EARLY PERFORMANCE OF PLANTED TOTARA IN COMPARISON WITH OTHER INDIGENOUS CONIFERS

D. O. BERGIN

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

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ABSTRACT

The early performance of a selection of establishment trials and general plantings of totara (*Podocarpus totara* D. Don) and the other major indigenous conifer tree species of New Zealand has been assessed. Only the first 50 years of performance data were considered and these included single and mixed conifer plantings established throughout New Zealand by a range of agencies and individuals on a variety of sites.

Examination of a wide range of planted stands of indigenous conifers indicates that totara is the most tolerant of dry exposed sites. It is also the most light-demanding. Despite the large variation in sites and management histories, planted totara consistently grows best on open fertile sites. Average survival of totara is 60%, with a mean annual diameter increment of 6 mm and mean annual height increment of 26 cm, similar to that of rimu (*Dacrydium cupressinum* Lamb.) and kahikatea (*Dacrycarpus dacrydioides* (A.Rich.) de Laub.) over the first 50 years of growth. More successful plantations indicate that growth can be significantly greater with a mean annual diameter increment of 10 mm for totara, similar to that of kahikatea and kauri (*Agathis australis* (D.Don) Lindl.), and a mean annual height increment of up to 55 cm.

Keywords: planting; nursery; indigenous forest; growth; indigenous conifers; *Podocarpus totara*.

INTRODUCTION

Totara has been of great importance in the past to both Maori and early European settlers. With restricted logging of totara from old-growth forest, there is now a shortage of totara timber and increasing interest in evaluating the potential for planting and managing totara for aesthetic, amenity, environmental, and cultural reasons, as well as for wood production. Totara seedlings have been planted on many sites throughout New Zealand for well over a century (Department of Lands 1909; Pardy *et al.* 1992).

The establishment phase is critical for early survival and growth of indigenous New Zealand conifers. Newly planted seedlings are slow starters (Beveridge 1977) in comparison with exotic conifers. Most indigenous species are vulnerable for several years to competition

from grass on open sites, and from ground ferns, tree ferns, and shrub hardwood species on scrub and forest sites (Beveridge *et al.* 1985). Many plantings have failed or have suffered slow growth and survival due to poor site selection and lack of after-planting care and, on some sites, damage from browsing by deer (*Cervus* spp.), goats (*Capra hircus* L.), and possums (*Trichosurus vulpecula* Kerr) or grazing by domestic stock.

However, some planting programmes and establishment trials have shown that indigenous tree species can be established successfully on good sites, where planted areas have been released from weed competition and fenced to exclude animals. In addition to totara, the indigenous conifers often planted included rimu, kahikatea, matai (*Prumnopitys taxifolia* (D.Don) de Laub.), miro (*Prumnopitys ferruginea* (D.Don) de Laub.), tanekaha (*Phyllocladus trichomanoides* D.Don), and kauri. A number of planting trials by the Forest Research Institute and some operational planting by the former New Zealand Forest Service have been documented and give a range of growth performance of the major indigenous conifer species. These include extensive planting of the indigenous conifers in many North Island regions (Pardy & Bergin 1992) and on the West Coast of the South Island (Forest Research Institute 1984) from 1960 onwards, and planting of kauri during the 1970s and 1980s (Halkett 1993). To varying degrees, these species have also been successfully established in single- or mixed-species stands in many recreation parks and botanical gardens throughout the country. Numerous planted groves and small stands of indigenous conifers established on private land also show good growth rate and survival.

Planting of indigenous trees may have been done for various reasons (Bergin *et al.* 1988; Beveridge 1973; Beveridge *et al.* 1985; Pardy *et al.* 1992). Establishing groves, avenues, and specimen trees in domains, parks, and gardens will provide amenity and heritage values. Wildlife values can be enhanced, forest remnants extended, and seed sources replaced in areas cleared of the original forest cover. Water quality can be improved in productive pastoral and exotic forestry landscapes through revegetation of riparian areas. Partially logged forest can be artificially regenerated where natural regeneration may be scarce or slow in developing. On appropriate sites establishment of small woodlots can provide the option of specialty timber production.

In this paper are first briefly reviewed seeding characteristics, and the seed collection and plant propagation techniques developed throughout the 1900s, as well as the planting undertaken over the last century with a focus on totara but with comparisons with the other, frequently planted, indigenous conifers. The results of establishment trials and other plantations up to age 50 years are then summarised to provide an insight into the ecology and growth of planted totara in comparison with the other planted indigenous conifers.

BACKGROUND

Seed Collection and Germination

Totara produces annual seed crops that fluctuate in abundance, but seed is easily obtained in most years (Beveridge 1973). Beveridge (1964) found that ripe seed of totara and most of the other podocarps is available from mid-March to May in central North Island forests. In a nationwide collection of seed for a provenance study on totara, sound seed was generally easier to collect from semi-mature stands on farmland than from mature trees in high forest (D.O.Bergin, C.E.Ecroyd unpubl. data). Farmland trees had relatively large

crowns compared with those on tall mature trees which were often small and storm-damaged and where tree vigour and seed crops were reduced, probably by possums.

Seed of totara is stored in moist cool conditions, without significant loss of viability for at least 2 years (Forest Research Institute 1980). Germination is usually successful for most seedlots although it can occur in two phases. The bulk of seedlings emerge in spring within 4 weeks of sowing, followed by a second crop in autumn (Bergin & Ecroyd 1987). Delayed germination has also been reported for totara seed within forest duff collected from beneath seeding trees (J.W.Herbert unpubl. data).

In a 7-year study of seed crop periodicity and seed abundance of a selection of conifer species in high forest at Pureora Forest Park, Beveridge (1973) reported that rimu and kahikatea showed the most marked periodicity. Kahikatea produced the heaviest seed crops, while matai failed to produce good seed crops, largely due to insect attack. On the other hand, totara and, to lesser extent, miro had light but regular seed crops. Other studies show tanekaha has not only irregular seeding but also uneven seed ripening and a high incidence of empty seed. Much of the seed of rimu, matai, and miro can be damaged by rodents (Forest Research Institute 1980); this happens to a lesser extent with kahikatea (Beveridge 1964). Mason (1958) found that possums eat totara, miro, and matai fruits but not rimu fruit. Beveridge (1964) observed yellow-crowned parakeets (*Cyanoramphus auriceps*) destroying totara seed.

