TOTARA

ESTABLISHMENT, GROWTH, AND MANAGEMENT

David Bergin

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Front cover insert: *Emergent totara and younger trees along the forest edge in Pureora Forest Park, with mixed shrub species edging the picnic area in the foreground.*

Back cover: *Close-up of a wheku or mask made from totara, carved by James Rickard.*

TOTARA
Establishment, growth, and management

David Bergin

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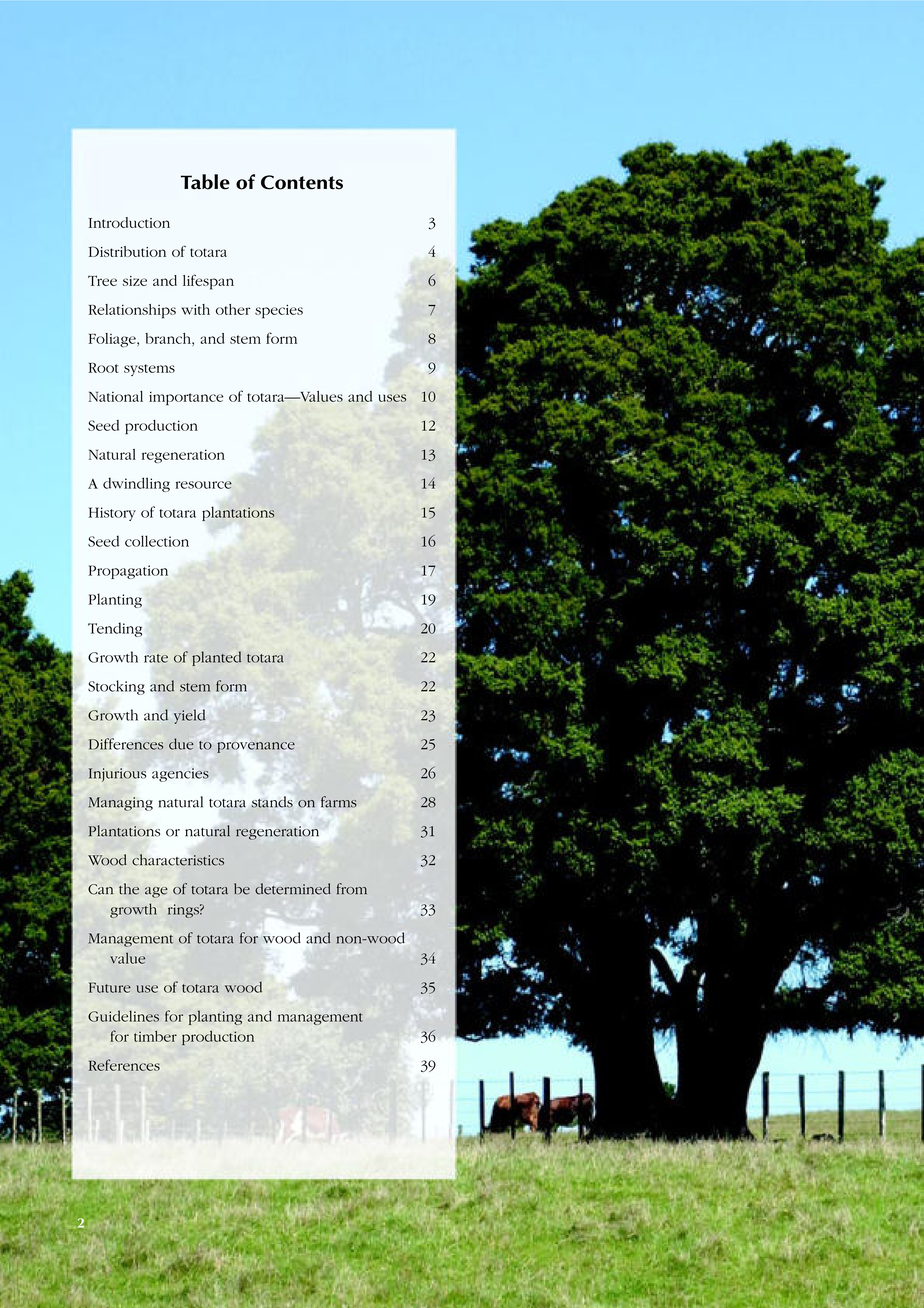

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INTRODUCTION

Totara (*Podocarpus totara* D.Don) is one of New Zealand's important native coniferous tree species. It is widely distributed in lowland forests throughout the country and has been utilised for many purposes by both Maori and European settlers. At present, only small quantities of totara are available from private or Maori land, or from Crown land under the stewardship of the Department of Conservation, and these are reserved for infrequent Maori ceremonial use. Limitations on harvesting of native tree species have stimulated community interest in the planting and management of totara for wood production.

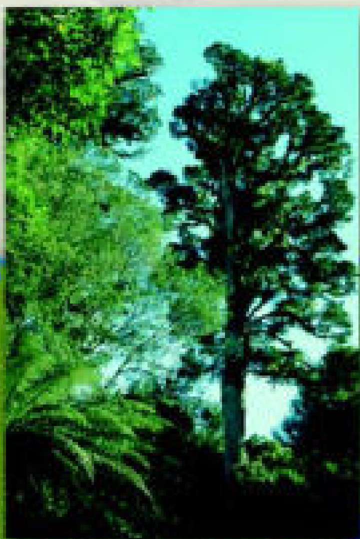
Many landowners, iwi (Maori tribal and subtribal groups), forestry consultants, and Government agencies consider that the development of sustainable management systems for the planting and management of native timber species will bring market and non-market benefits (Silvester and McGowan 2000). The establishment and management of "new" native forests for wood production on previously cleared land would stimulate community interest in New Zealand's natural heritage and culture. Biodiversity would be enhanced in a range of landscapes, and multiple-use forestry practices would be encouraged. Future generations of New Zealanders would have access to a sustainable native timber resource meeting cultural, social, and economic needs. Reliance on imported specialty timbers harvested from natural forests would be reduced if some locally-grown, preferably naturally-durable, native timber could be used. In addition, less dependence on locally grown exotic timbers treated with preservatives would be another benefit.

Totara has a wide range of features that deserve special consideration. These include cultural and heritage values, timber durability in heartwood, superior machining qualities, and an extensive natural distribution range. The species tolerates a wide variety of sites and is amenable to tending. Seedlings are easily raised in the nursery and there are good prospects for genetic gains to be made in terms of growth and form. This Bulletin describes past use, current distribution, and useful characteristics of totara. Guidelines are provided for establishment and management for timber production, as well as for other environmental and cultural benefits.

DISTRIBUTION OF TOTARA

Totara is found in lowland and lower montane forest between sea level and about 600 m in the North Island, and up to 500 m in the South Island (Allan 1961). It is most abundant in the central North Island and has a more discontinuous distribution in the South Island. Although Allan (1961) recorded the presence of totara on Stewart Island, Wilson (1982) considered that only Hall's totara occurs there, some trees having thicker bark and therefore resembling totara.

In the days of early human settlement, totara was often found with matai on well-drained flood plains, where both species were widespread, and on the deeper pumice deposits of the central North Island (McSweeney 1982). Totara stands began to decline as they were felled for various purposes and were also inadvertently destroyed by forest fires.



The arrival of Europeans and the selection of land for farming where totara was dominant, resulted in forest removal and utilisation of timber for construction and fencing (Bergin 2000).

Today, remnants of old-growth totara forests in the central North Island are protected from harvesting. Totara and Hall's totara can be found mixed with rimu, miro, and occasionally kahikatea and matai throughout the North and South Islands, especially in Taranaki, Wanganui, Westland, and Southland.

On the volcanic soils of the central North Island, totara and matai stands were previously common. Regeneration often occurred after Maori fires or abandonment of living areas and pa. Regeneration also occurs on flood plains and over hill country in many regions but is particularly common in Northland, the lower North Island, and in Westland. Here scattered large-crowned trees or established groves of semi-mature trees are a prominent feature of the rural pastoral landscape. Second-growth totara-dominated stands 50 to 120 years old became established in grass or in reverting scrub dominated by manuka (*Leptospermum scoparium*) and sometimes by gorse (*Ulex europaeus*) following clearance of forest.

TREE SIZE AND LIFESPAN

Totara grows as a canopy or emergent tree and survives for many centuries. It is generally up to 30 m high with a trunk up to 2 m in diameter. The bark on older trees is thick, stringy, and furrowed. In their list of "100 Great Trees" of New Zealand, Burstall and Sale (1984) described three specimens of totara and one of Hall's totara. The largest is the Pouakani totara in Pureora Forest, south Waikato (height 39 m; diameter 3.6 m). They estimated that this tree would contain 77 m^3 of timber if the trunk were sound. Due to the brittle nature of the crown and inevitable breakage of branches and stems in storms, the maximum height of many giant totara trees is not usually maintained.

Because the large old trees are usually hollow, estimation of age from annual ring counts is difficult. Larger specimens could be 1000 years old or more. Some totara in the Whirinaki Forest, central North Island, are considered to be over 800 years old (Ebbett 1992, 1998).

The Pouakani totara in Pureora Forest, central North Island, estimated to be 1200 years old, is the largest giant remaining, with a diameter of 3.6 m and height of 39 m. Height is often reduced in such emergent trees by storms to leave shaggy crowns (inset).

RELATIONSHIPS WITH OTHER SPECIES

Totara is a conifer and a member of the family Podocarpaceae ("podocarps") which includes other well-known timber species confined to New Zealand: rimu (*Dacrydium cupressinum*), kahikatea (*Dacrycarpus dacrydioides*), matai (*Prumnopitys taxifolia*), and miro (*Prumnopitys ferruginea*). The podocarp family is found mainly in the Southern Hemisphere although some members occur as far north as Japan and the Himalayas (Enright *et al.* 1995).

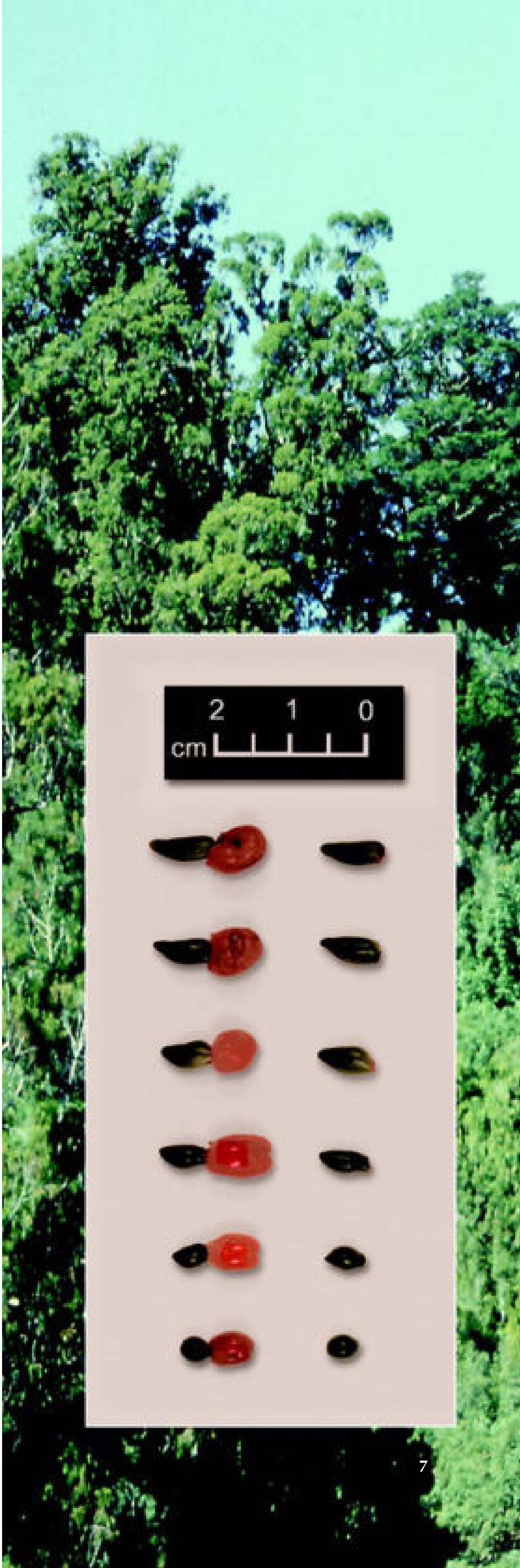
In contrast to most Northern Hemisphere conifers (e.g., pine, spruce, larch, fir), the female "cone" in many of the Southern Hemisphere species is reduced to one or a few scales bearing a single ovule which is a feature of New Zealand podocarps. The seeds are borne on a fleshy receptacle (totara, kahikatea, rimu) or enclosed in a fleshy fruit or drupe (miro, matai), and the seeds are dispersed by birds.

