Proceedings of a Workshop on Scientific Issues in Ecological Restoration

Compiled by M. C. Smale and C. D. Meurk

Held at Manaaki Whenua - Landcare Research, Ilam, Christchurch.

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Proceedings of a Workshop on Scientific Issues in Ecological Restoration

held at Manaaki Whenua - Landcare Research,
Ilam, Christchurch, on 22–23 February 1995

Compiled by

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Errata

Missing captions from figures on pages 23 and 24:

Fig. 1. Proportion of indigenous and exotic plant species by total land area in New Zealand.

Fig. 2. The rate of introduction of vascular plants into New Zealand (ex Atkinson & Cameron, 1993)

Fig. 3. Generalised diagram of a linked forest productivity-soil process model (ex Pastor & Post, 1985).

Ref: Pastor, J.; Post, W.M. 1985: Development of a linked forest productivity-soil process model. Environmental Sciences Division Publication No. 2455, ORNL/TM-9519, US Department of Energy.

Page 29, Fig 3: The caption text "Differences in diameter growth rate...signed ranks test." was included unintentionally, and does not relate to this paper.

CATALOGUING IN PUBLICATION

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Cover photographs by C.D. Meurk

Front Cover Left: 1990 sesquicentennial native heritage planting by school children at Beckenham Park, Christchurch. Pond margin sequence comprises sedges, harakeke, toetoe, koromiko, coprosmas, cabbage trees, manuka, ribbonwood, and kahikatea.

Front Cover Right: The same site, three years later, showing rapid establishment of the tussocks, with the woody species developing more slowly.

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Contents

Introduction

A two-day workshop on 'Scientific issues in ecological restoration' was hosted by Manaaki Whenua – Landcare Research, Ilam, Christchurch on 22-23 February 1995. The workshop comprised a field excursion, especially to interact with land managers and practioners, which visited restoration projects in Christchurch City and its environs, an evening function, and a follow-up day of presentations and discussions. Its objectives were to:

- review current and future work in this field;
- identify significant gaps in our scientific knowledge of the subject;
- examine social and cultural issues that need to be addressed;
- understand management needs;
- recommend directions for new work and means of establishing communication links;
- publish proceedings of the workshop.

This bulletin contains abstracts or full texts of papers presented at the workshop. Transcripts of ensuing discussions are held by the organisers, but most points are covered in the papers that follow. One tangible outcome of the workshop was an internet bulletin board set up by David Norton. The means of subscribing to this are outlined below.

1. To subscribe to the bulletin board, you should send an email message to the following address: **nzecorest-request@csc.canterbury.ac.nz**

   Your message should contain the following words only in the body of the message: subscribe nzecorest firstname lastname [e.g., subscribe nzecorest jo brown]

   Once your message has been received you should get a brief message back telling you that you have been subscribed. If you want to unsubscribe from the list, you send a message to the same address, but say **unsubscribe** rather than subscribe. **Don't** send any other messages to this address.

2. Once you have subscribed to the bulletin board, you can then send messages to the board and receive messages from it. All messages sent to the board will be automatically sent out to all subscribers. To send a message to the board, send your message to the following address: **nzecorest@csc.canterbury.ac.nz**

   Do not send a subscription request to this address, as you will not be subscribed and your message will go to all other subscribers!

3. If you are having any problems with the bulletin board (e.g., can't subscribe) then send a message to the following address outlining the problem you are having: **nzecorest-owner@csc.canterbury.ac.nz**

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Field Excursion Notes for the Workshop 'Scientific Issues in Habitat Restoration'

Colin D. Meurk

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The intention was to set the scene with a journey of stories in the land; of natural fragments in a fragmented cultural landscape; of a lost heritage, and a rediscovery; of a plan to mend the fractures and restore an environment that has evolutionary, cultural and functional meaning - which acknowledges and helps us to interpret the layers and dimensions of history.

The following brief descriptions list for each landscape or locality the soils and landforms, vegetation, place or function in the City or District, and some features, proposals, potentials, issues, or questions that were discussed. The localities are shown in the map on the centre pages, in the context of soil-landform features of Christchurch and a proposed greenway around the City.

Harewood (drive past):

- *Waimakariri*[1] and *Selwyn* gravelly, free-draining soils;
- Remnants of Plains dry shrub-grasslands, and kowhai-kanuka-matagouri and cabbage tree woodlands lie beyond the airport;
- Part of proposed circular park around Christchurch (the 'Greenway' concept, see map and explanation at the end of these notes);
- Need to preserve remnants, restore woody elements on finer-textured soils, retain landscape integrity, create linkages along the Waimakariri River, restore birds - weka, surrogates such as Australian quail for extinct species?

Waimakariri terrace backswamps (view upstream from motorway bridge):

- *Selwyn-Kaiapoi-Taitapu* soil sequence;
- Regenerating native swamp-forest species (karamu, pittosporums, kowhai, cabbage tree, tree tutu, ferns, swamp species) under willow;
- Part of proposed circular park around Christchurch;
- Enrich with native swamp forest species (kahikatea, matai, manatu-ribbonwood, tarata-lemonwood etc.).

Northern Motorway (also The Groynes and Otukaikino):

- *Selwyn-Kaiapoi-Te Kakahi-anthropogenic* soil complex;
- Mosaic of riparian land, wetlands (largely willow-covered), dry farmland, and the motorway border with grass, pines, eucalypts etc.;
- Part of proposed circular park, proposal for landscape-environmental 'sculpture' along motorway corridor as an experience of historical layers and identity of Canterbury for travellers at the gateway to the City - the beginnings at Otukaikino (memorial park being restored to wetland and swamp forest in willows at south end of motorway) and at Pinehaven (Woodend Lions Club) in the north;
- Sterility of traditional exotic amenity trees for native wildlife; opportunities on motorways generally.

Matawai Park Rangiora:

- *Taitapu-Kaiapoi* soils;
- Vicinity of former Rangiora-Tuahiwi-Woodend Bush;

1 *Local Soil Series names are* Selwyn *and* Waimakariri *(very recent coarse textured or free-draining alluvium),* Kaiapoi *(mottled periodically wet loam),* Taitapu *and* Te Kakahi *(gleyed generally saturated loam),* Waimairi *(peat),* Waikuku *(stable sandy loam),* Kairaki *(fresh sand),* Motukarara *(wet saline gley soils),* Cashmere *(hill soils derived from basalt),* Takahe *(hill soils derived from loess).*

- Completely synthetic from mid 1970s, theme areas of beech, podocarp-hardwoods, swamp forest and wetlands;
- Where to now? There are too many edges and not enough core areas.

Kaiapoi Pa:

- *Waikuku-Kaiapoi-Taitapu-Waimairi* soil sequence;
- Remnant pukio (tussock sedge) swamp vegetation;
- Principal cultural centre for Ngai Tahu; Pa sacked in early 19th century, native plantings have been carried out by Tuahiwi people since 1970s with volunteer groups, habitat restoration concept plan prepared in late 1980s, and gradual progress towards revegetation and establishment of harakeke weaving resource; wider concept for restoring resources along whole coastal belt;
- Harsh climate - frost, drought, and flood; issues include necessity for supervision of labour, weed control at critical times; is it fulfilling Ngai Tahu goals?

Otukaikino:

- See above;
- Open swamp, grey willow carr, and crack willow border;
- Joint venture between Department of Conservation and Lamb & Hayward Funeral Directors to gradually replace willow forest with kahikatea-pokaka-manatu swamp forest as memorial park, part of circular park;
- Balance between clearing willows and creating new weed problems versus utilising nursery value of existing vegetation; what is ideal, user-friendly way of conveying planting plans to planters and managers; need for definitive instructions on willow control techniques, use of herbicides etc.

The Groynes (lunch):

- See above;
- Native terrace swamp forest species have been planted among willows since 1980s;
- Recreational area on South Branch of Waimakariri River, attempts to re-establish *Utricularia* and *Mazus pumilio* on grazed margins of ephemeral ponds, part of circular park;
- Problems with wildlife raising bacterial levels in water.

Styx Mill Basin (drive past):

- *Te Kakahi-Waimairi* soils;
- Remnant open marshland and willows; the only *Sphagnum* on Plains;
- Being developed as a wetland-farm park by City Council;
- But recreation threatens to dominate conservation of rare, hard to restore, low fertility marshes, resulting in more medium to high fertility swamps which are commonplace and less diverse.

Travis Swamp (drive past):

- *Aranui Complex* soils (*Waikuku-Kaiapoi Taitapu-Waimairi* sequence);
- Largest, lowland open freshwater wetland and largest population of pukeko in Canterbury, the only manuka on the Plains; bounded by inland sand dunes, several regionally rare plants (*Drosera binata, Baumea rubiginosa*).
- City Council now own northern half, campaign continues for remainder to be purchased and developed as nature heritage park as key link in City Circular Park/Greenway[2];

[2] Stop Press: the City now owns the entire undeveloped area of ca. 125 ha, incorporating the entire soil sequence and enormous scope for restoring most of the habitat types of Christchurch.

- Grey willow, blackberry and gorse problems; regeneration under willows; cattle as a management tool to sustain grazing marshes and birdlife; creation of ponds and islands for greater wildlife diversity; manipulation of water levels; recreation planning.

North Brighton sand dunes (1990 project):

- *Kairaki* sands;
- Marram and lupins, Monterey cypress and pine;
- Restored indigenous sand binders and coastal bush species;
- Harsh climate on sand plains behind dunes, drought, recreational pressures.

Estuary, Te Huingi Manu Wildlife Reserve and Humphreys Drive (drive through):

- *Motukarara* saline soils and *Taitapu-Waikuku anthropogenic* sequences;
- Saltmarsh species and wading birds in created dabbling ponds;
- Various plantings, including native look-alikes (pampas grass, Australian ngaio), around estuary and lower Heathcote (Baker trials on toxic dredgings) by City Council; McCormacks Bay bird islands, Ferrymead plantings, exotic trees as bird roosts, 'Great Green Planting Machine' on *anthropogenic* soils (joint project between Department of Conservation and Applefields), part of circular park concept;
- Broadening and softening edge to estuary.

Aynsley Tce, Heathcote River (1990 Project):

- River bank, terrace backswamp (*Taitapu*), scarp slope (*Kaiapoi*) and *anthropogenic* soils;
- Sequence of kowhai-koromiko to sedge harakeke-toetoe-shrub to manuka-cabbage tree to manatu-kahikatea-pokaka to totara-matai-hardwoods to kanuka woodland;
- Insect attacks on manuka and pittosporums (also on hills), toxic landfills, NIMBY syndrome (not in my back yard), vandalism!

Beckenham Ponds and Thorrington School (drive past):

- Riparian sequences, river connections, changing priorities of controlling agencies (e.g. schools) threatens permanence of sites; problem with connections/permanence in time and space, poor wildlife value of most exotic landscape trees that dominate garden city concept.

Victoria Park:

- *Takahe-Cashmere* hills soils sequence;
- Old plantings of *Olearia paniculata* etc.;
- Wrong provenances; do these plantings speed up or divert direction of succession in dry climates?

