauri is likely to have high heritability and, if individual trees that contain above-average amounts of heartwood can be identified, it should be possible to use sapwood radial dimensions as the basis for inclusion of superior heartwood characteristics in breeding programmes.

A selection of products made from swamp kauri wood. Continuing demand for kauri for high-quality uses cannot be sustained using recovered swamp kauri or old logging material. Planting and managing kauri offers future options for a sustainable supply of wood with scope for using the high proportion of sapwood from relatively fast-grown trees.

Kauri wood has excellent working properties, the straight fine even grain giving a high-quality finish.

Growth rings in kauri are usually formed annually. The increment core taken from a natural stand (lower) *shows a slower growth rate than the one from a planted stand* (upper).

Growth rings in kauri

The density of woody tissue formed in kauri stems varies from season to season. The darker, more compact tissue formed in winter can be seen as fairly well-defined rings in cross sections of the stem. Meylan and Butterfield (1978) described the rings as moderately distinct to distinct. The first suggestion that they represented annual growth increments came from an account by Cheeseman (1913) of observations made on cross-sections of trunks of young kauri trees planted in 1865. Ahmed and Ogden (1987) confirmed that the rings are usually formed annually and that their number and size (measured on narrow cores taken by boring horizontally into the stem) can be used to assess tree growth rate and age. A close relationship has been demonstrated between radial growth rates measured with dendrometer bands placed around the trunk and rates estimated from increment cores (Palmer and Ogden 1983). Neither of these methods of measuring growth rate causes any lasting damage to the tree. In a study of stem heartwood content, Steward and Kimberley (2002) found that the counting of growth rings from increment cores under-estimated the age of kauri trees by about 5%.

Management of kauri for wood and non-wood values

Long-term management for wood

Management options designed to retain the values associated with high forest are likely to be preferred if the major objective is production of kauri timber. Extraction of selected stems, rather than clearfelling, will be required on many sites.

Barton (1999) described management options for extraction of kauri trees from pole-stage stands. These were aimed at the maintenance of a multi-aged forest in which natural processes known to increase tree growth rate are reproduced wherever possible, especially during the juvenile stage. Trees were expected to reach harvestable size in 80–100 years. Referring to silivicultural systems described by Mathews (1989), Barton argued that although single-tree selection causes less disturbance, group selection creates larger canopy gaps and allows more light to penetrate to the forest floor. This stimulates the early growth of saplings and poles. Removal of competition from faster-growing broadleaved species may be necessary, but growth of manuka and kanuka, which are useful nurses for young kauri, should be encouraged (Enright *et al.* 1993)

Economic analysis

Barton and Horgan (1980) calculated that kauri grown on an 80-year rotation would provide a return on investment of less than 2%. Herbert *et al.* (1996) found similar internal rates of return (2–3%) for rotations of 60–80 years. Results from both studies implied that other non-timber benefits would be required in order to reach the expected market rates of return for investment in forestry in New Zealand. It should be pointed out that growth rates of kauri are similar to those of many species used for commercial forestry in the Northern Hemisphere.

Most of the non-timber values associated with forests cannot be quantified although they offer many kinds of rewards. It is possible that the financial value of plantations of certain native tree species, including kauri, will increase as the use of imported decorative timbers from non-sustainable sources becomes less acceptable.

Silvicultural systems requiring minimal input are economically advantageous and this is especially true for slow-growing tree species. The use of naturally regenerating or planted manuka as a nurse for young kauri can reduce establishment costs and improve tree form. The alternative of dense stocking (e.g., 2500 stems/ha) with expensive kauri seedlings would involve high establishment costs and subsequent wastage, since more than half of the plants would eventually be thinned out.

Planting of larger seedlings at lower densities (400–500 stems/ha) to avoid later thinning could be a viable alternative in sheltered lowland sites, providing that rapid canopy closure is not required for the control of weeds. Trees could be planted at near-final spacings of 4–5 m apart to give a density of 400–625 stems/ha.