Podocarpus totara, known simply as "totara" is closely related to three other species:

- *Podocarpus hallii* Kirk ("Hall's totara"), a tree commonly 20 m tall but sometimes up to 30 m; up to 2 m diameter; with thin, often papery bark. Like totara, it occurs throughout New Zealand but it is often found at higher altitudes, on a wider range of soil types including those of low fertility, and on colder and wetter sites. Seedlings and saplings are more shade-tolerant than those of totara. Hall's totara seeds are long, narrow, and often pointed whereas totara seed is ovoid (Bergin and Kimberley 1992).
- *Podocarpus nivalis* Hook. ("Snow totara"), a prostrate shrub up to 3 m tall, with wide-spreading branches, found on upper forest margins and in subalpine scrub.
- *Podocarpus acutifolius* Kirk, a dwarf, needle-leaved shrub or (more rarely) a small tree up to 9 m high, found on stony alluvium in north Westland.

Hybridisation

New Zealand species of *Podocarpus* hybridise freely, and the hybrids have a wide range of seed and leaf shapes and tree forms (Webby *et al.* 1987). A distinct variety, *P. totara* var. *waihoensis*, which is an introgressed hybrid of totara and *P. acutifolius*, occurs in lowland Westland (Wardle 1972). Totara hybridises with Hall's totara where the two species overlap. Examples can be found in Pureora Forest, central North Island, where there is a range of seed shapes and bark types (Bergin and Kimberley 1992). At right is shown the long narrow seed of Hall's totara at the top and the ovoid seed of totara at the bottom, with intermediate forms of probable hybrids between. Some crossing between the two species occurs even at low altitudes; this is quite common — for instance, on Banks Peninsula and in Southland.



Totara seedlings a few months old, with linear sharp pointed leaves arranged in a spiral around the stems.

Naturally established 3.5-m-high totara sapling approximately 10 years old, established in grass; open growing saplings form a dense branchy habit and often have multiple leaders.

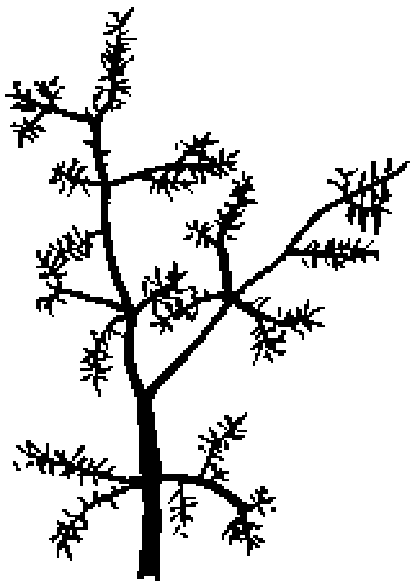
FOLIAGE, BRANCH, AND STEM FORM

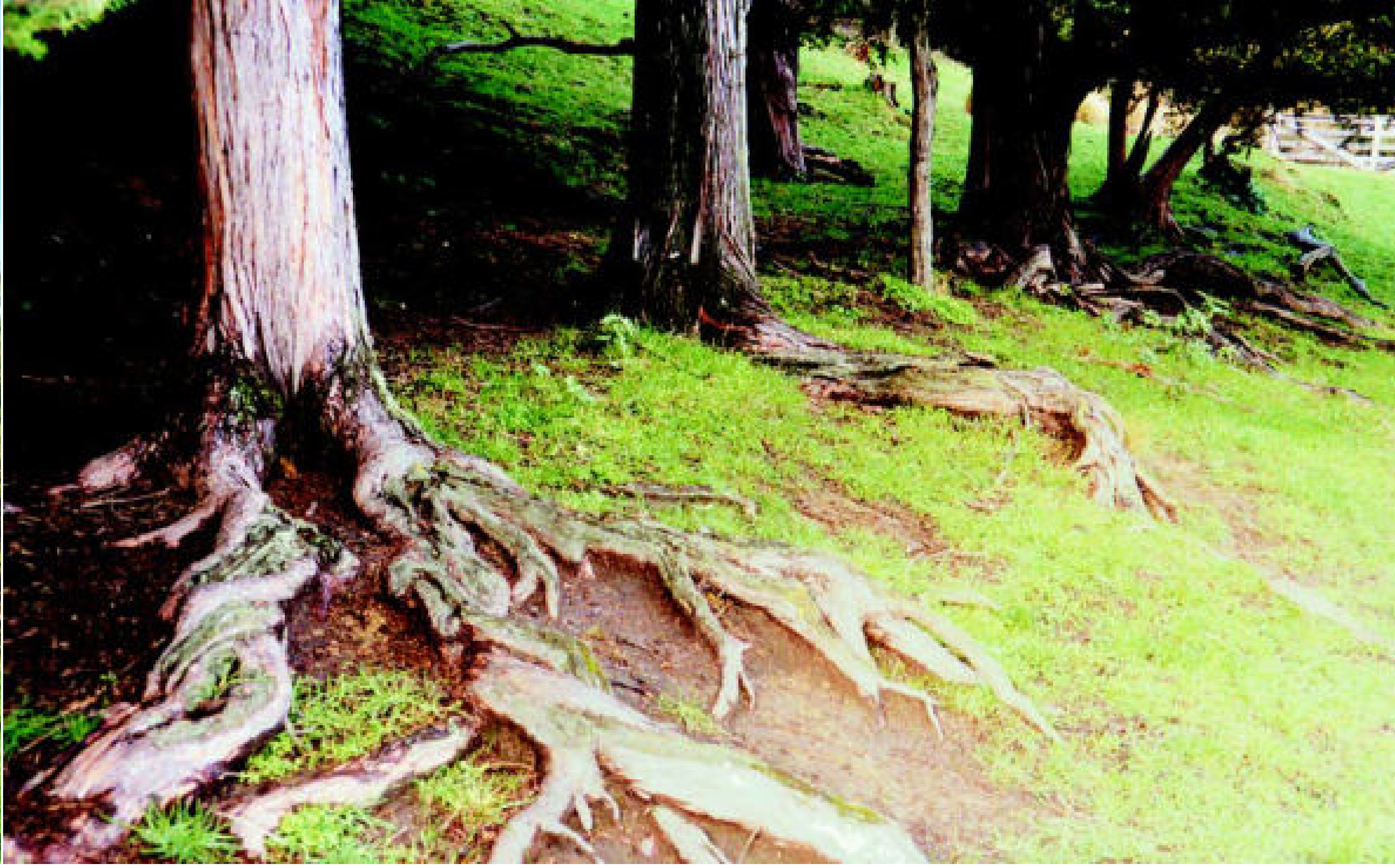
Seedlings of totara have two, occasionally three, persistent curved cotyledons (seed-leaves) (Philipson and Molloy 1990). Foliage leaves are flat, linear, sharply pointed, 24–40 mm long × 2–2.5 mm wide, and develop in a spiral arrangement on the stem. Dormant buds occur in the axils of some leaves in an apparently irregular pattern. Some of these develop during the first growing season to produce more or less horizontal lateral branches. Seedlings develop into laxly-branched saplings without any abrupt change in foliage morphology or plant habit. Leaves of semi-mature and mature trees are 10–30 mm long × 1–4 mm wide and are arranged in two more or less opposite rows.

Depending on local conditions, totara may exhibit up to four periods of active growth during the spring, summer, and autumn of a single season. Flushes of growth occur at all ages.

Totara seedlings and saplings growing in canopy gaps or with side shading usually have straight, often single-leadered stems. In open conditions, larger seedlings and saplings may become multi-stemmed as the leader loses dominance over the lateral branches. Strong growth of the lateral branches contributes to formation of the rounded crown characteristic of semi-mature and mature trees on open farmland.

Totara trees growing within dense high forest in the northern parts of the species range are tall, often with single leaders and small crowns unless emergent; in southern localities they are usually shorter and have large boles, basal buttresses, and more heavily-branched crowns (Philipson and Molloy 1990).





Extensive lateral root systems exposed in an 86-year-old totara stand planted on Banks Peninsula. Severe trampling by stock in this stand, which is located adjacent to cattle yards, has probably contributed to slow growth.

ROOT SYSTEMS

Totara tree root systems are irregular and variable, even within the same soil type (Hinds and Reid 1957). They consist of a framework of large subsurface or surface laterals which often spread further than the crown; obliquely-descending peg roots; and feeding roots which bear nodule-like structures and permeate the humus layer.

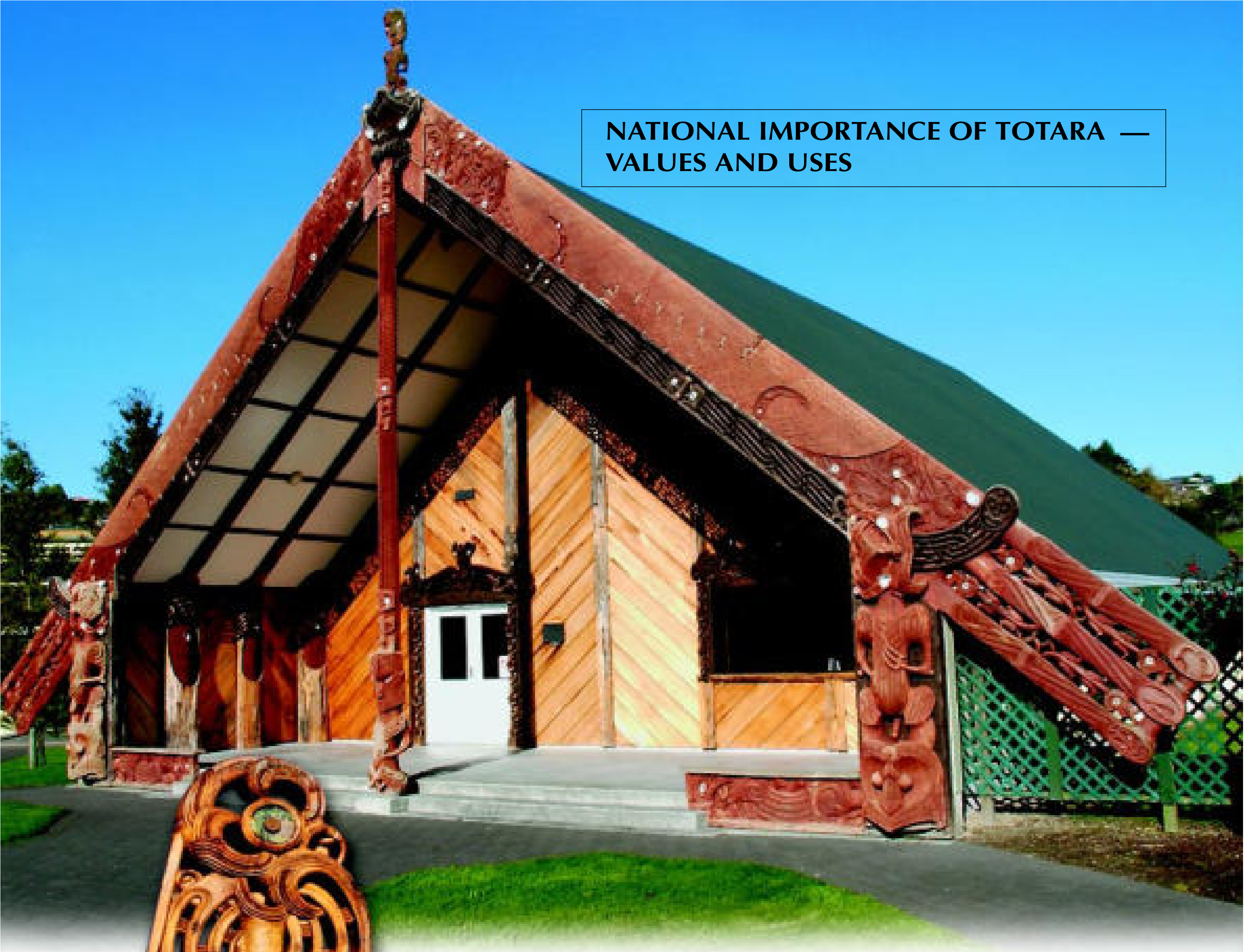
Root systems of bare-rooted seedlings are vigorous and distinctly golden in colour when fresh. Lateral roots and occasionally main roots appear to be abundantly nodulated but the “nodules” are in fact modified lateral root structures of a type found only in podocarps (Baylis *et al.* 1963). They are sometimes infected with phycomycetous mycelia. Bond (1967) showed that an endomycorrhizal fungus was necessary for growth of totara in poor soils deficient in available phosphorus and calcium.