The accompanying map (see centre pages) is a simplified soil pattern of Christchurch which provides a template for understanding the natural history of a locality and for guiding ecological restoration activity. The sites visited on the excursion are numbered.

The hatched area around the perimeter of the City is a proposed 'Greenway' or circular (linear) park. This is designed to encapsulate a representative cross-section of the City's surviving natural features, create a continuity between them, and develop a focus for ecological restoration at both the community and landscape levels. Proposed walkways and cycleways are indicated by the dashed trail which links the special features and accommodation facilities. The key natural features of the Greenway are (clockwise from the northern boundary): Waimakariri River backswamps (regenerating swamp forest in willows) – Brooklands Lagoon (saltmarsh) and Styx River (freshwater wetland and riparian lands) – Bottle Lake pine plantation and sand dunes to New Brighton – Travis Swamp, Horseshoe Lake and Cockayne Reserve (freshwater wetlands) – Avon – Heathcote Estuary – Port Hills (silver tussock grasslands, shrublands and forested valleys) – Wigram Retention Basin and Heathcote River (wetlands and riparian lands) – Riccarton Bush (kahikatea forest remnant) and Avonhead – McLeans Island (dry danthonia grasslands, shrublands and woodlands).

Such a concept is vital to a conservation stategy which establishes a sustainable presence of nature in the City – a new, multidimensional generation of 'Garden City'. The necessary elements to achieve this vision are substrate and topographic diversity, large area, adequate buffering, core sanctuaries with concerted predator control, and landscape connectivity through ecological restoration and management. The City is currently considering the proposal through the City Planning process as directed by the Resource Management Act (1991).

References to this evolving concept are as follows:

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A Department of Conservation perspective on ecological restoration

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The Department of Conservation's mandate is primarily to manage the 'Conservation Estate', and focuses on threatened species recovery, weed and pest control, people management (tourism and recreation), and improving the representativeness of protected lands. However, through 'Atawhai Ruamano', 'Conservation Management Strategies', and the Biodiversity Convention a longer-term vision identifies ecological restoration as an important aspect of the Department's activities. Consequently a workshop was held in July 1994, and a discussion paper is in preparation which documents issues and proposes a set of goals and objectives. This paper paves the way for further discussions and the development of policy to guide Conservancy Restoration Strategies.

Current understanding identifies a range of reasons why ecological restoration is important. Ecological disruption – land clearance, drainage, introduction of species, and so on – has resulted in ecosystem fragmentation, a large number of threatened species both nationally and locally, loss of full representativeness among indigenous ecosystems, and loss of natural character in the landscape. Owing to the large number of very small protected areas (one quarter are less than 1 ha in size), the 'estate' is not likely to be sustainable in its present form. The lack of capacity for migration is disastrous in the long term.

Conservancy strategies must be based on understanding the *need* for restoration, in turn based on the spatial pattern of habitat and the nature and degree of disruption to essential ecological processes. A significant aspect is involvement of the community, not only to encourage enthusiastic support for all aspects of restoration but also because the greatest needs for restoration lie outside the Crown estate, on private land. The creation of riparian corridors across lowland New Zealand may be the single greatest opportunity for ecological restoration. Local government, interest groups, and landowners are important stakeholders for ecological restoration.

Although there has been much innovative work on the restoration of species and islands, understanding of landscape ecology, fragmentation ecology, ecosystem management, and other restoration-related fields of applied ecology is limited. The Department is keen to foster the collation of existing information and field experience, identify gaps in understanding, and participate in a network for exchange. It is hoped that this workshop on science issues will help clarify the key science needs which are critical to furthering ecological restoration in New Zealand.

Ecological basis for restoration in mainland New Zealand

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Introduction

There has been a tremendous worldwide upsurge in interest in restoration as a technique for reversing habitat degradation (Jordan *et al.* 1987, Cairns 1993, Hobbs 1993, Saunders *et al.* 1993). Although restoration in New Zealand has historically focused on islands (Daugherty *et al.* 1990) there has been increasing interest in mainland restoration (Atkinson 1988, 1994, Norton 1991, Langer 1993, Barker & Simpson 1995). I largely follow Atkinson (1988, 1994) in defining ecological restoration as 'the active intervention and management to restore or partially restore biotic communities, both their plants and animals, and the associated physical environment as fully functioning and sustainable systems with a predominance of indigenous species.' This article outlines some key issues and questions pertinent to ecological restoration on the New Zealand mainland.

Why is restoration important?

Hobbs (1993) has suggested that there are three main ways in which restorations can be directly useful for conservation: provide additional habitat, provide buffer zones, and establish corridors linking existing fragments. It is clear that in many parts of New Zealand the extent of habitat loss means that it will not be possible to add further areas to the conservation estate, because such areas simply do not exist. Restoration is therefore the only means available to address some of the gross imbalances in representativeness that occur in our Protected Natural Area system (e.g., Awimbo *et al.* 1995). Restoration can also provide buffers to mitigate the effects of external factors such as edge effects (e.g., Murcia 1995) and to link previously isolated fragments through the development of corridors (Hobbs 1992). Furthermore, restoration is an important tool for dealing with highly degraded sites such as mines within conservation areas (Norton 1991), and can assist in integrating productive and non-productive land uses. For example, in the Western Australian wheatbelt extensive habitat loss has led to serious soil salinity problems. Restoration plantings are being widely undertaken to mitigate this, and these plantings also have considerable potential for nature conservation (Hobbs & Saunders 1993). Restoration also provides one of the most accessible ways in which local communities can become actively involved in nature conservation and see positive results as restorations develop through time.

What can we expect from restoration?

Most definitions of restoration focus on the idea of re-establishing what might have occurred on a site had it been undisturbed. The idea of 'natural' communities and ecosystems is commonly implied, but what do we mean by natural in the New Zealand context? I suggest that natural is a value judgement. For some it may be a pre-European condition, say AD 1840, while for others it may be a pre-human condition, say AD 800; see O'Connor *et al.* (1990) for examples. However, this use of the term 'natural' imposes a very static perspective on restoration. Ecosystems are continually changing, and it is impossible to recreate past conditions because of extinctions and invasions. Even more important, the global environment is continuing to change, and it seems naive to think that we could restore to a specified historical condition.

I suggest as an alternative that we should focus on trying to establish ecosystems that have a predominance of indigenous species – both plant and animal – that are able to sustain themselves largely free of direct human intervention. Clearly the species chosen will need to be appropriate to the site (see next section), but this definition allows for the dynamic changes that predominate in all ecosystems. This approach also emphasises the importance of considering ecosystem processes. To be successful, restorations need to reestablish ecosystem processes such as seed dispersal and parasitism, rather than specific assemblages of species.

Ecological basis for restoration

A number of key ecological issues underlie restoration, and provide us with the conceptual frameworks we need to better understand and implement restorations.

(1) *Choice of ecologically appropriate species.* Restorations need to be based on species that are appropriate to the environmental conditions present at the site. Landform-vegetation relationships in adjacent areas of unmodified vegetation can provide useful models from which to develop restoration programmes (Norton 1991).

(2) *Natural succession as a model for restoration.* After disturbance at a site, the system readjusts over a period of time (succession). In restoration we are often attempting to facilitate natural successional processes, and on grossly disturbed sites (such as mines) to compress the successional process. Natural successional patterns within unmodified vegetation can provide strong indications of the species that are most likely to be suitable for restoration plantings.

(3) *Use of genetically appropriate plant material.* Limited studies of morphological variation within New Zealand plants show that for some species there is considerable regional variation, suggesting that there are also regional genetic differences. As a result of this it has been suggested (e.g., Simpson 1992) that restoration plantings should be based on plant material of local provenance. While the question of genetic integrity and the potential impact of non-local genotypes 'polluting' local genotypes is largely anecdotal, the precautionary principle of environmental management would suggest that it is prudent to use plant material of local origin where possible. Use of local material may also be advantageous because of better adaptation to local environmental conditions (e.g., tolerance of frosts).

(4) *Letting nature dictate composition and structure.* While it may be technically possible to recreate a very specific ecosystem, it would seem likely that in most instances this would involve considerable human input to ensure that desired species are present in the right proportions. However, restorations have the potential to be expensive (plantings alone can cost $10 000/ha), and it seems imperative to develop restoration techniques that work with – rather than against – natural processes. It would seem better, therefore, to chose species for planting that will grow fast and provide early cover in order to facilitate the establishment of other plant and animal species, and then let nature sort out future composition and structure. The emphasis is therefore on initially planting species that are appropriate to the site (see above) and that will facilitate the establishment of other species and hence the development of the restoration into a self-sustaining ecosystem.

(5) *Focus on processes rather than species.* Restorations are about more than just collections of plants; to be successful they need to be self-sustaining. So the choice of initial species should take into consideration those species that are likely to facilitate the arrival of other species (e.g., by planting species producing fruit that attract seed-dispersing birds) and create environmental conditions (soils and microclimates) suitable for indigenous animals.

The general approach to restoration advocated here is one in which the primary objective is to ensure that a good plant cover develops on the site, within which ecosystem processes can operate, and then let the system develop without further direct human input.

Issues for restoration ecology

Restoration ecology is a relatively new branch of ecology, and although it has generated wide interest internationally, the conceptual and theoretical frameworks that must underlie any branch of science are still in their formative stages; see Pickett & Parker (1994) for an interesting discussion. This is particularly true for New Zealand, where research in restoration ecology has been limited. While we can and should learn from research undertaken outside New Zealand, there are a number of issues and questions that we need to tackle within this country. The following questions warrant further investigation, and may contribute towards developing a better understanding of restoration ecology in New Zealand.

- How do we maximise planting success? (This question relates to the variety of technical issues associated with planting and subsequent maintenance, e.g., weed and pest control, fertiliser, spacing, nurse species.)
- Does initial planting composition and pattern matter? (Restorations may be cheaper and more successful by initially using fast-growing native or even naturalised species, rather than attempting to use the most ecologically appropriate species. Does the use of these species affect longer-term development of the planting with respect to the establishment of native plant and animal species?)
- How do we facilitate establishment of native animals, both vertebrate and invertebrate? (It is easy to put plants in the ground, but much harder to establish native animals, especially at sites distant from possible colonisation sources. Can we develop techniques that facilitate the establishment of these species?)
- When do restorations become self-sustaining ecosystems rather than plantings? (Can we identify a point during a restoration when we can be confident that the system has become self-sustaining and can persist without further direct human input?)
- At what stage is a restoration deemed successful? (This question is related to the previous one, and reflects the need in a number of restoration programmes – for example after mining – to be able to say confidently that the restoration has been successful. What makes a successful restoration?)
- What is the role of non-native species in restoration plantings? (There has been considerable debate over the use of non-native species such as gorse (*Ulex europaeus*) and tagasaste (*Chamaecytisus palmensis*) in restorations. Do these species have a role to play, how do they affect the establishment of native species, and will they be eliminated from the restoration with time?)

Conclusion

This article has discussed a number of issues that I see as central to the science of restoration ecology. As restoration becomes increasingly more important on the New Zealand mainland, we need to ensure that our research is both assisting with the technical aspects of restoration (planting and maintenance) and critically testing hypotheses concerning the value of restoration in achieving nature conservation goals.

