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Future Forest Erosion Species Trial Final Report

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Landcare Research

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

Project and Client

- As a component of MSI programme ‘Forest and Environment’ (C04X0806) led by Scion and Future Forests Research, Landcare Research was subcontracted to established a trial in 2010 of exotic species, examine their below-ground growth performance and to report progress annually. This report is the third and final report.

Objectives

- Establish a trial in 2010 to assess root development of nine tree species over 3 years to determine their suitability for erosion control.
- Undertake plant excavations each year after planting to examine above- and below-ground growth parameters for trial plants.
- Provide an annual progress report and a final report on completion of the trial.

Methods

- A randomised block treatment with three samples of each species for each of 3 years was established in July 2010 near Gisborne.
- Plants are extracted annually and above- and below-ground parameters assessed and related to root collar diameter (or to diameter at breast height).

Results

- A few more losses occurred in Year 3 of the trial. All Douglas-fir had died, and five of the remaining Year-2 replicates were damaged to varying degrees.
- At age 3, the best performing species across a range of parameters was alder, then blackwood, cherry, and cypress.
- By Year 3 some of the early differences due to size of planting stock have begun to be evened out.
- Alder in particular, has grown extremely rapidly and in terms of total root length and other metrics clearly outperforms all other trial species. Cypress, cherry, blackwood and redwood also performed well, while radiata, while initially slow to establish, showed rapid growth between Years 2 and 3.
- Total root length > 1 mm diameter was greatest in a Year-2 alder at 1508 m with the Year-3 alder having 1268 m and a Year-3 cypress, 1269 m.
- Mean root spread was greatest in a Year-3 blackwood at 10.3 m with the Year-3 alder having 7.7 m.
- Mean below-ground biomass was greatest in alder (8.96 kg) followed by cherry (6.2 kg) and cypress (5.1 kg).

Discussion and Conclusions

- Differences between species for many growth parameters, including root metrics, may not fully emerge until the plants are considerably older – beyond 4 years old.
- At completion of this trial, it is clear that some species outperformed others across a range of parameters.
- Alder’s rapid growth and similarity to the performance of existing soil conservation plant species (poplar and willow) makes it a prime candidate for consideration as a species to be used in erosion control (notwithstanding other potential issues such as tree spread, i.e. wildlings).

INTRODUCTION

Future Forests Research and Scion, within MSI research programme ‘Forest and Environment’ (C04X0806), subcontracted Landcare Research to establish a trial of exotic species in 2010. The aim of the trial was to use annual measures of below-ground growth performance to assess the suitability of these species for erosion control in North Island hill country.

The sustainability of the New Zealand forest industry and its resilience in the face of climate change are key drivers for the shape of future forests. In future, there is likely to be an increasing focus on non-wood benefits and values or services from forests be they plantations or indigenous forests (O’Loughlin 2005). One of those services relates to the use of forests for controlling or reducing erosion.

There is well-established literature on the benefits of trees, shrubs and grasses for reinforcing soils to control or reduce both surficial and mass-movement erosion (e.g. Phillips et al. 1990; Marden & Rowan 1993; Phillips & Marden 2005; Stokes et al. 2008). However, while it is acknowledged that vegetation imparts additional strength to soil via its reinforcing root network, the amount of information on the development and growth of a species’ root system is generally sparse, particularly for larger trees.

The collection of below-ground information of plants is difficult, time-consuming, and expensive, but such data are necessary to develop quantitative models that incorporate root information for use in predicting the effects of vegetation on slope stability (Schwarz et al. 2010; Phillips et al. 2011) and hence the effectiveness of revegetation policies.

We focused on the root development in a field plot trial established near Gisborne of young exotic species considered potential candidates for future ‘erosion forests’. Species selection was guided by Scion.

This report is the third and final report detailing the annual growth of trialled species. We also briefly comment on the results of this trial in a broader context of known information from other New Zealand tree root investigations.

OBJECTIVES

- Establish a trial in 2010 to assess root development of nine tree species over 3 years to determine their suitability for erosion control.
- Undertake plant excavations each year after planting to examine above- and below-ground growth parameters for trial plants.
- Provide an annual progress report and a final report on completion of the trial.

METHODS

The Gisborne field trial site is located on a low-lying, even-surfaced alluvial terrace adjacent to the Taraheru River, in Gisborne City. The soil is free-draining Te Hapara Typic Sandy Brown Soil (Hewitt 1998) and requires irrigation in summer. The soil does not have any physical or chemical impediments to root development to at least about 1.2 m depth, other than a variable-depth water table. The climatic regime is also favourable to tree growth and thus the site represents an almost ‘best case’ scenario for examining root development. The current trial was established on the same site as previous trials that examined plant growth performance, to allow comparison between native and exotic species (Marden et al. 2005). The trial plot (50 × 20 m) was tilled to a standard depth (c. 200 mm) before planting.

In the trial, a randomised block treatment with three replicates of each species for each of 3 years was established in July 2010. Species trialled and their nursery treatments are listed in Table 1.

Seedlings were supplied by Scion’s Nursery in Rotorua (Table 1). As part of commercial nursery practice, the roots were conditioned/undercut. Plant spacing was 2.5 m. To ensure the survival of 1-year-old seedlings, weed mat was laid to reduce competition from weeds, trickle irrigation was installed, and wire cages were placed over plants to limit browsing damage by hares (*Lepus europaeus*) and pūkeko (*Porphyrio p. melanotus*).

Table 1 Seed sources and nursery treatment

Species	Common name[1]	Source and treatment
Quercus robur	Oak	Seedlings sourced from a local tree where seed had fallen and germinated in leaf litter/bark garden. 2009 germination.
Eucalyptus fastigata	Eucalypt	Direct open-ground-sown into commercial nursery bed, October 2009.
Pseudotsuga menziesii	Douglas-fir	Direct open-ground-sown into commercial nursery bed, October 2009.
Sequoia sempervirens	Redwood	Direct open-ground-sown into commercial nursery bed, October 2009.
Prunus serrulatus	Cherry	Transplanted from under a local tree where the seed had fallen and germinated in the leaf litter. 2009 germination.
Acacia melanoxylon	Blackwood	Direct open-ground-sown into commercial nursery bed, October 2009.
Alnus rubra	Alder	Direct open-ground-sown into commercial nursery bed, October 2009.
Cupressus lusitanica	Cypress	Direct open-ground-sown into commercial nursery bed, October 2009.
Pinus radiata	Radiata	GF 19 improved seed. Direct open-ground-sown into commercial nursery bed, October 2009.