Seed of totara and most of the other conifers can be collected from beneath seeding trees during and immediately after seedfall. In contrast, kauri seed is more difficult to obtain as trees have to be climbed to collect cones before they shatter, scattering seed over a wide area (Halkett 1983).

There are no major differences in moist cool storage requirements of totara seed compared with the other conifers that are attached to fleshy receptacles, or enclosed in a berry that encourages bird dispersal (Forest Research Institute 1980). Dry cool storage is required for long-term storage of the wind-dispersed seed of kauri (Preest 1979).

As with totara, there is generally good germination of rimu, kahikatea, and kauri (Forest Research Institute 1980). Matai and miro are renowned for delayed germination and this has prompted a number of experiments to enhance germination (e.g., Preest 1963) but no significant improvement has been achieved. With Hall's totara (*Podocarpus hallii* Kirk), which is closely related to totara and with which it can hybridise, Bergin & Ecroyd (1987) not only had difficulties in collecting significant quantities of seed, but also found high proportions of empty seed, resulting in poor germination of 15 seedlots collected from several regions. Consumption of Hall's totara seed by possums as reported by Nugent *et al.* (1997) may cause reduced seed crops with this species.

Raising of Seedlings

Extensive research and operational propagation programmes over the last 40 years have resulted in reliable systems for raising of seedlings of most indigenous conifer tree species in large numbers at reasonable costs. For large-scale nursery stock production, raising plants from seed is the most economic and effective means (Forest Research Institute 1980). For the faster-growing conifers totara, kauri, kahikatea, and rimu, the cost for 2-year-old seedlings raised in containers is likely to be around $3, but open-grown

seedlings for large-scale planting are likely to cost less. Some indigenous conifer species have also been vegetatively propagated from cuttings, including totara (T. Faulds pers. comm.) and rimu (Dakin & Mearns 1975). The technique may be useful for restoration on a small scale where local seed is not available, and for future genetic improvement studies.

Totara seedlings can be raised either in open beds as bare-root stock or in containers (Beveridge *et al.* 1985). Seedlings grow from seed to a planting height of 50–80 cm in 3–5 years in nurseries on cooler upland sites, such as at the Forest Research Institute nursery in Rotorua at 300 m a.s.l. (Forest Research Institute 1980), but they grow faster in nurseries on warmer lowland sites. Standard bare-root nursery practice in the 1980s was to broadcast-sow seed in open beds and then line-out seedlings in other beds at 15 × 15 cm spacing (J.C.van Dorsser, D.O.Bergin unpubl. data). Lined-out seedlings were kept under shade cloth for 12 months and remained in the beds for a further 1 or 2 years depending on growth. Three months before planting in winter or early spring, seedlings underwent undercutting and root wrenching to encourage development of a compact fibrous root system and to facilitate lifting, with most operations done with tractor-powered machinery. Totara is among the easiest species on which to encourage a vigorous fibrous root system. Like most of the podocarps, totara has distinctive short roots that may become infected with an endophytic mycorrhizal fungus (Baylis *et al.* 1963), which may assist growth in nutrient-deficient soils (Bond 1967).

Most nurseries raise seedlings in containers, which allows more flexibility in holding stock over from one season to the next and enables seedlings to be planted over a longer period. Seed is broadcast onto seed trays and germination takes place within 4 weeks in a heated glasshouse. Once seedlings are 5–7 cm high, they are pricked out individually into containers and transferred to larger containers, depending on length of time stock will be grown in the nursery and size of seedlings required (Mark Dean, Naturally Native New Zealand Plants, pers. comm.). Totara can be grown to a height of 50–80 cm in 2 years in lowland nurseries, forming dense fibrous root systems similar to those of well-conditioned open-grown seedlings.

New Zealand conifers may also be raised from seed contained in forest humus or by the transplanting of small seedlings ("wildings"), which are lifted directly from appropriate forest sites and then grown in the nursery. In a detailed account of raising seedlings from seed contained in forest duff raked from the ground on several sites, including a forest-shrubland ecotone, pole stands, and individual trees at Pureora Forest, Herbert (unpubl. data) found good germination of totara. Beveridge (1962) showed that totara seedlings could be raised successfully by transplanting 5- to 25-cm-high seedlings from disturbed sites at the forest edge to nursery beds.

All the New Zealand conifer seedlings can be raised either in open beds as bare-root stock or in containers using methods similar to those used for totara (Beveridge *et al.* 1985). However, kauri has a tendency to form woody, vertically descending, tap roots with a feeble network of fibrous feeding roots compared with the mass of fibrous roots of totara. The root systems of the major podocarp species are shown in Fig. 1. These 4-year-old seedlings were raised in open beds at the Forest Research Institute nursery during the mid-1980s.

Both the forest humus and wilding methods are particularly useful for producing seedlings of matai, miro, and tanekaha which are slow to germinate from freshly collected

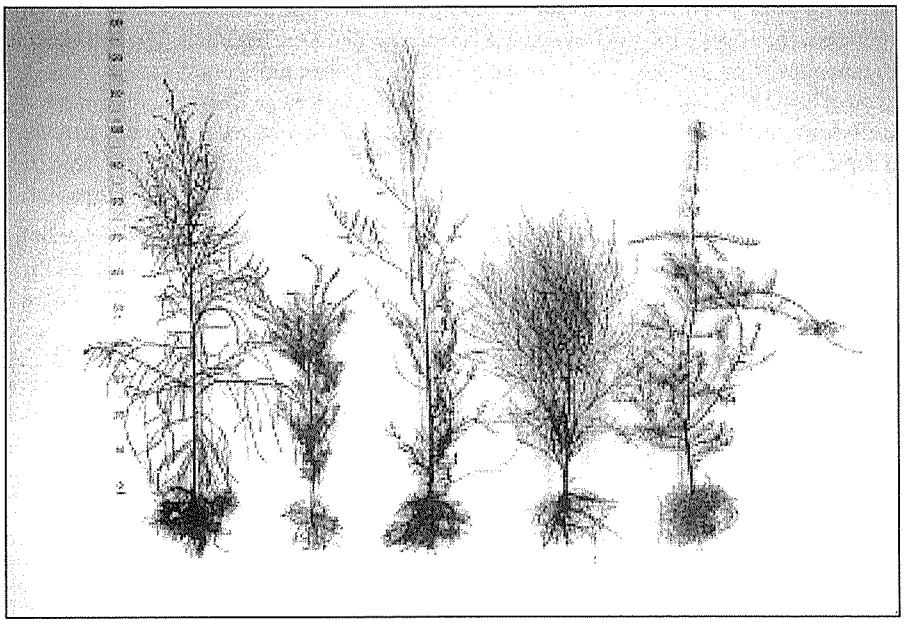

FIG. 1–Bare-root 4-year-old seedlings of the five major podocarp species raised in open beds at the Forest Research Nursery. Species from left to right are: rimu, miro, kahikatea, matai, totara.

seed. They are also worth considering for species that have irregular seed crops such as rimu. Large quantities of rimu seedlings can often be found under seeding trees along roadsides and similarly disturbed sites, where the right combination of shelter and site disturbance favours germination and early growth. However, for most of the indigenous conifers, collection of wildings is too labour-intensive for larger-scale operations compared with raising seedlings from seed.