Silvester and Bennett (1973) considered that the evidence for nitrogen fixation within podocarp roots was inconclusive. Slightly enhanced nitrogen-fixing activity associated with the roots was described as being essentially non-specific and located in the rhizosphere.

The ability of totara to produce new root systems after flooding has been highlighted a number of times (e.g., Foweraker 1929; McSweeney 1982; Campbell 1984). Roots can develop from totara trunks after silt has been deposited around them, even when the trees have fallen.

Totara form dense fibrous root systems as seedlings. Roots are covered in nodule-like structures typical of the podocarps; evidence of their function, including nitrogen fixation, is inconclusive.

NATIONAL IMPORTANCE OF TOTARA — VALUES AND USES



Totara was, and still is, the favoured species for construction and decoration of marae and waka taua (canoes). (Carvings by Lyonel Grant, Te Arawa.)

The early Maori quickly learned to appreciate the strength and carving potential of totara wood. A whare (house) dating from the twelfth century at Moikau, Palliser Bay, was found to be constructed from small shaped totara posts (Davidson 1987) and later examples of larger whare also contained totara. The timber was considered to be unequalled in terms of its physical properties which include ease of shaping, light weight, and durability. It has been used extensively over a period of 800 years in the construction and decoration of buildings and waka taua (ocean-going war canoes), and is still highly prized as a medium for the presentation of Maori art and history. Maori also used totara bark for thatching. The long, semi-detached outer strips could be obtained without killing or injuring the tree (Best 1916). The thick, fibrous bark material also played an important role in construction of fortified pa (villages), where it was used in outer defences as well as the buildings within (Clifton 1990). The inner bark was used to make patua or vessels for carrying and storing food (Best 1942), and pohatiti or kelp bags for storage and transport of muttonbirds (Simpson 1988).

In a report of the New Zealand Conservation Authority (1997), totara was named as one of five "icon" plant and animal species that were currently the focus of public controversy about decline and the need for protection. Totara was listed as a resource currently being sought for cultural use by Maori in 10 of the 15 New Zealand Conservancy regions.

European settlers arriving in the early nineteenth century regarded totara from old-growth stands as an important special-purpose timber (Hinds and Reid 1957). Totara heartwood was found to be amenable to all types of machining, and was easily brought to a smooth finish. It was considered to be superior to kauri for many end uses. The timber can be used for joinery and furniture, and finishes well with a coating of oil or wax. Chemical preservation of heartwood is unnecessary because natural durability makes it resistant to most of the agents causing timber decay.

Totara timber was once widely used for exterior joinery, fence posts, battens, buildings, bridges, railway sleepers, foundation piles, and shingles (Clifton 1990; Duguid 1990). In the 1920s it was much in demand for construction of houses, bridges, and wharves, and for poles, rail-ties, paving blocks, cooperage, and wood-pipe staves (Garratt 1924). Principal high-grade heartwood products in the 1950s were sashes and doors, tanks, vats, and boat components (Hinds and Reid 1957). Lower grade totara timber was used for fence posts and battens, survey pegs, transmission poles, and house piles.

Totara sapwood can be used for building exteriors and is resistant to attack by the borer *Anobium* (Hinds and Reid 1957). Sapwood is moderately resistant to pressure treatment with copper-chrome-arsenic (CCA) preservatives (Clifton 1990).

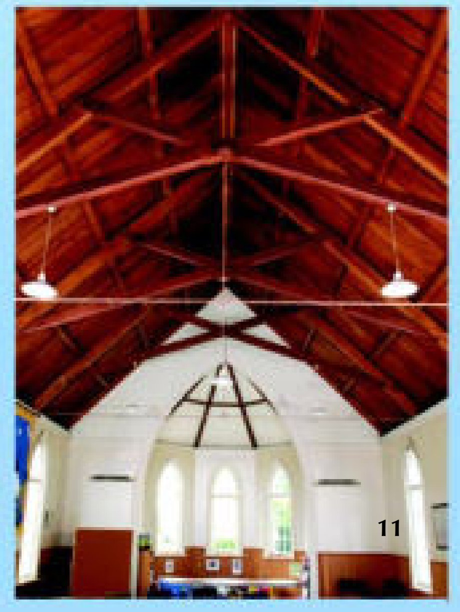
In recent years only small amounts of totara wood, including recycled timber, have been available. These have been used for production of hand-crafted boxes, bowls, platters, and rustic furniture by local craft workers.

Above and right: *Early logging often removed only the totara from many forests as the durable heartwood was in high demand for construction and fencing.*

Below: *Joinery in early buildings was most often made of heart totara. Chemical extractives in totara retard drying of normal primer paints and so special totara primers with low oil content were used.*

Right: *Totara has been used for both the beams and panelling in the roof of St Stephen's Church, Cambridge, built in 1871.*

Lower left: *In recent times, totara recycled from posts and buildings has been used for turning and for rustic furniture.*



Green catkins developing on a male tree release pollen in spring.

The 3- to 5-mm-long, ovoid, green seeds are attached to red, orange, or occasionally yellow succulent receptacles that attract birds.

SEED PRODUCTION

Totara is dioecious, i.e., trees are either male or female. Male trees produce abundant, 10- to 15-mm-long, yellow-green catkins on short branchlets all over the crowns. These are formed and release pollen in spring (W.M.McEwen unpubl. data). Female trees produce glaucous ovules in October-November on short stout stalks near the base of the new shoot growth. Ovules are fertilised 2–3 months after wind pollination and the fruit ripens in autumn. The 3- to 5-mm-long, ovoid, green, nut-like seeds are located on red, orange, or occasionally yellow, swollen and succulent receptacles on tips of modified branchlets Each receptacle bears one or sometimes two ovules.

Seed dispersal

Most totara seed ripens between mid-March and May in the central North Island (Beveridge 1964). Here planted trees bear seed after 20 years on upland sites (A.E.Beveridge pers. comm.) and within 10 years on lowland sites (Bergin 2001). Compared with other tall podocarp tree species, totara produces small to moderate quantities of seed in most years. Large old trees may have smaller yields (Beveridge 1973). Empty seeds are occasionally found on ripe fleshy receptacles.

Large quantities of seed fall at the base of female trees. Seed is also distributed by native and exotic birds. Beveridge (1964) found that in central North Island forests the most active dispersers of podocarp seed, including totara, are kereru (*Hemiphaga novaeseelandiae*), tui (*Prosthemadera novae-seelandiae*), and bellbirds (*Anthornis melanura*). These birds swallow the fruit but digest only pulp and the seeds pass intact through the digestive tract. The only bird observed to destroy totara seed was the yellow-crowned parakeet (*Cyanoamphus auriceps*). Totara plants often grow along fencelines where they germinate from seed dropped or defecated by perching birds. Seed is also dropped in flight by tui and starlings (*Sturmus vulgaris*); blackbirds (*Turdus merula*), common in both forest and grassland, almost certainly spread totara (A.E.Beveridge pers. comm.). Silvereyes (*Zosterops lateralis*) are also major dispersers of totara seed (J.G.Innes pers. comm.).

Totara seedlings readily regenerate along fencelines from seed dropped or defecated by perching birds.

Seed distribution beyond 40 m is carried out primarily by birds and also possibly by water. Beveridge (1964) considered that birds are essential for the regeneration of podocarps in areas of scrub where there are no female trees. In a study on Mount Tarawera, Rotorua, Burke (1974) found totara seedlings up to 4.8 km from the nearest trees and concluded that birds were the dispersal agents.

Totara is often the most common indigenous tree in many pastoral landscapes where it has regenerated along riparian areas, sometimes with kahikatea, on fresh surfaces created by periodic flooding. As well, it is found on steep hillsides with sparse weedy grass cover under light to moderate grazing.

NATURAL REGENERATION

Site tolerance

Simpson (1988) has drawn attention to the "great ecological vigour" of totara. The species is adapted to a range of climates and sites, is moderately resistant to browsing, and is therefore found in many different site types throughout the country. It once occupied coastal sand dunes, swamp margins, alluvial valleys and plains, volcanic areas, and hill slopes (e.g., Duguid 1990). The most productive stands are found on well-drained lowland alluvial soils, but trees grow well on a range of other soil types (Esler 1978). Totara is more tolerant of dry soils and seasonal drought than other podocarps and native conifers, but it is intolerant of poorly drained soils (Hinds and Reid 1957; Bergin 2001). It is the most light-demanding of the podocarp species.

Natural seedling establishment in forest

Most totara seed germinates in the forest during late spring and summer after the autumn seedfall (Beveridge 1964). There is a long natural dormancy period (70–140 days) during winter months (Hinds and Reid 1957). In Pureora Forest, Beveridge (1973) observed that podocarp regeneration was rare under dense canopy but occurred more frequently below a gradually-opening canopy of large broadleaved trees and in fire-induced scrub. Norton (1991) recorded similar regeneration patterns in Westland forests. Podocarp regeneration occurs in old cutover forest and along tracks associated with the controlled selective logging of virgin forest. Where large totara trees are left standing, numerous seedlings become established without tending. As well as seed dispersal by birds, the amount of irradiance reaching the forest floor appears to be an important factor determining the extent of natural podocarp regeneration.

Regeneration of totara occurs along logging tracks and previously-disturbed forest boundaries and scrub patches. Young totara, rimu, and matai are common members of the scrub communities found on gently rolling country adjacent to mires and high forest in the Waipapa Ecological Area, Pureora Forest (Leathwick 1987). McSweeney (1982) suggested that totara exhibits more of the characteristics of a forest pioneer species than matai. In a survey of the matai/totara flood plain forests of South Westland, he observed vigorous totara regeneration in large windthrow gaps, forest margins, open scrub and grassland. Matai regeneration was confined to areas with a continuous forest canopy.

Miller and Wells (2003) have confirmed that totara regenerates prolifically on gorse-covered river terraces in south Westland, particularly on raised surfaces (rafted logs and silt patches).

Totara regenerates along with or within the other pioneers manuka, kanuka, and gorse that establish on grazed hill-country farmland. These totara seedlings will overtop the manuka and gorse within 2–3 decades.

Regeneration on farmland

Results of a study of pastoral hill-country in Northland (Bergin 2001) confirmed that totara regenerates readily in pasture, and provided support for Burns' (2000) view that the dynamics of totara regeneration correspond to the catastrophic regeneration mode of Veblen (1992). Forest clearance by early settlers was a catastrophic disturbance which provided conditions suitable for successful totara regeneration. Totara grows better on steep hill slopes with a sparse weedy grass cover than on flatter sites dominated by pasture species. Bare ground on steep slopes and vegetation suppression by continuous grazing are considered to be factors which contribute to successful establishment of the relatively unpalatable plants. Totara can therefore be regarded as a pioneer species. Unlike other common pioneers (e.g., manuka, kanuka (*Kunzea ericoides*), gorse) totara is dependent on birds for seed dispersal. The presence of a local seed source and appropriate populations of birds clearly influences the rate of colonisation. Spatial cluster patterns of vegetation in the Northland study resemble the successional patterns of other plant communities containing bird-dispersed species (Silvester 1964; Wardle 1991). Seedlings regenerate in patches surrounding isolated taller saplings that act as bird perches.

On steep hill country pasture, stands of totara with a closed canopy are characterised by a relatively uniform stem size since thinning by natural mortality occurs with age. No other tree species is likely to regenerate if grazing is continuous, and a monoculture of totara develops. The trees will overtop manuka and gorse within 2–3 decades, and kanuka within approximately 100 years.