[1] Common name used in this report

Extraction of root systems and measurement methods followed established procedures (Watson et al. 1999; Czernin & Phillips 2005; Marden et al. 2005). Root systems were extracted using an air spade (an ultrasonic high pressure device to remove soil from around the roots) and/or by hand, particularly in the first year after planting.

Once removed from the ground, the plants were destructively sampled to determine a number of parameters, all of which were related to root collar diameter (ground line diameter) and diameter at breast height (1.35 m; dbh) (where plants were large enough). Ten sample trees for each species were also destructively sampled at the time of planting (Year 0). Components were oven-dried and biomass is given as dry weights (grams).

Various parameters can be used to assess the performance of a species in terms of its erosion-control effectiveness (Phillips et al. 2000; Stokes et al. 2009). Parameters used to measure above-ground growth were height, canopy spread, root collar diameter (rcd) and dbh (where applicable). Those to measure below-ground growth comprised maximum depth of roots and spread of lateral roots. The latter, together with canopy spread, was taken as the average of the maximum diameters measured in two directions, i.e. at right angles to one another. The root system of each plant was photographed before being partitioned into its biomass components.

Above-ground biomass was measured by separating the foliage, branches and stem. Below-ground components were partitioned into root bole, tap, lateral, and sinker roots. Roots were further partitioned into diameter size-classes (<1 mm (fibrous), 1–2, >2–5, >5–10, >10–20, >20–50, >50–100 mm) (Watson & O'Loughlin 1990), and the total length of roots in each diameter size-class (excluding fibrous roots) was measured.

Extractions were made in July 2011 after 1 year in the ground for three of each species according to the trial design. Year-2 extractions were conducted in late June and early July 2012 after 2 years in the ground. The final extraction took place in late May and early June 2013.

Though three alders survived through to Year 3, one tree only (Tree 2) was randomly selected for full excavation and processing as resources were insufficient to deal with the remaining two due to their size. Following final extractions, the trial site was decommissioned and returned to the Eastland Institute of Technology.

RESULTS

Survival

There were minor losses of blackwood, redwood and eucalypt soon after planting, due, we suspect, to browsing by animals (rabbits *Oryctolagus cuniculus*/pūkeko) or from the water table rising into the rooting zone over the winter months and causing subsoil waterlogging. Douglas-fir showed initial signs of stress due to the post-planting ‘ wet period’ but losses at Year 1 were not significant enough to compromise the objectives of the trial. However, at Year 2, all Douglas-fir had died. Some trees (5 of 24) also sustained ‘damage’ in the second year of the trial, exhibiting broken branches or toppling likely caused by wind. Trimming of an adjacent shelter belt may also have contributed to above-ground damage. At Year 3, 19 of the 27 trees marked for extraction had survived. Of these blackwood, alder and radiata had three surviving replicates with the other species only two each (Douglas-fir had all died in Year 2).

General Description

The nine trialled species were a mix of evergreen and deciduous trees and exhibited a range of tree form. Canopy shape and density were variable with some species having a bushy shrub-like appearance and others more streamlined canopies and forms. In a similar manner the below-ground appearance of the root systems was also variable. Several species had low root density and ‘spidery’ elongated roots (blackwood, eucalpyt, oak) (see photographs in Appendix 1). Alder and cherry had dense branching root systems, while redwood and cypress had dense but feathery roots. Radiata had long laterals with limited branching. Alder, redwood and cypress roots were reddish in colour; radiata, orange; blackwood and oak, pale brown; cherry, pale brown to white; and eucalypt, dark brown.

Growth Performance Parameters

Results from Years 1 and 2 are included in earlier reports (Phillips & Marden 2011, 2012, unpublished). Examination of the whole dataset (Years 1–3) indicated that the differences between species for most parameters at the time of planting carried through to Year 3. At ages 2 and 3, the best performing species across a range of parameters was alder, followed by blackwood, cherry, and cypress (Table 2, Figures 1–7). Alder was the tallest tree at Year 3 (6.4 m) with cypress (4.9 m) and eucalypt (4.0 m) also performing well (Figure 1).

Table 2 Example data for alder and cherry (mean values except for 3-year alder)

Parameter	Alder				Cherry			
	0 year	1 year	2 years	3 years	0 year	1 year	2 years	3 years
Number of trees sampled	10	3	3	1*	10	3	3	3
Tree height (m)	0.83	2.86	4.73	6.43	0.79	1.51	2.60	2.70
Canopy spread (m)	0.11	0.97	3.73	4.40	0.13	0.55	1.08	1.93
DBH (mm)	N/A	20	60	80	N/A	8	19	28
Root collar diameter (mm)	13	49	144	129	9	27	63	101
Maximum root spread diameter (not radius) (m)	0.39	2.60	6.70	7.70	0.22	1.69	2.38	4.90
Maximum root depth (m)	0.18	0.28	0.42	0.50	0.17	0.21	0.22	35
Total above-ground biomass (g)	18	996	11105	12071	11	232	2180	4551
Total below-ground biomass including stump/root bole (g)	20	731	8314	8959	11	197	2088	6200
Total root length > 1 mm (m)	4.1	140	1508	1268	1.63	29.63	181	403
Total root length > 2 mm (m)	1.8	44	637	513	1	11	80	122

N/A = not assessed.