Planting

Hundreds of thousands of indigenous seedlings were planted during the course of the last century. Planting of totara in the early 1900s by the Lands Department was in response to concerns over the diminishing natural forest resource in some regions. Some 546 500 totara seedlings were reported to have been planted at that time (Department of Lands 1909). Of these only a fraction are known to have survived, and can be found today in small remnant stands.

A major planting programme of indigenous conifer species that included totara was initiated in the late 1950s when 500 000 seedlings of indigenous tree species, raised in the Forest Research Institute nursery, were planted out on a range of forest and scrub sites (Beveridge 1977). Seedlings were dispersed to New Zealand Forest Service (NZFS) Conservancies (especially for Westland planting), private owners, and various agencies and authorities. During the late 1950s and the 1960s, large-scale experimental plantings

were undertaken, including some 30 000 seedlings planted in trials on the Mamaku Plateau, 10 000 seedlings planted on the Kaingaroa Plateau, and 12 000 at Woodhill. The aim of this programme was to establish nursery-raised seedlings of indigenous conifers on previously logged or heavily disturbed sites where natural regeneration was generally scarce or absent (Pardy & Bergin 1992). Plants were then to be monitored and released from weed growth, but some sites proved difficult to maintain where resources were limited. Some plantings did, however, have high survivals, and were included in this assessment of early performance.

From the mid-1970s, NZFS Conservancy nurseries started to grow large numbers of indigenous conifers, notably at Cambridge, Sweetwater, and Kaingaroa Nurseries in the North Island, and at Reefton and Rangiora Nurseries in the South Island. Extensive enrichment planting took place in selectively logged podocarp forests at Pureora (e.g., Guest 1985) and Whirinaki. Up to 40 000 podocarps were planted annually at Pureora (Beveridge 1979) and this continued until the early 1980s. With the demise of the NZFS in 1987 and consequent lack of tending, release of overhead canopy, and regular assessments of performance, as well as changing forest policy, many planted areas were abandoned, forgotten, lost, or destroyed. Some of those that survived have been included in this analysis of early planting performance.

A similar picture has emerged with relatively large-scale planting of kauri undertaken during the 1970s and 1980s where up to 50 000 seedlings were raised annually at the NZFS Sweetwater Nursery, north of Kaitaia in Northland (Beveridge 1979; Halkett 1983). These seedlings were planted out in several forests in Northland, Great Barrier Island, Coromandel Peninsula, and the Kaimai Ranges. Seedlings were planted in small gaps or lines cut in scrub or under thinned tall kanuka stands where there was little or no effective natural regeneration of kauri. Unfortunately, from the hundreds of thousands of seedlings planted, at many sites there is little evidence of successful establishment of kauri where seedlings were not adequately released (e.g., observations at Coromandel planting sites, Max Johnston pers. comm.). There has been some successful planting of small stands of kauri such as on alluvial soil beside streams on Great Barrier Island and on previously farmed land at Victoria Valley and within short second-growth forest at Trounson Kauri Park, Northland, established around the 1950s.

METHODS

Performance of Planted Stands

Existing databases from planting trials and management-scale planting programmes carried out by the Forest Research Institute and the New Zealand Forest Service respectively over the last 50 years were interrogated and summarised to evaluate performance of the major indigenous timber conifers. Planted stands established by other agencies were also included, such as the mid-1980s survey of indigenous plantations, which covered mainly private and local authority land (Pardy *et al.* 1992). All stands that were known to exist and which had sufficient survival and some history of assessment were included. Growth parameters, stand information, and site characteristics were tabulated for each planting trial and general planting. These included stand age, stand type (e.g., plantation, shelterbelt, underplanting, mixed-species stands, amenity and park planting), mean height, and, for all but the younger stands, mean diameter at breast height (dbh, taken at 1.4 m above ground).

Mean annual increments for height and dbh were calculated and the sample minimum and maximum growth rates for plantings were included where information was available. Survival percentages were based on assessments undertaken during remeasurement or were estimated for the larger stands where clear information was available on original plant spacing. Other information on stand characteristics was briefly described such as stem density, tree form, whether trees where dominant, co-dominant or suppressed, and any management history that was significant.

Establishment performance and site information were also collated for the other major indigenous conifers. Like totara, three of these species — rimu, kahikatea, and kauri — have been relatively widely planted in many regions of New Zealand. The other three species (matai, miro, and tanekaha) have been planted on a more limited basis.

Site Index and Data Analysis

Site index (height at age 40 years) was estimated for totara covering all planted stands and trials assessed. The site index equation derived by Bergin & Kimberley (2003) for developing growth and yield equations for planted totara was used:

$$H_{40} = 0.5 + (H - 0.5) \times e^{7.69\left(\frac{1}{T^{0.403}} - \frac{1}{40^{0.403}}\right)}$$

where H is height, H_{40} is the site index, and T is stand age (height of seedlings at planting was assumed to be 0.5 m).

Variation in site index of planted stands and trials associated with several site factors was explored by analysis of variance using ANOVA and LSD (SAS 1990). The site factors were:

- Degree of cover and exposure to sunlight:
  - (1) open — established on open sites, as plantations or small stands;
  - (2) medium — planted within existing cover of manuka (*Leptospermum scoparium* J.R. et G.Forst.), or in forest gaps, or along cut lines, with at least initial releasing;
  - (3) shade — planted within forest or scrub, under a canopy, with little or no subsequent releasing.
- Fertility — (high, medium, low-medium, low) based on classes of soil type nutrient status (Soil Bureau 1954, 1968) for the North Island and the South Island respectively.
- Altitude of planting site (m).
- Geographic location of plantings (Northland/Auckland, Waikato, central North Island, East Coast, Taranaki, South Island).