One workshop in Auckland, Rose and Heather, employs 35 craftsmen making high-quality furniture from swamp kauri. As supplies of swamp kauri become exhausted, where is the future resource of kauri to come from?

Non-timber values

Conventional economic analysis is based on the financial value of timber alone and does not support investment in the establishment of plantations of slow-growing native tree species (Horgan 2000). Most of the native tree stands planted over the last century were established for more than one reason (Pardy *et al.* 1992), and the rationale often included a desire to increase the land area covered by native forest, to control soil erosion, to provide food and shelter for wildlife, and to provide amenity areas (Forest Research Institute 1997). In recent years, tree absorption of carbon dioxide, a "greenhouse gas", from the atmosphere has been put forward as a reason for planting forests. Kauri trees are associated with specific Maori values, and for all New Zealanders the spiritual dimension will undoubtedly continue to be a feature of the rationale for planting, maintaining, and harvesting kauri in this country.

Ultimately, some landowners will want to remove and use kauri wood from managed stands. Consideration of timber- and non-timber values will require careful attention to harvesting methods if the character of high forest is to be maintained. It is possible for low-impact logging regimes to be used in mixed age/mixed species stands; these extract timber but allow retention of the near-natural character of the forest (Benecke 1996). Long-term management of kauri and other native tree species will need considerable specialist input if selection methods similar to those prescribed for long-rotation species in the Northern Hemisphere are to be developed in New Zealand.

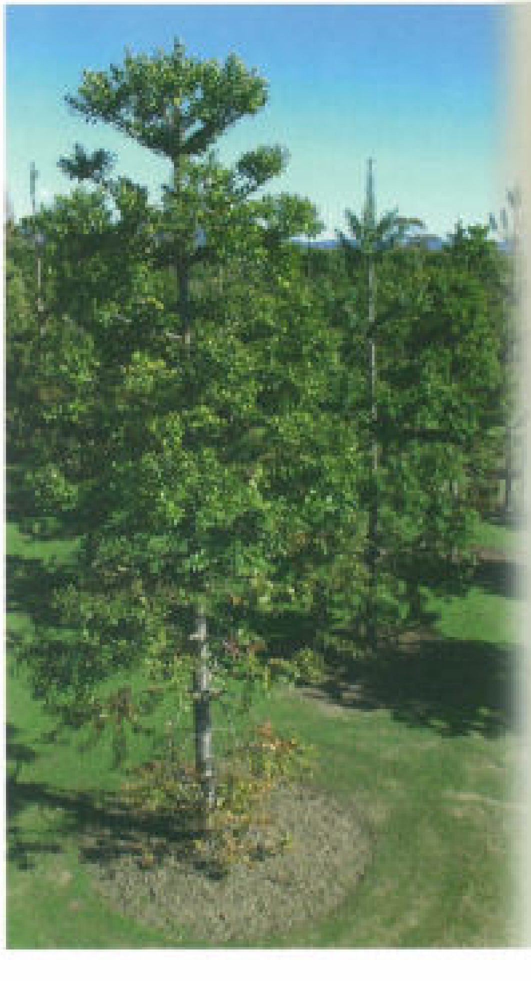
This recent planting in downtown Auckland perhaps reflects kauri's status as one of New Zealand's icons.

One scenario for the management of growth and timber yield in a kauri plantation

The development of silvicultural prescriptions for landowners wishing to establish kauri plantations should be based on knowledge of the ecology of the species, information about the results of tending in existing plantations, and an appreciation of the practicality and cost-effectiveness of recommended methods. One scenario that fulfils all these requirements would involve the planting of 500 large kauri seedlings/ha on a site covered with naturally regenerated or planted manuka or kanuka. The stand would be thinned to 80–100 kauri stems/ha when the trees began to compete with each other, causing an overall decrease in growth rate (diameter increment). Two thinnings carried out when the stand mean stem diameter reached 40 cm and 60 cm could be expected to yield 140 m^3 heartwood and 320 m^3 sapwood. A final-crop mean stem diameter of 90 cm would be reached within 120–150 years at a mean annual diameter increment rate of 6.0–7.5 mm. At clearfelling the stand would be expected to yield 150–190 m^3 heartwood/ha and 130–170 m^3 sapwood/ha in 6-m-long butt logs with a mean diameter of 90 cm.