*Three trees survived, only one was sampled (randomly chosen)

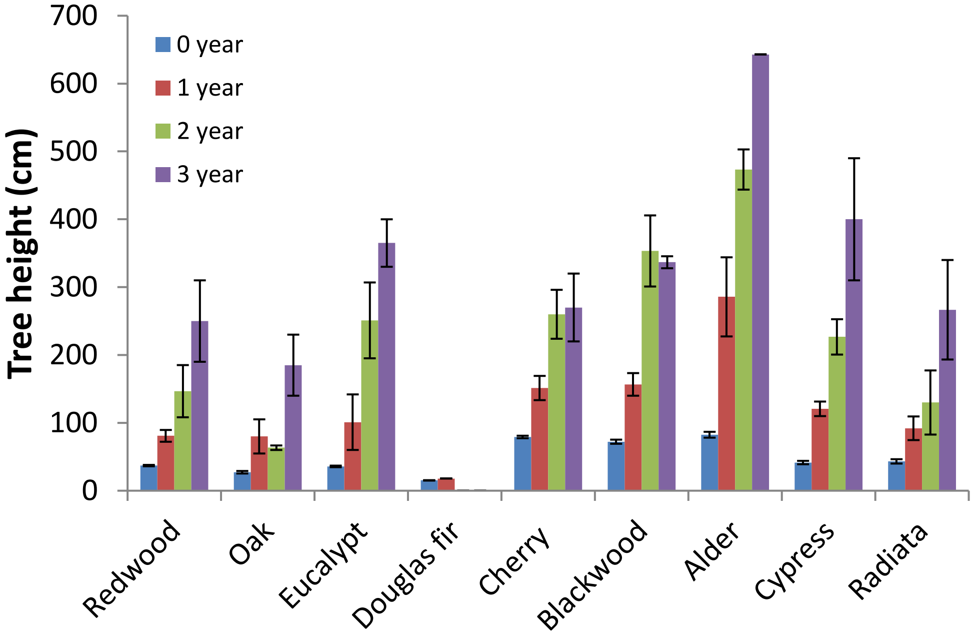

Figure 1 Mean tree height for each trial species at planting (0 year), 1 year, 2 years, and 3 years. Vertical bars are one standard error of the mean.

Root Spread

Largest root spread was in a 3-year-old blackwood at 10.3 m with one Year-2 blackwood having 9.0-m root spread. The Year-3 alder had a root spread of 7.7 m though one Year-2 tree had a spread of 8.5 m. Blackwood had a mean root spread of 6.9 m, eucalpyt 4.5 m, and cherry was 3.2 m (Figure 2).

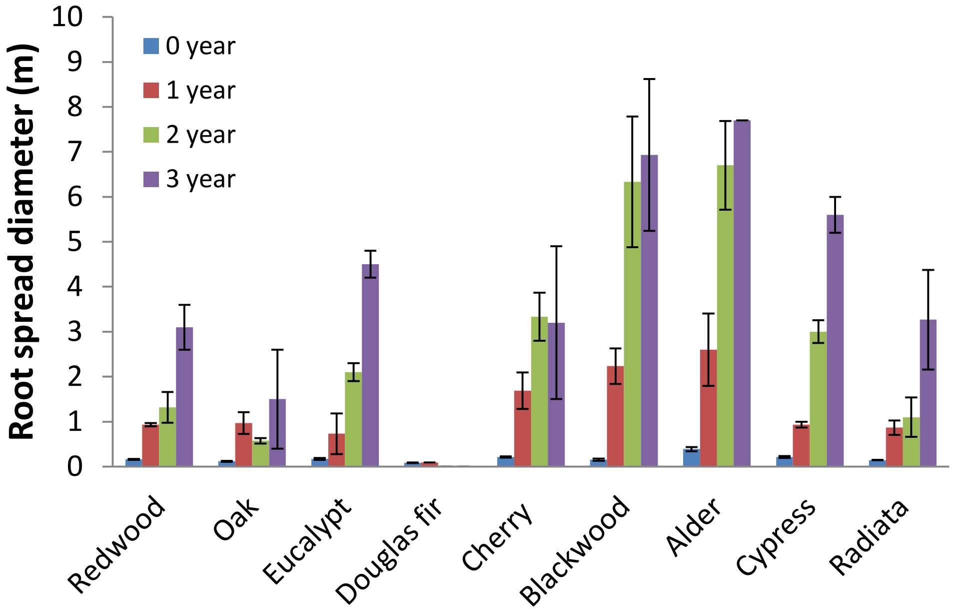

Figure 2 Mean maximum root spread (diameter) for each trial species at planting (0 year), 1 year, 2 years and 3 years. Vertical bars are one standard error of the mean.

Root Depth

Root depth was highly variable between species (total mean range at Year 2 was 0.18–0.45 m) and trends established in Year 1 continued through to Year 3 (Figure 3). Roots did not go deeper than about 0.5 m.

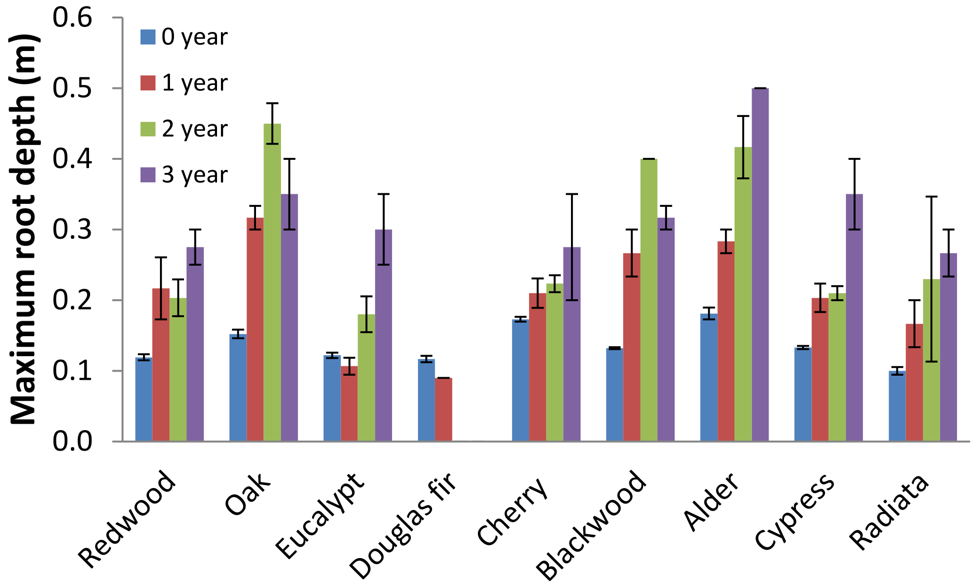

Figure 3 Mean maximum root depth for each trial species at planting (0 year), 1 year and 2 years. Vertical bars are one standard error of the mean.