Statistical analysis of variation among species, and effects of sites and management regimes, proved difficult in the absence of experiments with balanced treatments across sites. There was significant variability in growth responses evident among species, planted on a wide range of sites and with different histories of management. Site index was estimated for each species using the totara site index equation, as separate site index equations do not exist for the other species. A one-way ANOVA was used to compare site indices for the seven species.

Assessment of Selected Planting Trials

A comparison of growth performance of different species and establishment methods was carried out for a selection of planting trials where more detailed records of planting site, history of management, and stand assessments had been made. Sample sizes ranged from 20 to 200 trees/species at each site. To update some of these trial assessments, several Forest Research Institute planting trials were remeasured from 1998 to 2000 in the Auckland region, the central North Island, and the east coast of the North Island. These included plantings of totara, rimu, kahikatea, kauri, and matai. All trials were planted from 10 to 40 years ago on a range of sites, and included interplanting of podocarps with *Eucalyptus* spp. to provide shelter on exposed open sites. Representative samples of at least 20 trees of each species were remeasured for height and dbh at each trial site. General tree form and stand characteristics were also recorded, including type and degree of any overtopping vegetation and ground cover.

In addition, a selection of the best-performing planted stands was tabulated separately to give the potential growth performance of New Zealand indigenous conifers.

RESULTS

General Performance

Most planted stands of indigenous conifers are located in the North Island (Fig. 2). Major differences in site types and management after planting were evident from stand records as well as from field inspections of some sites. For the three major podocarps (totara, rimu, and kahikatea) average survival and growth rate were similar across all stands assessed (Table 1). Mean survival was 48–59%, mean annual dbh increment 5–6 mm, and mean annual height increment 26–30 cm. Kauri had performed the best of all species at 85% survival, dbh mean annual increment (MAI) 6.6 mm, and height MAI 37 cm, reflecting the better sites that kauri was planted on, often within recreational parks.

Estimated site index comparing the seven conifer species showed that kauri, at 14 m, was significantly higher than all other species (Table 2, Fig. 3). There was no significant difference in heights of kahikatea, rimu, and totara. Small sample sizes of miro and matai are reflected in the larger standard errors for these species.

TABLE 1–Average survival and mean annual dbh and height increments for all stands assessed for the indigenous conifer species.

Species	Number of stands	Survival (%)	MAI dbh (mm)	MAI height (cm)
Totara	51	59	6.0	26.1
Rimu	39	54	4.8	25.7
Kahikatea	39	48	5.0	29.6
Kauri	36	85	6.6	37.0
Tanekaha	23	62	3.8	21.2
Matai	9	46	3.4	14.6
Miro	5	–	4.7	24.4

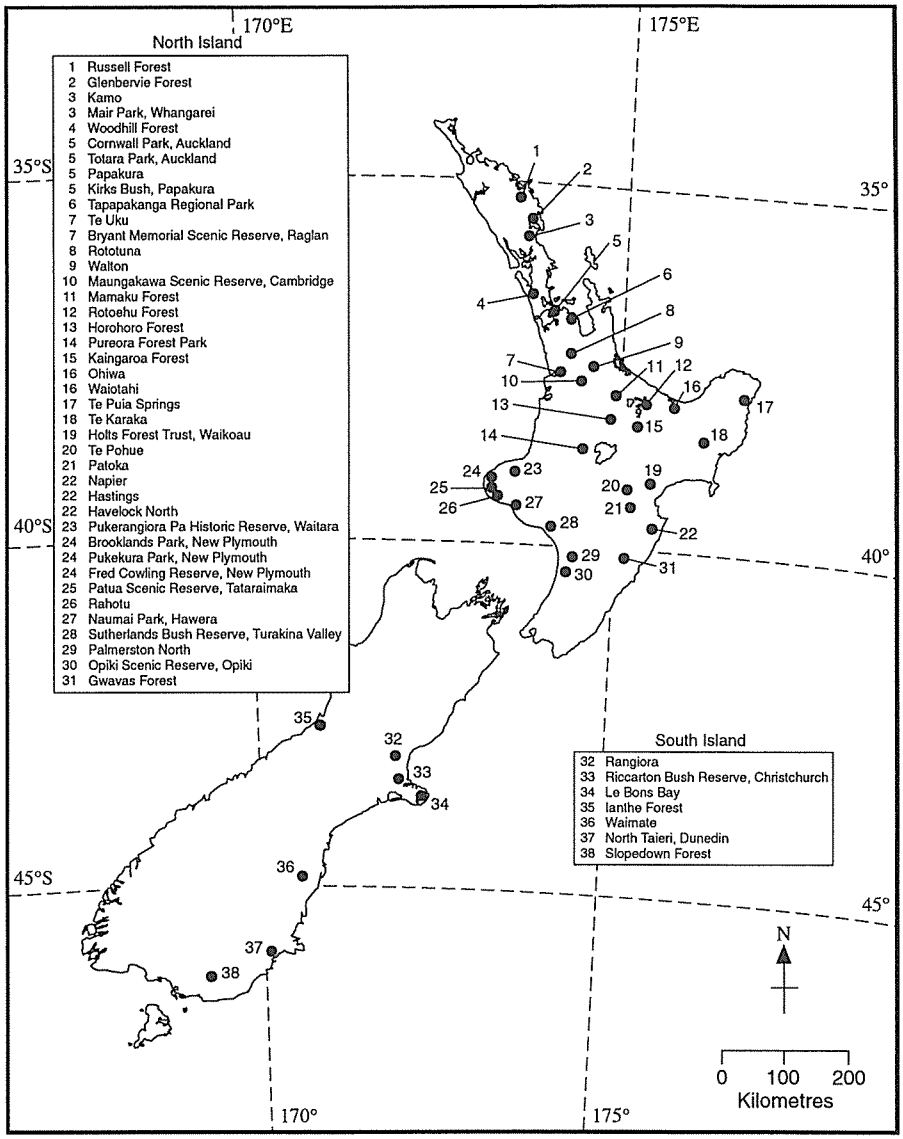

FIG. 2–Location of planted stands, planting trials, amenity belts, and shelterbelts of indigenous conifer tree species for which early performance data have been collated. Several species are planted at many of the sites listed.

