Rehabilitation of lowland indigenous forest after mining in Westland

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CONTENTS

Abstract

Rehabilitation techniques for native forest have been investigated at an opencast coal mine site in cut-over beech forest on alluvial river terraces at Giles Creek near Reefton, Westland.

A pilot trial, on an existing overburden dump, illustrated the difficulty of establishing native tree and shrub species on unmodified mine spoils where there had been minimal soil replacement, and indicated the necessity of correct site preparation techniques to overcome such factors as poor drainage.

The survival and growth of nursery-raised native woody species and natural regeneration were examined in three covering treatments consisting of (1) overburden gravel, (2) mixed forest soil, and (3) layered forest soil. Survival of bare-root and container-grown plants, 4.5 years after planting, was better in gravel than in mixed and layered soil because of poor survival of beech species in forest soil (due to root rot fungi). However, plant growth in overburden gravel was minimal. Height growth in layered soil was nearly twice that in mixed soil. Adventive rush species dominated natural regeneration in mixed soil because of poorer drainage, whereas native and adventive herb species dominated in layered soil.

Field and glasshouse trials showed that nitrogen was the major deficient element for plant growth in overburden materials containing little or no soil or organic material. Positive responses to phosphorus were obtained in gravels and mixed soil, but not in material containing fine sandstone associated with the coal seams.

Seeding was found to be successful for establishing pioneer shrub species such as karamu and manuka.

A trial has been established on a mined, gorse-prone, alluvial site to examine the establishment of native species in the presence and absence of gorse and pioneer shrubs.

1. Introduction

The objective of this project was to investigate methods for rehabilitation of native tree and shrub species after opencast mining operations on alluvial terrace land in Westland.

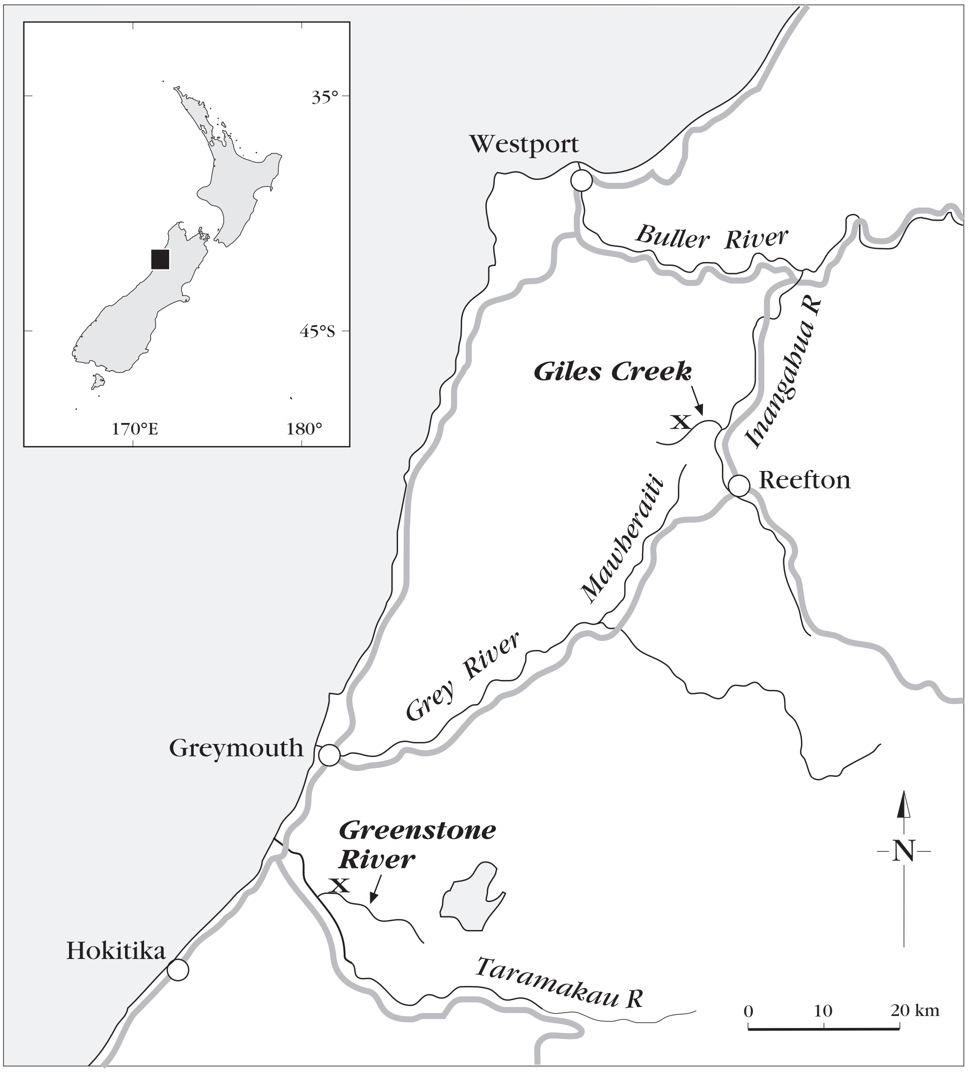
Site restoration, or rehabilitation, is a general requirement of mining under Clause 17 of the Resource Management Act, 1991. Most efforts to reclaim mined land have focused on the establishment of pasture or exotic plantation forestry. However, significant mineral and coal deposits under, or adjoining, areas of indigenous forest are being mined or prospected within public conservation lands, administered by the Department of Conservation (DOC), especially in the Coromandel and Westland regions. Rehabilitation to indigenous forest is now a consent requirement for many mining licences, particularly on public conservation land. Information is available on methods for the establishment of native forest species on sites where there has been little soil disturbance (Beveridge et al. 1981, 1985; Evans 1983; Porteous 1993), but is lacking for mined sites where soil disturbance has been catastrophic.

In 1990, Forest Research (formerly known as the Forest Research Institute), Christchurch, and Landcare Research (formerly Department of Scientific and Industrial Research Land Resources), Palmerston North, staff initiated a collaborative project to examine techniques for revegetating alluvial terrace land disturbed by mining in indigenous forest areas in Westland for DOC. Mining for gold or coal is widespread on a range of alluvial sites in Westland, including areas of public conservation land (Mew & Ross 1997). The collaborative research has been carried out on a DOC mining lease at Giles Creek, near Reefton, (Figure 1) where Dunollie Coal Mines Ltd. are extracting coal by opencast mining from a terrace site covered by beech forest.

The Forest Research rehabilitation project was initiated with a reconnaissance description of the indigenous forest, and a trial to test establishment of native woody species on an existing overburden dump formed by the mining operation. In earlier episodes of mining in Westland, soil was generally not salvaged and replaced on overburden materials or tailings after mining, a practice which is considered to have substantially slowed the regeneration of native forest (Fitzgerald 1987). There are no reports of studies for Westland, or elsewhere in New Zealand, however, which have compared the performance of native forest species on overburden materials with that where soil has been replaced. With pasture and crop species, studies have generally shown greater productivity where soils have been replaced as separate layered horizons (topsoil over subsoil) than as mixed horizons (Widdowson and McQueen 1990; Power et al. 1981; Simcock 1993), though not in all cases (Simcock 1993). A major focus of the research was therefore to examine the impact of soil salvage, soil replacement and horizon mixing on the survival, growth and nutrition of nursery-grown, native tree and shrub species, and on natural regeneration. Landcare Research staff played a key role in the design and installation of the soil treatments in this study. The effect of deep ripping to loosen overburden gravels compacted by machinery during soil replacement also was examined. Other studies at Giles Creek have included field and glasshouse fertiliser trials with native species on different substrates, and a trial to test establishment of native species by seeding. A trial has recently been initiated to examine establishment of native species on a gorse-prone mining site.

Much of the research has been published in scientific journals and popular articles. This report summarises the published material and presents some of the unpublished research on establishment by seeding, fertiliser use, and establishment of native species on a gorse site.

Figure 1. Map showing the location of Trials 1–6, Giles Creek and Trial 7, Greenstone.



2. Study site, Giles Creek

Most of the research has been located on alluvial river terraces at the Giles Creek coal mine, Inangahua catchment, North Westland (Figure 1). Elevation at the mine site is 200 m and annual rainfall is 2 900 mm (Davis et al. 1997).

Soils are dominantly allophanic brown soils of the Ahaura series, with acid brown soils of the Ikamatua series on younger terraces, and acid gley soils of the Maimai series occurring in poorly drained sites (soil nomenclature follows Hewitt, 1992) (Ross & Mew 1993). The soil organic and topsoil layers have an average depth of 30 cm, and overlie subsoil layers of similar total thickness. The soils overlie varying thicknesses of alluvial gravels which, in turn, overlie the coal seams. Mudstone and sandstone layers are associated with the coal seams.

The forest in the study site was cut over in the early 1980s for podocarps, (mainly miro (*Prumnopitys ferrugineus*) and rimu (*Dacrydium cupressinum*)), red beech (*Nothofagus fusca*), and some silver beech (*N. menziesii*). A forest structure was still present prior to mining. Beech species dominate the canopy and sub-canopy of forest adjoining the mine site.

3. Forest description, Giles Creek

Objective: To measure the species composition of forest destined for removal in the mining operation at Giles Creek to determine suitable rehabilitation species.

3.1 METHOD

Forest reconnaissance descriptions were made of 11 plots located along a traverse in cut-over forest destined for mining, using the method described by Allen & McLennan (1983). The plots were located at approximately 50 m intervals, commencing 50 m from the access road, along a 500 m long traverse. Additional plots were located in unlogged terrace forest at the south-eastern end of the mine area, and in seral vegetation on previously disturbed areas near the access road.

3.2 RESULTS

The forest that existed before the mining operation was cut-over in the early 1980s (Davis & Langer 1997b). Red beech, podocarps (mainly miro and rimu), and some silver beech were extracted, but a cut-over forest structure remained between skid tracks. The sites described were on a terrace, with good surface stability and generally adequate drainage. A full description of the cut-over forest, before the mining front, and of nearby unlogged forest, is given in Davis & Langer (1997b), and a species list for the terrace beech forest is appended (Appendix 2).

The canopy of the remaining cut-over forest was predominantly silver beech, in a mixture with red beech and mountain beech (*Nothofagus solandri* var. *cliffortioides*), with the occasional cedar (*Libocedrus bidwillii*). The beeches also were present in the sub-canopy, with silver beech predominant. Mountain toatoa (*Phyllocladus alpinus*) also was often dominant in this generally low-density, understorey tier. The shrub understorey, below 5 m, had an array of species, varying in abundance at each site. Dominant species included the three beech species, mountain toatoa, pepperwood (*Pseudowintera colorata*), rohutu (*Neomyrtus pedunculata*), and *Coprosma* sp. aff. *parviflora*. The vascular plant ground cover was even more diverse, with an abundance of ferns, including bracken (*Pteridium esculentum*). Seedlings of beech species were present in moderate numbers, and podocarp seedlings generally were present in the vicinity of seed trees.

Unlogged, terrace forest adjoining the mine consisted of a red/silver beech mixture with red beech sometimes dominant. The understorey was diverse, though the 5–12 m tier was of low density with both beech species, lancewood (*Pseudopanax crassifolius*), wineberry (*Aristotelia serrata*), and broadleaf (*Griselinia littoralis*) present. The shrub tier was predominantly pepperwood (*Pseudowintera colorata*), and *Coprosma* sp. aff. *parviflora*, with other species similar to those found in the cut-over forest. The vascular plant ground cover was generally high and diverse, and beech, miro, and kahikatea (*Dacrycarpus dacrydioides*) seedlings were usually present.

The disturbed areas of well drained and reasonably stable granite gravel mounds formed from drainage cuts alongside the access road had a 10–40% ground cover of vascular plants. Himalaya honeysuckle (*Leycesteria formosa*) predominated and extended to about 3 m in height. Other species present included silver beech, wineberry, mountain toatoa, bracken, rush species, ferns, and some grasses. Gorse (*Ulex europaeus*) was generally absent on disturbed sites in the area.