Root Length

Alder had the greatest total root length (all roots >1 mm in diameter) of trial species at Year 2, ranging from 1347 to 2262 m (Figures 4 and 5). A Year-2 alder had the greatest total root length of all trees excavated, at 2262 m, considerably more than the random Year-3 alder chosen for excavation. Figure 9 compares this trial's results with data for other species from earlier trials (Marden et al. 2005; Phillips et al. 2012).

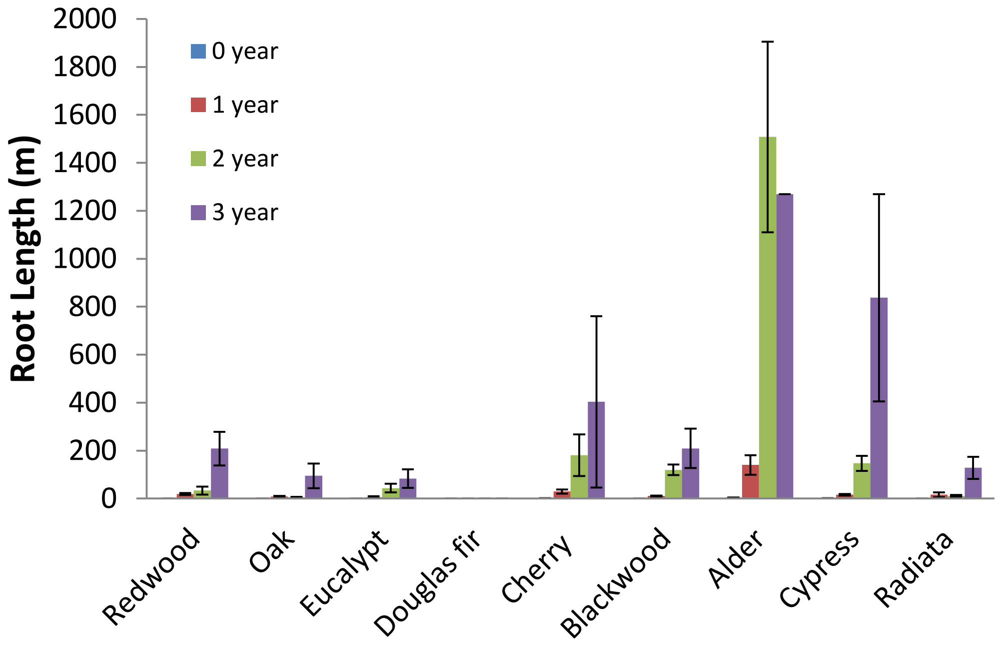

Figure 4 Mean total root (>1 mm in diameter) length for each trial species at planting (0 year), 1 year, 2 years, and 3 years. Vertical bars are one standard error of the mean.

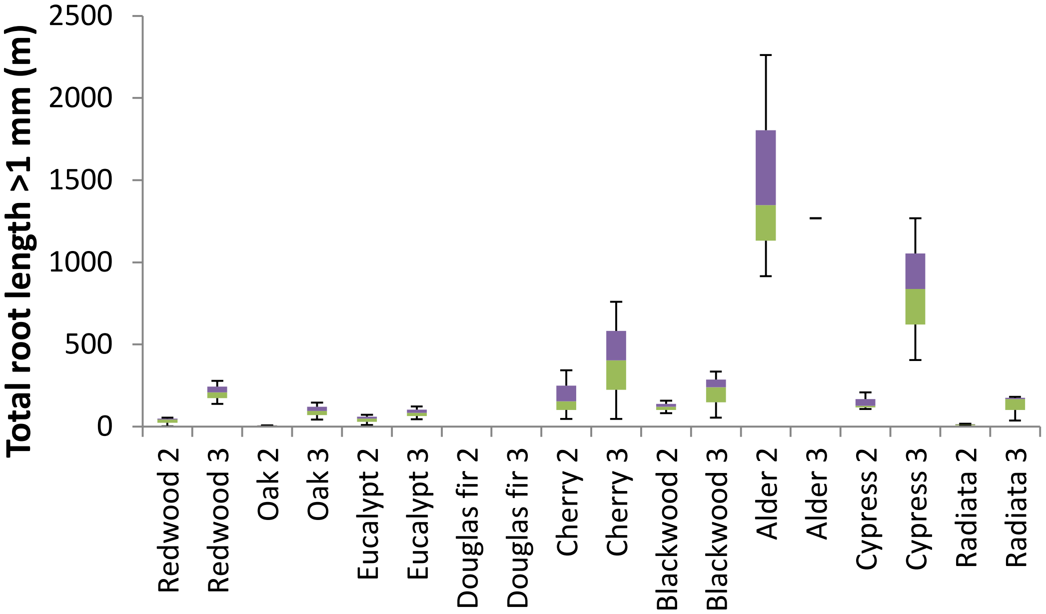

Figure 5 Box-and-whisper plot of Year-2 and Year-3 total root length data > 1 mm (m). Note no Douglas-fir and only one Year-3 alder tree.

Biomass

Mean above-ground biomass of 3-year-old cypress reached 29 kg, with the largest of the two trees having 46 kg above and 8 kg below ground (including root bole or stump) (Figure 6). Alder was the next best performing species in mean total biomass and had the greatest below-ground biomass of all species at both Year 2 and Year 3, closely followed by cherry.