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Ecological restoration in riparian ecotones: a way forward for conservation

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Introduction

The contemporary New Zealand landscape and biota reflects a history of colonisation, land clearance, and development. The statistics are well known: indigenous forest has been reduced from 78% to 23% of the land area, 90% of wetlands have been filled in or drained, 40% of the terrestrial birds that existed before human arrival have become extinct, four endemic plants are presumed extinct, and a multitude of species are classed as threatened (Atkinson & Cameron 1993).

As a signatory to the Biodiversity Convention, New Zealand is legally committed to the conservation of indigenous biodiversity, and ensuring that the use of biodiversity occurs in a sustainable manner. The convention requires that signatories take steps to establish and manage protected areas, to sustainably manage biological resources both within and outside protected areas, and to rehabilitate and restore degraded ecosystems. New Zealand's legislation provides a framework for achieving these ends. For example, the Reserves Act 1977 requires the establishment of legally protected areas, the Conservation Act 1987 requires the protection and preservation of indigenous biota, and the purpose of the Resource Management Act 1991 is to promote the sustainable management of natural and physical resources.

Just over 30% of New Zealand has protected area status and is managed by the Department of Conservation. Examination of the reasons why land was protected shows that a large proportion was set aside for scenic purposes or because it was considered unsuitable for economic development. The fertile lowlands, which were the most biologically productive and supported a high level of indigenous biodiversity, are under-represented in the Protected Area Network. The Protected Natural Areas Programme has sought to redress this imbalance by identifying the best of what is left in order for it to be protected. However, in some areas it is almost impossible to find any remnant natural areas that would warrant protection under the current PNAP approach (e.g., Awimbo *et al.* 1995). It is obvious that ecological restoration, or *active intervention to reinstate lost species or physical conditions* (Atkinson 1995), will be a prerequisite for conservation in some lowland areas.

The challenge is going to be to integrate the needs of conservation with the needs of landowners. The key here is sustainable land use, i.e., the requirements of the Resource Management Act 1991. If it can be shown that landowners receive ecological services and benefits from ecological restoration then it is more likely to proceed. Some definitions of ecological restoration refer to recreating a near-prehuman state (Atkinson 1995). It should be apparent that this purist view of ecological restoration is not going to happen on private land; landowners are not going to want to return productive land to forest or wetlands (e.g., Jennings 1992) unless there is a clear and tangible benefit to them.

It is possible to integrate conservation and sustainable land management through ecological restoration in a way that will move conservation ahead from its current holding pattern. I shall briefly discuss the restoration of riparian margins as a case in point.

Riparian margins: their ecological importance and restoration

Rivers and streams are a characteristic feature of the New Zealand landscape owing to a mountainous topography and frequent rainfall. Collier (1994) estimates that there are some 4 million kilometres of stream and river channels on mainland New Zealand. Because of widespread clearance of indigenous vegetation, a significant proportion of these now flow through exotic pastoral landscapes where introduced willows (*Salix* spp.) are the typical riparian tree (Johnson & Brooke 1989) and adventive species such as watercress (*Nasturtium* spp.) and starwort (*Callitriche stagnalis*) characterise the instream macrophytic flora (Howard-Williams *et al.* 1986).

The value of riparian margins (ecotones[1]) for biodiversity conservation becomes apparent when

[1] An ecotone is a transition zone between adjacent ecological systems, having a set of characteristics uniquely defined by space and time scales and by the strength of the interactions between adjacent ecological systems (Holland 1988). Riparian vegetation can be seen as the transition between a wetland or a river and an adjacent dryland forest.

perusing the ecological literature. Natural riparian ecotones contain a diverse range of habitats and support high species diversity (Naiman *et al.* 1993, Risser 1990). These areas are in a constant state of flux, as they are frequently disrupted by flood events and debris flows, and consequently plant species richness varies considerably in time and space. The consequent mosaic of habitats thereby allows a wide variety of species – including birds, reptiles, and invertebrates – to coexist (Naiman *et al.* 1993).

Studies in the United States reveal that riparian vegetation provides some of the richest and most valuable animal habitat in the drier western part of the country (see authors in Knopf & Samson 1994). While some species are characteristic of ecotones and adapted to their dynamic nature, others (e.g., birds) may use ecotones only periodically, e.g., for breeding, overwintering, or as a stopover during migration (see authors in Knopf & Samson 1994, Large & Petts 1994), or to obtain seasonal food supplies. The survival of these species may in fact depend on the presence of riparian ecotones in an area (e.g., Hehnke & Stone 1978, Samson 1979).

Indigenous riparian vegetation also regulates and maintains in-stream environmental conditions, and provides a food source and habitat for many indigenous freshwater fishes. Clearance of riparian vegetation is implicated in the decline of some indigenous fish species (McDowall 1990).

Rivers are natural linear corridors through the landscape. The restoration of riparian vegetation would provide an opportunity to link fragments of indigenous habitat, thereby providing access to resources, as well as providing extra habitat. It appears that many indigenous species will not cross open farmland to reach new or seasonal habitats. For example, Potter (1990) demonstrated that brown kiwi (*Apteryx australis*) will not move between habitat patches if the distance is greater than a few hundred metres. This also appears to be true for some invertebrates (Hutcheson & Hosking 1994). Restored riparian corridors could be a means of revitalising habitat fragments.

The potential conservation benefits from restoring riparian margins appear obvious, yet, as mentioned, it is important that the potential ecological services provided to landowners are also identified. The benefits to landowners of restoring riparian vegetation could perhaps best be demonstrated by the ability of riparian vegetation to filter nutrients, reduce water runoff, and minimise erosion (e.g., Howard-Williams *et al.* 1986). Maintaining or improving water quality is a directive of the Resource Management Act 1991, whereby landowners are responsible for controlling the effects of their land use practices. The use of riparian vegetation to act as natural and relatively inexpensive filters is very desirable. Riparian vegetation could also act as a windbreak, sheltering stock and/or crops, provide aesthetic value by attracting conspicuous birds such as kereru (*Hemiphaga novaeseelandiae*), tui (*Prosthemadera novaeseelandiae*), and korimako (*Anthornis melanura*), and act as a reservoir for natural predators of crop pests (Wratten, this volume).

Conclusion

New Zealand's fertile lowlands once supported a high level of indigenous biodiversity, but now provide this country's most productive farmland. Ecological restoration in the lowlands will be a prerequisite for advancing conservation. This, however, will be resisted if a purist view of ecological restoration is proposed. The challenge lies with conservation managers, environmental managers (e.g., regional councils), and landowners to work together to develop strategies which integrate land-use practices with the restoration of indigenous communities and habitats. Restoration of riparian margins is likely to provide ecological, environmental, and production benefits to all parties, and provide a way forward for conservation.

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Hangups and hopes for habitat restoration

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Background

Habitat restoration is undoubtedly a key strategy for making gains in nature conservation. The state and condition of nature in the world, even in 'clean green' New Zealand, is at a critically low ebb. This has serious consequences for the fate of the intrinsic worth of biodiversity, for human physical and economic survival, and also for our social, cultural, and spiritual well-being. Restoration of the physical environment may yet prove to be an indicator of a wider psychological – even moral – restoration in society.

It is therefore important that the process does not become derailed by inadequate or inaccurate knowledge, or by avertable failures which are damaging to morale. Many factors can affect the success of a habitat restoration exercise – theory, resources, planning, vagaries of climate, soils, weeds, destructive animals (including alienated or thought-less humans), and public will. Some of these factors are beyond immediate human control; but the raw materials of habitat restoration science are the controllable items (or physical resources) and their optimisation. Public will, prioritisation, and theory are crucial to successful praxis, and so political and economic considerations come into it. Clear objectives that have been achieved through wide consultation will minimise the risk of agendas becoming confused. Of course different groups may have different ultimate goals, but consensus must be achieved in relation to the immediate objectives and the methods to be employed.

Here I will debate three issues to illustrate some key themes in the practice of restoration. It has been said that the goal of habitat restoration is to mimic some 'former state' or original natural system that occupied the site at some particular historic time. The more sophisticated version of this is to accept that the model is not static, and neither should be the copy. However, I believe that this is still an unnecessarily restrictive definition, unless the purpose is to create a garden or an artificial display of some particular era. It is doubtful if construction of museum pieces like this actually fulfills the definition of restoration of a sustainable ecosystem. Much heat can be generated in trying to agree on the time frame that is being copied. Another contentious issue that I wish to briefly address is the definition of genetic purity – what is the criterion for 'local'? Finally, I will touch on spatial scale – metarestoration, or the goal of blurring the distinctions between production and conservation at the landscape level.

Time frames

Time frames are red herrings! The objective should be to mimic natural (or unsubsidised) species patterns, concomitant with *current* environmental gradients, and processes that reflect the intrinsic (stochastic) dynamics and adjustments to changing environments. Thus it is more productive to apply restoration goals to processes rather than to a time-limited state. The aim should be to maximise the opportunities for establishing as great a range of species as possible of the putative local flora and fauna in the overall landscape. This is a sieving technique in which one doesn't try to second-guess all the subtleties and multiple, overlapping gradients of nature, but puts everything into a *pot-pourri* and allows the environment to sift through the material and select out the species 'it' wants.

Ideally the larger landscape will accommodate all the species of a sere – the full sequence of natural community development for a site type[1]. Of course

1 This may be problematic with ephemeral habitats like wetlands in cultural landscapes. Most of the wetland-creating forces in the developed landscape are now being controlled in this country. When they occur catastrophically, engineering works are implemented in an attempt to restore the former productive uses. In any case there are only exotic species available to colonise the site. Maintenance of natural, temporal assemblages in a culturally controlled landscape may therefore require artificial rejuvenation of fresh habitats. A creatively 'destructive' style of engineering may be necessary together with an initially enhanced supply of indigenous wetland species such as along water races in reservoirs. This would ensure that early successional stages are retained at sufficient density to enable a natural response to natural destruction of mature ecosystems when that occurs. The engineered solution may be less sustainable than relying on natural perturbations, but is especially manageable and relevant to fast-reacting systems such as mesotrophic wetlands.

there is no single, legitimate assemblage of plants for a site. In a natural succession there is a continually changing procession of species. And each time the procession is allowed to unfold there will be a chance element, within some defined limits of species composition, for any particular stage of the process. Actual communities are mosaics of the infinite combinations of seral stage and random dispersal.

Nevertheless, we should strive to be as authentic as possible in following the environmental gradients. Our science is obliged to perfect the fit between environment and species for reasons of ecological understanding, economics, and aesthetics. But survival to reproduction by several individuals of each species in a site might often be a more important and realisable goal than getting the optimal competitive zonal positions correct initially. This will ensure that propagules are available to produce a second and subsequent generation of each species appropriate to the microsites. These cross-generational assemblages will converge iteratively towards a 'natural' pattern or the 'right place' along the available environmental gradients, regardless of whether the substrate is artificial or unmodified. There is nothing to say that a landfill cannot have a 'natural' vegetation. 'Natural' does not exclusively mean that it was present in the past, nor even in a broader sense that it involves indigenous species. It is the existence of uncontrolled (by human intervention) processes that is the key criterion for naturalness, as recognised in the Resource Management Act. The mere fact that such a substrate did not exist historically makes no difference to the authenticity of a species arrangement that faithfully reproduces itself or changes to another combination according to the soils and climate. After all, there were environmental combinations that existed in the past that no longer exist, even in undisturbed environments, and there must be contemporary natural environments that have no historic analogue.