3.3 DISCUSSION

Beech species dominated the canopy and sub-canopy tiers of cut-over forest on the main river terrace before the mining front at Giles Creek. Silver, red and mountain beech, and prominent species in the lower tiers, including lancewood, wineberry, pepperwood, *Coprosma* sp. aff. *parviflora,* mountain toatoa, and Hall's totara (*Podocarpus hallii*), could all be considered as appropriate rehabilitation species after mining at Giles Creek. Broadleaf, also, was prominent in the lower tiers, but is too palatable to animals to be recommended for use in rehabilitation (see results of Trial 1). The occurrence of three of these species, namely silver beech, wineberry, and mountain toatoa, in seral vegetation on disturbed sites suggests that they may be particularly useful rehabilitation species.

4. Native forest species on raw overburden trial

4.1 TRIAL 1: ESTABLISHMENT OF NURSERY-RAISED NATIVE FOREST SPECIES ON RAW OVERBURDEN

Objective: To provide information on the survival and growth of native tree and shrub species on an existing overburden dump which had minimum soil replacement. Additional objectives were to compare establishment of bare-root and container-grown stock of native forest species, and to examine the need for animal control measures for plantings of native species at Giles Creek.

4.1.1 Method

The material capping the dump was composed mainly of finely-weathered material from the granite gravels that overlay the coal seam, but included forest soil horizon and sandstone interburden material (Davis & Langer 1997b). The material was moderately acid, had low or very low levels of organic carbon, total N, available P, and exchangeable cations (K, Ca, Mg), and cation exchange capacity was low. Chemical analysis of the raw overburden material is provided in Table 1, Appendix 1. Prior to establishment of the trial, the area had a herbaceous vegetation cover dominated by rush (*Juncus* spp), lotus (*Lotus pedunculatus*), and Yorkshire fog (*Holcus lanatus*). This cover was removed by spraying with herbicide in late July, 1990, and regenerating vegetation was controlled with release sprays applied in May 1991 and December 1992.

Ten tree and shrub species were planted in the trial (Table 1). Of these, six were planted as both bare-root and container-grown stock, the remainder were planted as bare-root stock only. The stock available at the time of planting was not grown specifically for the trial, and stock types of some species varied considerably in size, largely because of differences in age. For silver beech, in addition to bare root and container stock, plants were transplanted from near the mining site for comparison with nursery-grown stock. This technique had been used with some success previously by the mining company at Giles Creek.

A single tree of each species and stock-type combination was planted randomly in each of ten blocks (each block consisting of two adjacent rows) in a fenced plot, and also in an adjacent unfenced plot (20 blocks in total). The fenced/unfenced comparison was used to provide information on animal browsing. The plants were spaced at one metre intervals, along rows one metre apart. Plant survival and heights were measured periodically to determine treatment effects. The final assessment was made in April 1994.

4.1.2 Results

This trial, on an existing overburden dump with minimum soil replacement, was characterised by high mortality in most species, and slow growth rates in surviving plants of all species (Table 2) (Davis & Langer 1997b). The high mortality and slow growth rates are attributed to a combination of factors, including poor drainage, soil infertility, particularly nitrogen deficiency, browsing by hares, and, in the case of ribbonwood, the poor quality of planting stock. Despite being located on the top of an overburden dump, the site was poorly drained, and surface water lay in low-lying microsites for long periods

TABLE 1. PLANT SPECIES AND MEAN HEIGHTS OF BARE-ROOT AND CONTAINER-GROWN STOCK AT PLANTING, TRIAL 1, GILES CREEK.

SPECIES	COMMON NAME	HEIGHT (cm) BARE-ROOT	CONTAINER
Nothofagus fusca	red beech	41	80[1], 19[2]
Nothofagus menziesii	silver beech	52[3], 47[4]	54
Nothofagus solandri var. *cliffortioides*	mountain beech	82	-
Podocarpus totara	totara	41	42
Dacrycarpus dacrydioides	kahikatea	52	67
Griselinia littoralis	broadleaf	46	15
Coprosma robusta	karamu	34	-
Pittosporum colensoi	rautawhiri	47	-
Coriaria arborea	tree tutu	24	-
Plagianthus betulinus	ribbonwood	91	50

[1] 2.5-year-old stock

[2] 1-year-old stock

[3] nursery-grown stock

[4] transplanted from forest

after rain. Plant growth was poor and mortality was high in plants established in these depressions, indicating that good drainage is likely to be important in establishing native woody species on rehabilitated mine sites in medium-to-high rainfall environments.

Survival was highest in kahikatea, indicating a tolerance of this species to poorly drained substrates. Two species, broadleaf and karamu (*Coprosma robusta*), survived well in the fenced plot, but these species were severely browsed in the adjoining unfenced plot. Six of the ten species were planted as both bare-root and container-grown stock. For most species, bare-root stock performed as well as container plants; the former have advantages in terms of cost of stock, handling logistics, and cost of planting. Transplants of small, silver beech from nearby forest fared almost as well as nursery-raised stock.

4.1.3 Discussion

The results of Trial 1 illustrate the difficulty of establishing native tree and shrub species on unmodified mine spoils where there has been minimal soil replacement, and indicate the necessity for correct site preparation techniques, to overcome such factors as poor drainage and substrate infertility.

The use of palatable species such as broadleaf and karamu should be avoided unless adequate animal control is possible. Severe browsing of both species occurred in the third year of the trial, indicating that, to be successful, animal control work would need to be maintained over a long period. Survival of red, silver, and mountain beech on the overburden dump was poor and the need for further work, to determine causes of failure and successful establishment practices for these species, is noted later. However, despite poor survival of beeches in the trial, large wilding transplants (at least 1 m tall) of silver beech, by the miner on a similar substrate adjoining the trial, have established and grown well.

TABLE 2. SURVIVAL AND HEIGHT GROWTH OF NATIVE TREE AND SHRUB SPECIES FOUR YEARS AFTER PLANTING ON AN OVERBURDEN DUMP. ALL VALUES ARE MEANS OF BARE-ROOT AND CONTAINER STOCK. VALUES FOR SURVIVALS ARE MEANS OF FENCED AND UNFENCED PLOTS, THOSE FOR HEIGHT GROWTH ARE FROM THE FENCED PLOT ONLY. TRIAL 1, GILES CREEK.

SPECIES	SURVIVAL (%)	HEIGHT GROWTH (cm/year)
Red beech	1	-
Silver beech	20	8
Mountain beech	5	3
Totara	75	3
Kahikatea	100	5
Broadleaf	42	3
Karamu	50	16
Rautawhiri	35	16
Tree tutu	10	4
Ribbonwood	17	–1

5. Soil salvage and replacement trial

5.1 TRIAL 2: SOIL SALVAGE AND REPLACEMENT

Objective: To determine the effect of soil salvage and replacement, horizon mixing, and ripping of underlying gravels on the survival and growth of nursery-raised plants, and on natural regeneration.

5.1.1 Method

Substrate

The area of the Giles Creek mine site selected for the soil replacement trial consisted of alluvial gravel overburden material arising from the mining operation, which had been transported and dumped on the site, to a depth of approximately 10 m, and levelled to form a platform prior to 1991 (Davis et al. 1997). The material had been compacted by earthmoving machinery. Three plots of approximately 0.1 ha were defined and, in February 1991, one half of each plot was ripped at 1.5 m intervals to a depth of 80 cm.

Using an hydraulic excavator, soil was stripped from logged forest ahead of the mining front after tree stumps had been removed. The stripping was achieved in two ways: either all O, A, B and a minimum amount of C horizon material was removed as a mixture, or the O and A horizon material was removed separately from the B and C material.

Between February 1991 and February 1992, each 0.1 ha plot was covered with one of the following to a depth of 60 cm:

1. Overburden gravels;
2. Mixed soil: mixed organic, mineral topsoil and subsoil material;
3. Layered soil: 30 cm of mixed organic and mineral topsoil material over 30 cm of predominantly subsoil material.

Open drains, 1 m deep, were dug round each plot to intercept run-off water from the surrounding area, and to prevent water movement between plots.

Chemical characteristics of the stripped soil materials, sampled from the trial plots prior to planting, and, for comparison, of in-situ Ahaura soil were determined by Landcare Research (Table 2, Appendix 1). Soil materials from the trial plots were re-sampled for the same suite of analyses after five years.

Species and planting stock

Within each of the ripped and unripped treatments in each of the three covering treatments, two replicates, each of 17 species-planting stock combinations (Table 3) were planted in early September 1992. Within replicates, species planting stock combinations were planted in rows containing either 12 or 13 individual plants, spaced at 1 m intervals. Rows were spaced 1 m apart.

With the exception of kahikatea and totara, plants for the trial were raised from seed collected from the Maimai Ecological District (North Westland Ecological Region, McEwen 1987) in autumn 1990. Plants of the two podocarp species were four-year-old seedlings obtained from a nursery and were not of Westland origin. Seed of the remaining species was germinated in seed trays in October 1990 and subsequently transplanted into 'root trainers', and grown on prior to transplanting into polythene bag containers (container stock), or into field nursery beds (bare-root stock) producing two-year-old seedlings. Not all species were grown as both container and bare-root stock (Table 3). Because of the different nursery growing conditions, different stock types of the same species varied in size at the time of planting.

Seven of the species used were recommended by Norton (1991) as potential species for restoration of alluvial or glacial outwash surfaces disturbed by mining in the Grey-Inangahua bioclimatic region. Three additional species, namely koromiko, fuchsia and kahikatea, were included because of their occurrence as either seral or tall forest species on alluvial terraces in the immediate vicinity of the trial site. One additional species (totara, *Podocarpus totara*) was included because of its widespread occurrence on young, alluvial terraces in the region, prior to its removal by logging. Beeches were included because they were a dominant component of the stripped forest, even though survival of nursery-raised stock has often been poor (Wardle 1984).

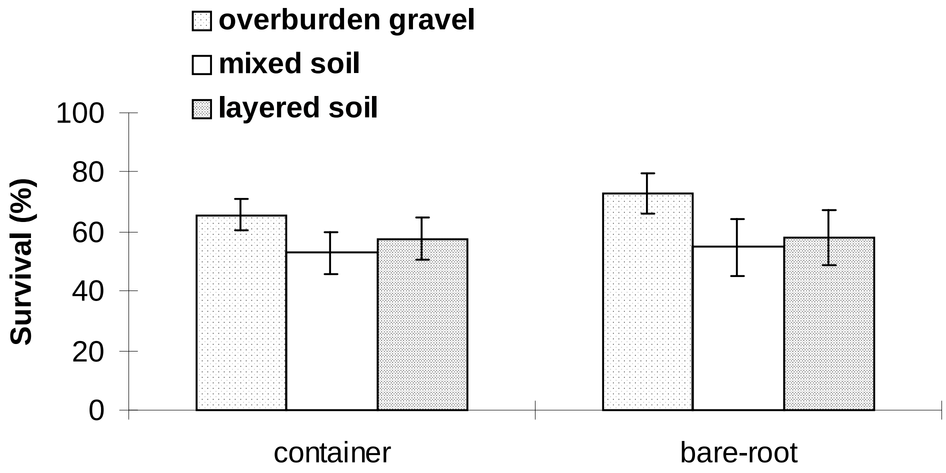
All plants were sprayed with 'Treepel' (egg powder mixed with acrylic resin sticker) animal repellent at planting, and again at three months after planting. Some hand weeding of white clover (*Trifolium repens*), which developed around the base of container-grown stock, was also undertaken. Apart from hand weeding of occasional gorse and broom (*Cytisus scoparius*) plants, no other weed control was carried out.

The height of all plants was measured at planting, and survival and height were measured in spring and autumn for the first two years, and thereafter in autumn. Current season foliage of species with good survival on all three covering

TABLE 3. SPECIES PLANTED AND MEAN HEIGHTS OF BARE-ROOT AND CONTAINER-GROWN STOCK AT PLANTING. TRIAL 2, GILES CREEK.