Despite the variability of the data, there were significant trends in growth of totara, with faster height growth on open sites than on shaded ones (Table 3). Planted totara on open sites were estimated to have a site index of 12 m, similar to totara planted in lines or gaps within forest or scrub cover. Both these cover categories were significantly higher than seedlings planted under heavy shade (Fig. 4). There was also a significant difference in estimated site

TABLE 2–Estimated site index (height at age 40 years) for the indigenous conifer tree species based on all stands located throughout the country. Within each column, values followed by the same letter are not significantly different (p = 0.05). Test for species differences, $F_{6,186} = 6.02$, $p < 0.0001$.

Species	Number of stands	Site index (m)	Standard error
Kauri	36	14.1 a	0.77
Kahikatea	39	11.2 b	0.74
Rimu	39	10.2 bc	0.74
Totara	51	9.7 bc	0.65
Miro	5	9.1 bcd	2.07
Tanekaha	23	8.4 cd	0.99
Matai	9	5.3 d	1.54

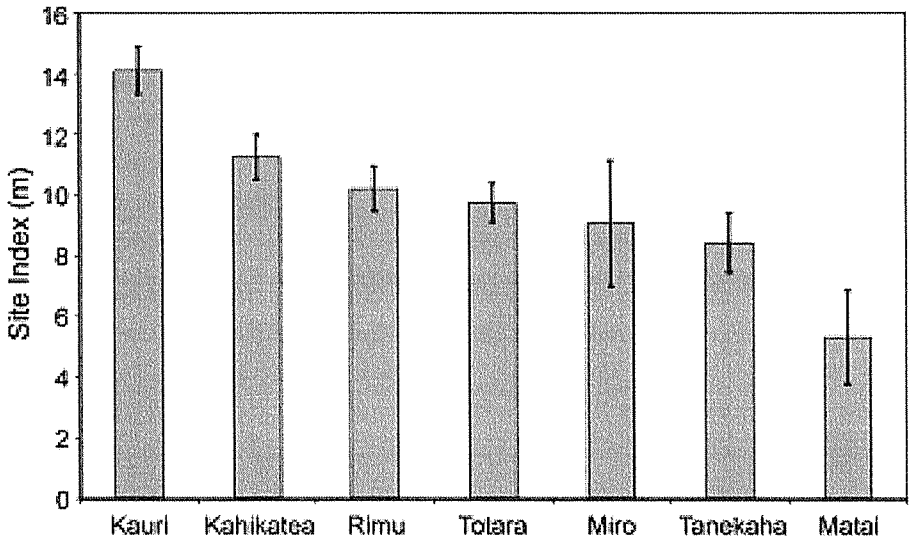

FIG. 3–Estimated site index (height at age 40 years) for the indigenous conifer tree species based on all stands located throughout the country. Error bars indicate standard errors.

index of totara between the high and low fertility categories (Table 4). However, results for medium and low-medium fertility sites did not give a good linear relationship from high to low fertility; this suggests shortcomings in using broad soil-fertility categories and the possible influence of other factors such as variability in stand management between sites (Fig. 5).

There was no significant correlation between performance of planted indigenous conifers and altitude and geographic location of the planting site.

TABLE 3–Estimated site index (height at age 40 years) for 51 planted totara stands located throughout the country, by cover class category. Site index values followed by the same letter are not significantly different ($p = 0.05$). Test for cover category differences, $F_{2,45} = 12.91$, $p < 0.0001$.

Cover category*	Number of stands	Site index (m)	Standard error
Open	21	11.9 a	0.95
Medium	15	10.9 a	1.04
Shade	15	6.8 b	1.20

* Cover category: Open = stands established on open sites as plantations or small stands;
Medium = seedlings planted within existing cover of manuka or forest in gaps or along lines and released initially at least;
Shade = seedlings planted within forest or scrub under a canopy with little or no subsequent releasing

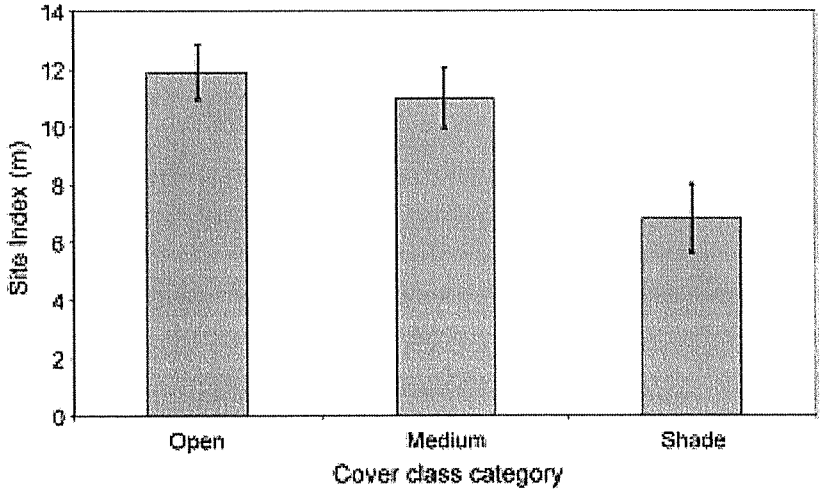

FIG. 4–Estimated site index (height at age 40 years) for 51 planted totara stands located throughout the country, by cover class category. Error bars indicate standard errors.

Performance of Conifers in Selected Trials

Early growth performance of 15 well-documented planting trials is given in Table 5. This allows more detailed comparison of growth performances of the species where site type and stand management histories are known. Stands ranged in age from 10 to 40 years. Totara, rimu, and kahikatea were planted at most sites, allowing direct comparisons of performance of these species. Two sites had only totara, while kauri, tanekaha, and matai were included in some sites where sufficient samples occurred.

Survival assessment was recorded for most stands and varied from less than 20% for totara at Ianthe Forest, South Westland, up to 95% at Holt's Forest Trust, Hawke's Bay (Table 5). Both diameters and heights varied widely. Mean annual increments gave clear

TABLE 4–Estimated site index (height at age 40 years) for 51 planted totara stands located throughout the country, by fertility category for each site, based on soil descriptions from Soil Bureau (1954) for the North Island and Soil Bureau (1968) for the South Island. Site index values followed by the same letter are not significantly different (p = 0.05). Test for fertility category differences, $F_{3,45} = 3.76$, p = 0.017.