Genetic purity

'Local' could refer to one side of the Southern Alps, a province, an Ecological Region or District, or a catchment. The seriousness of the crime of 'importing' plants from other neighbourhoods will depend objectively on whether the regional genetic differences are allelic or merely based on gene combinations and frequencies. Research may eventually throw some light on this, but in the meantime it is better to be cautious. Given the arbitrariness of Ecological District/Region boundaries in terms of gene flow, however, I would suggest that the most distant source that should be used in habitat restoration is the Ecological Region and those Ecological Districts contiguous with it. This should be expanded to include the nearest population(s) where locally extinct species are concerned.

One can imagine situations where the nearest population may not be the most appropriate. For example, consider a proposal to re-establish kanuka on a deep, loessial soil on the Canterbury Plains, but the only sources remaining in the Ecological Region are stunted genotypes (?) growing on hard, gravelly surfaces which could not be intensively farmed. As a result of this historical accident, all the taller-growing forms of deeper soils, and indeed the original greater genetic diversity, have been lost to the Plains. In such circumstances, I would suggest there is a case for restoring a larger gene pool by selecting material from surrounding hill country, beyond the Ecological Region borders.

There is also a pragmatic aspect. While we should strive to be as faithful as possible to the local gene pool, the reality is, I suspect, that when communities of interest are fired with enthusiasm and want to get stuck in, imposition of very strict standards and unavailability of suitable material are likely to lead them to circumvent the standard, and even conceal the true origins of the stock they are planting. This would be counterproductive, and perhaps the equally important demand to place on restoration projects is that a record be kept of the provenance of the plantings. Perhaps a register of restoration sites could be established that documents such baseline information. This would in any case be invaluable for future research and provide the key to that 'acid test' of our understanding of ecosystem structure and function. Starting from there and finishing here; did it work? I would hasten to add that I'm not advocating the importation of genotypes from afar into a situation where there is available plenty of local material of the species.

Landscape and cultural goals

There are many situations in which full ecosystem construction is not the direct aim, nor is it possible. Rather the need is to establish a greater mass of indigenous species in the landscape so that a greater continuity of bird food is available and our cultural landscape establishes a solid, indigenous visual quality – to reinforce our cultural norms and traditions and national or regional identities. A practical means of achieving this is by substituting native species for exotic utilitarian plantings, e.g., in shelterbelts, hedgerows, and plantings for amenity and water and soil conservation.

Baseline studies should be carried out to determine the present level of indigenous habitat in the landscape. From a knowledge of the wildlife associated with existing levels of habitat (in different regions) some realistic targets for restoring landscapes, with viable native bird populations, might then be established. For example, it seems likely that the lower Canterbury Plains support less than 0.5% cover of native plant species in (commercially) unproductive areas that would be potentially available for restoration, such as hedgerows, shelterbelts, road and rail corridors, parks, picnic areas, river banks and floodplains, scarps and gullies, private gardens, and uncultivated corners. Appropriate targets, towards a more sustainable indigneous system, may be 1% cover in 10 years, 2% in 15 years, 5% in 25 years, 10% in 50 years, and 25% in 100 years. These are modest targets for the discretionary lands, and the hope would be that a transition to indigenous dominance in the landscape would be realised more quickly. The realisable goal will ultimately be defined by constraints of wildlife-gene flow, population dynamics, minimal areas and connectivity, social mores, and practical considerations.

In general, habitat restoration involves a human component at the outset where the aim is to provide a catalyst for natural processes to take over. Human intervention should gradually decline, and involvement move towards more passive appreciation and enjoyment. When human-induced and 'natural' communities have become indistinguishable, sustainable populations of indigenous species are re-established across the land (e.g., when a wide range of native plants have become 'weeds' in urban gardens and are of equal prominance in colonising wild places), and the landscape linkages are repaired, then we shall know that we have arrived. We must not get hung up on how perfect is our initial mimicking of some historical state. That is a mirage. Our task is to provide the materials for nature to take over, to establish the simplest, quickest, and cheapest means of getting the species back onto the land, to determine the minimal sustainable habitat presence in the landscape, and to design optimal configurations of wild space in confined landscapes where other uses are pre-eminent, that would achieve that sustainability. For the vision of that new cultural landscape in New Zealand, that seamlessly integrates productive pursuits and nature conservation, we may have to look, somewhat paradoxically, at an ideal of the English countryside as imagined by Capability Brown, or much later by the authors of the Biosphere Reserve concept.

The balance of indigenous and adventive plant species as an underlying issue in ecological restoration

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Introduction

I shall briefly discuss the following topics with the aim of triggering discussion on science issues underlying ecological restoration in New Zealand:

- the current balance of indigenous and exotic species in New Zealand;
- some implications of those data;
- the pressure on indigenous vegetation from exotic introductions;
- uses of a forest gap succession model as a predictive tool for planning and managing ecological restoration projects.

Although ecological restoration suggests the rebuilding of whole ecosystems, the views presented here will focus largely on the vegetation component.

What is ecological restoration? Some people will have noticed subtle variations in the titles on information provided for this workshop. 'Ecological restoration', 'restoration ecology', and 'habitat restoration' have all appeared in writing or been mentioned at some time. All are important and related but have slightly different connotations, and produce a variety of mindsets amongst people of different backgrounds or interests.

A more all-encompassing and sweeping approach to the subject is to define the whole field of endeavour, and say that we are all interested in some form of 'restoration of biodiversity', which of course begs the question 'what is biodiversity?' There have been many attempts to define biodiversity, and most attempts include concepts like the variety and variability of species (alpha diversity), and populations (beta diversity), all of the processes and ecological conditions occurring between them, and their interactions with the landscape and climate.

This is idealistic and all-encompassing but rather difficult to get to grips with in any practical way. We need to pick off bite-sized pieces to deal with step-by-step along the way.

A simplistic measure of biodiversity restoration is the presence or absence of species. Species richness has long been a key measure of ecological diversity. Most ecological diversity indices use a combination of number of species present (richness) and some measure of their distribution or evenness of spread (Kinako 1983). Higher species numbers allow higher functional diversity, greater process diversity, and greater productivity, although beyond a certain threshold of species numbers – and assuming that structural complexity is maintained – productivity does not necessarily increase with increasing species richness (see Baskin 1994).

Ecological restoration also needs to occur at many scales, because ecosystems come in a variety of scales. Restoration ranges from the microscale of a few square metres of herbfield re-created in somebody's garden, through medium-sized projects of a few hundred or thousand square metres typified by those visited during this workshop, to landscape-scale work that is required to restore whole mountain ranges or catchments, in China or the Amazon Basin for example.

The current balance of plant species

The New Zealand vascular plant flora currently has about equal proportions of indigenous and exotic species. Not only has the total native species complement been matched by adventives but so also has the land area been dominated by those species. There are about 6 million hectares of indigenous forest and alpine grassland and about 7 million ha of horticultural/agricultural/improved pasture, but where does the remaining ~15 million ha of New Zealand fit? Are those indigenous communities devoid of adventives, and the considerably modified ones really bereft of native plants?

The answer to the first question is: somewhere in between (and they are often the focus of restoration projects). The answer to the second question is: most definitely no!

By using a broad-scale vegetation typing system (e.g., Newsome 1987), and an example species description(s) for each type, it is possible to build a picture of the way in which indigenous and exotic species interact, along with the land area that can be attributed to the proportioned flora.

Refs: Allen *et al.* 1994, P.J. Bellingham pers. comm., Best & Bellingham 1989, Cameron 1990, Canaham 1961, Lee *et al.* 1986, Mark *et al.* 1988, McQueen 1961, B.P.J. Molloy pers. comm., Newsome 1987, Norton 1989, Ogle 1976, 1989, A.B. Rose pers. comm., Simpson & Mason 1984, Scott 1993, D. Scott pers. comm., Smale 1990, Treskonova 1991, Wardle 1991, Wright & Cameron 1985, Wright 1978, 1979.

Indigenous purity is area- and remoteness-dependent. Small areas in remote locations which contain only indigenous species can always be found. But even in the most remote locations at a larger scale there are almost always a few adventive plants present (e.g., wall lettuce – *Mycelis muralis*, catsear – *Hypochoeris radicata*, Scotch thistle – *Cirsium vulgare*, Yorkshire fog – *Holcus lanatus*). As well, in those apparently pristine environments, probably half the birds present, all the mammals, and an unknown proportion of invertebrate species are adventive. Equally, though, in arable and pastoral lands indigenous species are often aggressive invaders (e.g., manuka – *Leptospermum scoparium*, rushes – *Juncus* spp., sedges – *Carex* spp., *Muehlenbeckia*, *Leptinella*, *Rytidosperma*, *Dichondra*).

Some implications

The salient point about the indigenous/adventive mix is that it is dynamic. All mixtures along the curve are shifting with time. Intensive and active management is required to maintain either end of the scale. Agricultural and horticultural management maintains the adventive-dominated ecosystems by production, cropping and grazing. The indigenous end of the curve is treated with a certain amount of nonchalance, with a presumption that our large-scale indigenous ecosystems are self-sustaining. Such a presumption may be unwise.

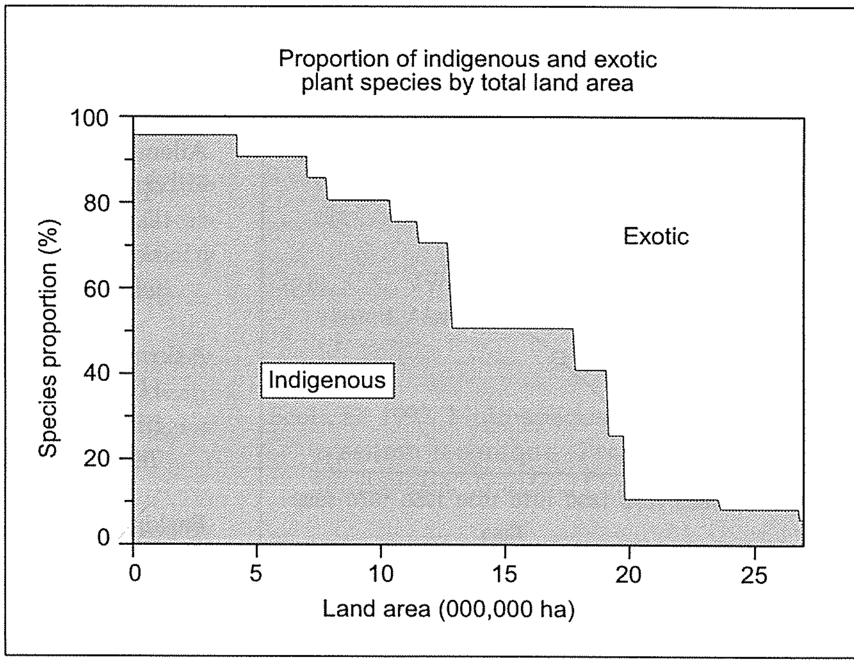
With time and freedom from disturbance all communities drift towards a shifting equilibrium. Where that equilibrium positions itself depends on the competitive behaviour of the species comprising the ecosystem. At present the equilibrium appears to favour a majority of indigenous species. Even though the overall adventive species presence in New Zealand more-or-less equates with the natives, many are not truly adventive and fewer still are aggressive invaders. So the current balance is still with native species. For example, dense stands of gorse (*Ulex europaeus*) which have developed in areas where human influence has tried to maintain exotic pastures change back into indigenous shrubland (and possibly into forest) given sufficient time and freedom from further disturbance (Lee *et al.* 1986). A similar progression has been noted in exotic pine plantations (Allen *et al.* 1995, McQueen 1961).