A DWINDLING RESOURCE

Concern about exploitation of the native forest timber resource and the dwindling of old-growth forest was first expressed more than a century ago. Up to the 1880s the productivity of native forests had been regarded as virtually inexhaustible. By 1900, Government officials and some sawmillers acknowledged that native forests were likely to be cut out within 40 or 50 years (Roche 1990). It became obvious that the increasing demand for construction timber could not be satisfied by the clearfelling of natural tree stands. Gradual acceptance of the need for native forest reserves became apparent during the late nineteenth century.

In spite of the development of a forest plantation industry based on introduced conifers, exploitation of the native old-growth forest continued until the late twentieth century. Although pressure generated by informed public debate eventually led to changes in forest policy, totara and other native tree species were still being felled in central North Island Crown forests in the early 1980s. Protests by environmental groups (some members climbing into the crowns of large totara trees to prevent felling) were evidence of public reaction to the exploitation of native forest (Edmonds 1978; New Zealand Native Forest Restoration Trust 1992).

By the early 1980s public pressure was placed on central Government to cease the logging of old-growth native forest on Crown land in the North Island. Similar action in the South Island was not taken until 2001.


The New Zealand Herald
Thursday January 19th 1978

Treetop Vigil in Efforts To Protect Big Totaras

Te Kuiti

Staff Reporter

Conservationists and the Forest Service reached a stalemate yesterday over the fate of a 40-hectare block of native bush in the Pureora State Forest.

Giant Totaras

No Threat

HISTORY OF TOTARA PLANTATIONS

Early experience

Efforts to establish plantations of New Zealand native species, including totara, date back to the 1870s. Comparison with native European, North American, and Australian species indicated that New Zealand species grew too slowly to provide the impetus necessary for the development of a plantation forest industry in this country. Large areas were planted with exotic species instead (Roche 1990).

The 1913 report of the Royal Commission on Forestry reinforced the perception that all native species were slow-growing and therefore unsuitable for management for timber production. A section on the economics of forestry based on trees taking 80 years to mature referred to **"the utter absurdity of suggesting such a tree as the totara for afforestation purposes"**. This conclusion was based on results from early experimental plantations of selected native and exotic species in New Zealand in which some 550 000 seedlings of totara and a total of 5000 seedlings of three other native species had been planted (Department of Lands 1909). The disproportionate numbers probably reflect the relative ease of totara seed collection and nursery culture and its adaptability to a wide range of site types.

One totara plantation was established at Puhipuhi in Northland between 1905 and 1909. Seedlings grown at the local Ruatangata Nursery just north of Whangarei were planted on 100 ha of cleared land (Department of Lands 1909). This suggests that foresters had recognised a need to replenish the dwindling natural totara resource. The Puhipuhi plantation was accidentally burnt a few years later and only small remnants exist today. These serve to demonstrate the potential of totara for plantation purposes. If the planting of native timber trees had been continued, plantations approaching 100 years of age would have been ready for harvesting today or in the near future.

A 100-ha plantation of totara was established at Puhipuhi, Northland, in the early 1900s. Unfortunately, most of the plantation was accidentally burnt a few years later, leaving only a few small remnants on this dairy farm.

Later planting

Some planting of native tree species was continued by the New Zealand Forest Service, by local authorities in parks and recreation areas, and by private landowners. From the late 1950s, half a million seedlings of native species were planted out on a range of forest and scrub sites. A number of large trials incorporating rimu, totara, kahikatea, and some matai and tanekaha were established on the West Coast, in Hawke's Bay, the central North Island, and north Auckland (Beveridge 1977). Some of these plantings were adequately maintained, but many were not and have been abandoned.

During the late 1970s and early 1980s up to 40 000 podocarps per year were being planted in the central North Island forests of Pureora and Whirinaki (Beveridge 1977). In addition, numerous small plantations of single or mixed species of a wide range of native timber trees were planted throughout the country on private land, in public reserves, and in urban parks (Pardy *et al.* 1992). Many of these stands were established on fertile lowland sites and have been well-maintained. They are thus indicators of the potential growth rate and form of major native tree species in planted stands up to 100 years of age.

SEED COLLECTION

Planning for large-scale totara planting programmes is relatively easy. Locally-sourced seed can be collected in most years. Male trees can be distinguished by fallen brown catkins during seed collection time and this makes it easier to recognise female trees.

Ripe seed is green and the attached bright red, orange, or yellow receptacles soon shrivel and become detached under storage. From mid-March to May, seeds can be collected by hand from the lower branches of smaller trees. Sheets of hessian or similar material can be suspended on poles or laid on the ground to catch seed beneath large trees. In late autumn/winter, fallen seeds which have turned brown and become detached from the receptacles can be picked up from the ground. These will germinate successfully (Bergin and Kimberley 1992).

Only seed filled with white- or cream-coloured endosperm with a visible embryo (small white dot in the centre of the cut seed) is viable. Some seed may be shrivelled or empty. The proportion of seed that is sound can be checked during collection by cutting a representative sample of seeds in half.

Totara develops a vigorous fibrous root system which makes it ideal for raising as bare-root seedlings.

Many nurseries produce totara seedlings 60 to 70 cm high in polythene planter bags (PB2 and PB3) within 2 years of sowing seed.

PROPAGATION

Germination

Germination of totara seed sown in spring generally occurs within 6 weeks although it can continue on an irregular and sporadic basis and may take up to a year (Forest Research Institute 1980a). Delayed germination has been reported for totara seed in forest duff collected beneath seeding trees (J.W.Herbert unpubl. data).

Seedling production from sorted seed

Moist cool storage of totara seed for several weeks may give more even germination. This mimics fallen seed on the forest floor over winter. The seed can be stored for 6–18 months under moist cool conditions without loss of viability (Forest Research Institute 1980a).

As a result of research and operational propagation programmes during the past 40 years, seedlings of most native conifer tree species can now be produced in large numbers at reasonable cost. Totara seedlings are raised either in open beds as bare-rooted stock, or in containers (Beveridge *et al.* 1985), and reach a planting height of 50–80 cm in 3–5 years in nurseries on cool upland sites (Forest Research Institute 1980a). This period is reduced in warmer lowland nurseries. In the 1980s bare-rooted stock was produced. Seed was broadcast-sown in the open and seedlings lined-out at 15 × 15 cm spacing were kept under shade cloth for 12 months. Depending on growth rate, they remained in the beds for a further 1–2 years. Root cutting and wrenching for 3 months before lifting in winter or early spring encouraged the development of a compact fibrous root system and facilitated removal. Tractor machinery was used for most of the operations. Totara develops a vigorous fibrous root system more readily than many other tree species.

Today, most nurseries raise totara seedlings in containers. This allows more flexibility since stock can be held from one season to the next and seedlings can be planted over a longer period. Seed broadcast on to trays of seed-raising mix in a heated glasshouse germinates within 4 weeks. Seedlings 5 to 7 cm high are pricked out, one per small container. Transfer to containers of increasing size depends on length of time in the nursery and the size of seedlings required.

Seedling production from forest duff and wildings

The upper layer of forest litter (duff) containing fallen totara seed can be raked up in autumn and spread over seed-raising mix in boxes or beds. Totara seedlings can then be picked out and transplanted (Herbert unpubl. data).Beveridge (1962) showed that 5- to 25-cm-high totara seedlings transplanted from disturbed sites at the forest edge could be raised to standard specifications in nursery beds. These labour-intensive techniques are more suitable for small-scale operations.

Production of plants from cuttings

Totara cuttings, which readily form roots even where stem and leaf material is taken from very old trees, have been used for plant production on a small scale (T. Faulds pers. comm.). This method may eventually be used to propagate tested clonal material from trees with superior growth rate and form. No work has yet been done to test the effects of parent tree age on the characteristics of totara plants developed from cuttings.

PLANTING

Planting techniques

On upland sites, totara grows best when planted in late winter or early spring. In warmer districts, autumn planting will allow a longer period of establishment before the onset of summer droughts (Bergin and Pardy 1987). Although applications of a range of fertilisers (e.g., slow-release NPK formulations; blood and bone manure) in upland areas did not have a significant effect on growth and survival (Beveridge *et al.* 1985), glasshouse trials have indicated a positive response to increased nutrient levels (Hawkins and Sweet 1989). Other factors are likely to mask the effect of nutrient addition on difficult sites. Planting pattern and density will vary according to the site type and the reasons for establishing the plantation. Information from planted and natural stands suggests that stem form and branch development can be influenced by spacing, but no detailed analysis of the effects of these factors has been carried out.

Planting sites

Choice of planting site has a critical effect on survival and growth rate.

Forest sites — The planting of small groups of totara (1–1.5 m spacing) in canopy gaps in order to take maximum advantage of overhead light has been recommended for degraded high forest, cutovers, and bush remnants on farms (Beveridge *et al.* 1985). The planting pattern can be varied to make use of areas of disturbed soil away from the root systems of large trees, but this will increase relocation problems when the young trees require releasing from competing vegetation.

Scrub sites — Totara and kahikatea establish more successfully on open sites than other podocarp species, but use of a cover of hardy shrubs such as manuka, kanuka, and kohuhu (*Pittosporum tenuifolium*) as nurse species will improve survival and growth, and reduce the risk of frost damage. Group- or line-planting of totara is appropriate for scrub sites depending on density of cover and height of the canopy (Forest Research Institute 1980b).

Open sites — Without side shelter, stem form is likely to be poor, and a large proportion of totara will be multi-leadered if planted at low stocking. Canopy closure for a totara plantation on a lowland North Island site established at 2 x 2 m spacing occurred at about 8 years. An alternative to planting only totara is to plant a cover of less costly shrub species such as manuka that will give quicker canopy closure, and then interplant totara.

Standard planting techniques, including a well-cultivated pit and firming of soil around seedling roots, will improve survival and early growth.

Inset*: Teasing apart root systems of pot-bound plants will result in improved root development that will reduce toppling, particularly on exposed sites*

Planting totara within cut lines or in natural gaps in manuka, kanuka, and shrub hardwood cover will improve survival and growth, particularly on exposed sites.

These totara plantations at Holts Forest Trust, Hawke's Bay, show that totara can be successfully pruned and multiple leaders reduced to one leader to produce clear straight boles; 30-year-old stand pruned to 3 m (above) *and 50-year-old stand pruned to 5 m* (below).

TENDING

A national survey evaluating the plantation performance of native trees up to 100 years of age showed that competition from grass, ferns, and shrub hardwoods was the main problem in recently-planted stands. Totara is intolerant of overtopping. Lack of releasing was found to be the main cause of failure and affected both survival and growth rate (Pardy *et al.* 1992). Removal of overtopping vegetation is necessary for at least 2–5 years after planting, the objective being maintenance of a canopy gap to promote optimum growth (Bergin and Pardy 1987). Trees reaching about 2 m in height are able to compete with other vegetation although it may be necessary to remove climbing plants to prevent saplings in canopy gaps from being suppressed.

Historically, very little tending of planted stands of most native tree species, including totara, has been carried out (Pardy *et al.* 1992). Pruning to 3 m in a 23-year-old planted totara stand in Hawke's Bay, and up to 5 m in an East Coast stand, had no apparent detrimental effect on external stem quality or tree health.

Initial trials and anecdotal evidence indicate that removal of only the multiple leaders and steep angle branches, even from an early age, is likely to improve wood quality. Interplanting totara within short scrub in lines or small groups where a canopy gap occurs improves stem form.

A small group of planted podocarp seedlings in this forest gap will be lost if not released from vigorous ferns.