	SPECIES	COMMON NAME	HEIGHT (cm)	
			BARE-ROOT	CONTAINER
Trees	*Carpodetus serratus*	Marbleleaf	-	20
	Dacrycarpus dacrydioides	Kahikatea	72	98
	Nothofagus fusca	Red beech	39	43
	Nothofagus solandri var. *cliffortioides*	Mountain beech	43	30
	Podocarpus totara	Totara	67	-
Shrubs	*Aristotelia serrata*	Wineberry	-	38
	Coprosma robusta	Karamu	38	25
	Coriaria arborea	Tree tutu	16	23
	Fuchsia excorticata	Fuchsia	-	30
	Hebe salicifolia	Koromiko	31	33
	Leptospermum scoparium	Manuka	-	45

Figure 2. Survival of container-grown and bare-root plants in three covering treatments, 4.5 years after planting. Values are means of ripped and unripped plots, and of 10 and 7 species for container and bare-root plants respectively. Bars show ± 1 se. Trial 2, Giles Creek.



treatments was collected in April 1994, for determination of nutrient concentrations. Collections for three species (koromiko (*Hebe salicifolia*), karamu, kahikatea) were made from both types of planting stock, while collections for a further four species—manuka (*Leptospermum scoparium)*, wineberry, marbleleaf (*Carpodetus serratus*), totara—were from plants from one stock type only. Foliar nutrient concentrations were determined at the Invermay AgResearch laboratory.

Both beech species included in the trial suffered severe mortality in mixed and layered soil. Six mountain beech and two red beech plants, ranging from relatively healthy to recently dead, were excavated from the layered soil treatment in July 1994 and examined for the presence of pathogens.

Natural regeneration

To examine the effect of covering treatment on natural regeneration of native and exotic species, twenty 0.25 m^2 rectangular plots were established along four transects, located midway between randomly-selected, planted rows in the ripped half of each covering treatment in the soil replacement trial. Plots were located at 2 m intervals along the transects, unless rocks or woody debris prevented insertion of the metal pegs used to locate the plot corners; in such instances plots were sited at the nearest point along the transect where pegs could be inserted. Ground cover and the plant species present in each plot were recorded annually in summer or autumn, and the frequency of occurrence of each species was calculated.

5.1.2 Results

Soil chemistry

Changes in soil chemical properties over the 5 year duration of monitoring were generally insignificant. All samples showed declines in sulphate-S, especially the replaced subsoil of the layered soil treatment and mixed soil. This is thought to reflect leaching losses of sulphate. The only other notable change was a decrease of about 1.5% total carbon in the topsoil of the layered soil replacement. Decomposition of salvaged and replaced O and A horizon materials, accompanied by very low organic matter returns under the newly planted forest vegetation, accounts for this decline. Interestingly the carbon content of the mixed soil increased by about 0.5%, probably as a result of organic returns from the prolific growth of rushes which have dense root systems.

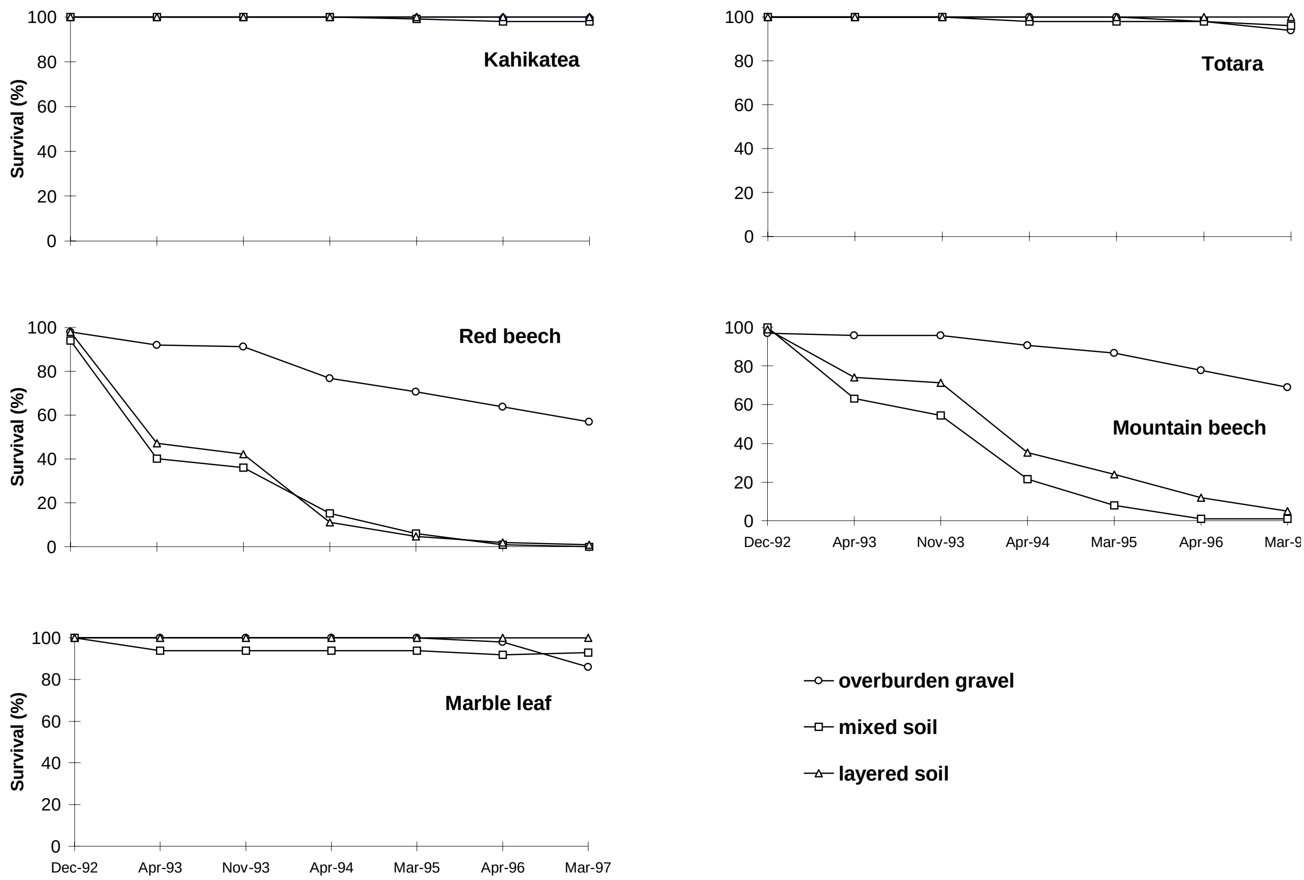


Figure 3. Survival of tree species in three covering materials after 4.5 years. Values are means of bare-root and container-grown stock, and of ripped and unripped plots. Trial 2, Giles Creek.

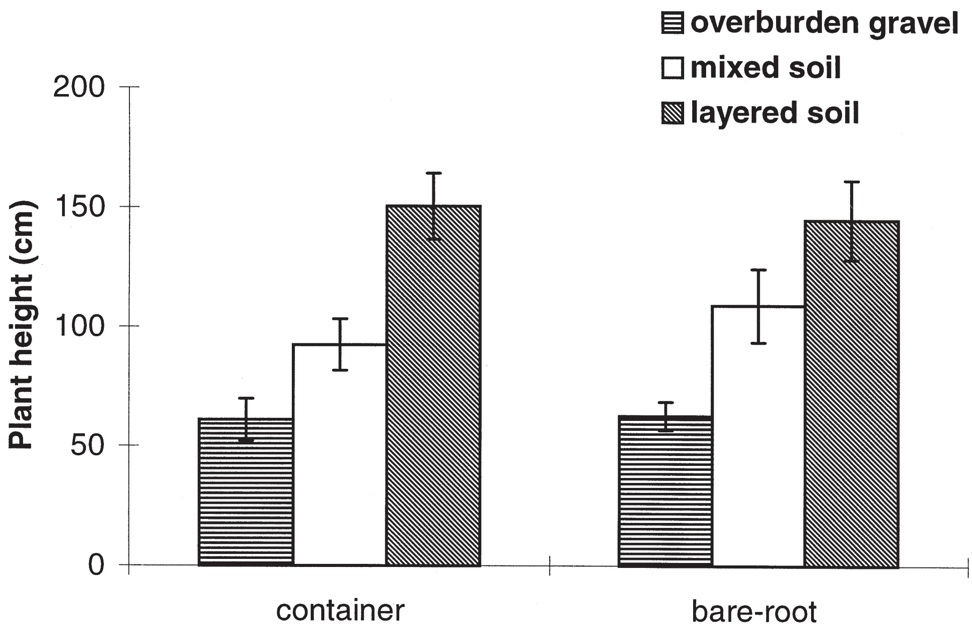
Survival and growth of nursery-grown plants in different covering materials

Plant Survival: After 4.5 years, mean plant survival of both container-grown and bare-root stock in overburden gravel exceeded that in mixed soil, while survival in layered soil was intermediate (Figure 2). The better overall survival in overburden gravel was largely due to high mortality of the beeches, in both soil covering treatments, while they survived relatively well in overburden gravel (Figure 3) (Davis et al. 1997).

In contrast, some species (kahikatea, totara, koromiko, marbleleaf, karamu, manuka) survived well in all three covering materials, while others (tree tutu (*Coriaria arborea*), fuchsia (*Fuchsia excorticata*)) survived poorly. In one species (wineberry), survival after 4.5 years was higher in layered soil than in overburden gravel or mixed soil. Most mortality in the beeches, tree tutu and fuchsia occurred during the first two years, and in the beeches and fuchsia most mortality in soil occurred over the summer periods, indicating that the mortality in these species may have been associated with moisture stress. While overall survival was high in overburden gravel, there was some indication of increasing mortality in some species (marbleleaf, karamu) in that material in the fifth year of the trial.

Plant Growth: Plant growth in the different covering materials was compared using species which survived well in all three substrates. Karamu was omitted from the comparison as, although it had high survival, it was frequently and heavily browsed by hares.

Figure 4. Height of container-grown and bare-root plants with more than 50% survival in all covering treatments, 4.5 years after planting. Karamu is omitted because of browsing. Values are means of 5 and 3 species, for container and bare-root plants respectively. Bars show ± 1 se. Trial 2, Giles Creek.



Mean plant height of both container-grown and bare-root stock in layered soil exceeded that in mixed soil which, in turn, exceeded that in overburden gravel (Figure 4). The difference between layered and mixed soil was apparent in all species and stock type combinations and, for the tree species, increased with time. Mean height growth over the duration of the trial was 10 cm in overburden gravel, 49 cm in mixed soil and 96 cm in layered soil. A few container-grown plants of the N-fixer, tree tutu, survived and appeared healthy in overburden gravel, but never exceeded a height of 60 cm, as summer growth was cut back over the winter period.

Foliar nutrient concentrations of nursery grown plants in different covering materials

Mean foliar nutrient concentrations of N, S, K and Cu in both mixed and layered soil exceeded those in overburden gravel (Figure 5). In contrast, mean concentrations of P, Ca, and Mn, and also of Al, which is potentially toxic, were lower in plants growing in soil than in overburden gravel. Only the mean concentration of N in layered soil substantially exceeded that in mixed soil, while the converse was true for Fe. Mean concentrations of P, S, K, Ca, Mg, B, Zn Cu, Mn, and Al generally were similar in the two soil treatments.

Effect of ripping on nursery-grown plants

Ripping of the underlying overburden material, to a depth of 80 cm, had no influence on mean plant survival or height of container-grown or bare-root stock in any of the three covering materials, and had no effect on foliar nutrient concentrations.