A further lesson for ecological restorers is to judge where along the curve their particular patch fits. Such an understanding will act as a useful guide as to whether they should be adding indigenous species or subtracting adventive ones. Normally both actions will be required, but adaptive management should be practised, and an understanding of the likely direction of natural drift will be beneficial in directing the most efficient use of resources.

The mixing of indigenous and exotic species means that new communities will evolve, and will be with us forever. The goals of ecological restoration will similarly be affected. The ultimate goal may well be ecological purity, but realistic and practical endpoints will necessitate acceptance of some type of mixed community.

The pressure on indigenous vegetation due to the rate of exotic introductions

Since humans have increased and spread to the furthest corners of the globe they have facilitated the spread of species 'clever' enough to be useful or 'cunning' enough to tag along for the ride. The arrival of exotic species in New Zealand is no exception. Since the arrival of people at these shores a millennium ago, the known introductions of vascular plants, both deliberate and accidental, have grown until the exotic vascular flora almost equals the indigenous vascular flora in total number of species. The problem has been long recognised (Allan 1936, 1940, Clark 1949), but despite stringent border controls which ban some known undesirable species, new introductions are occurring at an ever-increasing rate (Atkinson & Cameron 1993).



Controls on the importation of plants seem rather haphazard, and more related to whether a plant is carrying a potential agricultural pest than its inherent potential as another competitor. Although the bulk of the new introductions may well be horticultural or agricultural species, in time some will find a wildland habitat to their liking and colonise it. Work is required on more rigid screening of introduction applications. Groups concerned with conservation and restoration need to have more input to the organisations responsible for developing policy in this regard. Such screening could be carried out by the use of computer succession models which woulxd reveal the likely habitat each species could occupy and its effects in the local indigenous community. The necessary species growth and tolerance details required to conduct an analysis could be requested from the applicant as part of the application.

Uses of a forest gap succession model as a predictive tool for planning and managing ecological restoration projects

Models have been used for many years to predict forest succession and composition for particular environments. LINKAGES is one well respected forest development and succession model which was first developed in the eastern United States in 1972 and has since been continually adapted, upgraded, and improved for many applications globally. It is currently being applied locally to predict the effects on forest composition of any expected global climate change.

When provided with an extensive array of parameters on each included species, including autecological, physiological, and environmental requirements, and then simulated for a number of years, resulting outputs of species composition measured in biomass or density are produced. Species can be added or subtracted at any stage. A number of obvious applications in aiding ecological restoration come to mind.

- In a site at an early stage of restoration more use could be made of microclimate-altering exotic species. What would be their ultimate fate?
- Is it necessary to remove what appear to be potential nuisance species from restoration sites or reserves, or will they succumb to successional pressure naturally, saving considerable effort and cost, and over what time scale?
- How invasive are woody weeds such as sycamore (*Acer pseudoplatanus*), holly (*Ilex aquifolium*), or buddleia (*Buddleja davidii*)? Do they become major ecosystem components, and what do they replace along the way?
- If all applications for bringing new species were required to provide a list of key species parameters, they could be tested for invasion potential very simply.

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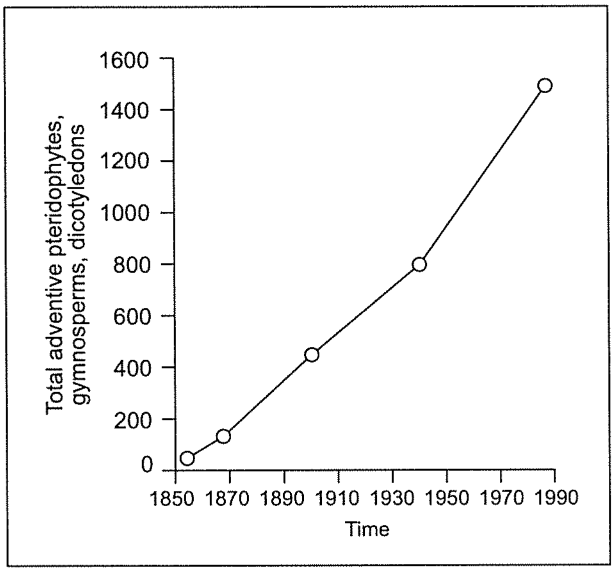

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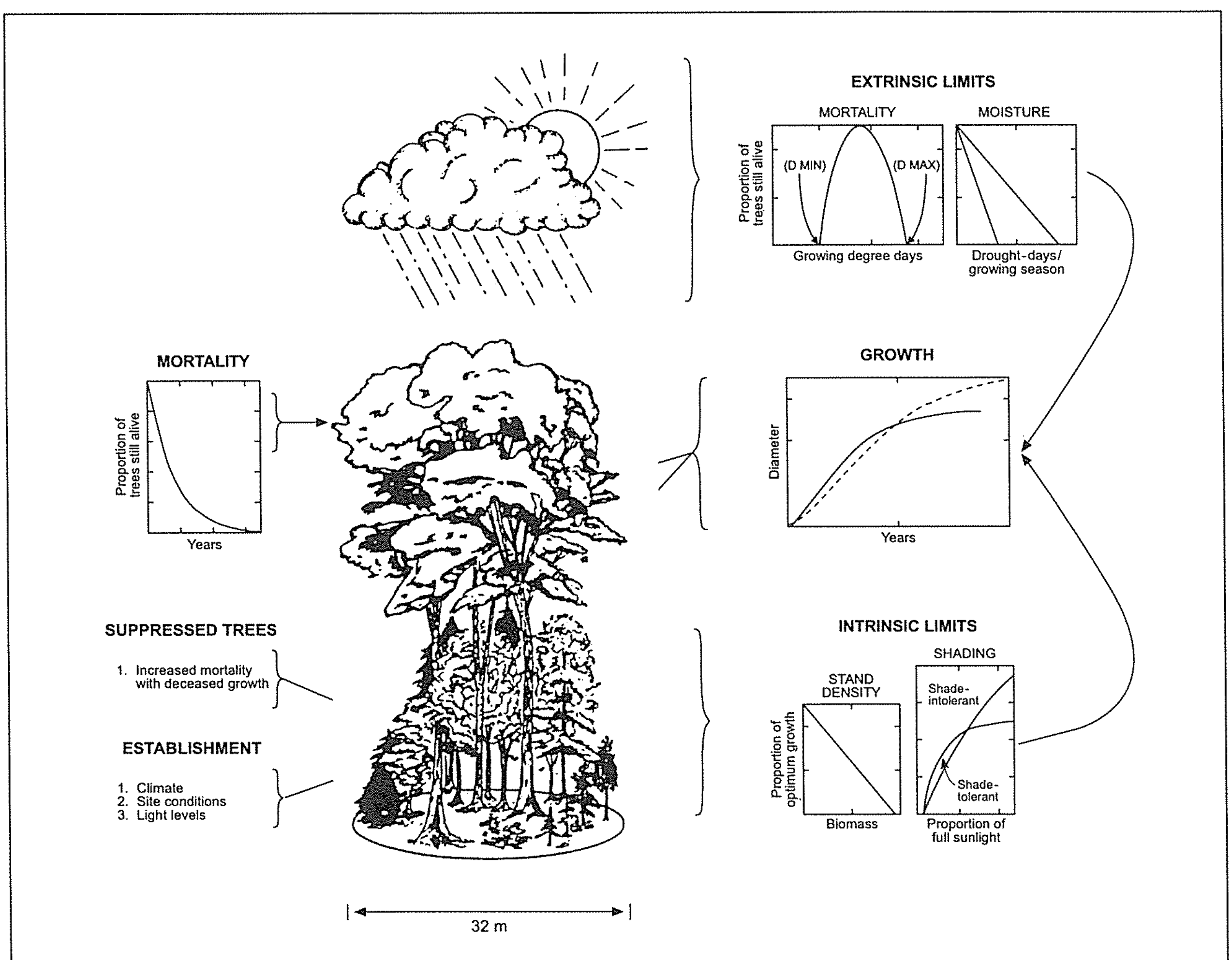

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Some perspectives on plant genetic variation and ecological restoration

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Introduction

This contribution relates to two articles influential in determining principles applied in New Zealand to ensure that genetic contamination of natural plant communities doesn't occur through restoration planting.

Godley (1972) indicated that the scientific value of areas of indigenous vegetation would be lowered by planting species outside their geographical range or in habitats in which they did not occur naturally, and that local populations should provide plant material for restoration plantings. Use of local populations was recommended to lessen intraspecific genetic contamination of natural populations, and arose from understanding of genetic variation in New Zealand *Sophora* species (kowhai) populations (Godley 1979).

Timmins & Wassilieff (1984) adopted Godley's concerns, stressing that intraspecific genetic contamination was not well understood and that, because of this, we should exercise caution. They set out 'appropriate planting practices', stating that for indigenous plantings in reserves "Seeds or young plants should be obtained from the same patch of vegetation or the same catchment as the planting site." Where it was known that a species varies on an even more local scale, then gathering of propagation material and its planting should relate to that scale. They provided a list of native plants known at that time to show significant genetic difference between populations. The list of species has been expanded in the last decade, but we have gained only a little more understanding of the functional significance of genetic variation of populations within native species that would allow us to be certain that the cautionary approach is needed. We also have to be realistic and accept that the appropriate practices set down by Timmins and Wassilieff are probably not always followed, through either ignorance or the impracticality of obtaining genetically matching planting material.

To contribute to thinking about this issue, examples are presented from my observations of genetic variation of plants growing in New Zealand to indicate what might happen if new genetic material is introduced by restoration planting.

Environments are very efficient in accepting pre-adapted plants. When I studied the genetic variation of sheep's sorrel (*Rumex acetosella*) in New Zealand early in the 1960s, I found distinctive differences in populations from different geographical regions and habitats (Harris 1970a,b, 1973). This variation indicated adaptation to various habitat factors. In a plant introduced by Europeans to New Zealand, this process of genetic sorting and adaptation had taken place in less than 200 years. However, when I compared the variation of *Rumex acetosella* in New Zealand with that in its indigenous area, Eurasia, I found that only one entity of the species complex had successfully naturalised in New Zealand. A similar situation applies to *Hieracium*. However, the widespread naturalisation of *Hieracium* had to wait until ecological niches became available to which a few of the *Hieracium* microspecies were pre-adapted. It is suggested that this niche was created by aerial topdressing with phosphatic fertiliser of the high country from the 1960s onward (Fan Jiangwen & W. Harris, unpublished experiment).