Opposite page —

Top left: *As densely stocked stands develop, whether natural or planted, the small-diameter and often-horizontal branches die back under reduced light levels, become brittle, and break off. Removal of these small branches is therefore not essential in tending operations.*

Top right: *These totara were planted within gaps in 2- to 3-m-high manuka that had been planted on an open site. Side shade has contributed to small branches and a low incidence of multiple leaders.*

Lower left: *A significant proportion of totara in this 12-year-old totara plantation at 2 × 2 m spacing (2500 stems ha^{-1}) have multiple leaders and steep angle branches.*

Lower right: *Removal of multiple leaders and only the larger steep-angle branches is recommended to improve stem form. This can be initiated from sapling stage by cutting branches as close as possible to the main stem.*



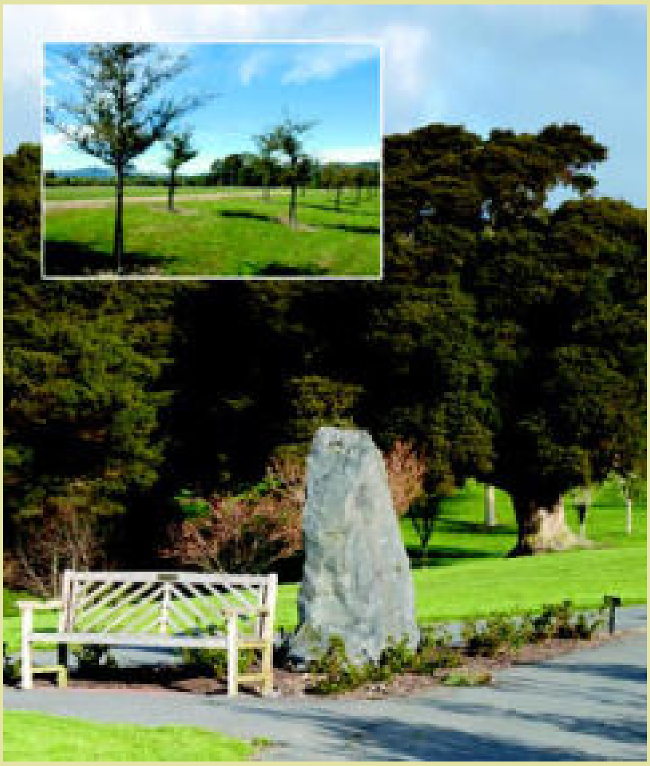

GROWTH RATE OF PLANTED TOTARA

Podocarps develop slowly after planting out. On cool upland sites, annual height growth of totara accelerates after the second year to an average of 20 cm. Tall seedlings (60–80 cm) planted on good sites have reached a height of 2 m in 5 years with a survival rate exceeding 90% (Beveridge *et al.* 1985).

Thirty-seven planted totara stands and shelterbelts 20–80 years old and growing on fertile lowland sites were assessed in a national survey (Pardy *et al.* 1992). In these trees the mean annual diameter (1.4 m above ground level) growth rate was 8 mm and mean annual height growth 25 cm. At age 75 years the average height was estimated to be 18 m and diameter 55 cm.

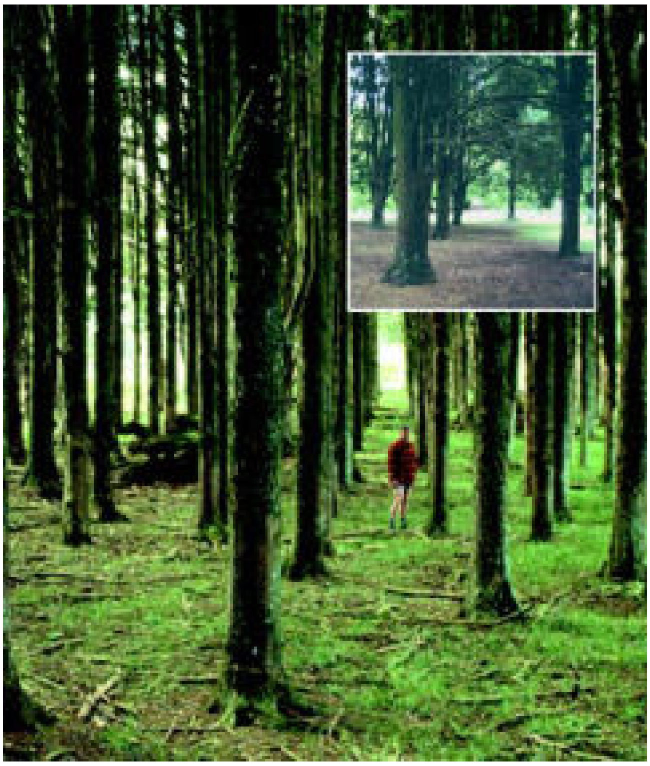
From a review of the performance of planted conifers up to 50 years of age (former New Zealand Forest Service plantings and those on private land), Bergin (2001) found that the average survival rate of totara was 60%, the mean annual height increment 26 cm, and mean annual diameter increment 6 mm. These values were similar to those for rimu and kahikatea despite wide variation in site quality and management history.

The more successful totara plantations, located on open fertile sites, had a mean annual height increment of up to 55 cm and a mean annual diameter increment of 10 mm.



Totara is one of the most popular native trees planted in amenity areas, with fast growth rates on these often well-managed fertile sites

STOCKING AND STEM FORM



These two stands that have not been pruned illustrate the effect of spacing on tree form and branching. A 90-year-old plantation at 1.2- to 1.5-m spacing has a high proportion of clear straight boles, many of which are branch-free for 10 m. In contrast, a 70-year-old stand (inset) *planted at 5-m spacing has short stems, multiple leaders, and large persistent branching to low level.*

Totara in high forest often has a tall straight bole with no branching at lower levels. In contrast, trees standing alone on farmland or planted in shelterbelts invariably develop large crowns with live branches near ground level.

Height and tree form are influenced by stand density. A dense 90-year-old totara stand planted in Northland at 1.2- to 1.5-m spacing was found to have excellent stem form: a high proportion of the interior trees had 5- to 10-m clear boles and small lightly-branched crowns (Pardy *et al.* 1992). By contrast, 70-year-old totara planted 4–6 m apart in Cornwall Park, Auckland, had short stems, multiple leaders, and large persistent branches near to ground level.

Stem form of totara is closely linked to initial stocking rate, the degree of competition within the stand, and the rate at which the canopy closes. Due to higher light levels, widely-spaced tree stands (planted or naturally established) contain a high proportion of individuals with multiple stems and coarse branching. At higher stocking rates a greater proportion of trees have single leaders and only small branches on the lower stem.

GROWTH AND YIELD

Planted stands

Wide variation in growth rate was observed in 13 planted totara stands ranging between 10 and 100 years of age (Bergin 2001), attributable to differences in site type, management history, and stocking rate. The relationship of growth with age was more direct for diameter than for height. This study showed that an average annual height increment approaching 55 cm and an annual diameter increment of 10 mm can be achieved on the best sites with good management. Less than one-third of the potential growth rate can be expected on poor sites.

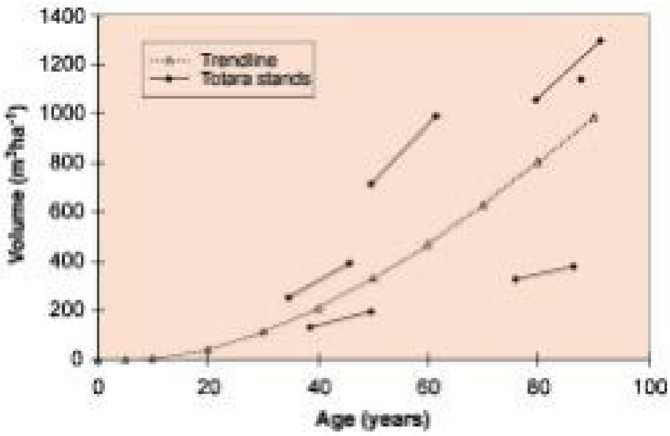


Figure 1. Totara volume/age curve derived from measurement of eight planted stands located on a range of sites. The dashed line shows an average volume/age curve for 1000 stems ha^{-1}, assuming no mortality. Solid lines show actual volumes of six plantations with comparable stocking.

Growth model

A very crude growth model based on data from eight planted stands up to 100 years of age (Figure 1) shows that total stem volume growth is slow at first but accelerates during the second 50-year period (Bergin 2001). The model indicates that a mean basal area of 100 m^{2}ha^{-1} and mean volume of 800 m^{3}ha^{-1} might be expected at age 80 years. Predicted current annual volume increment (no adjustment made for mortality) is less than 7 m^{3}ha^{-1} at age 30, increasing to 14 m^{3}ha^{-1} at age 60 (Table 1). This rate is lower than that predicted for two exceptionally productive 60-year-old kauri stands (18 m^{3}ha^{-1}) on a Taranaki site (Herbert *et al.* 1996).

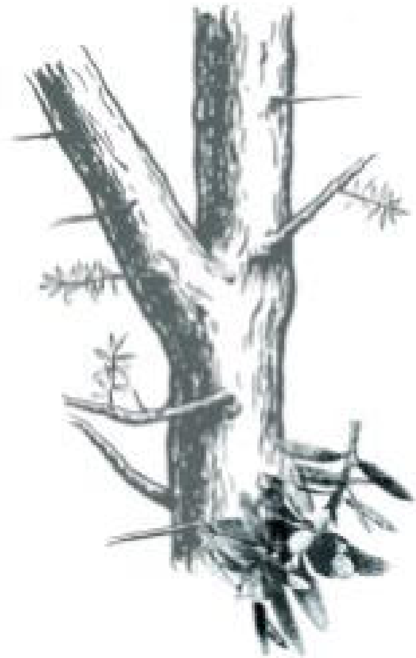


Table 1. Predictions of stand growth for totara at 1000 stems ha^{-1} based on data from six plantations with comparable actual stockings located on a range of sites. Volume is based on total stem height and a volume equation for kauri pole stands (Ellis 1979) because a volume equation for totara does not exist.

Age (years)	Mean height (m)	Mean diameter (cm)	Basal area (m^{2}ha^{-1})	Volume (m^{3}ha^{-1})	Mean annual volume increment (m^{3}ha^{-1})	Current annual volume increment (m^{3}ha^{-1})
10	3.7	6.4	3	6	0.6	0.6
20	6.7	13.0	13	43	2.2	3.7
30	9.3	18.0	25	112	3.7	6.8
40	11.5	22.3	39	208	5.2	9.7
50	13.4	26.2	54	329	6.6	12.1
60	14.9	33.1	70	470	7.8	14.2
70	16.2	35.7	86	629	9.0	15.9
80	17.3	36.3	103	803	10.0	17.4
90	18.2	39.3	121	989	11.0	18.6

Comparison with exotics

Growth rates of planted totara are significantly greater than those of naturally regenerating stands (Table 2). However, even planted totara is much slower than the most widely planted exotic conifers in New Zealand: radiata pine (*Pinus radiata*), Douglas-fir (*Pseudotsuga menziesii*), and cypress (*Cupressus macrocarpa* and *C. lusitanica*). The estimate of 470 m^3ha^{-1} total tree volume for planted totara at 60 years is only a fraction of the 400–900 m^3ha^{-1} expected for 25- to 30-year-old radiata pine (Maclaren 1993). The average mean annual increment of recoverable volume of Douglas-fir in New Zealand is 17 m^3ha^{-1} at age 60 compared with the estimated 8 m^3ha^{-1} total tree volume of planted totara. Growth of Douglas-fir is also slow over the first 30 years (Miller and Knowles 1994). Mean annual increment in New Zealand cypress plantations can be as high as 15 m^3ha^{-1} (Miller and Knowles 1992).

Table 2. Comparison of estimated growth rates for planted and natural totara with those of major exotic forestry species grown in New Zealand

Species	Stand age (years)	Mean height (m)	Mean dbh (cm)	Volume (m^3ha^{-1})	MAI (m^3ha^{-1})
Totara (planted)	60	15	33	470	8
Totara (natural)	60	11	17	110	2
Radiata pine	30	40	45	400–900	13–30
Douglas-fir	60	44	53	1000	17
Macrocarpa	40	35	40	240–600	6–15

Management history

Early records and performance of planted totara stands indicate that management has been very variable. Many plantations were neglected and others were located on poor or inappropriate sites. Better growth than that predicted from the preliminary model can be expected, especially on good-quality lowland sites where seedlings are kept free of weed competition in early years.

Effect of stocking rate on yield

Planted totara shows a clear trend towards decreased diameter as stocking rate increases. At age 40, average diameter is 35 cm in low-density (e.g., 400 stems ha^{-1}) plantings, 20 cm at 1000 stems ha^{-1}, and 15 cm at 2000 stems ha^{-1}.

The totara provenance trial 12 years after planting, on a previously grazed farm site, Tapapakanga Regional Park, south of Auckland. Differences in growth, tree form, and heartwood development between the 36 different provenances are being monitored.