Natural regeneration

Little vegetative cover had developed on any of the substrates by the end of the first year after plot construction (Figure 6). Cover developed more rapidly over the following three years in layered, than in mixed soil but, in the fifth year, declined markedly in layered and increased in mixed soil, so that the two treatments had similar amounts of cover (c. 38–40%) five years after plot

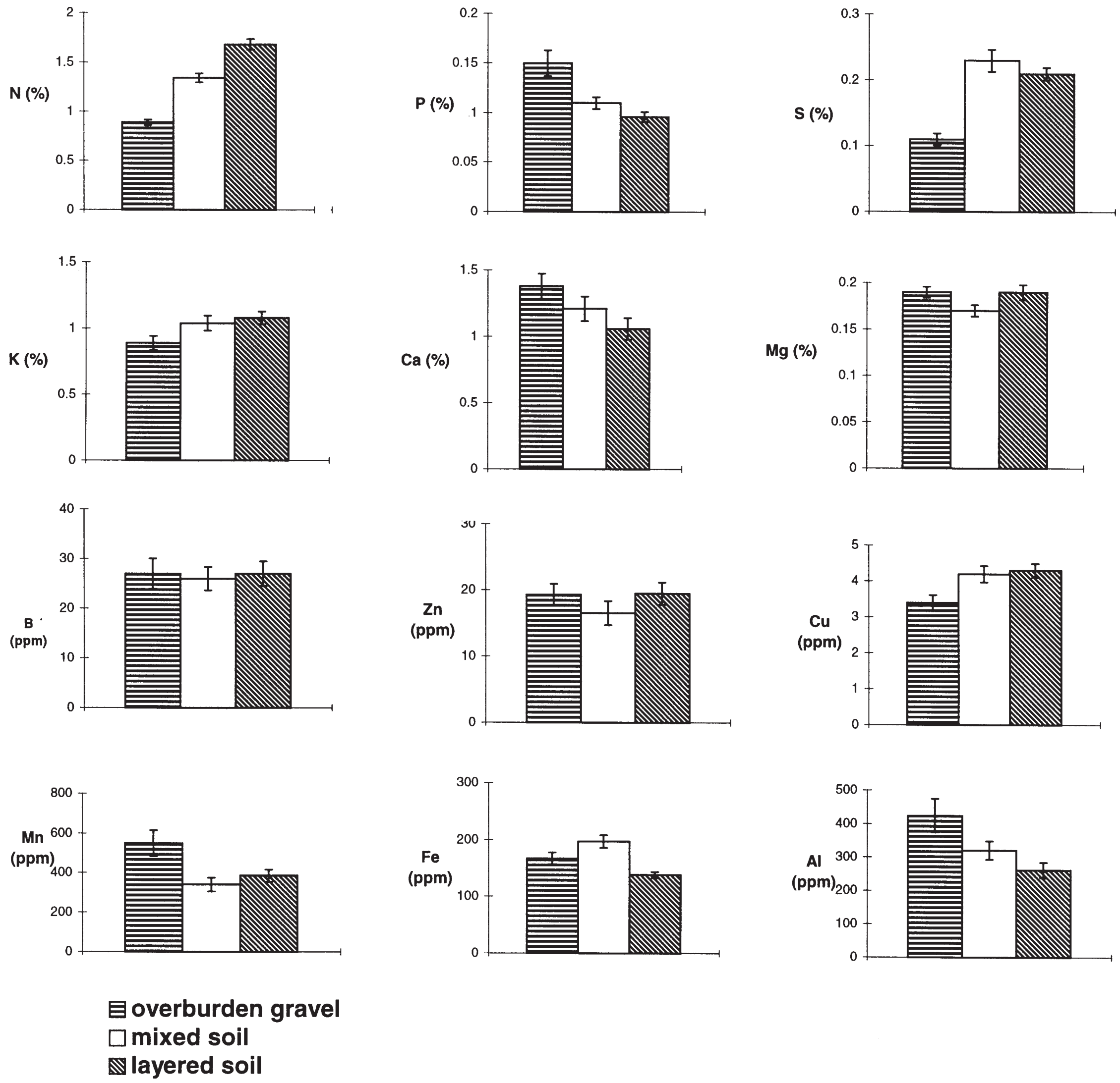


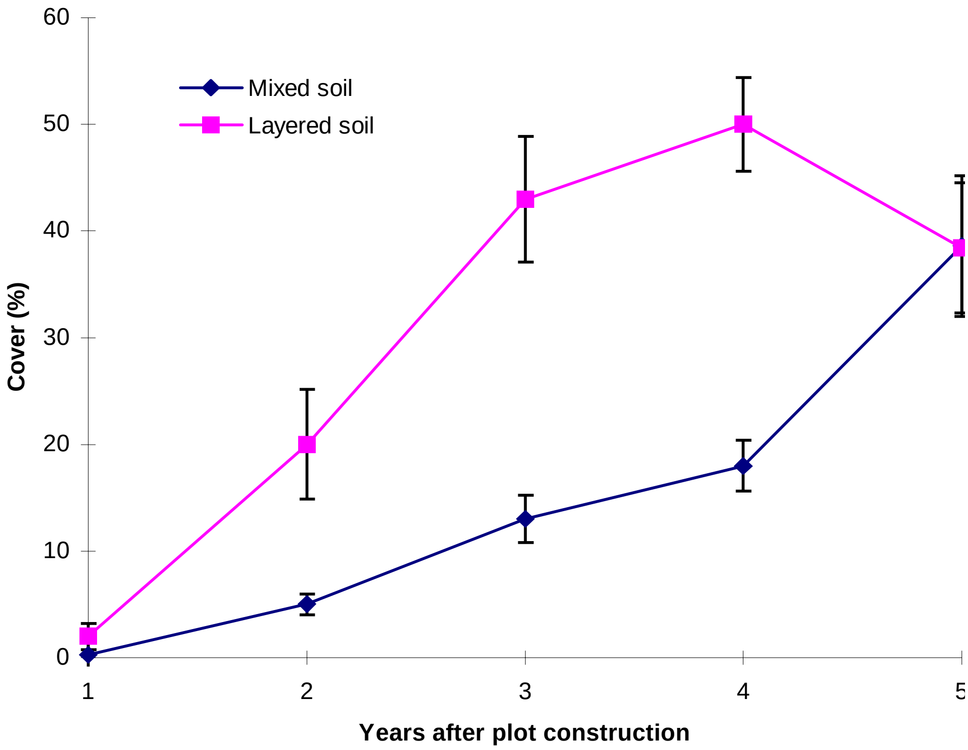
Figure 5. Mean foliar nutrient concentrations in three covering materials. Values are for current season foliage and are means of ripped and unripped plots, and of 10 species × planting stock combinations. Bars show ± 1 se. Trial 2, Giles Creek.

construction. Plant invasion in overburden gravel without soil covering was negligible, with ground cover remaining at less than 1% after five years.

The adventive flatweed species, *Hypochoeris radicata*, occurred at the highest frequency in both mixed and layered soil in the fifth year of the trial (species list, Appendix 3). In mixed soil, however, tall growing adventive rushes were physiognomically dominant. The trailing native herb, *Nertera depressa*, occurred at high frequency in both mixed and layered soil, and provided much of the ground cover in the latter treatment. Thus the invading vegetation in layered soil was of lower stature than in mixed soil; in mixed soil 75 % of plots had vegetation (mainly rush species) exceeding 50 cm in height, whereas only 15 % of plots in layered soil had vegetation over 50 cm. The total number of adventive and exotic species invading the plots was similar in the two treatments (Appendix 3).

Excluding seedlings arising from planted stock, only two seedlings of indigenous woody species (*Gaultheria antipoda* and a small leafed *Coprosma* species) were present in the regeneration plots after five years; both were present in layered soil

Figure 6. Development of ground cover from natural regeneration in mixed and layered soil. Values are means of ripped plots only, n=20. Ground cover in overburden (not shown) did not exceed 1%. Bars show ± 1 se. Trial 2, Giles Creek.



only. However, a number of mountain toatoa seedlings established in layered soil outside of the regeneration plots. No beech or podocarp seedlings other than mountain toatoa were present in the regeneration plots, or have been noted in the wider plot area. A few small silver beech plants, however, survived the soil stripping and replacement process, in layered soil only, and established well. Seedlings of the adventive woody shrub, Himalaya honeysuckle, established in regeneration plots in both layered and mixed soil.

By the end of the third growing season, substantial numbers of koromiko and manuka seedlings were present around the base of planted stock, in both layered and mixed soil, but not in overburden gravel material. The most vigorous seedlings in mixed soil were present in potting soil in planting sites of container-grown plants. No seedlings of other planted species were noted.

5.1.3 Discussion

Plant growth on gravels

Apart from the beech species, survival of planted stock was generally similar in the three covering materials. Growth of surviving plants, however, was poorest in overburden gravel mainly because of N deficiency. Mean foliar N and S concentrations were substantially lower in plants growing in overburden gravel than in those in both layered and mixed soil, while K and Cu concentrations were marginally lower. A glasshouse fertiliser trial with red beech and karamu, however, showed that P was the only macro-nutrient, other than N, likely to be deficient in overburden gravel, indicating deficiency of S and K to be unlikely. The high available P levels in overburden gravel (Table 2, Appendix 1), and foliar P concentrations of plants growing in that material (Figure 5), indicate that P deficiency also is unlikely to have limited growth there. No fertiliser trial or foliar diagnostic information is available to determine whether Cu deficiency may have limited plant growth in overburden gravel. Foliar concentrations of the potentially toxic element Al, in plants from overburden, exceeded those in both soils, but the pH of the gravel material (5.6) was too high for Al toxicity to occur. Tree tutu was the only N-fixing species included in the trial, and the few plants of this species which survived the establishment phase were the only plants of any species that appeared vigorous in overburden gravel, further suggesting that N deficiency was the primary factor limiting growth in that substrate.

Despite the location of the trial site in a high rainfall zone, short periods of drought may occur near the surface of the free-draining overburden material during summer, which could reduce growth over an initial growing season before plant roots extended to deeper layers (Jackson 1994). Water balance data show, however, that dry periods were restricted during the first growing season of the present trial (Jackson 1994), and are unlikely to have contributed to the poorer growth in overburden gravel.

Plant growth on replaced soil

Growth of both bare-root and container-grown plants was consistently better in layered than in mixed soil. Poor drainage is likely to have contributed to the inferior growth in mixed soil; the forest subsoil material has little structure, and even when mixed with topsoil and organic material from the forest floor, drainage remained restricted. Tensiometer and oxygen diffusion measurements showed that the mixed soil treatment remained saturated with water and deficient in oxygen for long periods after rainfall events, in contrast to the layered soil treatment (Jackson 1994). The dominant rush cover which developed reflects the poor drainage in mixed soil.

Improved N, and to a lesser extent P, nutrition also is likely to have contributed to the better growth in layered soil. Nitrogen was the only nutrient for which foliar concentrations were significantly greater in layered than in mixed soil. Two species (marbleleaf and kahikatea) responded to N in the presence of P at planting in an adjoining fertiliser trial in mixed soil (Section 6.3). One of these (kahikatea) responded to additional N applied at the beginning of the third growing season, and there was a response to P in the following (fourth) growing season. The foliar concentrations of the other nutrients and of Al were generally similar in the two soil covering treatments. Therefore, improved N and P availability appears to be the main nutritional benefit of replacing soil as layered rather than as mixed horizons.

The present results raise the question of whether subsoil horizons need to be salvaged and replaced in high rainfall environments. In lower rainfall zones, the water storage capacity of subsoils is likely to be important for plant survival and growth. Studies with crop species in North America have demonstrated the value of subsoil replacement in low and medium rainfall environments (Fehrenbacher et al. 1982; Halvorson et al. 1986), but there have been no studies conducted where precipitation approaches that at Giles Creek.

Survival of beech species

Survival of nursery-raised beech seedlings in other studies has often been poor; the causes of failure being attributed to smothering by grass, browsing by rabbits and hares, drought during the first summer, and unseasonal frosts (Wardle 1984, p. 280). In the present study smothering (or competition from other species) and browsing were not factors, and the high survival of both species in overburden gravel indicates that frosting also can be discounted. Most mortality occurred over the summer months suggesting that the poor survival was likely to be due to moisture stress. Since moisture stress would be expected to be greater in the freer draining gravels, the summer mortality in the replaced soils suggested a problem with water uptake, rather than with water availability, possibly caused by root rot pathogens in those substrates. Three species of root rot fungi, *Phytopthora cinnamomi, Pythium acanthium,* and *Py. ultimum*, were isolated from the roots of the plants excavated from layered-horizon soil and examined for pathogens in July 1994. All plants were infected by one or the other of the three species, predominantly the former, and one plant was infected by both species of *Pythium*. *Phytopthora cinnamomi* has been shown to kill two-year-old beech seedlings under high moisture conditions (Rawlings 1962). Recent research (Marschner & Dell 1994; Newsham, et al. 1995) indicates that mycorrhizal infection may protect roots from soil pathogens so it is possible that mycorrhizal interactions may be involved in resistance of wildings to root rot fungi, which caused mortality in the nursery-grown seedlings. New research by Landcare Research and Forest Research is now investigating the influence of mycorrhizae on the effect of forest soil pathogens on beech survival.