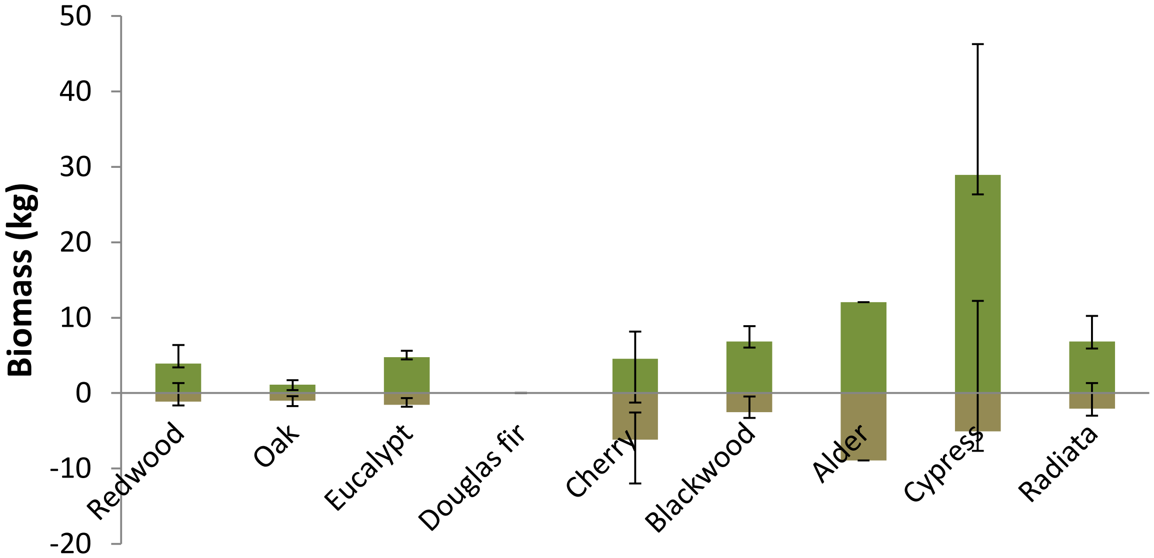

Figure 6 Mean above-ground (green) and below-ground biomass (brown) for each trial species at Year 3. Vertical bars are one standard error of the mean. Note no Douglas-fir and only one Year-3 alder.

Allometric Relationships

Relationship between Root Collar Diameter and Total Root Length

Allometric relationships are used to predict tree growth on the basis of an easy-to-measure above-ground parameter such as dbh or root collar diameter (rcd). Because our trial species were young and the number of replicates low, fitting trendlines with limited data points may not be appropriate. Other root studies have tended to fit power-law curves to the data to provide some predictive capability (e.g. McIvor et al. 2009; Phillips et al. 2012).

The allometric relationships between rcd and (a) total root length of all roots greater than 1 mm in diameter and (b) below-ground biomass for each species have R^2 values ranging from 0.71 (redwood) to 0.99 (eucalypt) (Appendix 2). Total root length data for each species plotted against rcd is shown in Figure 7.

If all data are combined, Equation 1 could be used to predict total root length and Equation 2, below-ground biomass, where rcd is in millimetres. Alder tend to be outliers in the complete dataset (Figure 7). Relationships using dbh have much lower R^2 values (0.5–0.7).

Equation 1 Total root length > 1 mm (m) = $0.009\ \text{rcd}^{2.22}$ $R^2 = 0.83$

Equation 2 Below-ground biomass (g) = $0.013\ \text{rcd}^{2.63}$ $R^2 = 0.89$

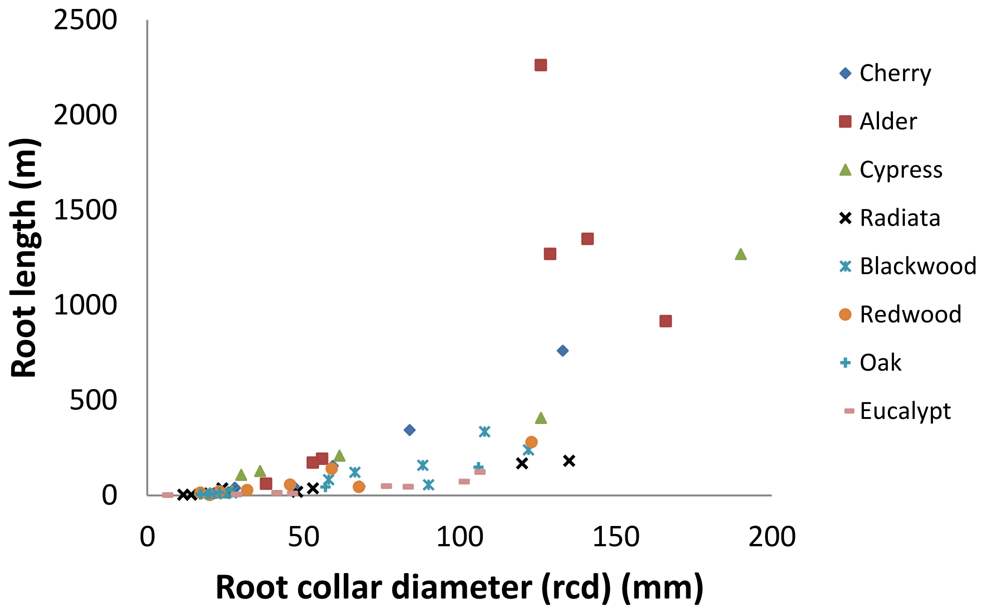

Figure 7 Total root length of all roots greater than 1 mm (m) against root collar diameter (rcd) (mm) for all trialled species. Note no Douglas-fir as these did not survive.

Comparison with Other Species

Because tree root excavations are time-consuming, the number of investigations of root systems in New Zealand are limited. Many involve assessment of only one or a few specimens of different ages and usually from only one site. This obviously restricts the amount of data available from which to make interspecies comparisons, but also it limits the capability to develop statistically-reliable predictive models or tools.

However, in relation to soil reinforcement, metrics such as total root length can be used to gain insights into the ‘potential’ performance of species in terms of erosion control. Figure 8 illustrates data for species from this trial, along with those from earlier studies, including data from other exotics (poplars (Veronese and Kawa) and willows (Tangoio)) and native species.