Canopy closure began 8 years after planting, with the stand established at a density of 2500 stems ha^{-1}. The dead brittle lower branches are easily broken off to leave clear lower stems 12 years after planting.

DIFFERENCES DUE TO PROVENANCE

Provenance differences observed among seedlings

Geographically-separated populations (provenances) often develop different characteristics. Differences in the growth, stem form, and leaf characteristics of totara seedlings were observed when seed collected from 42 provenances throughout New Zealand was sown in a nursery trial (Bergin and Kimberley 1992). An example is the slower growth of seedlings from southern latitude provenances compared with those from further north. As a result of this study it was recommended that any future extensive planting for conservation purposes should be based on seed from a local source. At the same time it was recognised that there is considerable scope for genetic improvement of totara. Where the objective is high-value timber production, selection of provenances with fast growth and good tree form might be considered.

In a separate study of the 42 seedlots (Hawkins *et al.* 1991), higher altitude provenances (150–540 m a.s.l.) produced seedlings that were more tolerant of cold temperature than provenances from low altitudes (30–100 m a.s.l.). This suggests that environmental selection for frost hardiness has resulted in the evolution of populations of totara that are adapted to the current local climate.

Provenance differences observed in plantations

Seedlings from the nursery provenance trial were used to establish a plantation trial in a frost-free lowland site at Tapapakanga Regional Park, south of Auckland. The tree stands have been intensively maintained and monitored since establishment 11 years ago. Results at age 11 have confirmed earlier indications that totara tree height, diameter growth, and stem form vary with provenance. Differences in height were significantly correlated with latitude ($r = -0.58$) and mean annual temperature ($r = 0.54$) of the place of origin. Seed from northern latitudes produced trees that tend to grow faster and to have better form than those derived from seed collected in southern latitudes (Bergin 2001). There is considerable variability within populations, indicating that improvement of totara growth and stem form of locally-sourced material is a possibility.

A breeding programme capitalising on genetic variation within and between totara provenances is likely to result in significant improvement of productivity and wood quality. This would involve selection of seed from trees with a faster growth rate, straight unforked stems, and lighter branches.

Geographic and climatic factors do not account for all of the variation in growth and form of totara. There is a considerable amount of gene-flow between populations and this is likely to decrease local genetic differentiation. The agents are wind pollination, which can occur between totara trees separated by considerable distances, and seed dispersal by birds. The size of native bird populations has decreased in recent times, but the influence of increasing numbers of introduced fruit-eating birds such as starlings, blackbirds, and thrushes (*Turdus philomelos*) will probably ensure continued dispersal of seed, particularly around the fringes of native forest remnants and between groves and scattered trees.

Stick insects can defoliate new growth on totara. Control of insects and fungi is not practical on a large scale.

Trees under stress may show signs of insect attack. Small holes in the bark (top) *and tunnelling in the cambial zone and in the outer sapwood* (lower) *are caused by small, native, longhorn beetle larvae.*

INJURIOUS AGENCIES

Insects

Among the podocarp species, totara is the most susceptible to defoliation by insects. Beveridge (1962) observed a high incidence of insect attack on seedlings raised in a nursery at Pureora. There, tortricids (leafroller caterpillars) caused the most severe damage through the destruction of terminal buds. This stimulated the production of long horizontal side shoots or multiple leaders. Geometrids (looper caterpillars) appeared to attack the leaves, but not the buds, and therefore had less effect on the form of the seedlings. Phasmids (stick insects), often abundant in crowns of mature podocarps, also damage totara seedlings.

Three insects are found only on totara and other podocarps. These are a scale (*Madarococcus totarae*), an aphid (*Neophyllaphis totarae*), and a weevil (*Peristoreus flavitarsis*). Species which cause damage to totara but also have other hosts are a weevil (*Pachyurinus sumptuosus*) and a cerambycid (longhorn beetle *Navomorpha lineata*) which often kill leaders and branches of young trees, a geometrid (*Pseudocoremia suavis*) and a tortricid (*Ctenopseustis obliquana*) whose larvae consume the leaves of newly-flushed shoots. Stick insects (*Acanthoxyla* spp.) also feed on new shoots (Forest Research Institute 1982a).

Totara seedlings and small saplings are frequently damaged by cicadas (Cicadidae), unidentified leaf miners, and stem-boring insects. Lloyd (1949) reported that totara seedlings and saplings were severely damaged by cicada oviposition in branches and stems and that this sometimes led to breakage. He found widespread cicada damage where the light intensity was higher and suggested that totara regeneration might be vulnerable where the canopy is opened up by logging or releasing. Cicada damage is only a problem at the seedling and sapling stages when the bark is thin. Wounds caused by cicadas provide entry points for larvae of *Madarococcus totarae* and *Neophyllaphis totarae.*

Larvae of the native two-toothed longhorn beetle (*Ambeodontus tristis*) bore in the dead sapwood and heartwood of a number of softwood species but are more common in rimu and kahikatea than in totara (Hosking 1978).

Severe dieback of totara due to death of buds and shoots; causes are unresolved but insects, fungi, and possums can all damage new growth.

Corynelia tropica *fruiting bodies on totara.*

Fungi

Unthrifty totara seedlings in Pureora nursery were found to be infected by *Corynelia tropica* which formed yellow patches on leaves (Beveridge 1962). In older trees this fungus produces yellow or pink oval spots between the midribs and margins on both surfaces of the needles and also on twigs and fruit (Hood 1985). Prominent black, coral-like fruiting bodies develop within the spots, mainly on lower needle surfaces. They appear in summer on new foliage of seedlings and trees of all ages. Severe *C. tropica* infection, death of terminal shoots, and malformation have been found to follow browsing of seedlings and saplings by deer (Hinds and Reid 1957). Similar attacks occur after frost damage (A.E.Beveridge pers. comm.). Hood (1985) considered that this fungus is generally harmless and of little significance, although the buildup of heavy infections may limit shoot growth and destroy fruit.

Hinds and Reid (1957) reported that heart rot caused by *Inonotus lloydii* is found in old totara trees which are usually hollow. This honeycomb decay (sometimes referred to as kaikaka) only occurs in the heartwood and is especially common in the central North Island.

An investigation into the cause of totara dieback in the central North Island (Forest Research Institute 1982a) where several fungi have been found, failed to prove that any of the organisms isolated were pathogenic. To a greater or lesser degree, all insects and fungi associated with totara can damage new growth. Bud and shoot loss was prevented by year-round spraying with a mixture of two fungicides and an insecticide at regular intervals. However, intensive treatment of this kind is not practicable on a large scale and is only likely to be used for the preservation of individual trees.

Frost

At altitudes of 500–550 m in the central North Island, seedling growth flushes that have not hardened off are frequently damaged by early or late frosts (Beveridge 1973). Frost damage occurs in most years and has a negative effect on height increment.

Browsing

Deer cause some damage to seedlings and saplings of totara where browsing pressure is very high (Hinds and Reid 1957). Seedlings planted within a deer enclosure were moderately damaged; branch tips were removed (J.G.Innes pers. comm.).

Browsing of totara by possums (*Trichosurus vulpecula*) can be significant. In a major study of the diet of possums in Orongorongo Valley near Wellington, Mason (1958) found that totara foliage, fruit, and seeds were eaten and trees were sometimes severely damaged. In central North Island forests, the spring and autumn leaf flushes are probably a large component of the early winter diet, particularly when other more palatable species become limited (A.E.Beveridge pers. comm.). Possums ingest fleshy receptacles and seed and so reduce the amount of seed available for regeneration, though it is not known whether the seed is digested or disseminated. Exclosure trials have shown that possums eat young shoots and bark of planted podocarp seedlings (Forest Research Institute 1980a). It is likely that possums contribute to crown dieback of totara which can be widespread in natural forests.

MANAGING NATURAL TOTARA STANDS ON FARMS

Natural regeneration of totara occurs on hill slopes of farmland in many regions where there is a local seed source, even in the presence of grazing cattle (right). *The site above at Kaeo, Northland, was in pasture 10 years ago. Saplings and seedlings of totara are now invading the slope.*

In many parts of New Zealand, totara is a prominent feature of the rural landscape. Scattered trees and groves of young totara are common in productive pasture in Northland, Waikato, King Country, Horowhenua, Wairarapa, Nelson, Kaikoura, and the West Coast (Wardle 1974). Most of these are 50–120 years old. Clearance of the original forest by early settlers and conversion to farmland has provided conditions which favour totara regeneration. Indeed, more totara may be growing in New Zealand now than in the past.

Establishment

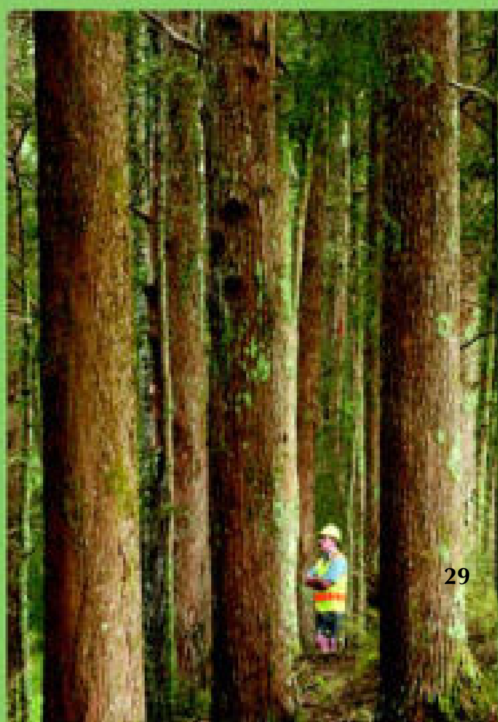
Under natural conditions, dense, even-aged stands of totara can develop on disturbed surfaces in open sites. In the forest these sites result from catastrophic events such as flash floods and landslips. Pasture in hill country also provides open sites and totara is likely to become established if a local seed source is present, particularly on lightly grazed steep slopes dominated by poor quality pasture species. Totara is relatively unpalatable to cattle and, to a lesser extent, to sheep, and seedlings will develop without exclosure of animals.

Bergin (2001) found that the presence of cattle often provided suitable sites for seedling establishment on the steep slopes of pastoral hill country in Northland. Here exposure of soil through trampling and the shortening of grass facilitates colonisation by shrub and tree species, and only the more palatable ones, many with potential for suppressing totara, are removed by grazing. C.Miller and A.Wells (2003) observed that the presence of cattle improved the establishment of *Podocarpus totara* var. *waihoensis* on river terraces. They found that gorse grew more rapidly than totara when the animals were removed. Totara seedlings are likely to develop only when the gorse stands become older and more open.

Development of stands

Monitoring of naturally-regenerating areas on Northland farms shows that where totara is frequent, other species will be progressively suppressed and the totara will be relatively uniform in stem size and form as it reaches semi-maturity (Bergin 2001).

On hillsides in Northland, small thickets of saplings develop within 20 years and give rise to pole-stage stands by age 40–60 years. Thinning through natural mortality can reduce stand density from 60 000 stems ha^{-1} to less than 1000 stems ha^{-1} at this stage. Semi-mature trees will have an average diameter of 30 cm within 100 years.



Top: *Regenerating totara develops into thickets of small saplings within 20 years on suitable sites. Stem density of this 19-year-old stand at Kaeo, Northland, exceeds 60 000 stems ha^{-1}. Mean stand height is 2.6 m and diameter at breast height is 3.3 cm. Infilling of gaps around the edge of the stand is continuing, making age estimates of such stands difficult. On other sites, manuka, kanuka, and gorse may occur in various proportions.*

Above: *Clustering of totara is evident in this dense totara-dominant stand where tracks have been kept open by grazing farm stock that contribute to removal of lower dead branches. Intense competition is resulting in larger trees dominating the stand and eliminating small-diameter saplings.*

Top right: *It is likely that this 60-year-old naturally regenerated pole stand at Glenbervie, near Whangarei, started as a dense stand of totara like the thickets illustrated above. Intensive competition has resulted in self-thinning to a density of nearly 10 000 stems ha^{-1}. Lower branches have died and rotted to leave clear stems up to 6 m high on many trees. Canopy height is 11.4 m and average diameter is almost 20 cm. Evidence of higher stocking density can be seen in the numerous dead stems lying on the ground throughout the stand.*

Centre: *A further stage in the sequence is the development of a semi-mature stand of trees where density has reduced to around 1000 stems ha^{-1} on this farm site at Herekino, near Kaitaia. Mean stand age is estimated at 125 years. Height is 20.5 m and diameter at breast height is 30.1 cm. Many trees have branch-free lower boles. Numerous fallen stems and dead standing and unthrifty trees indicate that thinning of this stand is continuing.*

Bottom right: *This dense totara stand on a hillside on the same Kaeo farm as many other younger stands is estimated to be over 150 years of age. It is likely to have originated as a dense thicket on reverting land previously cleared or burnt, and followed a sequence of stand development similar to that described.*

Management of regenerating stands

Methods for managing natural totara stands require evaluation. They could involve early intervention, delayed intervention, or no intervention at all. Repeated thinning of sapling thickets is labour intensive, but will maximise the rate of early growth. If thinning is delayed to the pole stage, stem density will have been reduced by natural mortality but growth will be slower. Absence of intervention will allow very slow development into a potential wood resource for future generations.