Mountain beech plants surplus to the trial were planted on a mudstone surface (arising from beneath gravel overburden) near the trial site at Giles Creek, and these showed good (83%) survival after three years and appear vigorous. In common with the overburden gravel, the mudstone contains no forest soil, suggesting that the presence of forest soil may have contributed to the high mortality of the beech species in both the mixed and layered soil treatments. The soil may provide a source of root rot fungi, and/or a suitable environment for their survival, growth and infection of beech plants. The failure of the beeches in soil is consistent with better natural establishment of beeches on raised surfaces such as rotting logs, stumps and root mounds (Wardle 1984, Allen 1987). Logs and stumps are clearly soil-free environments, while root mounds, which are caused by windthrow, are characterised by exposure of subsoil, which may provide a less favourable environment for root rot fungi than organic and topsoil material.

Effect of ripping of underlying gravels

Ripping of underlying overburden gravel, with open drainage channels surrounding each treatment, had no significant impact on the survival, growth or nutrition of either bare-root or container-grown plants. The unsorted overburden gravel contained a high proportion of coarse material which allowed good drainage and presumably inhibited significant compaction by machinery during soil placement. Tensiometer measurements showed that ripping had only a small effect on water potential in overburden gravel, and no effect on oxygen diffusion rate (Jackson 1994).

Effect of soil replacement on natural regeneration

Natural regeneration in overburden gravel was negligible. By the end of the second growing season after planting, the soil plots had assumed a markedly different appearance, with adventive rush species dominating in mixed soil, and the mat-forming native herb *Nertera depressa* dominating in layered soil. Although other species established over the following years, tall-statured rushes continued to dominate in mixed soil, while shorter vegetation dominated in layered soil. Ground cover developed more rapidly in layered than in mixed soil but cover never exceeded 50%, and, in the final assessment year, declined to be similar to that in mixed soil. The decline in cover may be associated with reduced summer rainfall over the 1996/97 summer; rainfall for the December to March period in the neighbouring Maimai catchment was 72% of normal for the years 1990–97 (J. Payne, pers. comm.). The relatively slow rate of cover development in both soil treatments indicates that there may be a substantial period of time after soil spreading, in the largely gorse-free environment at Giles Creek, when native forest species may be introduced, either by planting or seeding.

Apart from seedlings arising from planted stock, ten (45%) of the species recorded in the regeneration plots in layered soil at the final assessment and six (27%) of those in mixed soil were recorded in an inventory of forest immediately adjoining the mine site, but only 4 and 1 of these respectively were native species. These results suggest that soil replacement has only a limited capacity to introduce native species from the original forest, but the timing of the earthmoving operations in the present study (February) in relation to seedfall needs to be considered. Most seed of beech species, for example, is shed between the months of March and May (Wardle 1984, p. 259), while most seed germinates in spring in the first year after seedfall, with little seed remaining viable after 18 months (Wardle 1984, p. 265). The best time for carrying out soil stripping and replacement operations to obtain optimum numbers of viable seed may therefore be between June and September, after most seed fall has occurred, and prior to the period of peak germination, though this may only be useful following a good seed year. This also may apply to other woody forest species as seedlings of only one species, mountain toatoa, established in significant numbers in layered soil. Plants of this species may have arisen from seed spread by birds after the plots were constructed, as seedlings have been noted away from the trial site on disturbed areas adjoining forest.

6. Fertiliser trials

6.1 TRIAL 3: FIELD RESPONSE OF KARAMU ON RAW OVERBURDEN TO NITROGEN AND PHOSPHORUS FERTILISER

Objective: To determine the N and P requirements of karamu growing on an existing overburden dump.

6.1.1 Method

This fertiliser trial was established on the overburden dump at Giles Creek (Davis & Langer 1997a) adjacent to Trial 1, and the site and site preparation methods were as described for that trial. Soil chemical properties are as for Trial 1 (Table 1, Appendix 1).

The trial was planted with 30 cm high one-year-old, bare-root karamu plants in a fenced plot in early August, 1990. The plants were spaced at one metre intervals, along rows one metre apart. Four fertiliser treatments were applied at the time of planting: (1) no fertiliser (control), (2) superphosphate alone (110 g tree), (3) urea (24 g/tree) plus blood and bone (150 g/tree), and (4) urea (24 g/tree) plus blood and bone (150 g/tree) plus superphosphate (110 g/tree). The rates of elemental N and P applied in the four treatments were as follows (g/tree): (1) N=0, P=0; (2) N=0, P=10; (3) N=20, P=7; (4) N=20, P=17. Blood and bone was used in addition to urea, to supply N, to provide a slowly-available, organic form of N in case of rapid loss of inorganic N from urea by leaching. The fertiliser application, but without blood and bone, was repeated at the beginning of the third year, in September 1992. Fertilisers were applied by placement in a spade notch, about 5–10 cm deep and 10–20 cm from the stem base. The trial was laid out as a randomised block design with five replicates, each replicate consisting of five adjacent, individual plants per treatment. Plant heights were measured at establishment and periodically thereafter, to determine treatment effects.

6.1.2 Results

On the overburden dump, karamu responded significantly to treatments containing urea, and blood and bone (predominantly N), but not to superphosphate (P) (Figure 7). The response to urea and blood and bone was observed at the end of the first growing season, and the difference in height growth that developed at that stage was maintained throughout the remaining measurement periods, but did not increase, even after the second fertiliser application. It is possible that the better growth of karamu in the treatments containing N was partly due to P, as the organic form (blood and bone) applied in the first application contained some P, and there may have been some interaction between the two nutrients. However, this seems unlikely because of the lack of a response to P alone. Further, there was no additional benefit from supplying P, as superphosphate, over and above the urea plus blood and bone treatment.

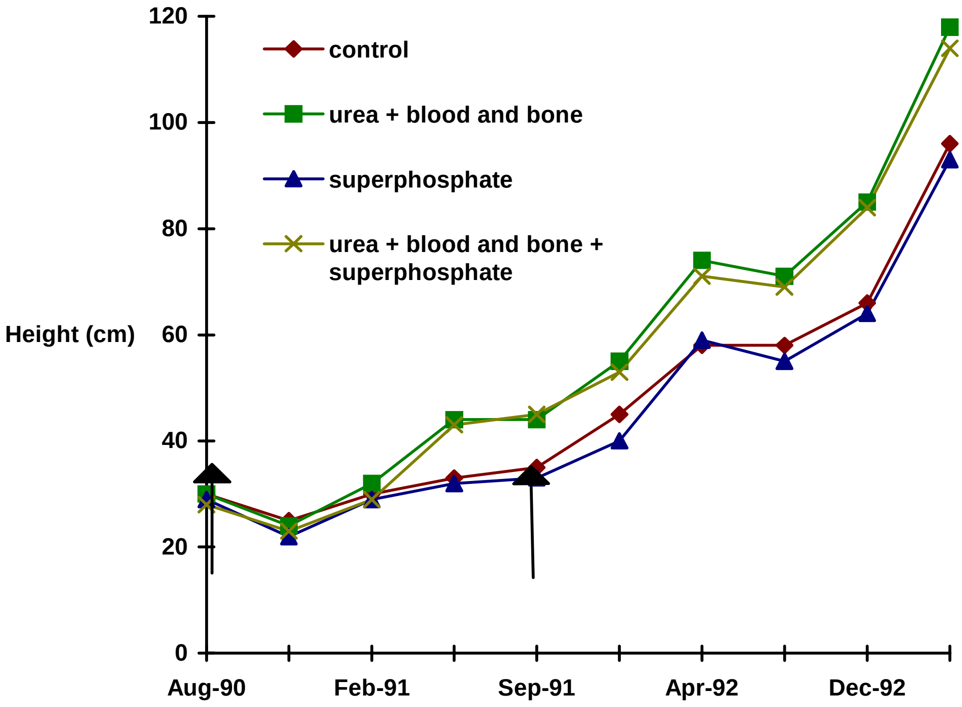


Figure 7. Effect of fertiliser on the growth of karamu on an overburden dump. Arrows indicate timing of fertiliser applications, Trial 3, Giles Creek.

6.2 TRIAL 4: GLASSHOUSE RESPONSE OF KARAMU AND RED BEECH ON GRAVEL AND MIXED SOIL TO MULTIPLE NUTRIENTS

Objective: To determine N, P, S, K, Ca, Mg, B, and lime requirements of karamu and red beech growing on stockpiled soil and gravel overburden materials.

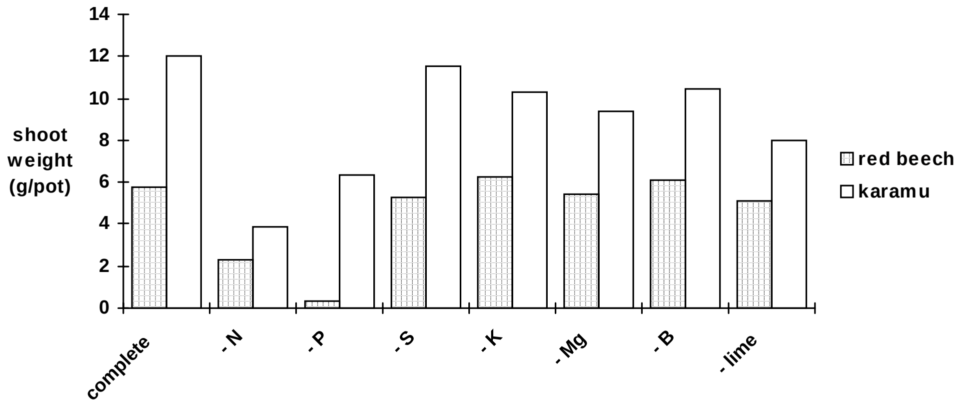
6.2.1 Method

Soil and overburden gravel materials for the glasshouse trials were collected from the surface of stockpiles at Giles Creek in August 1990. The soil consisted of organic, A, and B horizons mixed in unknown proportions, as stripped from the mine site after logging, and subsequently stockpiled. The soil had a moderate CEC, was strongly acid, and contained low levels of organic carbon (C), and total N, and very low levels of exchangeable cations and available (Olsen extractable) P (Table 1, Appendix 1).

Gravels underlying the terrace soils are predominantly granite and gneiss, though greywacke and schist materials also were present. The gravel material collected for the pot trial was less acid than the soil, and had higher exchangeable Ca and Mg levels, but lower CEC, C, and N levels than the soil. As with the soil, exchangeable K and available P levels were very low (Table 1, Appendix 1).

Soil and gravel materials were passed through sieves to remove coarse rock and root fragments, and thoroughly mixed before potting in 1.6 litre pots. Potential nutrient deficiencies of N, P, S, K, Mg, and B, for both red beech and karamu, were determined by applying a series of complete nutrient supplements which omitted one of the above elements at a time. Lime was applied to the soil, but not to the gravel, to counteract the possibility of ammonium toxicity developing from the applied ammonium nitrate. Omission of lime was included as one of the treatments. The lime

Figure 8. Effect of nutrient omissions on the growth of red beech and karamu on stockpiled soil. Trial 4, Giles Creek.



was mixed throughout the soil prior to potting, while all other nutrients were applied to the soil surface in solution after potting, at the time of planting, in late October 1990, and in two further applications, in mid December and in mid February. The trials were run concurrently and adjacent to each other on the glasshouse bench, and were laid out in randomised block designs with five replicates.

Seedlings of both species were raised in a mixture of forest duff (collected from under forest at Giles Creek), sand, and peat, mixed in proportions of 1:1:1, and were transplanted (5 per pot) into the pots when they were 2–3 weeks old, and 2–5 cm in length. The trial was watered, as required, with a semi-automatic system, employing individual drippers which delivered approximately 160 mL to each pot over a five minute interval. The trial was harvested in early April 1991 after a period of five months. At harvest, plant shoots were cut at the soil surface, dried at 70°C, and weighed.