Changes in the genotypic structure of populations can be rapid. Just how quickly the genetic structure of a population of interbreeding plants can change through natural selection was made clear in my studies with the late Dr Ray Brougham (Brougham & Harris 1967, Harris & Brougham 1970). We created ryegrass populations with a wide genetic base by mixing two cultivars, 'Grasslands Ruanui' perennial ryegrass (*Lolium perenne*) and 'Grasslands Manawa' short rotation ryegrass (*Lolium perenne* x *L. multiflorum*). Mixing these cultivars in seed mixtures to establish new pastures was common practice at the time, and even more complex mixtures are used today. We subjected pasture sown with the mixture to different grazing regimes, and followed the survival of ryegrass genotypes in the population by measuring the change of frequency of several genetically determined

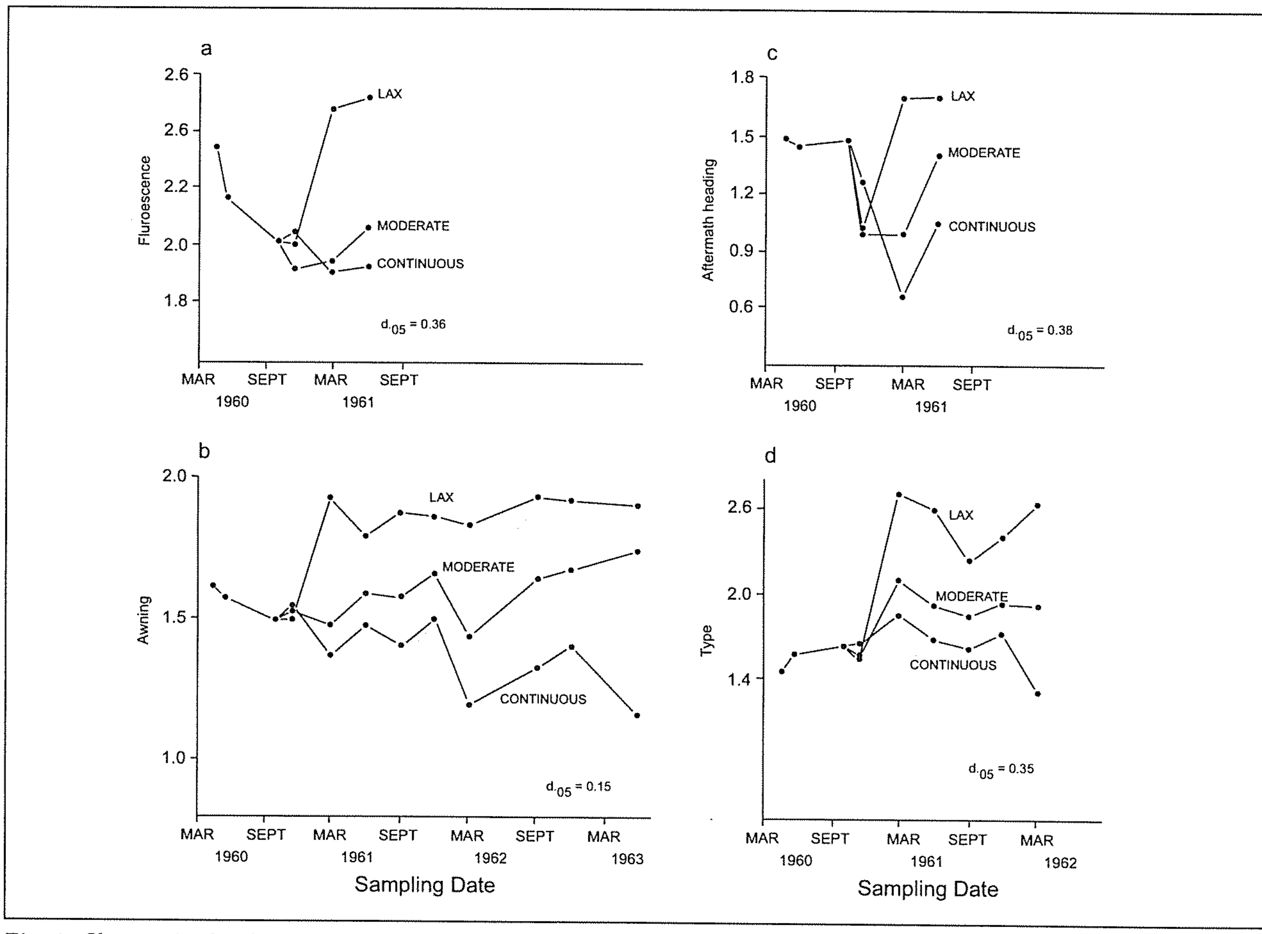

Fig. 1. Changes in the characteristics of surviving ryegrass plants in a mixed sowing of 'Grasslands Ruanui' and 'Grasslands Manawa' ryegrasses under three grazing treatments (from Brougham & Harris 1967).

characters. Quite different ryegrass populations developed within a year of the application of the grazing treatments (Fig. 1). As well as indicating how quickly shifts of genetic structure can occur in populations of competing herbaceous plants, these results suggest the usefulness of beginning with a plant population with a broad genetic base as a buffer against the management variables acting on a plant community.

Shrubs are vertically challenged. The closest I have come to carrying out an experiment with native woody plants similar to the work with ryegrass was when I compared 71 populations of manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides* and *K. sinclairii*) raised from seed collected at sites throughout New Zealand. These plants were grown at 1 m spacing, and it took about 3 years before they started to crowd each other. Before they began to compete for light, height and breadth measurements showed clear habit differences between populations (Fig. 2). For many of the populations these differences were related to the phenotypic stature in their communities of origin. As the planting matured the shrubs of low stature were shaded to the extent that they did not flower, and in a few years they died. This outcome was most apparent for the prostrate kanuka found on geothermally heated soils (*K. ericoides* var. *microflora*). Where the plants of this population were surrounded by other manuka and kanuka in the experimental layout they were shaded, and died within a few years. But plants of this population grown on the border of the layout remain alive 11 years after planting. This shows how misfits in a population of competing woody plants can be quickly eliminated; in the example given, the key factor was competition for light.

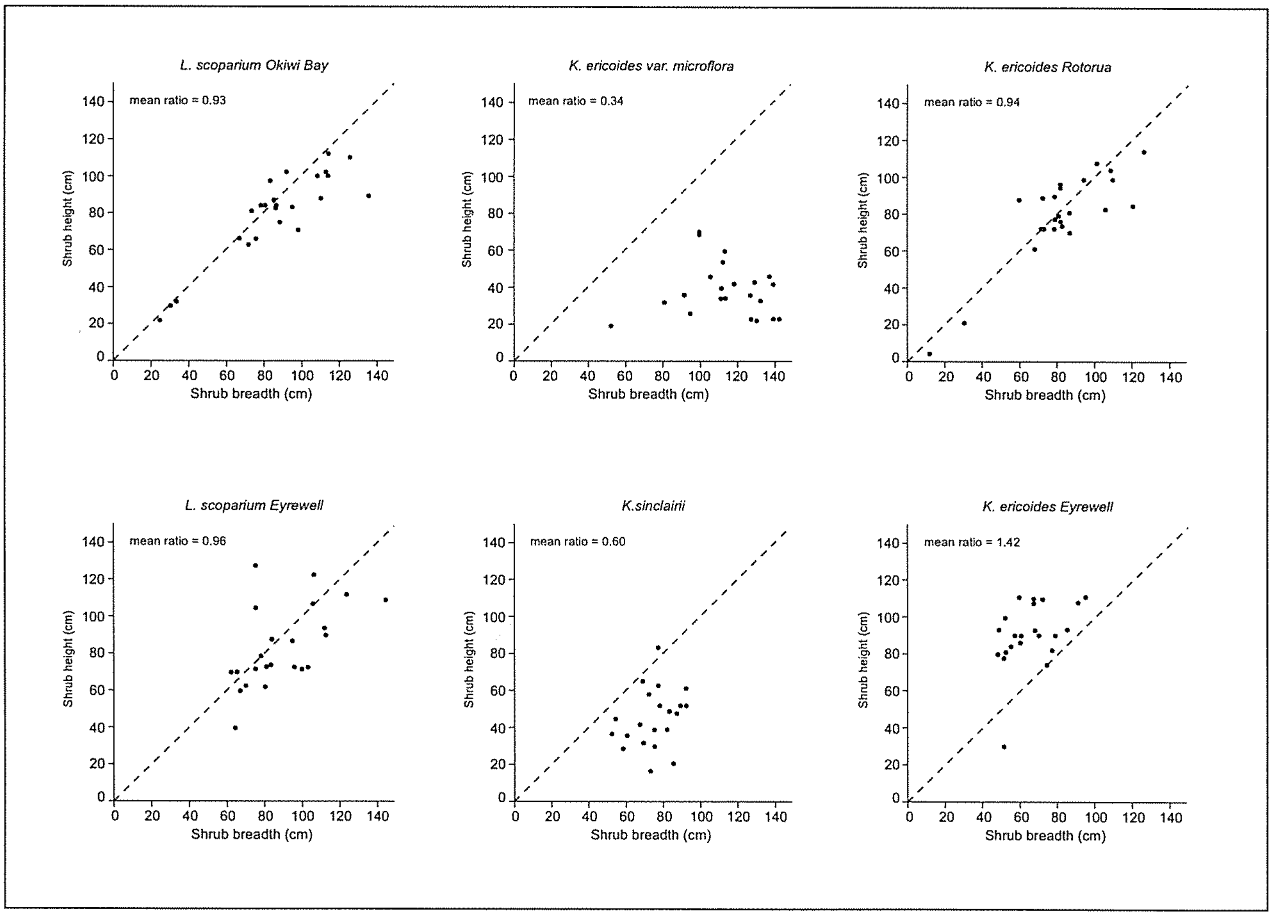

Fig. 2. Height plotted against breadth of individual shrubs in six tea tree populations after 19 months growth under uniform garden conditions at Lincoln. Means of the height-to-breadth ratio are shown for each population (from Harris 1994).

Genetic reconstitution by strong edaphic selection pressures. The kanuka endemic to Great Barrier Island (*Kunzea sinclairii*) occurs in a restricted area around Mt Hobson. I have not been to the island, but the population raised from seed collected from plants in this area was used to confirm the status of *K. sinclairii* as a species (Harris *et al.* 1992), and also led to the discovery of an intergeneric hybrid, *Kunzspermum hirakimata* (Harris 1993). This hybrid is sterile, and it is most unlikely that the seed from which it was raised would have produced a plant that would have survived in the wild. Brian Molloy – who has seen *K. sinclairii* in seral communities on formerly forested areas – also saw hybrids with *K. ericoides*, which is abundant on Great Barrier Island. Seedlings raised from an open-pollinated plant of *K. sinclairii* adjacent to *K. ericoides* plants at Lincoln show that the species hybridise freely. This raises the question as to why *K. sinclairii* has not been genetically overwhelmed by the more abundant *K. ericoides*. Evidence suggests that the genotype that characterises *K. sinclairii* is reconstituted by very strong edaphic pressures, and that its refugial niche in the absence of disturbance may be very small.