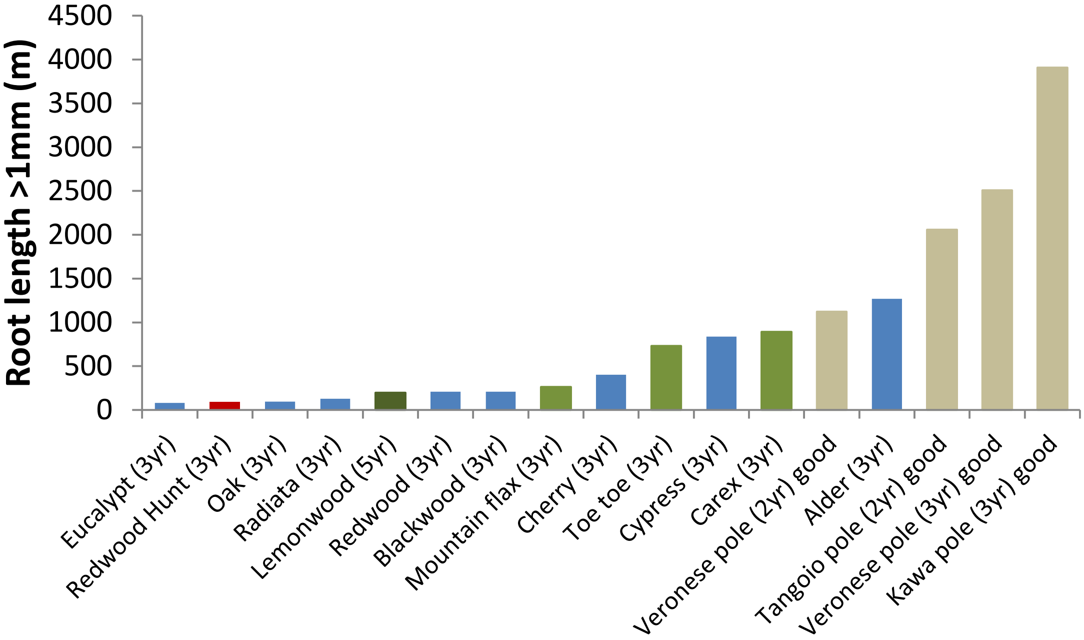

Figure 8 Comparison between mean root length from this trial (blue bars) and that of other species for which there are root data. Data on 3-year-old redwood (Hunt) are from Phillips et al. (2012), and other are species from published (Marden et al. 2005) and unpublished sources. ‘Good’ refers to a good growing site.

DISCUSSION

The significant difference in planting material as it came from the Scion nursery is probably the biggest factor in interspecies variation in the range of parameters measured in the early years of growth. Seedlings of alder, cherry, and oak were considerably larger plants than those of radiata pine and Douglas-fir, and this continued to show for the first year or two of growth in the trial plot. The trial aimed to use ‘nursery-raised’ planting grades that would normally be used by the forest or ‘establishment’ sector rather than having planting materials of the same size and grade. However, at Year 3 some of the smaller seedlings such as radiata, redwood, and cypress had ‘caught up’ and exhibited strong growth between Years 2 and 3.

While it is possible to make some general observations about plant performance, these should be taken in the context that ‘true’ differences between species are unlikely to emerge until the plants are considerably older – at least beyond 4 years from planting. Based on our observations, the size of planting stock may may be a useful predictor of early performance.

Differences in growth may also be attributed to environmental factors such as the presence of a high water table at the time of establishment, which for some species such as Douglas-fir may have been an inhibiting factor and ultimately was probably responsible for their non-survival, while in others such as alder it may have enhanced growth. Our trial indicated that Douglas-fir was not suited to the field conditions at this site, and is probably not suitable for sites with periodic waterlogging. Edaphic factors such as soil type are often cited as the major factor controlling plant growth (e.g. Phillips & Watson 1994). However, the trial site was reasonably uniform and the soil being a sandy loam without stones provided an ideal growing medium that did not impede the lateral growth of the plants. The presence of the seasonal water table and a compacted layer beyond 0.5 m may have limited the development of vertical root growth in some species.

After 3 years’ growth it is clear that some species have outperformed others in terms of the parameters deemed inportant for soil reinforcement and hence erosion control. Whether these levels of performance will persist beyond this is unknown. Based on what was observed, all these exotic species showed some value as potential future erosion forest species, with eucalypt and oak showing the least potential. Top performers overall were alder, cherry and cypress, followed by blackwood, radiata, and redwood. However, the benefits of erosion control using alders need to be weighed against the downstream and potentially long-term costs of avoiding invasion of this species into wetlands and riparian areas with native values, and of channel blockage (e.g. Stanley 2002 [attached as Appendix 3]; Howell 2008). Cherry can also be highly invasive outside of riparian areas as it is bird dispersed.

Blackwood, eucalypt, oak and radiata have lower root density at ages 1–3 years old compared with alder, cherry and cypress. Earlier studies show cherry and cypress have similar root lengths to equivelent-aged native toetoe (*Cortaderia*) and *Carex* spp.. Oak, eucalyptus, redwood, radiata pine and blackwood had root lengths similar to or less than 3-year-old mountain flax (*Phormium cookianum*) or 5-year-old lemonwood (*Pittosporum eugenioides*).

Species such as alder exhibited rapid growth and it is unlikely that this growth will be overtaken by other species even after 5 years. Alder’s rapid growth and similarity to the performance of existing soil conservation plant species (poplar and willow, see Figure 8) make it a prime candidate for consideration as a species to be used in erosion control (notwithstanding other potential issues such as tree ‘wildling’ spread, etc.). This confirms the view that some exotic species, many of which may be colonising species in their country of origin, have such rapid growth across a wide range of environmental conditions that make them excellent candidates for erosion control. Root lengths of exotic plants such as alder, poplar and willow significantly outperform our native plants, with only 3-year-old non-woody species such as carex and toetoe being close.

If similar trials are contemplated in future, we recommend that in order to obtain accurate interspecies comparisons over the first 1–3 years of plant age, plant materials that are of the same size at establishment will be required. An additional point worth noting is that once trees reach heights exceeding about 5 m tall, with root collar diameters greater than about 150 mm, the effort required to excavate and analyse the root systems takes proportionately much more time than for smaller trees. This explains why there is a general lack of quantitative root data for larger trees in the published literature.