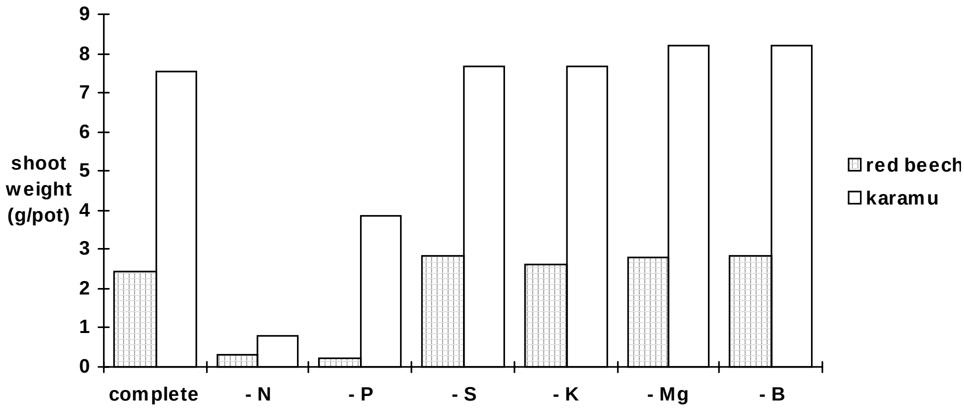
6.2.2 Results

There were significant differences in plant yield between nutrient treatments on both substrates (Davis & Langer 1997a). In soil, there were major yield reductions when both N and P were omitted, and smaller, but still significant reductions when lime and Mg were omitted (Figure 8). There were no significant yield reductions when S, K, or B were omitted. In the treatment where N was omitted, the leaves of both species exhibited pronounced nutrient deficiency symptoms; in karamu, the older leaves became yellow, while in red beech, the older leaves were red. Mean yields of karamu were twice those of red beech, and the two species responded differently to the omission of nutrients. Karamu was more severely affected by the omission of N, Mg, and lime than red beech (red beech was unaffected by the omission of Mg and lime), whereas red beech was much more severely affected by the omission of P.

In gravel, there were major yield reductions when N and P were omitted from the complete nutrient treatment, but there were no reductions when S, K, Mg, and B were omitted (Figure 9). Again, N deficiency symptoms were apparent in the treatment where N was omitted. Mean yields of karamu were three times those of red beech. The major difference between species was a much greater effect from omitting P on the growth of red beech than on karamu.

In all nutrient treatments, the yields of both species in soil were greater than those in gravel. The differences were most marked in the treatment where N was omitted, indicating the importance of the soil horizons in supplying this element.

Figure 9. Effect of nutrient omissions on the growth of red beech and karamu on overburden gravels. Trial 4, Giles Creek.



6.3 TRIAL 5: FIELD RESPONSE OF FOUR SPECIES ON MIXED SOIL TO NITROGEN AND PHOSPHORUS FERTILISER

Objective: To determine the N and P requirements of shrub and tree species growing on mixed horizon soil material in a field trial at Giles Creek.

6.3.1 Method

This trial was established adjoining the soil salvage and replacement trial (Trial 2) referred to above, on the same surface as that prepared for the mixed soil treatment, and at the same time. Soil chemistry data is as for mixed soil in Trial 2 (Table 2, Appendix 1). The trial consisted of a randomised block design, with N and P fertiliser treatments applied in factorial combination to four species, namely kahikatea, red beech, karamu and marbleleaf, grown in containers. Individual plots consisted of a single row of eight plants, spaced at 1 m apart. Rows were spaced at 1 m intervals, and there were three replicates. Nitrogen (as urea) and P (as superphosphate) were applied in spade slots (see Trial 3) at rates of 20 g N and 10 g P/plant respectively, at 3 months after planting. A repeat application was made at the beginning of the third growing season. Plant heights were measured at planting and in autumn for four years after planting.

6.3.2 Results

Results are presented for kahikatea and marbleleaf only. Results are unavailable for red beech because of high mortality, and are not presented for karamu because of severe and frequent browsing by hares. A small but significant response to N, in the presence of P, occurred in the first growing season, but not in the following year (Table 4). The second application of N at the beginning of the third growing season increased height growth in kahikatea. In contrast, marbleleaf responded to P but not N (Figure 10).

6.4 DISCUSSION

On mine overburden materials containing little or no soil or organic material, N is likely to be the major deficient element for plant growth. Nitrogen was deficient in the soil used in the pot trial, very deficient in the gravel material, and responses to N were obtained in the field trials on raw overburden and on mixed-horizon soil. However, in the latter trial, contrasting responses were evident to the second application of N; kahikatea showed a strong height growth response to the second application while marbleleaf showed no response. In contrast, marbleleaf responded more strongly to P fertiliser. The two species tend to occur on fertile soils, suggesting they may have similar nutritional requirements, although kahikatea is more prominent on poorly drained soils (Norton 1991, Wardle 1991). However, a comparison of foliage analysis data of plants in the soil replacement trial suggests the species differ nutritionally; marbleleaf had substantially higher foliar N levels than kahikatea (and all other species) on mixed soil, while kahikatea had substantially higher P levels (data not presented). These differences are consistent with their differing fertiliser responses. It is possible that the lack of response to N by marbleleaf also reflects the fact that only height growth was measured. Marbleleaf was much more strongly branched than kahikatea, therefore measurement of stem or crown diameter, or biomass, may have provided a more sensitive measure of N response for marbleleaf. The fact that marbleleaf showed a height growth response to P, however, and had greater mean height growth in the trial than kahikatea, does not support this argument.

Differences in fertiliser response also were observed in the pot trials where the growth of red beech was reduced to a much greater extent than that of karamu when P was omitted from the otherwise complete nutrient additions. Together, the differences suggest that the need for fertiliser application may depend on the species planted as well as on the substrate.

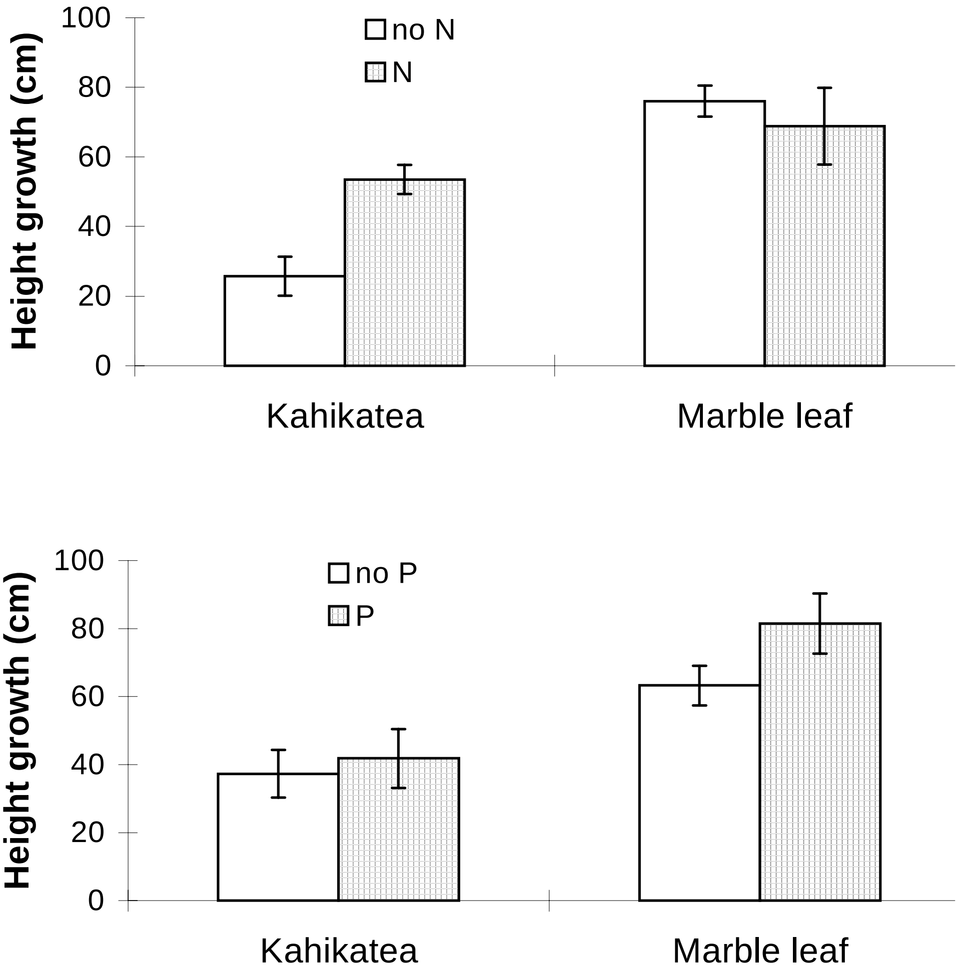
Responses to P were obtained in the glasshouse pot trial (Trial 4) on both substrates, and in the field trial on mixed soil (Trial 5), but not in the field trial located on the raw overburden dump (Trial 3). The lack of response on the latter surface may be explained by the fact that the substrate contained fine sandstone material from between the coal seams, which can contain high concentrations of calcium-bound P (C. Ross pers. comm). This P is not extracted by the Olsen method for determining plant available P.

For equivalent treatments, mean yields of both species on gravel in the glasshouse trial varied from 18% (where N was omitted) to 74% of those on soil. These results show the efficacy, particularly for ecosystem N levels, of stripping and stockpiling soil separately, and respreading it on overburden materials. Where sufficient soil is not available to cover highly N-deficient overburden materials such as gravels, there is

TABLE 4. PROBABILITIES OF A SIGNIFICANT TREATMENT EFFECT ON ANNUAL AND CUMULATIVE HEIGHT GROWTH OF KAHIKATEA AND MARBLELEAF FROM ANALYSIS OF VARIANCE OF THE FERTILISER TRIAL ON MIXED SOIL. VALUES OF > 0.10 ARE SHOWN AS ns (NOT SIGNIFICANT). TRIAL 5, GILES CREEK.

	1992/93	1993/94	1994/95	1995/96	1992/96
Species	<0.01	<0.01	0.04	0.01	0.01
Nitrogen	<0.01	ns	0.05	ns	ns
Phosphorus	ns	ns	ns	0.06	0.09
Spp. × N	ns	ns	0.01	<0.01	0.01
Spp. × P	ns	ns	ns	0.01	ns
N × P	0.05	ns	ns	ns	ns
Spp. × N × P	ns	ns	ns	ns	ns

Figure 10. Effect of nitrogen and phosphorus fertiliser on the cumulative height growth (1992–96) of kahikatea and marbleleaf on mixed soil. Fertiliser was applied at planting and a repeat application was given at the beginning of the third growing season. Trial 5, Giles Creek.



strong case for using legumes to provide nitrogen, as leaching of nitrate from mineral nitrogen fertilisers is likely to be a problem, especially in gravels in higher rainfall zones. The glasshouse trial demonstrated that P, which can be provided at relatively low cost as superphosphate, was the only element apart from N likely to be deficient on gravels.

Small responses to lime and Mg occurred on the soil used in the glasshouse trial, but there was no indication of a response to S, K, or B. The responses occurred in karamu only, possibly because of the faster growth rate of this species, but were of insufficient magnitude to recommend application of Mg fertiliser or lime in field situations.

7. Direct seeding of native species trial

7.1 TRIAL 6: ESTABLISHMENT OF NATIVE SPECIES BY SEEDING

Objective: To determine if native, woody species can be established by seeding on mine overburden.

7.1.1 Method

A trial was established to study the potential of direct seeding for establishment of native species, as an adjunct to planting with nursery-raised seedlings. The trial site was flat and mainly consisted of replaced overburden gravels with some soil and forest slash. Seed of karamu, tree tutu, manuka, kahikatea and wineberry was selected for direct seeding. Kahikatea and wineberry seed was stratified by exposing the seeds to moisture and near-freezing temperature, as recommended from nursery experience to break dormancy. All seed was sown by hand in September 1991 in three plots measuring 3 m × 2 m, with a further three unseeded control plots of the same size. Seed weights and sowing rates are given in Table 5. Fertiliser (urea 200 kg/ha and superphosphate 500 kg/ha) was applied in spring 1992. Seedling survival and heights, and establishment of other native and exotic species, were recorded in four randomly located 50 cm × 50 cm sample subplots located within each seeded and control plot.