Fertility category	Number of stands	Site index (m)	Standard error
High	9	12.3 a	1.27
Medium	17	8.9 b	0.87
Low-medium	12	10.6 ab	1.33
Low	13	7.8 b	1.23

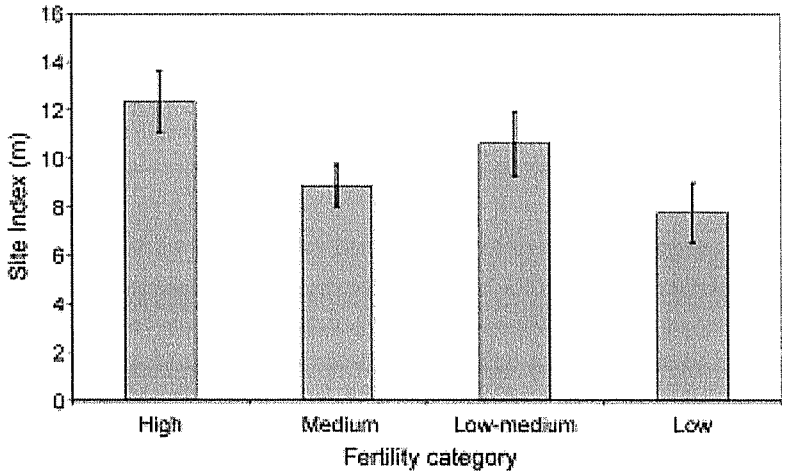

FIG. 5–Estimated site index (height at age 40 years) for planted totara stands located throughout the country, by fertility category for each site based on soil descriptions from Soil Bureau (1954) for the North Island and Soil Bureau (1968) for the South Island. Error bars indicate standard errors.

indications of the extremes of growth rates between many sites for all species. The poorest performing sites for all species were Gwavas, Ianthe, Slopedown, and Russell Forests where nearly all trees were less than 3 m high 17–23 years after planting. Performance at Woodhill Forest was not much better, especially for trees planted under a kanuka (*Kunzea ericoides* (A.Rich.) Joy Thomps.) canopy. The fastest-growing stand was the youngest plantation of totara at Tapapakanga, established on a lowland farm pasture site, with a diameter MAI of 8.6 mm and height increment of 55 cm. Annual height increments of 20–25 cm and dbh of 2–4 mm for totara, rimu, and kahikatea of about 25 years of age on the upland sites at Mamaku and Kaingaroa (approximately 500 m a.s.l.) reflect the cooler climate and shorter growing seasons. The higher growth rates at the other central North Island site at Pureora probably reflects sampling bias where only small numbers of surviving trees were measured. Growth rate of podocarps often increases as planted trees approach pole stage (10 cm dbh) when leaders break through competing hardwood and fern

vegetation 10–15 years after planting, and can be seen in increased width of growth rings (Beveridge *et al.* 1985). Compared with most of the central North Island plantings, the faster growth rate of totara at Glenbervie north of Whangarei, with a MAI of 30 cm height and 7 mm diameter, is a reflection of this warmer northern lowland site.

Site factors (e.g., climate, exposure, soil type, drainage) and degree of after-planting care are major influences on performance. The southern cooler sites at Ianthe and Slopedown had no releasing after planting and Ianthe was poorly drained (Forest Research Institute 1984). Poor growth at Russell and the closed canopy site at Woodhill were largely a result of dense competition from weed growth and low light intensities under a canopy. The exceptionally droughty site at Woodhill located on an old sand dune was a major factor in the poor growth of all podocarps planted on this site. Growth of podocarp seedlings at Russell was also poor because of the low-fertility, stony clay loam soils. Releasing of seedlings from competing vegetation, whether it was grass in early years as at Tapapakanga, or ferns and shrub hardwoods as at the Holt's and Glenbervie sites, clearly improved growth of all indigenous conifers. Such growth is probably due as much to reduction of competition as it is to improved light levels (Beveridge 1973).

Within sites there was a difference in relative performance between species that provides insights into their ecological characteristics. The poor drainage at Ianthe was reflected in low survival and growth of totara and rimu and the correspondingly better performance of kahikatea. At Woodhill, groups planted under canopy and in cut gaps with similar survival rates demonstrated the persistence of indigenous conifers, although increased light levels in the open canopy site were clearly beneficial as growth rates were significantly faster for height and diameter across all species. The poorest performing species on the sandy soils at Woodhill under an open canopy was kahikatea with a survival rate of only 54% compared with totara which had the highest survival of 87% 25 years after planting. Tanekaha had good survival and the fastest height growth while rimu also performed well on this site.

Form of planted trees varied with species and density of planting. Totara and rimu, in particular, often formed bushy crowns with large-diameter short boles and coarse branching and multi-leaders if planted on open sites. In comparison, the apically more-dominant kauri, kahikatea, and tanekaha retained an upright crown form, often with a single leader.

Best-performing Stands

The best-performing planted stands from all plantings evaluated in this study are listed in Table 6, demonstrating the potential performance of the major indigenous conifers (where there were reasonable sample sizes). Survival was over 70%, with mean annual increments exceeding 8 mm for dbh and 40 cm for height growth for totara, rimu, kahikatea, and kauri.

DISCUSSION

Totara was initially the most commonly planted of all the indigenous conifer species (Department of Lands 1909) and this probably continued until the 1970s, when large numbers of kauri were planted in the upper North Island. Factors that contributed to wide-scale and sustained planting of totara include its natural distribution throughout the country,

TABLE 5–Early growth performances of well-documented planting trials.