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APPENDICES

Appendix 1: Photographs of root systems 3 years from planting

Oak

Radiata

Redwood

Blackwood

Cherry

Cypress

 **Alder**	 **Eucalypt**

Appendix 2: Allometric relationships

Species	**rcd(x, mm) vs Total root length (y, m)**	**R^2**	**rcd(x, mm) vs BGB (y, g)**	**R^2**
Redwood	$y = 0.022x^{1.97}$	0.72	$y = 0.0195x^{2.3575}$	0.94
Oak	$y = 1.53x - 24.40$	0.97	$y = 0.1853x^{1.9299}$	0.94
Eucalypt	$y = 0.002x^{2.31}$	0.99	$y = 0.0022x^{2.8692}$	0.98
Douglas fir	No data		No data	
Cherry[1]	$y = 0.0259x^{2.0447}$	0.80	$y = 0.0412x^{2.4987}$	0.83
Blackwood	$y = 0.017x^{2.0144}$	0.91	$y = 0.0124x^{2.6637}$	0.95
Alder	$y = 0.0269x^{2.1878}$	0.89	$y = 0.0896x^{2.311}$	0.93
Cypress	$y = 0.0634x^{1.9001}$	0.87	$y = 0.0363x^{2.4123}$	0.84
Radiata pine	$y = 0.0641x^{1.6207}$	0.88	$y = 0.0138x^{2.4631}$	0.96

Cherry = *Prunus serrulata* (see below)

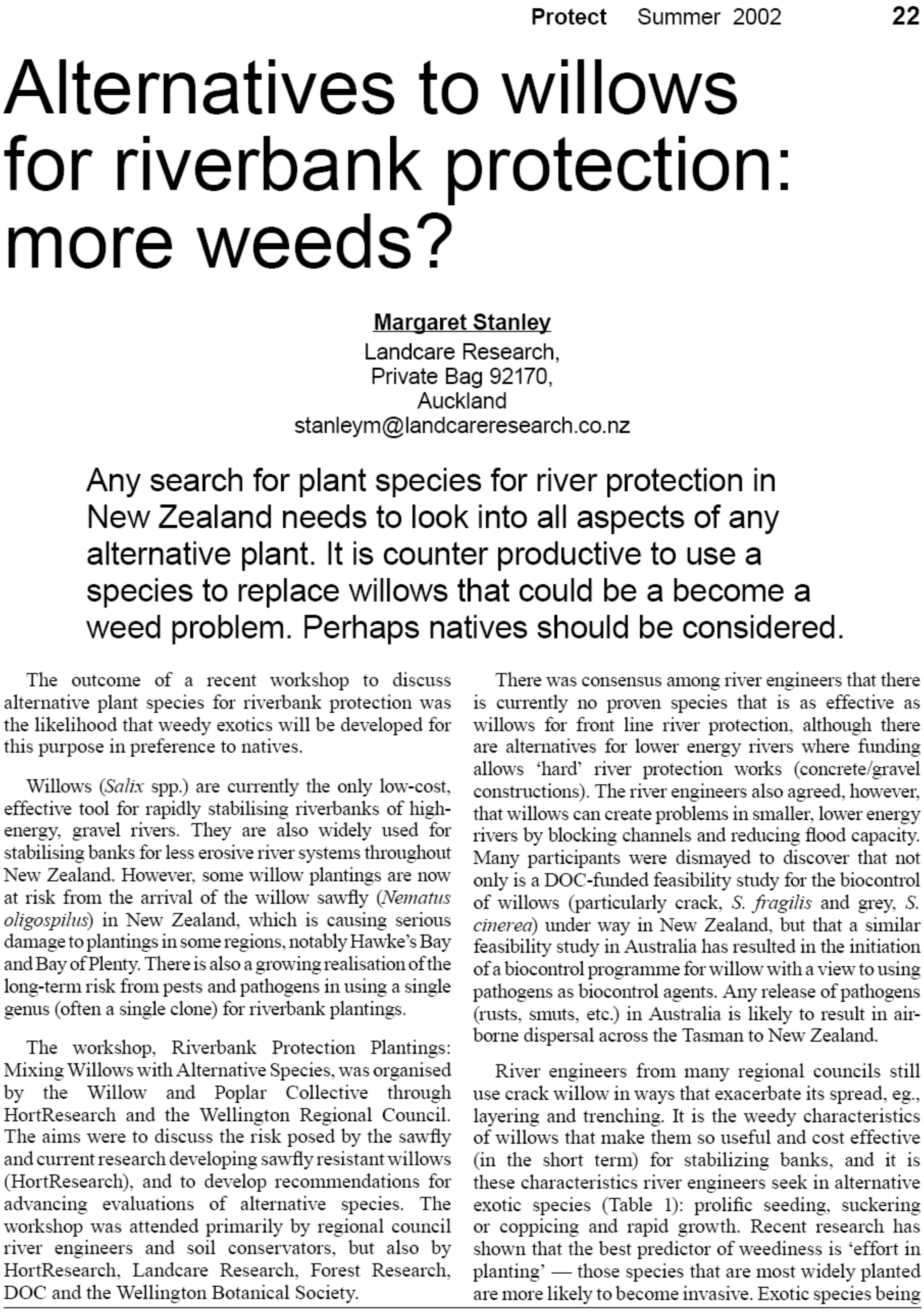
Prunus serrulata leaves and fruit Photo: Weedbusters

Prunus serrulata
Japanese hill cherry

- Deciduous, small tree up to 12 m tall
- Produces suckers
- Leaves with long, pointy, marginal teeth and elongated points at the leaf tip
- Branches and young stems have a silky sheen
- Clusters of flowers, white to deep pink, appear in spring
- Fruit typically red to black although cultivated varieties often do not fruit

http://ecan.govt.nz/publications/General/wilding-prunus-species-wom-feb12.pdf

Appendix 3: Stanley (2002)



Protect Summer 2002 22

Alternatives to willows for riverbank protection: more weeds?

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Any search for plant species for river protection in New Zealand needs to look into all aspects of any alternative plant. It is counter productive to use a species to replace willows that could be a become a weed problem. Perhaps natives should be considered.

The outcome of a recent workshop to discuss alternative plant species for riverbank protection was the likelihood that weedy exotics will be developed for this purpose in preference to natives.