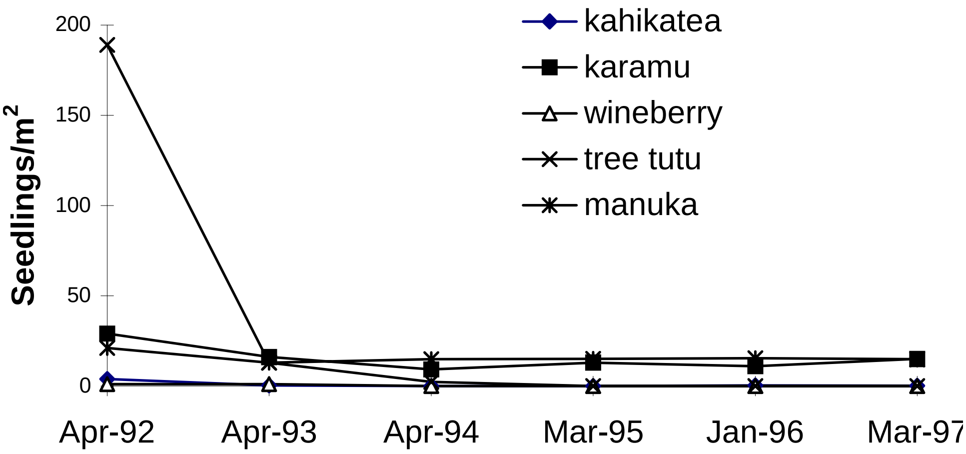
7.1.2 Results

Percentage emergence of germinating seedlings was particularly low for wineberry, manuka, and kahikatea (0.5–4%) but was higher for tree tutu and karamu (13–14%). First season establishment of the shrubs karamu, tree tutu and manuka was good (at least 21 seedlings/m^2, and up to 189 seedlings/m^2 for tree tutu) (Figure 11). The other two species sown, kahikatea and wineberry, produced only 1 and 4 seedlings/m^2 respectively. Subsequent mortality, in the first 2 years, was high for all species except manuka because of summer desiccation, or possible frosting, and severe N deficiency. Seedlings surviving the first winter responded strongly to fertiliser (superphosphate plus urea)

TABLE 5. SEED WEIGHT, STRATIFICATION, AND SOWING RATE. TRIAL 6, GILES CREEK.

SPECIES	SEED WEIGHT (seed/g)	SEED STRATIFICATION	SOWING RATE (seed/m^2)	SOWING RATE (g/m^2)
kahikatea	15	stratified	90	6.00
karamu	130	non stratified	220	1.69
wineberry	360	stratified	180	0.50
tree tutu	1 640	non stratified	1370	0.83
manuka	10 000	non stratified	1670	0.17

Figure 11. Seedling survival for native species directly seeded on replaced overburden gravels. Trial 6, Giles Creek.



application in spring 1992, but the fertiliser also stimulated competition from herbaceous weeds. Approximately 15 seedlings/m^2 of karamu and manuka were still present in the sixth growing season. No wineberry seedlings remained, and only two kahikatea seedlings (5–10 cm in height) were still present after 6 years. Vegetative ground cover was 57% and 42% for the seeded and unseeded plots, respectively, in the sixth growing season. Adventive species such Himalaya honeysuckle, Yorkshire fog, and lotus, with some native species, mainly *Nertera depressa* provided most of the cover.

7.1.3 Discussion

Seeding is potentially a relatively cheap supplement to hand planting, but success depends on the availability of sufficiently large quantities of viable seed, rehabilitation carried out in the right season, maintenance of optimum conditions during germination, and control of competition from invading exotic species (Porteous 1993). Western Australian mines frequently use direct seeding in reclamation, where the technique has been found to be highly successful (Simcock & Ross 1995). Minimal research on the effect of broadcast sowing of native seed has been carried out in New Zealand, rather studies here have concentrated on hydroseeding or the use of seed-laden slash (fascining) with species such as manuka. Good manuka germination was observed beneath manuka slash applied to a small area of mixed overburden gravel and soil at Giles Creek.

Results from the present trial indicate that broadcast sowing of seed has the potential for establishing some native pioneer species (such as karamu and manuka) to supplement planting of nursery-grown stock. The establishment in the trial area of koromiko seedlings (from planted stock) and of mountain toatoa, indicate that these species also may have good potential for establishment from seeding. It is likely to be a more suitable rehabilitation technique on sites such as Giles Creek where weed control is not a large problem. The seeding rates used in the trial for karamu and manuka resulted in around 15 seedlings/m^2 after six years, suggesting rates for these species could be substantially lower than that used here.

8. Effect of vegetation management trial

8.1 TRIAL 7: EFFECT OF VEGETATION MANAGEMENT ON REHABILITATION OF NATIVE FOREST SPECIES

Objective: To examine the establishment of native species in the presence and absence of gorse and pioneer native shrub species, and to examine nitrogen accumulation in the different vegetation treatments.

8.1.1 Method

A terrace of the Hohonu river at Greenstone, near Kumara, which had been mined for gold in 1992, was selected to establish this trial. Maimai or similar soils were present before mining (Mew 1980). After mining, gravels had been replaced and levelled, and the surface material contained some replaced soil. The site was used for sheep grazing but had not been fertilised, and vegetation was sparse and of short stature. Gorse seedlings were present and this species was expected to rapidly dominate the site. A cut-over podocarp forest remnant, which could provide a seed source for forest tree species, was present within 100 m of the site.

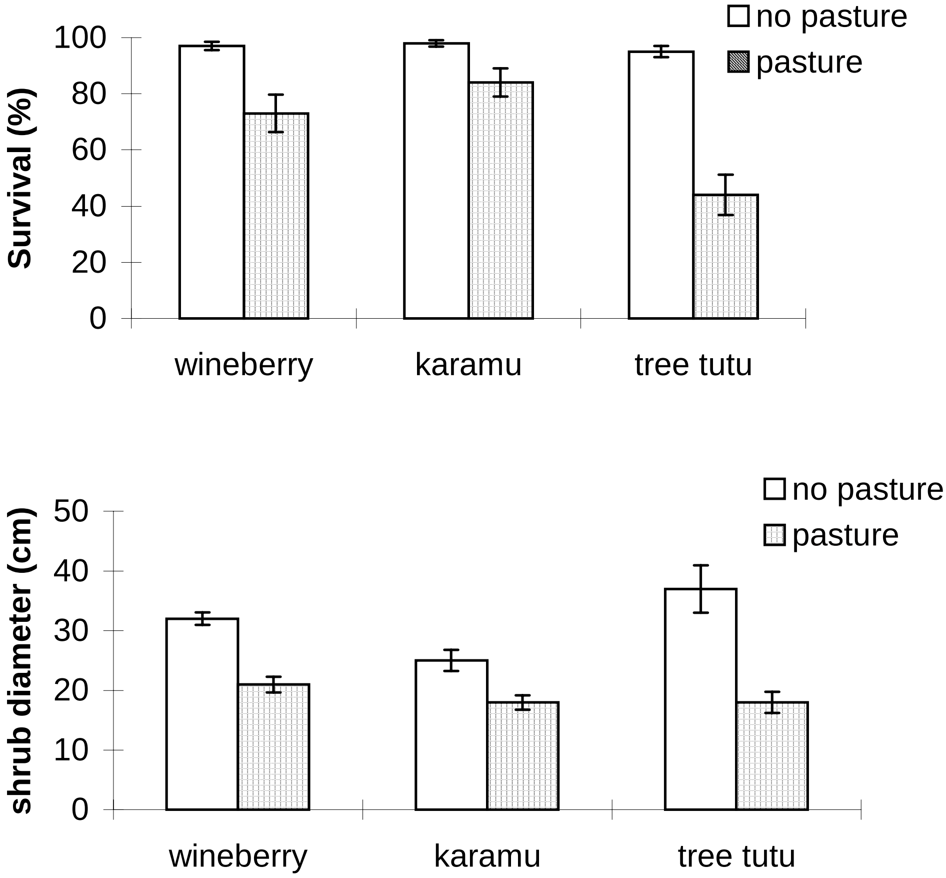
The site was fenced, and sprayed with herbicide (glyphosate) to remove existing vegetation in spring 1994. The vegetation treatments were applied to plots measuring 9 m × 6 m as follows:

1. No planting;
2. Planting with three pioneer shrub species in August 1996;
3. Pasture establishment in December 1994, followed by planting with pioneer shrubs in August 1996.

Except for treatment 3, the plots were maintained bare of vegetation from the time of the initial spray application until the shrubs were planted. In treatment 3, only gorse was removed, by spot spraying, up until the time of shrub planting. Since planting, gorse control has been either applied or not applied to each of the above treatments to give a total of six vegetation treatments. The trial was laid out in a randomised block design with four replicates.

The pasture, consisting of a mixture of Yorkshire fog (sown at 7 kg/ha), ryegrass (*Lolium perenne*) (20 kg/ha), and white clover (10 kg/ha), was sown in December 1994 and fertilised with molybdenised superphosphate (500 kg/ha) and urea (200 kg/ha). The fertiliser application was repeated in April 1995. In the continuing gorse control treatments, control has been maintained by spot spraying with glyphosate or hand weeding. Wineberry, tree tutu, and karamu were planted at 1 m × 1 m spacing in the treatments with pioneer shrub species, in August 1996. Mean shrub heights after planting were 13 cm and 28 cm for tutu and wineberry respectively. Karamu plants were taller (60 cm) but were cut back to 30 cm at planting to reduce potential wind damage. In the pasture plots, pasture was killed with herbicide prior to planting. It was noted that the

Figure 12. Effect of previous pasture on the survival and growth of three shrub species 9 months after planting. The pasture was established for 20 months prior to planting the shrubs, and removed prior to planting using herbicide. Trial 7, near Kumara.



pasture plots were more difficult to plant because of the presence of a root mat. Many grass grubs (possibly *Costelytra zelandica*) were present in pasture plots at planting. In November 1996, 45 g urea was applied in a spade slot to shrubs in all plots.

Soil samples were collected in December 1995, at depths of 0–5, 5–10, 10–20, and 20–30 cm from four pits located between plots, to provide initial soil chemical data. Shrub survival, and height and crown-diameter growth was measured at the end of the first growing season.

8.1.2 Results

Little regeneration of either gorse or indigenous woody species was evident at the time of the assessment, in March 1997. Survival and growth of all of the planted shrub species was lower in the pasture plots than when there had been no previous pasture (Figure 12). Several factors may have contributed to the lower survival and growth in the pasture plots, including competition from pasture species which began to regenerate over the summer–autumn period, damage from the grass grub population which had built up in the pasture plots, and the fact that shrub planting was more difficult (and possibly inferior) in the pasture plots because of the presence of the vegetation and the development of a root mat. Both wineberry and tree tutu appeared more vigorous in the non-pasture plots, whereas karamu, despite reduced growth, appeared healthier in the pasture plots, presumably as a result of increased N and P availability. In December 1997, there was still little gorse invasion in all treatments.

9. Management lessons for native forest rehabilitation in Westland

The work at Giles Creek has shown quite clearly the importance of salvaging and replacing soil materials after mining operations and, further, that it is much better to salvage and replace the organic/topsoil layer separately from the subsoil layer than to mix the two layers. In high rainfall environments, replacement of mixed soil will result in poorer drainage, rush invasion, and reduced growth of planted native species. Salvage and replacement of the organic/topsoil layer which contains most of the plant nutrients, and potential seed sources, is more important than salvage of the subsoil layer.

Good site drainage, to minimise invasion and competition from exotic rushes, is essential for many woody native species (other than wetland species). Therefore, appropriate site preparation and earth moving techniques, such as ripping, construction of drainage channels, and use of low ground pressure machinery, may be needed. However, such techniques may be insufficient to alleviate poor drainage created by placement of subsoil materials close to the soil surface in high rainfall areas.

Stumps, logs, slash, surface organic material and topsoil from the existing forest should be salvaged for site restoration where possible. Their replacement helps to create a rough surface, which provides a variety of microsites for plant establishment, and may enhance natural regeneration of the forest. The miner at Giles Creek has developed a method which involves excavation and replacement of the tree stumps and associated root plates, which includes organic and mineral soil layers as well as living vegetation. The method appears successful and could be adopted elsewhere.