Thinning and/or pruning offer some scope for the improvement of totara stem form and growth rate if landowners are willing to modify natural processes. Current research is focusing on site and stand factors that influence tree growth, wood quality, and the development of heartwood. Trials are being established to evaluate the effects of thinning and pruning regimes on diameter growth rate and stem form.

The first of several proposed thinning trials in different-aged stands of naturally regenerating totara in Northland was established at Herekino by local silviculturalist Owen Lewis. The trial comprised separate thinned blocks with densities of 1600, 1200, and 800 stems ha^{-1}, and an unthinned control of 2500 stems ha^{-1}. Trees have been pruned to at least 6 m. Permanent Sample Plots have been established in each treatment block to monitor stand stability and long-term growth responses to thinning.

PLANTATIONS OR NATURAL REGENERATION?

Current information, although sketchy, indicates that growth of totara is slower in natural stands than in plantations. Diameter at breast height in 60-year-old plantations (33 cm) is nearly twice that recorded in natural stands (17 cm). This can be explained by intensive intra-species competition in natural stands which reduces the rate of diameter growth of individual stems. Mean height at 60 years is 15 m in plantations but only 11 m in natural stands. The reasons for this are not clear but may be related to site quality.

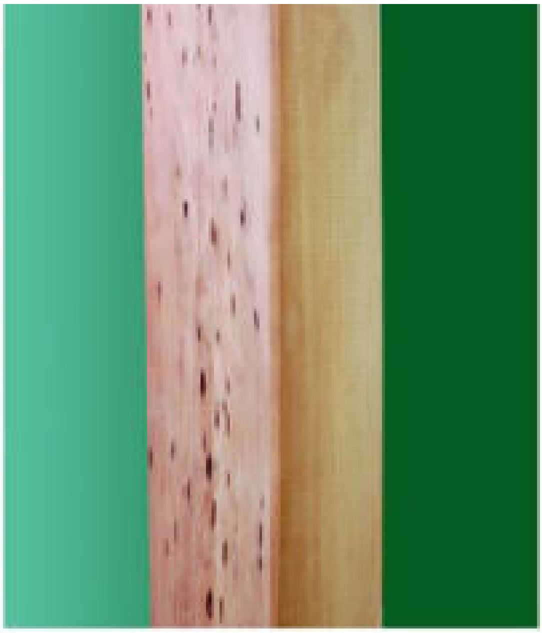
Estimates of basal area and volume yield are thus higher for planted stands than for natural stands of the same age, but more data will be required before recommendations about management can be made with confidence. Natural stands do offer some economic advantage because they bypass the need for seed collection, nursery culture, and planting operations. They will continue to be a source of specialty timber without further silvicultural treatment.

Present knowledge indicates that planting offers the best opportunity for rapid development of a totara resource for future generations. While opportunities exist for the management of natural stands on hill country pasture, the establishment of plantations provides more scope for realising maximum growth and yield through use of sheltered and fertile sites.

50-year-old plantation of totara pruned to 4 m, Te Karaka, East Coast.

Regeneration of totara with manuka and kanuka on farmland, Northland.

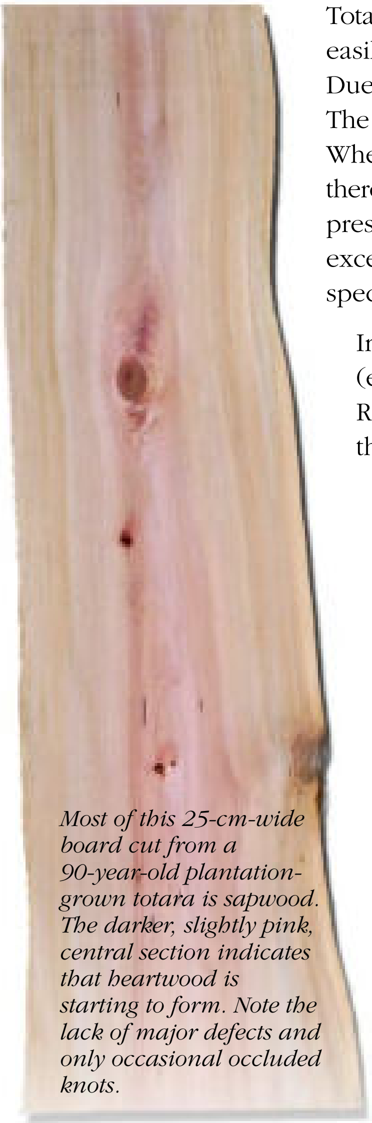
The pocket of rot in the sawn board (right) has resulted from a steep angle branch similar to that on the stem (left). Removal of these large upright branches and any double leaders as soon as they can be identified is likely to reduce defect in the wood.



Small branches which die and drop off appear to leave mostly small pin knots less than 10 mm in diameter which add feature to the timber.

WOOD CHARACTERISTICS

Development of heartwood



Most of this 25-cm-wide board cut from a 90-year-old plantation-grown totara is sapwood. The darker, slightly pink, central section indicates that heartwood is starting to form. Note the lack of major defects and only occasional occluded knots.

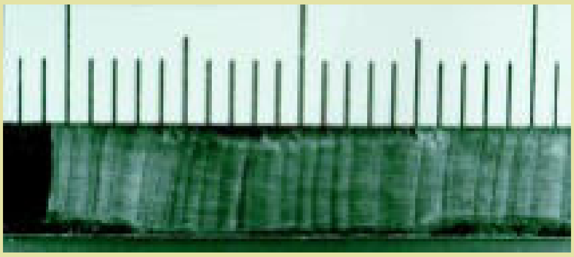
Totara heartwood has an even pinkish-brown colour. It is typically straight-grained and therefore easily split. The texture is fine and even and allows smooth cuts to be made across the grain. Due to slow and uneven drying, kiln treatment is not recommended (Hinds and Reid 1957). The alternative of air-drying may require many months (e.g., 9 months for 25-mm-wide boards). When dry, heartwood is dimensionally very stable (Harris 1961) but relatively brittle. It is therefore more suitable for posts and piles than for beams (Clifton 1990). The chemical extractives present in heartwood retard the drying of normal primer, but other properties make it an excellent base for paint. The development of water-based paints has removed the need for special primers with low oil content which were once required for totara wood.

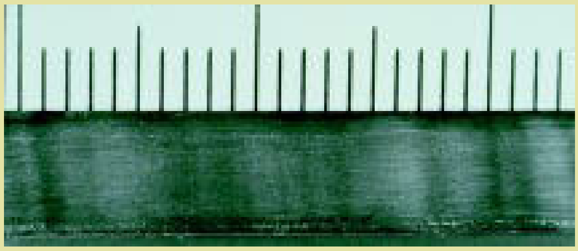
In a study of the natural durability of heartwood in a range of New Zealand-grown trees (exotic and native), totara was one of only five species described as "very durable" (Forest Research Institute 1982b). The expected service life in a ground-contact situation is greater than 25 years.

Until the late twentieth century, supplies of totara timber were derived from trees several hundred years old taken from old-growth forests. The bulk of the stem comprised heartwood which was surrounded by a narrow band of sapwood. In contrast, second-growth stands less than 100 years old have a high proportion of sapwood (Bergin and Pardy 1987). Although heartwood has superior wood qualities, sapwood can be used for furniture, joinery, and also for exterior woodwork as long as it is not in contact with the ground. The lower durability and lighter colour of sapwood restrict its usefulness, and the financial value of timber from young fast-growing trees containing a greater proportion of sapwood is therefore likely to be lower. Sapwood from trees older than 60 years may have better wood properties.

The small size of available samples of log sections and discs does not allow analysis of the effects of stand and site characteristics on wood quality and heartwood formation. Timber from totara trees less than 100 years old was found to have few major defects. Small knots from a knotty core were present, also occasional rot pockets, probably related to the slow rotting of large, steep-angled branches. Heartwood was forming in 90-year-old trees sampled from a plantation and a natural stand, but no correlation was found between the degree of heartwood development and site, stand, or tree characteristics.

CAN THE AGE OF TOTARA BE DETERMINED FROM GROWTH RINGS?





Increment cores taken from two trees from the same plantation at Puhipuhi, Northland. Clear growth rings are formed by slower-growing trees, although counts indicate that rings may not be formed every year (top)*. Indistinct rings are a feature of faster-growing trees* (lower)*, but indications are that more than one ring may be formed in some years as false rings are easily included in ring counts (scale: 1 mm between lines).*

It is not easy to count growth rings in totara. Hinds and Reid (1957) state that growth rings are poorly defined with latewood showing as slightly darker bands. Dunwiddie (1979) observed ring wedging and lobate growth in limited collections of increment cores taken at approximately breast height from mature totara. Cameron (1959) acknowledged that false rings could be mistaken for annual rings and considered that more than one ring might be produced in one growing season in warmer regions (Northland). The effect of multiple flushes on growth ring development is unknown but the ability of totara to produce late summer flushes may make annual growth rings less distinct.

Recent examination of core samples from a range of planted totara stands of known age (Bergin 2001) has again raised questions about the accuracy of age estimates based on ring counts. Estimates derived from 15–20 core samples per stand were within 10–15% of the actual age. Increment cores showing clear dark lines of latewood provided more accurate age estimates than cores with diffuse bands. Samples from small suppressed trees tended to produce under-estimates of age. Fast-growing trees (e.g., edge trees) had rings which were less distinct, and counts from the few core samples with distinct rings tended to over-estimate stand age.

When estimating the age of natural totara stands, slow-growing suppressed trees and individuals with large diameters (e.g., edge trees) should be avoided. Trees with an average stem size are more likely to produce an accurate estimate.

MANAGEMENT OF TOTARA FOR WOOD AND NON-WOOD VALUE

Multiple objectives

Most stands of native trees planted over the last century were established for more than one reason (Pardy *et al.* 1992). In addition to production of high-quality timber for specialty uses, the growing of totara is associated with specific Maori values. Best (1942), when discussing the spiritual significance of totara for the Maori, referred to the "special mythical origin assigned to it" and its status "as the principal member of the company of superior or lordly trees (rakau rangatira)". This veneration was, and clearly remains, an acknowledgment of its significance to the survival and well-being of the Maori people. The spiritual dimension will undoubtedly continue to be a feature of the rationale for planting, maintaining, and harvesting totara in New Zealand.

Planting totara and other native tree species will help to increase the area covered by native forest, control soil erosion, provide food and shelter for wildlife, thus enhancing biodiversity, and provide amenity areas for people (Forest Research Institute 1997). In recent years, tree absorption of carbon from the atmosphere and consequent reduction of "greenhouse gases" has been put forward as a further reason for planting forests of any species (Herbert *et al.* 1996).

Economics

Conventional economic analysis based on financial value alone does not support the establishment of slow-growing plantations of native tree species (Horgan 2000). Most non-timber values cannot be quantified but are likely to reward owners in many ways. However, the financial value of plantations of certain native tree species, including totara, is likely to increase as the use of imported decorative timbers becomes less acceptable.

Silvicultural systems requiring minimal input are economically advantageous for slow-growing tree species such as totara. The use of manuka as a nurse for young totara plants will reduce establishment costs and improve tree form in plantations; this is a cost-effective alternative to the dense planting of expensive totara seedlings which will require early intensive tending.