Alternatives to clearfelling would be the careful extraction of stems in small coupes or the milling of timber at the growing site. A potential difficulty in felling kauri at ages exceeding 100 years is that trees will have lost the monopodial "ricker" form and will have a massive spreading crown structure (Halkett 1983). Felling would be likely to cause damage to remaining trees.

Herbert *et al.* (1996) suggested that wholesale sawn timber prices for second-growth kauri, which depend on grade and dimensions (width), might be NZ$1200–$3500/m^3. In 2002, prices up to $7000/$m^3$ were reported (Steward and Kimberley 2002). While the initial estimate of heartwood yield was based on a standard 6-m butt log, Steward and Kimberley found that merchantable butt log lengths (branch-free) averaged 11 m (range 7–15 m). Estimates of volume yield based only on 6-m butt logs are therefore likely to be conservative. Greater diameters, greater recoverable log lengths, or maintenance of higher stocking rates without loss of diameter increment would all increase yield.



CONCLUSION

Kauri trees make a substantial contribution to the identity and culture of native forests in New Zealand. Kauri has long been regarded as the Lord of the Forest, inspiring the respect of all New Zealanders. The numbers of this important kiwi icon can be increased, and may even be restored to previous levels on selected sites. This Bulletin identifies ways in which kauri can be used to enrich indigenous forests and to provide a timber resource.

It is almost certain that the use of breeding programmes and improved nursery techniques will lead to the production of better-quality and faster-growing kauri seedlings in the future. Substantial increase in growth rates during the first 10–15 years and consequent reduction of rotation lengths can be expected to provide greater financial returns. Current wood quality studies evaluating the large proportion of sapwood in fast-grown kauri are giving encouraging preliminary indications of favourable wood properties.

We already have the ability to restore kauri to some of its former glory. The sustainable growth and use of kauri as a prized source of timber is an attainable dream for growers and investors.

QUICK REFERENCE GUIDELINES FOR PLANTING AND MANAGING KAURI

Seed collection

- Seed collection should be carried out as soon as cones mature. Ripeness is indicated by the appearance of scattered fresh cone scales under kauri trees in late summer or early autumn.
- Seed can be recovered from fallen, partially broken cones.
- Cones can be collected from rickers and semi-mature kauri in mid-summer before they disintegrate and scatter seed. Tree climbing should be attempted only by trained personnel. Do not put weight on dead and dying branches. Avoid damage to the trunk and branches when climbing or removing cones.
- Seed viability should be checked. Sound seed feels plump when squeezed gently between the thumb and forefinger. For a further check, select a representative sample of seeds and cut them in half with a sharp knife. Viable seeds are filled with white or cream-coloured endosperm.
- Seed viability deteriorates rapidly, often within a few months. If storage is necessary, place dry seed in airtight containers and keep at a cool temperature. Normal refrigeration at 4°C will help to maintain viability.

Seedling production

Kauri plants can be raised in containers. Shallow pots or bags may distort the taproot. Growth of seedlings in open nursery beds as bare-root stock may present difficulties due to slow development of a fibrous root system.