In some situations, non-soil materials arising from the mining operation (such as the mudstone associated with the coal seams at Giles Creek) may be used to supplement on-site soils. Alternative materials need to be evaluated prior to their use.

On an operational scale, fast-growing pioneer shrub and small tree species, which have more rapid crown-diameter growth than tall tree species, can form the initial basis of the restoration programme. They should include species that produce berries to attract birds. They will provide early site occupancy and reduce invasion opportunities for exotic 'weed' species. Smaller numbers of the desired tall tree species need to be included in the planting, especially if potential natural seed sources, that can be spread by birds, are limited.

Bare-root stock is normally cheaper to produce, transport and plant than container stock. Bare-root stock has performed well at Giles Creek and its use is recommended for some species (such as kahikatea, totara, koromiko, and karamu), especially where large numbers of plants are required.

Fertiliser, particularly nitrogen and possibly phosphorus, may improve the growth rates of some native plants, especially where organic and topsoil materials are limited in the absence of a vigorous N-fixing species. The benefit of fertiliser needs to be balanced against fostering the growth of aggressive weeds, or attracting browsing animals. Both N and P may be applied at planting in a spade slot, about 15 cm from the tree, at rates of around 20 g and 10 g of elemental N and P respectively.

Broadcast sowing of seed is an option that may be used for establishing some pioneer species (such as karamu, manuka and koromiko) to supplement plantings where local seed is readily available. Seeding rates of 0.1 g/m^2 for karamu and 0.01 g/m^2 for manuka may be appropriate.

Animal control is essential if palatable species, such as karamu and broadleaf, are to be planted. Animal control may be required for several years after planting.

10. Research needs

Timing of soil salvage and replacement operations in relation to seedfall of forest species is likely to be an important determinant of the ability of replaced soil to provide a source of plant propagules. Research to determine the effect of timing of topsoil stripping on propagule emergence for beech forest is being initiated with FRST funding.

Mortality of nursery-raised beech plants in replaced forest soil has been high. A number of factors suggest that lack of appropriate mycorrhizae may be involved in the poor survival of beech. Research to survey the intensity of mycorrhizal infection on roots of beech growing well and poorly in abiotic substrates, rehabilitated soils, and in adjacent ‘undisturbed’ sites, to determine whether there is a link between plant health and presence of mycorrhizae has commenced, also with FRST funding.

The soil replacement trial at Giles Creek represents a considerable resource which has the potential to provide further information for rehabilitation of mined areas. Annual assessments are no longer required for this trial, but a ‘watching brief’ should be maintained to follow changes over time to record further growth, mortality and seeding of planted stock, natural regeneration of native species, further invasion of weed species, and chemical and physical changes in the substrates.

The research to date has demonstrated the value of salvage and replacement of soil on mine overburden materials. However, techniques need to be developed for rehabilitation where there is insufficient soil to cover overburden. To this end, a trial planting (not reported on here) to test establishment of silver beech and wineberry in raw overburden gravels, using white clover as a legume to provide nitrogen, was established at Giles Creek in spring 1997. This trial should be monitored and reported on.

The trial established on a gorse-prone, alluvial gravel site at Greenstone, near Kumara, to examine establishment of native species (both planted and naturally regenerating) and nitrogen accumulation in the presence and absence of gorse and a sown legume has been monitored only once since planting in spring 1996. This trial requires annual maintenance for further gorse control, and measurement of the survival and growth of planted stock, and regeneration of native species.

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Appendix 1

TABLE 1. CHEMICAL CHARACTERISTICS OF THE RAW OVERBURDEN (0–20 cm) (TRIALS 1 AND 3), AND OF STOCKPILED SOIL AND GRAVEL MATERIAL USED IN TRIAL 4, GILES CREEK.

	pH	ORGANIC C (%)	TOTAL N (%)	CATION EXCHANGE PROPERTIES (me/100 g) CEC	K	Ca	Mg	OLSEN P (ppm)
raw overburden	5.4	0.8	0.15	7.3	0.13	0.87	0.82	0.4
stockpiled soil	4.7	2.6	0.12	14.4	0.13	0.95	0.29	1.0
stockpiled gravels	5.2	1.4	0.05	8.5	0.10	1.82	1.12	1.0

TABLE 2. CHEMICAL CHARACTERISTICS OF IN-SITU AHAURA SOIL, AND OF THE THREE COVERING TREATMENTS USED IN THE SOIL SALVAGE AND REPLACEMENT TRIAL. DATA PROVIDED BY C. ROSS, LANDCARE RESEARCH. TRIAL 2, GILES CREEK.

SOIL	HORIZON	DEPTH (cm)	pH (H_2O)	CARBON (%)	NITROGEN (%)	CEC (me/100 g)	EXCHANGEABLE CATIONS (me/100 g)				OLSEN-P (µg/g)	Bray-P (µg/g)	SO_4-S (µg/g)
							Ca	Mg	K	Na			
In-situ Ahaura	O	12–0	4.1	27.7	0.71	43.2	6.59	1.84	1.13	0.23	12	12	12
	Ah	0–22	4.5	6.5	0.23	18.4	0.15	0.17	0.08	0.03	0	3	2
	Bs	22–50	5.2	2.4	0.06	11.6	0.02	0.01	0.02	0.02	0	4	46
	BC	50–70	5.3	0.63	0.02	4.6	0.00	0.00	0.01	0.01	1	46	23
Overburden gravel	C	0–60	5.6	0.19	0.01	3.1	0.08	0.04	0.06	0.01	11	166	10
Mixed soil	O+Ah+Bs+BC	0–50	5.0	2.8	0.09	10.5	0.18	0.09	0.08	0.04	1	14	42
Layered soil	O+Ah	0-30	4.3	12.1	0.36	28.6	2.71	1.56	0.54	0.13	3	5	8
	Bs+BC	30–60	5.1	3.2	0.09	11.3	0.09	0.08	0.07	0.00	0	5	53

Appendix 2

SPECIES LIST FOR TERRACE BEECH FOREST, GILES CREEK

Lycopods	
Lycopodium volubile	climbing clubmoss
Ferns	
Asplenium bulbiferum	hen and chicken fern
A. flaccidum	hanging spleenwort
Blechnum colensoi	
B. discolor	crown fern
B. fluviatile	kiwakiwa
B. novae-zelandiae	
B. procerum	
Cyathea colensoi	
C. smithii	soft tree fern
Gleichenia microphylla	parasol fern
Grammitis billardierei	
Histiopteris incisa	water fern
Hypolepis rufobarbata	
Leptopteris superba	Prince of Wales Feathers
Paesia scaberula	lace fern
Polystichum vestitum	prickly shield fern
Pteridium esculentum	bracken
Rumohra adiantiformis	leathery shield fern
Sticherus cunninghamii	umbrella fern
Gymnosperms	
Dacrycarpus dacrydioides	kahikatea
Dacrydium cupressinum	rimu
Halocarpus biformis	pink pine
Manoao colensoi	silver pine
Libocedrus bidwillii	pahautea, cedar
Phyllocladus alpinus	mountain toatoa
Podocarpus acutifolius	
P. hallii	Hall's totara
Prumnopitys ferrugineus	miro
Monocotyledons	
Agrostis stolonifera	creeping bent
Astelia species	
Cortaderia richardii	toetoe
Gahnia pauciflora	
Holcus lanatus	Yorkshire fog
Juncus species	rush
Microlaena avenacea	bush rice grass
Uncinia species	hook grass

Dicotyledons

Aristotelia serrata	makomako, wineberry
Cardamine species	bittercress
Carmichaelia odorata	
Carpodetus serratus	putaputaweta, marbleleaf
Cirsium vulgare	scotch thistle
Coprosma ciliata	
C. colensoi	
C. foetidissima	
C. pseudocuneata	
C. rhamnoides	
C. rotundifolia	
C. sp. aff. *parviflora*	
Cyathodes juniperina	
Cytisus scoparius	broom
Digitalis purpurea	foxglove
Elaeocarpus hookerianus	pokaka
Fuchsia excorticata	kotukutuku, tree fuchsia
Gaultheria depressa	snowberry
Griselinia littoralis	broadleaf
Hebe salicifolia	koromiko
Hypochoeris radicata	catsear
Letospermum scoparium	manuka
Leucopogon fasciculatus	mingimingi
Leycesteria formosa	Himalaya honeysuckle
Myrsine divaricata	weeping mapou
Neomyrtus pedunculata	rohutu
Nertera depressa	
Nothofagus fusca	red beech
N. menziesii	silver beech
N. solandri var. *cliffortioides*	mountain beech
Parsonsia heterophylla	kaiwhiria
Pennantia corymbosa	kaikomako
Pseudopanax anomalus	
Ps. crassifolius	horoeka, lancewood
Pseudowintera colorata	horopito, pepperwood
Rubus australis	bush lawyer
R. cissoides	bush lawyer
Schefflera digitata	pate
Senecio jacobaea	ragwort
S. quadridentatus	
Viola lyallii	

Appendix 3

SPECIES FREQUENCY (%) ON NATURAL REGENERATION PLOTS, 5 YEARS AFTER PLOT CONSTRUCTION (n=20)

	Overburden	Mixed soil	Layered soil
Native species			
Blechnum fluviatile [1]			5
Carex dissita			20
Carex geminata		10	15
Carex secta		5	
Carex testacea		5	
Centella uniflora			15
Coprosma robusta [2]		5	
Coprosma sp.			5
Epilobium sp.		5	
Gahnia rigida		15	
Gaultheria antipoda			5
Gnaphalium ensifer		5	
Hebe salicifolia [1, 2]		5	15
Helichrysum bellidioides		5	
Histiopteris incisa [1]			20
Leptospermum scoparium [1, 2]		25	20
Nertera depressa [1]		65	80
Oreobolus impar			5
Paesia scaberula [1]			30
Pseudognaphalium luteoalbum		5	
Raoulia tenuicaulis	10		
Rytidosperma sp.		10	10
Thelymitra venosa		10	5
Adventive species			
Anthoxanthum odoratum			15
Crepis capillaris			10
Digitalis purpurea [1]			5
Hieracium pilosella		5	
Holcus lanatus[1]		30	55
Hypochoeris radicata [1]	15	100	95
Juncus canadensis		90	5
Juncus effusus		35	
Juncus sp.		5	
Lycesteria formosa [1]		10	20
Lotus pedunculatus	5		30
Senecio jacobaea [1]		30	15
Senecio sylvaticus		5	
Trifolium repens	10		

[1] recorded as present in forest immediately adjoining the mine site

[2] seedlings from planted stock

TABLE 2. CHEMICAL CHARACTERISTICS OF *IN-SITU* AHAURA SOIL, AND OF THE THREE COVERING TREATMENTS THE SOIL SALVAGE AND REPLACEMENT TRIAL. DATA PROVIDED BY C. ROSS, LANDCARE RESEARCH. TRIAL 2, GIL

	HORIZON	DEPTH (cm)	pH (H_2O)	CARBON (%)	NITROGEN (%)	CEC (me/100g)	EXCHANGEABLE CATIONS (me/100g)				OLSEN-P (µg/g)	Bray- (µg/g
							Ca	Mg	K	Na		
Ahaura	O	12–0	4.1	27.7	0.71	43.2	6.59	1.84	1.13	0.23	12	12
	Ah	0–22	4.5	6.5	0.23	18.4	0.15	0.17	0.08	0.03	0	3
	Bs	22–50	5.2	2.4	0.06	11.6	0.02	0.01	0.02	0.02	0	4
	BC	50–70	5.3	0.63	0.02	4.6	0.00	0.00	0.01	0.01	1	46
rden gravel	C	0–60	5.6	0.19	0.01	3.1	0.08	0.04	0.06	0.01	11	166
oil	O+Ah+Bs+BC	0–50	5.0	2.8	0.09	10.5	0.18	0.09	0.08	0.04	1	14
soil topsoil	O+Ah	0-30	4.3	12.1	0.36	28.6	2.71	1.56	0.54	0.13	3	5
	Bs+BC	30–60	5.1	3.2	0.09	11.3	0.09	0.08	0.07	0.00	0	5