Regeneration

Natural regeneration allows opportunistic management for timber production with minimal input, especially where intervention can be delayed until pole-stage stands have formed. Although these may take 50 years or more to develop, stand density is likely to be sufficient to allow removal of trees with poor form in order to boost the growth of final crop trees. Earlier thinning can increase diameter growth but costs will have to be carried over a longer period unless the rotation time has been significantly reduced.

The rationale for management of totara stands that have regenerated naturally on previously-farmed sites may also require justification and the analysis of non-market benefits. Natural groves of totara on steep hillsides with less-productive pasture cover are likely to improve property values through provision of erosion control, shelter, and visual attractiveness. In a pastoral environment, totara trees and stands can also provide additional habitats for wildlife and thus increase biodiversity.

Production

Ultimately, landowners will want to remove and use totara wood from managed stands. Consideration of the timber and non-timber values of the stand will require careful choice of harvesting methods if the high forest character is to be maintained.

Long-term management options that retain the values associated with high forest are likely to be preferred for the production of totara timber. Selection management systems rather than clearfelling will be required on many sites.

Regeneration studies of podocarps (Beveridge 1973; Herbert 1986; Smale and Kimberley 1993; Ogden and Stewart 1995; Ebbett 1998) indicate that successful regeneration occurs only when the over-arching canopy thins out. Totara is the most light-demanding of the podocarps, and selective harvesting methods designed to leave large canopy gaps will be required to promote re-establishment and growth in a single-species stand. It may be more prudent to encourage the establishment of other timber species with greater shade tolerance, such as some of the native hardwoods. Low-impact logging regimes can be used in mixed age/mixed species stands to produce wood while retaining the near-natural character of the forest (Benecke 1996). Long-term management of totara and other native tree species will need considerable specialist input if selection silviculture similar to that prescribed for long-rotation species in the Northern Hemisphere is to be developed in New Zealand.

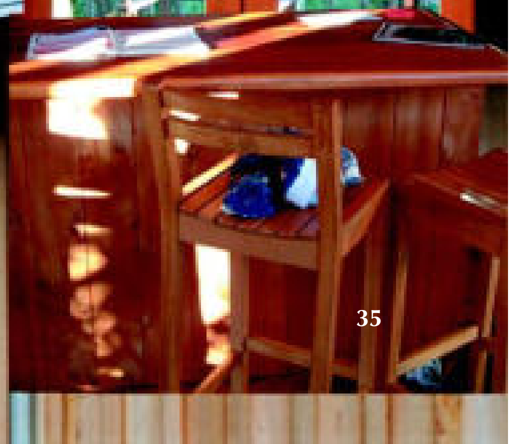
FUTURE USE OF TOTARA WOOD

Opportunities exist for the utilisation of wood from semi-mature (50- to 100-year-old) totara harvested from planted or naturally-regenerated stands on farm sites. With the realisation that totara can be managed for timber, the establishment of woodlots will allow the development of a small but sustainable supply of wood for carving, hand-crafting, furniture-making, and building. Local and overseas markets could be expanded.

Farm-grown totara wood is easy to work during carving (Noel Osborne, Te Wananga O Raukawa, pers. comm.) and cabinet-making (David Campbell, Kirkwood, Manakau, pers. comm.). The wood is said to be as hard as the heartwood derived from old-growth forest trees, and the finishing appears to be similar.

Examples of farm-grown totara milled for decorative and functional purposes indicate that the timber can be as attractive as that from old-growth indigenous forests or from locally-grown and imported exotic species. Wood from semi-mature trees is likely to have a mixture of colours and textures: the sapwood is light brown while transition wood and heartwood have pinkish tones. The range of knot sizes also enhances the decorative potential.

Dining and occasional tables, stools, interior and exterior doors and architraves, wall panelling, railings, and decorative panels and posts have all been produced from farm-grown totara, and its use for framing and exterior cladding of farm buildings continues. Further research is required to determine the potential of totara sapwood for other purposes such as external cladding for houses. Fence posts from pole-stage stands have been successfully treated with tanalising preservatives, but above-ground service without the need for chemical treatment is a possibility that should be tested.



GUIDELINES FOR PLANTING AND MANAGEMENT FOR TIMBER PRODUCTION

Seed collection

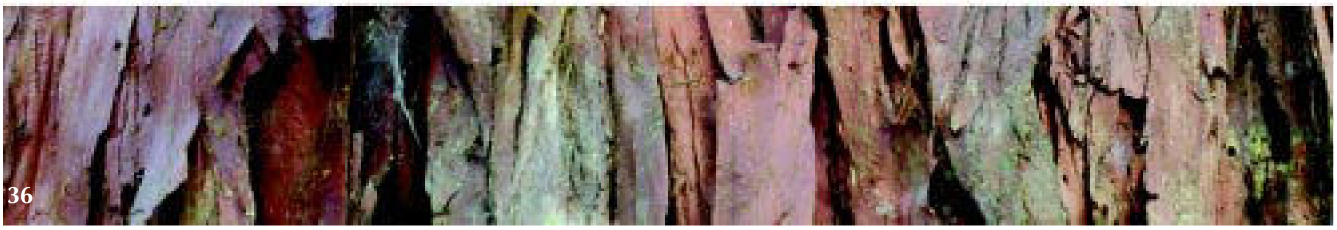
- Fresh seed can be collected each year. Identify female trees from autumn onwards by looking for fallen fruit on the ground below the canopy; male trees shed brown catkins (small cone-like structures) from summer onwards.
- Small amounts of seed can be picked from the branches when ripe. For larger quantities spread sheets of hessian or similar material under female trees in autumn. Fallen seed can be picked up from the ground during winter when it will be brown in colour and separated from the receptacles.
- Check overall seed viability by selecting a representative sample and cutting the seeds in half. Sound seed is filled with white or cream-coloured endosperm.
- Collect seed in autumn–winter. Seeds are ovoid and green when ripe and are attached to swollen red, orange, or yellow receptacles while on the tree. The receptacles shrivel after seedfall and the seeds eventually turn brown.
- Store seed under moist, cool conditions or in a refrigerator before sowing. No further treatment is necessary.

Seedling production

- Totara seedlings can be raised in containers, or as bare-rooted stock.
- Sow seed in autumn within a few weeks of collection 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 warm humid environment. Water as necessary.
- Germination usually occurs 3–4 weeks after sowing, but takes longer under cooler conditions. There may be a second phase of germination after several months.
- When seedlings are 5–10 cm high, prick them out into small containers or open beds. Protect from frost.
- In warm lowland nurseries, totara seedlings will grow to a height of 30 cm in 1 year and 60 cm in 2 years. Repot in larger containers when necessary.
- Current cost of 50-cm-high 2-year stock of totara in a variety of containers is $3 per seedling.
- Polythene planter bags (size PB3) are best for 2-year-old stock. Seedlings raised in small root-trainers tend to be spindly and may need staking when transplanted.
- Large-scale bare-rooted seedling production was practised successfully in forest nurseries during the mid to late 1900s and could reduce seedling costs.

Site preparation

- Fence planting areas to exclude stock.
- If practical, graze pasture to a low level before final exclusion of animals.
- Apply a pre-plant spray using glyphosate at least a week before planting.



Establishing totara plantations

Planting is the best way to establish totara on good sites.

- Select high-quality stock with a balanced root-to-shoot ratio. Inspect the root systems of a sample of container stock and reject the whole batch if root systems are distorted or root-bound.
- 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.
- Fertiliser treatment will be necessary on grossly nutrient-deficient soils.
- Totara can be planted on open sites or within vegetation cover in gaps that allow overhead light.

Planting on open ungrazed sites

Density of planting on an open site will be influenced by requirements for intensive releasing from other vegetation at low stocking rates, or by the need for repeated thinning if stocking rates are high.

Planting at lower rates (1000 stems ha^{-1} or less; 3- to 5-m spacing) will:

- reduce expenditure on seedlings and site preparation;
- increase the period before canopy closure and therefore the cost of weed control;
- increase the need for form pruning to promote development of straight single stems with light branching.

Planting at high rates (more than 2500 stems ha^{-1}, 2-m spacing or closer) will:

- promote relatively early canopy closure (within 10 years on good sites);
- reduce the need for later weed control;
- increase establishment costs, including early form pruning;
- improve stem form, reduce branch size once canopy closure occurs;
- reduce diameter growth rates 20–30 years after planting, due to the effect of between-tree competition. Judicious thinning will be required.

Use of nurse species

- Where possible, use existing vegetation cover less than 6 m high (e.g., manuka or kanuka) as a “nurse” to improve survival, early growth rate, and stem form. Planting lines can be cut at regular spacings.
- On open sites plant nurse species at 2- to 3-m spacing to control weed growth and provide shelter. Plant totara 3–5 years later.
- Tree lucerne (*Chamaecytisus palmensis*), known also as tagasaste, can be used as a temporary planted nurse on some sites although it is palatable to deer and domestic stock.
- Advantages associated with use of a 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 tree lucerne seedlings are cheaper than totara and can be interplanted to achieve a dense overall stocking rate.
- Disadvantages associated with use of a nurse species:
  - good forward planning is necessary as the nurse species must be established before totara is planted;
  - maintenance will be required to ensure that the nurse canopy does not close over young totara.

Tending of plantations

- Remove double leaders and large acute-angled branches from 3- to 5-m-high trees to ensure that the lower stem is relatively free from defects. This can be done with secateurs and pruning saws.
- Small branches on the lower stem will die back naturally and do not need to be removed.
- Monitor stands to determine timing of thinning likely to promote maximum growth rate. At present a regime similar to that for Douglas-fir is recommended.

Establishment and early management of natural regeneration

Costs associated with seed collection and the raising and planting of seedlings will be avoided if natural stands can be tended to promote good form and maximum growth rate. Since seed dispersal is fortuitous, site factors (e.g., heavy frost sites, very infertile soils) may limit growth rates.

- Locate young totara trees and stands. These occur in most regions of New Zealand if there is a local seed source, especially on the banks of rivers, streams, and lakes and on steep slopes in hill country pasture.
- Use a selective herbicide to kill problem brush weeds or blackberry (*Rubus fruticosus*) both of which are likely to be present on marginal sites. Manuka and kanuka can be retained as nurse species but should be prevented from overtopping the totara. Retain scattered totara trees as a seed source and protect bird habitats to encourage seed dispersal.

Planting for a seed source

Reverting farmland and cutover forest may lack totara trees. The planting of small totara groves will improve the likelihood of natural regeneration.

- Plant groups of seedlings on good sites in natural or cut gaps in the existing vegetation. These are likely to develop to reproductive maturity within a decade and will produce seed if both male and female trees are present.

Management of developing natural stands

If natural stands of totara are locally abundant, there is potential for the development of a long-term timber resource. Long-term management will depend on stand density.

- Where trees are widely spaced, apply form-pruning during the early (5–10) years to encourage single leader development.
- Dense stands can either be left to self-thin through natural mortality, in which case growth will be slower, or they can be thinned to reduce competition, in which case faster growth can be expected.
- To economise on labour costs, delay thinning until stand density falls below 5000 stems ha^{-1} through natural mortality. This is likely to occur within 40–50 years of establishment.
- Thin at regular intervals (e.g., 5–10 year intervals) to avoid stand instability and coarse branch development.

Animal and pest control

- Chances of totara seed dispersal by birds can be increased by management of predators, e.g., possums, mustelids, and rodents.
- Fencing, and possum and deer control, will reduce browsing and enhance the growth of totara stands. They will also increase species diversity.
- The control of fungal infections and insect damage by application of fungicides and insecticides is considered to be practical only for specimen trees.

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Forest Research is a Crown Research Institute based in Rotorua and Christchurch. Under its Indigenous Species Research Programme, the planting and management of a range of native tree species are being evaluated for timber production as well as 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 ; greg.steward@forestresearch.co.nz .

Tane's Tree Trust was formed in 2002 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 range from $25 for individual members to $100 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 .

INDIGENOUS TREE BULLETIN SERIES

Totara Establishment, Growth, and Management is the first in the New Zealand Indigenous Tree Bulletin series which summarise the latest information about management of planted and naturally regenerating native tree stands. The focus is on production as well as environmental, cultural, and social objectives.

Subjects for future Bulletins include: planting and managing kauri; techniques for planting native trees; planting and managing native hardwood trees.

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