- Seed should be sown as soon as possible after collection.
- Sow seed in autumn by scattering on to seed trays filled with a moist, standard, seed-raising mix. Cover with a 3- to 5-mm layer of mix and place the trays in a warm humid environment. Water as necessary.
- Germination occurs within 2–3 weeks in warm conditions.
- When seedlings are 5 cm high, prick out the most vigorous individuals into containers. Discard weak seedlings and those slow to emerge. Protect from frost. Transfer to larger containers when necessary.
- Polythene planter bags (size PB3) are commonly used for 2-year-old stock. Deeper containers allowing better taproot development may be worth investigation.
- Kauri seedlings will grow to a height of 30 cm in 1 year and 60 cm in 2 years in warm lowland nurseries.
- For planting out, select high-quality plants with a balanced root-to-shoot ratio. Inspect the root systems of a randomly selected sample of container stock and reject the whole batch if root systems are badly distorted, plants are root-bound, or insufficient fibrous roots have developed.
- The current cost of 50-cm-high 2-year kauri stock in a variety of containers is $3–4 per seedling.

Establishing kauri plantations

Kauri should be planted on open sites only if these are sheltered and warm. Best results are achieved by planting in gaps in light vegetation cover. This protects young plants from wind and frost while exposing them to the growth-stimulating effect of overhead light.

Use of nurse species

- Advantages associated with the use of nurse species:
  - provides shelter on exposed sites;
  - provides side shade which suppresses development of lateral shoots and reduces branch size;
  - decreases the incidence of multiple leaders;
  - reduces establishment costs. Manuka and kanuka seedlings are cheaper than kauri.
- Disadvantages associated with the use of nurse species:
  - good forward planning is necessary as the nurse species must be established before kauri is planted;
  - growth rate may be compromised by root competition and shading if the nurse plants are too vigorous;
  - maintenance will be required to ensure that the nurse canopy does not close over young kauri.
- Where possible, use existing vegetation cover less than 6 m high to nurse the kauri plantation. Cut planting lines for kauri at regular spacings.
- Recommended nurse species are kanuka and manuka. Blackwood (*Acacia melanoxylon*), slash pine (*Pinus elliottii*), and alders (*Alnus* spp.) could be considered but grow large quickly and may require early removal to avoid suppression of kauri.

Warm, open sites

- Fence planting areas to exclude stock and, if practical, graze pasture to a low level before final exclusion of animals.
- Spot spray grass with herbicide (e.g., glyphosate) at least 1 week before planting.
- Plant nurse species at 2–3 m spacing to control weed growth and provide shelter. Plant kauri 2–3 years later.
- Choice of initial stocking rate for an open site will influence establishment costs and also later requirements for releasing from other vegetation, branch pruning, and stand thinning.
- Planting at very low densities (less than 500 stems/ha: ≥5 m spacing) will:
  - require an excellent planting site and long-term weed control;
  - allow the use of larger more expensive stock and more intensive site preparation (e.g., extra soil cultivation);
  - increase the chance of gaps in the final-crop stand due to early losses or damage;
  - result in more heavy branching and hence may necessitate early pruning.
- Planting at moderate densities (approx. 1000 stems/ha: 3–4 m spacing) will:
  - increase expenditure on seedlings and planting operations;
  - increase the period before canopy closure and therefore the cost of weed control;
  - increase the need for and cost of form pruning.
- Planting at high densities (more than 2000 stems/ha: 2 m spacing or closer) will:
  - significantly increase planting costs;
  - remove the need for planting nurse species
  - reduce the period before canopy closure (this may be less than 10 years on good sites);
  - reduce the need for weed control;
  - improve stem form and reduce branch size;
  - reduce stem diameter growth after 20–30 years, unless between-tree competition is reduced by thinning.

Tending of plantations

- Exclusion of grazing stock and control of possums and deer will reduce damage due to browsing and increase species diversity in the understorey.
- Regular releasing from weeds, grasses, ground ferns, and woody shrubs will be required for up to 5 years after planting. Most establishment failures are due to lack of early weed control.
- Remove any double leaders and potentially persistent large branches when trees are 3–5 m high. This will reduce timber defects in the lower stem. Use secateurs on small stems and pruning saws or loppers on the larger ones.
- Small branches on the lower stem will be shed naturally. If desired, remove lower branches with a pruning saw, leaving a branch stub approximately 5 cm long. This will abscise naturally within a few months.
- Measure the trees regularly and thin the stand evenly when stem diameter growth rate begins to decrease.
- Fertiliser treatment will be necessary on nutrient-deficient soils. Apply just after thinning.