Willows (*Salix* spp.) are currently the only low-cost, effective tool for rapidly stabilising riverbanks of high-energy, gravel rivers. They are also widely used for stabilising banks for less erosive river systems throughout New Zealand. However, some willow plantings are now at risk from the arrival of the willow sawfly (*Nematus oligospilus*) in New Zealand, which is causing serious damage to plantings in some regions, notably Hawke's Bay and Bay of Plenty. There is also a growing realisation of the long-term risk from pests and pathogens in using a single genus (often a single clone) for riverbank plantings.

The workshop, Riverbank Protection Plantings: Mixing Willows with Alternative Species, was organised by the Willow and Poplar Collective through HortResearch and the Wellington Regional Council. The aims were to discuss the risk posed by the sawfly and current research developing sawfly resistant willows (HortResearch), and to develop recommendations for advancing evaluations of alternative species. The workshop was attended primarily by regional council river engineers and soil conservators, but also by HortResearch, Landcare Research, Forest Research, DOC and the Wellington Botanical Society.

There was consensus among river engineers that there is currently no proven species that is as effective as willows for front line river protection, although there are alternatives for lower energy rivers where funding allows 'hard' river protection works (concrete/gravel constructions). The river engineers also agreed, however, that willows can create problems in smaller, lower energy rivers by blocking channels and reducing flood capacity. Many participants were dismayed to discover that not only is a DOC-funded feasibility study for the biocontrol of willows (particularly crack, *S. fragilis* and grey, *S. cinerea*) under way in New Zealand, but that a similar feasibility study in Australia has resulted in the initiation of a biocontrol programme for willow with a view to using pathogens as biocontrol agents. Any release of pathogens (rusts, smuts, etc.) in Australia is likely to result in air-borne dispersal across the Tasman to New Zealand.

River engineers from many regional councils still use crack willow in ways that exacerbate its spread, eg., layering and trenching. It is the weedy characteristics of willows that make them so useful and cost effective (in the short term) for stabilizing banks, and it is these characteristics river engineers seek in alternative exotic species (Table 1): prolific seeding, suckering or coppicing and rapid growth. Recent research has shown that the best predictor of weediness is 'effort in planting' — those species that are most widely planted are more likely to become invasive. Exotic species being

River protection alternatives Continued

promoted as viable alternatives include *Acacia dealbata* and *A. melanoxylon*, both of which are serious weeds in South Africa where they are current targets in biological control programmes. These acacias are also currently being targeted for control by DOC because of their increasing invasiveness in New Zealand.

The use of native species as alternatives for riverbank protection was discussed at the workshop. However, lack of information about the root systems of native species, and the perception that natives are expensive, have slow growth rates and require high initial maintenance, are likely to restrict the use of natives in the front line of river protection. Field trials quantifying growth rates, coppicing ability and root structure of native species alongside willows is necessary to convince river engineers to use natives in riparian areas. Trials could also aim to decrease establishment costs and develop planting and maintenance guidelines specific to these riparian zones. Willows inter-planted with native species (nurse plant strategy) may offer rapid bank stabilisation while reducing weed impacts and enhancing biodiversity values when willows are removed in the medium term.

Greater interaction between regional council biosecurity staff and river managers may help raise awareness of the invasiveness of particular species used in riverbank protection plantings. River engineers and managers should be encouraged to trial native species rather than exotic weedy species. The species currently being promoted as alternative species pose a serious threat to the biodiversity of riparian and wetland areas. Although initial planting and establishment costs of willows and other exotics may be low, long-term maintenance costs can be high (willows must be maintained or they can cause erosion and flooding) and do not include the costs of removing willows/exotics from streams and wetlands where their impact is most severe.

River protection alternatives Continued

Species	Countries in which these species are invaders
Acacia dealbata Silver wattle	South Africa[1,2], Canada, USA, New Zealand
Acacia melanoxylon Tasmanian blackwood	South Africa[2], Canada, USA[4], New Zealand
Alnus cordata Italian alder	New Zealand (D. Stephens, DOC Waikato Conservancy)
Alnus glutinosa Black alder	Canada, New Zealand, Australia, South Africa
Alnus incana Grey alder	
Alnus rubra Red alder	New Zealand (D. Stephens, DOC Waikato Conservancy)
Casuarina cunninghamiana River she-oak	South Africa[2], USA[4]
Casuarina glauca Swamp she-oak	USA[4], New Zealand
Chaemaecytisus palmensis Tree Lucerne	Australia, New Zealand
Elaeagnus angustifolia Russian olive	USA[4]
Platanus acerifolia London plane	NOTE: *Platanus occidentalis* (sycamore) is highly invasive in New Zealand
Platanus orientalis Oriental plane	
Populus euramericana Veronese, Crowsnest, Fraser, Selwyn	
Populus hybrids Tasman, Otahoua, Weraiti, Toa, Kawa	
Populus alba X *glandulosa* Yeogi 1	NOTE: *Populus nigra* and *Populus alba* are invaders in USA, Canada, South Africa, New Zealand
Salix spp. Shrub willows (not *S. cinerea*)	Australia
Tamarix chinensis Tamarisk	USA[4], Australia, Canada, South Africa[1,3]
Ulmus pumila Siberian elm	USA

Table 1. Recommended list of alternative exotic species for riverbank protection. This list was circulated among all Regional Councils to encourage trial plantings of these species. Search for invasiveness was conducted for South Africa, Australia, New Zealand, USA and Canada. The invasiveness of some species is unknown. However, there is a high probability of invasiveness where another species in the genus is invasive.

1) Declared Weed Invader in South Africa: Prohibited plants. Must be controlled, or eradicated where possible (except in biocontrol reserves, which are areas designated for the breeding of biocontrol agents).

2) Declared Invader Plant in South Africa: Mainly commercial plantation spp. but also plants for woodlots, animal fodder, soil stabilisation, etc. Allowed only in demarcated areas under controlled conditions and in biocontrol reserves. Prohibited within 30 m of the 1:50 year floodline of watercourses or wetlands, or as directed by the executive officer.

3) Declared Invader Plant in South Africa: Mainly ornamental spp. No further planting allowed (except with special permission) No trade in propagative material. Existing plants may remain but must be prevented from spreading. Prohibited within 30 m of the 1:50 year floodline of watercourses or wetlands, or as directed by the executive officer.

4) Noxious weed in USA.