Trial site	Site and trial description and tending	Age at last assessment (years)	Species planted	Sample	Survival (%)	Average dbh (cm)	Dbh MAI (mm)	Average height (m)	Height MAI† (cm)
Tapapakanga Regional Park, Auckland	Plantation established in open on grass at 2 × 2 m spacing; coastal. Large crowns, coarse branching formed. Pre-plant grass control undertaken; regular maintenance.	10	totara	200	89	8.6	8.6	5.5	55
Gwavas Forest, Hawke's Bay	Line and group planting in shrub hardwood regrowth in logged beech forest; no releasing; severe damage by cattle and possums.	17	totara	96	71			1.9	11
			rimu	85	69			2.1	12
			kahikatea	87	75			2.1	12
Pureora Forest Park, central North Island (upland site)	Groups planted between *Eucalyptus delegatensis* on cleared podocarp forest site; minimal releasing; scattered mostly unthrifty eucalypt overwood. Altitude 550 m.	20	totara*	23		11.0	5.5	5.4	27
			rimu	20		12.2	6.1	5.7	29
			kahikatea	20		10.9	5.5	6.9	35
Ianthe Forest, West Coast (swamp forest site)	Groups planted in gaps cut in hardwood regrowth in strip-felled podocarp forest; no releasing from dense regrowth; poor drainage.	20	totara	19	18	2.9	1.5	2.6	13
			rimu	185	29	2.7	1.8	2.4	16
			kahikatea	114	72	2.8	1.9	1.9	19
Slopedown Forest, Southland	Groups planted in gaps cut in kamahi/wineberry regrowth after beech logging; no releasing from dense *Fuchsia*.	22	totara	42				2.2	9
			rimu	46				1.4	5
Holt's Forest Trust, Hawke's Bay	Lines planted in bracken; released annually; summer droughts occasionally.	23	totara	30	95	11.2	4.9	6.3	27
			rimu	30	90	8.0	3.5	5.5	24
			kauri	30	90	11.5	5.0	6.5	27
Russell Forest, Northland	Line planted in dense kanuka scrub and tree fern; some early releasing.	23	totara	181	34			1.6	7
			rimu	318	81			1.7	7
			kahikatea	223	72			2.8	12
			matai	131	54			1.1	5
			tanekaha	49	46			1.4	6

* Near upper altitudinal limit for totara at about 600 m a.s.l.
† Mean annual increments (MAI) do not take into account planting height.

Table 5: (continued)

Trial site	Site and trial description and tending	Age at last assessment (years)	Species planted	Sample	Survival (%)	Average dbh (cm)	Dbh MAI (mm)	Average height (m)	Height MAI† (cm)
Woodhill Forest, Auckland	Closed canopy — 25 tree groups planted under a canopy of manuka and kanuka; old sand dune country; releasing only first 2 years; exceptionally droughty sites on old sand dune.	25	totara	207	92	4.2	1.7	2.7	9
			rimu	150	86	2.8	1.1	2.7	9
			kahikatea	39	52	1.0	0.4	1.1	5
			tanekaha	80	80	4.1	1.6	4.4	16
Woodhill Forest, Auckland	Open canopy — 25 tree groups planted with cut gaps in manuka and kanuka; sand country; releasing only first 2 years.	25	totara	196	87	4.5	1.8	3.3	13
			rimu	176	64	6.8	2.7	5.9	22
			kahikatea	81	54	1.9	0.8	2.5	9
			matai	120	60	1.1	0.4	2.8	10
			tanekaha	72	72	6.6	2.6	6.3	24
Kaingaroa Forest, central North Island Plateau	Line planted beneath semi-mature *Pinus ponderosa*; provided shade and shelter; frosty cold pumice site.	25	totara	137	58	7.4	3.0	5.9	24
			rimu	140	62	6.9	2.8	5.0	20
			kahikatea	91	50	4.0	1.6	4.2	17
Mamaku Forest, central North Island*	Large groups planted in logged podocarp/tawa forest in hand-cut gaps.	26	totara	150	64	9.4	3.2	6.5	25
			rimu	105	53	7.4	2.8	6.6	25
			kahikatea	35	54	6.0	2.3	5.1	20
Mamaku Forest, central North Island*	Tractor-cleared gaps in logged podocarp/tawa forest	26	totara	138	44	9.8	3.8	6.3	24
			rimu	158	70	6.8	2.6	5.9	23
			kahikatea	145	81	6.2	2.4	6.6	25
Mamaku Forest, central North Island*	Tractor-cleared lanes in logged podocarp/tawa forest	26	totara	111	67	9.8	3.7	5.6	22
			rimu	166	68	8.3	3.2	6.0	23
			kahikatea	61	85	6.5	2.5	6.4	25
Glenbervie	Plantation established in scrub; some early releasing	35	totara	17	85	24.9	7.1	10.4	30
			kauri	29	90	25.5	7.3	14.6	42
Pureora Forest Park, central North Island* (550 m a.s.l.)	Perham Ave — planted with eucalypts on cleared site; minor early releasing from tall grass and blackberry; tall eucalypt overwood.	40	totara	22		16.1	4.0	10.2	26

* Near upper altitudinal limit for totara at about 600 m a.s.l.
† Mean annual increments (MAI) do not take into account planting height.

TABLE 6–A selection of the best performing planted stands of indigenous conifers established for up to 50 years illustrating the potential growth rates from planted stands.

Species	Site	Stand age (years)	Sample	Survival (%)*	Mean dbh (cm)	Dbh MAI (mm)	Dbh range (cm)	Mean height (m)	Height MAI (cm)	Height range (m)	Stand and site characteristics
Totara	Tapapakanga	10	200	89	8.6	8.6	5.7–10.1	5.5	55	4.7–6.5	Fertile. lowland, ex-pasture site; regular releasing
	Kamo	32	14	95	32.5	10.2	21–45	14.4	44	13.7–15.2	Shelterbelt; large crown trees; fertile lowland site
Rimu	Holt's Forest	6	31	95	2.8	4.7	2–4	2.9	43	2.4–3.6	Well maintained; pruning
	Cornwall Park	39	36	90	31.8	8.2	21.2–41.5	14.4	35	10.7–15.8	Well maintained; fertile lowland site
Kahikatea	Holt's Forest	18	20	80	18.0	10.0	12–22.9	11.8	59	10.4–13.4	Well maintained
	Cornwall Park	21	19	70	21.8	10.4	15–30.3	10.3	48	8.2–12	Well maintained; fertile lowland site
Kauri	Pukekura	22	15	90	25.0	11.4	14.3–34.2	11.5	51	7.5–13.3	Fertile high rainfall site; regular maintenance
	Kirks	31	40	100	28.7	9.3	15.4–39.4	14.6	45	12.2–17.5	Fertile lowland site; sheletered; good maintenance
Tanekaha	TePohue	25	11	-	16.3	6.5	13–20	9.1	35	8–11	Sheltered large garden; well maintained
Matai	Pukekura	50	16	-	16.0	3.2	12.3–20	9.9	19	9.6–10.4	Fertile high rainfall site; regular maintenance
Miro	Pukekura	22	2	-	9.9	4.5	8.8–11.1	4.6	20	4.6–4.7	Fertile high rainfall site; regular maintenance

* Survival of tanekaha, matai, and miro difficult to estimate from limited planting records

its tolerance of and generally good performance on a wide range of sites, and the ease with which it is raised for large-scale planting programmes. Consequently, millions of seedlings have been planted throughout the country over a century. However, there are virtually no extensive plantations of totara or of other indigenous conifers in existence today.