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The Kauri 2000 Trust

The Kauri 2000 Trust formed in 1999 has a vision to restore kauri forest in the Coromandel Peninsula. Inspired and chaired by local enthusiast Cliff Heraud, it evolved from a desire of local communities to celebrate the New Millennium by planting kauri seedlings on mainly public land where kauri forest once stood. The Trust offers a range of ways in which families, individuals, communities, businesses and schools can help plant kauri.

If you wish to support the work of Kauri 2000 or require further information, contact the Chairperson:
Vivienne McLean,
The Kauri 2000 Trust, PO Box 174, Whitianga.
Phone 07 866 0468, Fax 07 866 0459,
Email: kauri2000@paradise.net.nz,
Web: www.kauri2000.org.nz

The Kauri Museum, Matakohe

The Kauri Museum at Matakohe is administered by the charitable trust Otamatea Kauri and Pioneer Museum Board. Established in 1962, and with considerable ongoing community support, it provides a comprehensive range of exhibits and displays recording aspects of the kauri industry and local pioneers. The Kauri Museum is 45 km south of Dargaville on the west coast of Northland.

The Kauri Museum is located on Church Road, Matakohe, Northland.
Phone: 09 431 7417, Fax: 09 431 6969,
Email: thekauri@xtra.co.nz,
Web: www.kauri-museum.com

Waipoua Forest Trust

Waipoua Forest Trust was established in 1998 to provide an opportunity for members of the general community and Maori together to participate in and contribute to the restoration of the forest on the southern margins of the Waipoua Forest in Northland.

If you wish to become involved in the work of the trust or require further information contact the Project Manager:
Stephen King,
Waipoua Forest Trust, State Highway 12, RD 6, Dargaville.
Phone/Fax (09) 439 5678,
Web: www.waipoua.org.nz

Forest Research is a Crown Research Institute based in Rotorua and Christchurch. Under its Native Species Research Programme, the planting and management of a range of native tree species are being evaluated for timber production as well as from environmental and social standpoints.

For information on management of native species, contact Dr David Bergin or Greg Steward,
Forest Research, Private Bag 3020, Rotorua. Phone (07) 343 5899, Fax (07) 348 0952.
Email: david.bergin@forestresearch.co.nz or greg.steward@forestresearch.co.nz.

Tane's Tree Trust was formed in 2001 to encourage New Zealand landowners to plant and sustainably manage native trees for multiple use. The objectives of the Trust are: promotion of native forestry as an attractive land use option by consolidating and advancing the state of knowledge of native tree species; maximising economic incentives for establishing natives; resolving legal and political obstacles to the planting of natives; and encouragement of knowledge-sharing amongst stakeholders.

If you are interested in joining the network (subscriptions currently range from $30 for individual members to $113 for corporate members), or require further information, contact the Chairman: Ian Barton, 105 Cowan Rd, Hunua, RD3, Papakura. Phone (09) 292 4825, Email: ibtrees@ihug.co.nz, www.tanestrees.org.nz.

INDIGENOUS TREE BULLETIN SERIES

Kauri Ecology, Establishment, Growth, and Management is the second in this series of New Zealand Indigenous Tree Bulletins which summarise the latest information about management of planted and naturally regenerating native tree stands. Bulletin No. 1 is *Totara Establishment, Growth, and Management.* The focus is on production as well as environmental and social objectives.

Subjects for future Bulletins include: General techniques for planting native trees;
Guidelines for planting and managing native hardwood trees;
Monitoring performance of planted native forest stands.

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