Phenology, succession, and feeding the birds and bees. I have observed how many years it takes before tea trees first flower and at what time during the year they flower. Again, distinct differences between populations in these phenological characteristics have been revealed. Kanuka populations that flower early in their lives are also more prolific in their flowering, as indicated by the period over which they flower in a year (Fig. 3). What is the adaptive significance of this relationship? I entertain the idea that it reflects differences in the seral role of kanuka in different habitats. For example, when grown together at Lincoln the kanuka population from

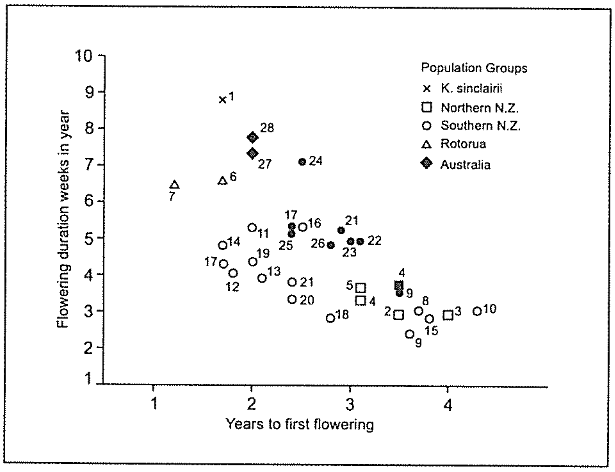

Fig. 3. The relationship between the number of years taken for Kunzea *populations to first flower and the number of weeks the populations flowered each year (from an unpublished manuscript by W. Harris). Differences in diameter growth rate of kanuka between plots were tested by* t*-test. Within plots, differences in seedling numbers between measurement years were tested by Wilcoxon signed ranks test.*

Bankside Scenic Reserve is shorter in stature and seeds sooner and much more prolifically than kanuka populations from nearby Banks Peninsula. These differences are possibly imprints of the disturbance that maintained the original kanuka-dominant shrublands of the dry Canterbury Plains, and the role of kanuka on the Peninsula as a seral species in the succession to forest. It would be quite inappropriate to use seed from the much more abundant kanuka on Banks Peninsula in any attempt to increase the area of the natural shrubland communities on the Canterbury Plains. It is hypothesised that differences between plants in their timing of flowering and fruiting have arisen through the co-evolution of plants and animals. Plants use animals for pollination and seed dispersal by attracting them and providing food as a reward. Studies such as that by Primack (1980) at Cass have shown that the constituent species of plant communities do not all flower at the same time. The sequence of flowering, fruiting, and seeding is important to maintain the viability of animal species that require nectar, pollen, fruit, and seed for their nutrition in phase with their life cycles. Thus, while Godley's concern was to protect the genetic integrity of natural plant communities in New Zealand, I suggest that the principles he invoked should be heeded if we wish to sustain the healthy function of all the organisms supported by restored habitats. Introduction of a plant population into a habitat with a phenology out of phase with that to which the animals using the habitat are adapted could be disruptive.

A special case for the oddities

The case to protect rare and endangered species is well established, although the means of doing this, including restoration of the habitats in which these species occur, are often less than satisfactory. But what is the situation regarding the protection of rare genetically determined characteristics in species that may be common and widespread? Are there examples of this kind of protection in New Zealand or elsewhere?

As an example of a possible candidate, there is an unusual form of manuka found by the late Andrew Purdie at windswept Okiwi Bay near Kaikoura. When this population was grown at Lincoln a proportion of the plants were very small and ball-shaped (Fig. 2). They took a long time to begin to flower, and the flowers they bore were hidden in the dense arrangement of short branches that arose from a very short trunk. The windshorn shrubs at Okiwi Bay suggest that this unusual form survives as an adaptation to a very windy environment. The plants with the dwarf form have all died at Lincoln, and seedlings raised from these plants all have a normal habit, suggesting that the gene(s) that determine the form are recessive. The long-term survival of this unusual form of manuka may depend on its conservation *in situ*, whereby the strong wind acts as a selection pressure maintaining a proportion of the dwarf genotype in the population.

Conclusion

With more information about the genetic characteristics of the plants used in restoration plantings it may be possible to be more precise in some situations, and in others less cautious, about the origin of the planting material. For example, in a site disturbed to the extent that it is at an early seral stage or where the 'pristine environmental state' has been markedly altered, for example by years of agricultural fertilisation, it may be better to introduce a broadly based genetic cocktail of a species than to use seed from a single local stand at an advanced successional stage. Natural selection will quickly sort out the genotypes that are best suited to the current levels of factors and the seral stage of the site being restored. These conditions may be quite unsuitable for genotypes characteristic of the 'pristine state'.

Where distinctive genetically determined forms of species are recognised the rule should be to not introduce material from other provenances of the species. Instead, emphasis should be placed on recognising the selective force that maintains the distinctive form of the species in the population, and that, once recognised, management should aim to maintain the force. A shelter belt to protect the Okiwi Bay manuka population would be quite inappropriate! In other situations it may mean maintaining burning and grazing or removing mineral nutrients.

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Restoration substrates: the answer lies in the soil

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Introduction

Soil, or the plant growth medium/substrate, is of fundamental importance in ecological restoration. The linkages and associations between soil conditions and flora – and, at a secondary level, fauna – are well established in an ecological framework. *The type of soil, whether natural, modified, or reconstructed, is an environmental factor which determines to a significant extent the vegetation pattern and, by association, other ecological factors.*

A few examples of soil – vegetation relationships in New Zealand serve to illustrate this fundamental principle.

- Poorly drained soils naturally support wetland plant communities.
- Xerophytic plants (e.g., matagouri – *Discaria toumatou*) are adapted to droughty soils.
- Sand dunes have their own characteristic plant communities dominated by species such as pingao (*Desmoschoenus spiralis*) and silvery sand grass (*Spinifex sericeus*).
- Tidal acid sulphate 'soils' support mangrove (*Avicennia marina*) vegetation.
- Soils with high nutrient status support different vegetation from soils which are infertile: e.g., kahikatea (*Dacrycarpus dacrydioides*) forest on fertile but poorly drained alluvial soils, and pakihi wetland vegetation on infertile perch-gley podzols.
- Forests of red beech and black beech (*Nothofagus fusca, N. solandri* var. *solandri*) tend to grow on more fertile soils than hard, silver, or mountain beech (*N. truncata, N. menziesii, N. solandri* var. *cliffortioides*).
- Red tussock (*Chionochloa rubra*) is adapted to wet soils, whereas short tussock grasslands are found on drier soils.
- Manuka (*Leptospermum scoparium*) tends to be ubiquitous, adapted to a wide range of soil conditions, whereas plants such as swamp maire (*Sizygium maire*) have much more specific environmental requirements, including soils.

We can 'engineer' the soil conditions – e.g., by irrigation, drainage, recontouring, fertilisation and liming, cultivation, mixing materials, adding organic materials such as compost, sewage sludge, and bark – to 'manufacture' or create different substrate environments. In the context of ecological restoration, we can:

- revegetate to suit the existing soils at a particular site;
- modify the soils to create appropriate substrates for the desired vegetation;
- create new soils from scratch, using soil or other soil-like media, including both organic and inorganic materials ('designer soils') to achieve a desired ecological result.

The interlinking of soils/substrates and plant communities is axiomatic. It is ironic, therefore, that the soil factor is too often neglected or taken for granted by engineers, landscape architects, and miners in restoration projects. Even plant ecologists are sometimes guilty of having paid too little regard to soils, or failing to account properly for soil factors in site restoration efforts. We would hope that soil scientists do not usurp the expertise of botanists, engineers, and landscape architects! A multidisciplinary approach is called for when dealing with many ecological restoration. Soils or substrates are a vitally important environmental factor.

The plant growth medium and ecological restoration

Plant growth media must provide four basic functions:

- supply air (gaseous exchange);
- supply water;
- supply nutrients;
- provide physical support.

Physical properties

The physical nature of the substrate, whether natural or modified, is a factor controlling the plant species which will survive on a site, and also affects growth rates. Physical properties determine aeration and water supply, and govern the rooting environment (support function).

Water retention and hydraulic properties (along with climatic and topographical factors) affect the soil moisture regime, which is a major determinant of plant species adaptation. Poorly drained Organic Soils and Gley Soils are at one extreme; droughty soils (e.g., Raw Soils, some Recent Soils, Semi-arid Soils) are at the other. Freely and imperfectly drained soils lie between these extremes. Moisture retention properties are effectively a measure of the buffering capacity of the soil to shift between waterlogging and drought, although the climatic regime is also of paramount importance. Plant selection and management especially needs to take account of the moisture regime of the soils at restoration sites. Use of 'Crystal Rain', mulching, or replacing topsoil/litter in planting programmes are ways of ensuring that seedlings do not suffer from dry soil conditions at establishment.

Soil compaction is another factor which is frequently observed at restoration sites. Compaction by machinery is common at sites where there has been a lot of vehicle traffic, especially on temporary roadways. This is particularly problematic when soil or overburden is moved during wet weather. Planting directly into small holes dug in extremely compacted ground, especially roadways, has occurred at a number of restoration sites that we have seen, with the expected results – plant death! Naturally compacted soil layers are also common, e.g., fragipans and duripans. Some plants are capable of extending their roots into compacted soils (e.g., manuka, lucerne – *Medicago sativa*) of relatively high strength, whereas most plants have restricted root development in compacted soils. Compacted soils are generally ameliorated by mechanical treatments, such as ripping, subsoiling, and surface cultivation, by addition of organic matter, or by choice of plants adapted to coping with compacted soil conditions. Prevention is better than cure, however.

Aeration, structure, texture (including stones and boulders), and thermal properties are physical attributes of soil which affect plant growth and development. All need to be considered as a part of the assessment or reconstruction of the soil regime for site restoration activities. It is often more difficult to modify soil physical conditions for plant growth than chemical properties.

Our understanding and knowledge of the edaphic requirements of indigenous plants, including soil physical limitations and responses to physical modification, tend to be based on natural ecosystems. There is scope for soil – plant interaction research in the context of ecological restoration.

Chemical and mineralogical properties

Soil chemical properties are a significant determinant of plant species occurrence. There are numerous natural examples of adaptation of plant communities to soil chemistry and mineralogy; some of the more extreme are:

- the peculiar plant assemblages known as 'serpentine vegetation', which are endemic to the ultramafic soils (high in metals such as nickel, chromium, and magnesium) in the Nelson/Marlborough and Fiordland regions;
- pakihi vegetation on very infertile Gley Podzols;
- totara (*Podocarpus totara*), kahikatea, and kowhai (*Sophora* spp.) flourishing on fertile Recent Soils on alluvial floodplains.