Of the seven indigenous conifer trees considered in this study, the natural range of kauri and tanekaha is restricted to the middle and upper North Island but, while most plantings of these species have taken place in the northern latitudes, there are plantations successfully established south of the natural range. Two, exceptional, relatively fast-growing, kauri stands occur in New Plymouth, some 120 km south of the natural range (Herbert *et al.* 1996).

This evaluation of surviving planted stands and trials indicates that many were established on poor sites after the best land was converted to farming and exotic forestry, and only a few stands received adequate post-planting maintenance. Both these factors are critical in early performance and effective establishment. Subsequent changes in landuse and ownership, and changes in the direction of central Government policies and initiatives, have also contributed to the lack of commitment to long-term stewardship and management of planted stands. All these factors have contributed to the perception that indigenous trees are not only difficult to establish, but are slow-growing.

The podocarps (totara, rimu, and kahikatea in particular) show remarkable persistence on poor sites although with extremely slow growth rates. This was evident at Woodhill where mean annual dbh increments around 1–2 mm were recorded for the 50–90% of surviving seedlings 25 years after planting on the sandy drought-prone site (Table 5).

Despite the variability in sites assessed in this study, analysis of site indices for totara across all plantings indicated a preference for open fertile sites, consistent with previous observations and studies (e.g., Ebbett 1998). Overall, totara has a similar growth rate to the other widely planted podocarps, kahikatea and rimu, with which it was often planted. Seedling growth studies of the three major podocarps have shown that totara responds to high fertility and high light intensities. In a comparison of growth responses to nutrition, Hawkins & Sweet (1989) found totara seedlings gained greater dry weight than rimu and kahikatea after 8 months' growth. When the five podocarp species — totara, rimu, kahikatea, matai, and miro — were planted under different levels of shade cloth and under various light intensities beneath the canopy of different vegetation types, totara and kahikatea had the greatest height response in the highest light levels (Ebbett & Ogden 1998). In comparisons of shade tolerances among the indigenous conifers, both planted seedlings and studies of natural regeneration, totara was the most light-demanding (Beveridge & Bergin 2000). The shade tolerances of planted conifers in the central North Island rank from light-demanding to shade-tolerant as follows — totara, tanekaha, kahikatea, matai, Hall's totara, rimu, miro. Similarly, Ogden & Stewart (1995) speculated that, after massive disturbance in high forest, initial cohorts of podocarps establish in the sequence from most light-demanding to the most shade-tolerant – totara, matai, rimu, miro. Although site variation in this evaluation has largely masked an evaluation of ecological preferences between species, results do show totara is less tolerant of shade than the other podocarps when planted together. Totara also tolerates drier sites, showing a preference for open, warm, frost-free sites, whereas kahikatea prefers moister sites. Performance of rimu

improves on sheltered sites where risk of desiccation by wind and drought is reduced. The few sites where kauri and tanekaha were planted with podocarps showed that these species generally grow faster than the podocarps.

All species have the potential to be severely affected by insect attack or animal browsing. For instance, rimu, kahikatea, and totara were damaged by severe possum browsing and cattle grazing and trampling at Gwavas Forest (Table 5). In enclosure trials, where planted podocarp seedlings were fenced to prevent browsing, possums were found to eat the young shoots and bark of planted seedlings (Forest Research Institute 1980). In general, however, totara seedlings are relatively unpalatable to most grazing animals except goats (A.E. Beveridge pers. comm.). Beveridge (1962) found totara seedlings near a podocarp forest canopy at Pureora with severe damage, particularly to new foliage, caused by defoliating caterpillars, which contrasts sharply with totara planted on open sites such as Tapapakanga, which were relatively free of insect damage.

Compared with performance averaged across all stands covering a range of sites and management histories, growth rates from the best-performing stands are a more realistic reflection of the potential of the indigenous conifers when planted on favourable sites and where plantations have been well managed (Table 6). Overall survival of the conifers is usually high as has been reported previously (e.g., Pardy *et al.* 1992; Beveridge *et al.* 1985; Beveridge & Bergin 2000). Without exception, all best-performing stands were on sheltered, fertile, lowland sites. Most were part of recreational parks, domains, or large gardens where they received regular maintenance and were kept free from competing vegetation.

Recommendations for planting podocarps were made by Beveridge & Bergin (2000), based mainly on trials on upland sites with adequate rainfall in the central North Island. Matching the species to the appropriate site, as well as selection of good microsites, is important. In disturbed forest, suitable microsites are canopy gaps where soil is disturbed, well-drained, and free from dense growth of tree ferns and root mats of large trees. On exposed open sites, early shelter must be provided using natural or planted indigenous species such as manuka, kanuka, kohuhu (*Pittosporum tenuifolium* Sol. ex Gaertn.), wineberry (*Aristotelia serrata* (G.Forst.) Oliver), and karamu (*Coprosma robusta* Raoul). Alternatively, where appropriate, exotic species can be planted to provide early shelter but must be removed before suppressing planted podocarps. On difficult sites with dense growth of vegetation, a small tractor may be required to clear a gap and lightly cultivate the ground. Vigorous grass cover on open sites needs to be controlled before tree planting.

A further consideration is the pattern of planting that will be determined not only by the site and species to be planted but also the objectives of planting. Cluster planting of three to five seedlings at 1–1.5 m spacing enables selection of suitable microsites in forest gaps, and groups are easily re-located for releasing compared with scattered individual trees. A flexible group planting pattern is more natural than rigid line planting, and groups can be planted to avoid poor sites such as compacted or wet ground and areas of dense fern.

Raising plants from seed is likely to remain the most economic and effective means for large-scale nursery production of most of the indigenous conifers. The transplanting of wildings and vegetative production from cuttings may be useful for some species where local seed is not available or seed is slow to germinate, such as for matai, miro, and tanekaha,

but is likely to be too expensive for large-scale planting programmes. Cuttings may also be useful in future genetic improvement studies. The use of large, well-conditioned, nursery-raised stock over 60 cm in height will give better survival and early growth. However, larger seedlings are more expensive, especially if raised in containers. The efficacy of using either container-grown or bare-root nursery stock for large-scale restoration programmes needs addressing (Dean 2000).

The overwhelming conclusion from the analysis of existing plantings is the need for adequate maintenance of seedlings after planting. Seedlings should be released from competing vegetation until they reach about 2 m in height, approximately 5 years after planting.

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