Soil mineralogy, a determinant of many other soil factors including both physical and chemical behaviour, is a function of the parent material and weathering regime. The mineralogy is a relatively unalterable factor for any given soil or material, at least in the short term, and you have to 'work with what you've got.' It can of course be altered or conditioned by importing other materials. Soil chemistry, however, can be relatively easily adjusted 'out of a bag' by the addition of fertilisers, manures, lime, gypsum, and dolomite.

The scientific literature and documented experience of responses to fertilisers and lime by New Zealand indigenous species are remarkably sparse. Most work has been done by the Forest Research Institute, and aimed more at production forestry using indigenous trees rather than at ecological restoration. Fertilisers are used commonly for promoting responses by a wide range of indigenous species in the nursery/home garden and landscaping industries. However, the 'shotgun/insurance' approach seems to predominate over any well founded strategy, as used for fertiliser programmes in agriculture and horticulture.

Work on site restoration at Giles Creek coal mine (Davis & Langer, this volume) has demonstrated poor responses to phosphorus and nitrogen fertilisers by a number of indigenous plants. But significant improvements in the growth rates of planted red beech from the application of diammonium phosphate have been noted by Department of Conservation staff at the Garvey Creek, Island Block CoalCorp mine near Reefton.

A subtractive nutrient pot trial by Davis (1990) on Waimarino lahar and Tangahoe siltstone substrates from the Ohakune-Horopito railway realignment showed nitrogen and phosphorus to be the most limiting nutrients for manuka and koromiko (*Hebe stricta*). Smaller responses to magnesium and potassium were recorded. Micronutrients (Co, Mn, Cu) were lacking in the siltstone. Similarly, Dakin (1976a,b, 1977) reported fertiliser responses for a range of indigenous species on compacted clay/silt materials from dam construction in the Hunua Ranges, Auckland. Magamp® (N, P, K, Mg) gave the best growth.

There appears to be a significant gap in our knowledge of the artificial culture and management of many of the species in our indigenous flora, especially with respect to attempts to engineer and accelerate the natural regeneration/revegetation cycle at disturbed and degraded sites.

Biological properties

The soil biological regime is often a critically important component in any ecological restoration project. This is often a contentious issue in designing or ameliorating substrates for degraded or disturbed sites.

Soil organic matter (SOM) – litter, fermentation and humus layers, and assimilated SOM in topsoils – is a particularly critical edaphic component. SOM is a major source of plant nutrients, especially for indigenous forests, as well as a conditioner of physical conditions such as water retention, structure, and aeration. Forest 'slash' (logs, stumps, branches) return is of considerable value in restoring plants, insects, and other biota because of nutrient cycling, microsite factors, and seed/seedling/insect sources.

Decisions on the relative merits of topsoil *vs* relatively sterile materials such as subsoils, overburden materials, sand, gravel, crushed rock, and tailings for plant growth media are debated. The nutrient, water retention properties, and soil structural properties of topsoil usually outweigh problems associated with weed seeds and pathogens (such as nematodes, root rots, and other soil-borne diseases and pests), at least in the longer term. It should be stressed that it took nature hundreds to thousands of years to create the microecology of topsoils. We can undo all of that in minutes by burying topsoil or failing to utilise topsoil resources in site restoration work. It is acknowledged that there are some circumstances where it is more appropriate not to use topsoils because of weed, pest, and disease problems. Cost and availability are other issues. Non-topsoil materials should be used where the intent is to restore a site through natural plant succession, starting with 'pioneer' algae, lichens, mosses, and nitrogen-fixing plants. However, the revegetation process will be very slow under these substrate conditions, especially if the material is coarse and no nitrogen fertilisers are added, and if the ground climate is severe. Generally we are interested in speeding up the natural revegetation process substantially at degraded sites.

The soil-borne flora and fauna is as important a component of ecological restoration as the aboveground biology. At most sites restoration tends to involve coping with what is there, or allowing nature to recolonise. Two noteworthy exceptions are the artificial 'seeding' of earthworms and inoculation with vesicular-arbuscular (VA) mycorrhizae or rhizobia for legumes. VA mycorrhizae are of particular interest for restoring indigenous forest ecosystems. Also, the use of forest duff and slash is very beneficial for a number of reasons.

Working with what you've got

In many ecological restoration situations it is only possible or practical to use the substrates that exist on the site. Erosion scars, riverbeds, and some mining/quarrying sites are good examples. Or the situation is such that the natural soil remains intact and only the above-ground ecology needs to be restored. In these situations it is necessary to suit the soil stripping and reconstruction and revegetation programmes to the soils/substrates. Species which are amenable to the soil conditions should be seeded and planted.

Modifying the substrate

It may be appropriate to change the substrates/soils on a degraded site to suit restoration aims.
For example:

- Mechanical treatments such as ripping and cultivation to create more favourable conditions for seeding or planting.
- Fertilising and liming to improve fertility status – as is standard practice for restoration to agricultural and plantation forestry production.
- Draining for species demanding well drained conditions; conversely, compaction or adding clay to create poorly drained sites for wetlands.
- Bringing in other materials such as organic wastes (sewage sludge, peat, compost) as surrogate topsoils, overburden mudstones/sandstones to extend limited soil materials through admixing, and artificial soil conditioners (e.g., lime, polyacrylamides) to change soil physical regimes.

'Designer soils'

This is the 'start from scratch' option – using the materials you already have on site, or importing others to create the substrates that suit ecological restoration purposes. It is the common situation at mining and construction sites where there is major earthmoving. It may be feasible to rebuild approximately the original soil profile form. At the other extreme, completely new and different substrates may be created using soil-like materials, both organic and inorganic.

An example is the conversion of pakihi wetlands in Westland to pastoral agriculture through alluvial gold mining. The impervious subsoil materials are buried in the tailings, and only the topsoil is re-spread over the freely draining tailings. In the Westland environment a relatively thin veneer of topsoil over gravels makes an ideal substrate for pasture.

Major construction/mining sites

Ecological restoration at sites where there are major earthworks – mines, dams, dismantled villages, the fringes of housing and industrial developments – involves a number of special considerations. The impacts of large machinery, the dictates of tight construction schedules, and changing engineering requirements are often significant factors in the restoration process. Engineering factors tend to drive what can and can't be achieved in site restoration. However, the fact that there is the capacity to engineer the restoration scheme is a bonus compared with situations such as erosion sites where there is little or no control over the substrates.

Substrates and revegetation

Ecological restoration requires an understanding of the factors controlling and limiting seedling establishment and growth. Substrates and topographic surfaces need to be used, designed, or modified according to the desired objectives, particularly with respect to revegetation. Ongoing management, such as weed and pest control, is of paramount importance, particularly in the initial phases of restoration.

Some examples from mine restoration

The following examples are cited to demonstrate the *principles* for designing, using, and managing soil and other materials in ecological restoration projects.

Martha Mine, Coromandel

Trials were established in 1985 to assess suitable growing media for pasture restoration on volcanic soils and overburdens. Mean annual rainfall is 2150mm with no water deficit in any month. Oxidised andesitic rock with and without lime and superphosphate additions, tailings, and topsoil were examined, along with soil depth (50 mm, 150 mm, 250 mm), and compared against an original *in situ* soil (Gregg & Stewart 1991, Gregg *et al.* 1990, Horne *et al.* 1990).

After three years, total pasture production from nil soil treatment (modified waste rock) was about 90% of the yield from soil treatments on modified waste and 10% higher than on unmodified waste rock. No differences in pasture growth were attributed to soil depth variation. Annual pasture yields for the soil over waste rock were similar to those from *in situ* soil. Yield data from the tailings site gave similar results to comparable modified waste treatments. The recommendation from this research for pasture rehabilitation on the bunds of the tailings pond was 100 mm of topsoil over oxidised waste rock modified by liming and superphosphate.

More recently Ms Kathy Mason, environmental officer at Waihi Gold Mining Co. Ltd, has initiated field trials on tailings restoration to pasture and indigenous species, including wetland plants.

Tailings to the surface *vs* a surface cover (15 cm) of organic composted materials are also being compared as growing media for pasture and four native species – flax *(Phormium tenax)*, kohuhu *(Pittosporum tenuifolium)*, cabbage tree (*Cordyline australis*), and manuka. The trials are at too early a stage to discuss the results fully, but since planting in 1993 the native shrubs have increased growth twofold. The pasture has benefited from compost addition, and contains more clover (*Trifolium* spp.) than non-compost plots.

Waimumu lignite mine restoration, Southland

A five-year land restoration experiment for lignite mining at Waimumu, Southland. (Widdowson *et al.* 1986, Widdowson & Ross 1987, Widdowson & McQueen 1990) examined methods of soil reconstruction, ripping, a low vehicle compaction treatment, drainage, and nitrogen fertiliser treatments. Loess (a Pallic Brown Soil) and overburden siltstone formed the reconstructed substrates. Mean annual rainfall is about 900mm.

Reconstructed soil resulted in pasture production about 90% that of the undisturbed soil. Mixing subsoil and topsoil or adding siltstone overburden to soil materials replaced by horizon gave pasture yields 70-80% those of *in situ* soil. Ripping and low vehicle traffic to relieve/prevent compaction significantly improved pasture productivity. Nitrogen fertiliser was also beneficial. Mole drainage did not have any measurable effect.

Beech forest restoration, Giles Creek coal mine, Westland

A series of field investigations at Giles Creek coal mine near Reefton is looking at methods for restoring beech-podocarp forest. Research on a range of growing materials/substrates is included (Ross & Mew 1992a,b, Jackson 1994, Ross *et al.* 1994), along with revegetation (Davis & Langer, this volume). Mean annual rainfall is 2900mm.

The materials used for site restoration are:

- topsoil and subsoil from Allophanic Brown Soils (with minor amounts of materials from an Acid Gley Soil and Recent Soil);
- overburden alluvial gravels (mostly granitic);
- overburden and interburden mudstone/ sandstone with admixtures of coal.

The main experimental plots are examining revegetation – using replanted indigenous seedlings – on:

- reconstructed soil profile over gravels;
- mixed organic, topsoil, and subsoil over gravels;
- gravels to the surface.

A subsidiary trial consists of plantings on overburden/interburden mudstone. Other trials involve a conglomeration of all of these materials plus mudstone/sandstone/coal fines. Surface respreading of forest slash and stumps or manuka slash are additional components, the miner having recently adapted this to a block of 'instant forest' where the tree stumps and associated soil and seedlings have been relocated.

The first two years of results have shown that soil replaced by horizon is the best growing medium for most indigenous plants except red beech and mountain beech. More beech seedlings have survived on both the gravels and mudstone, growth rates being better on the latter. Mixed soil materials have given results intermediate between those from reconstructed soil and gravels to the surface.

These alternative revegetation methods are showing reasonable results, and are certainly better than leaving bare substrates at the surface.

Pakihi restoration, Giles Creek, Westland

Another restoration research project at the Giles Creek coal mine is on pakihi wetland (Ross & Williams 1994). The soil is a Humose Perch-gley Podzol, and the floristic composition of the vegetation is in Group 4 of Williams *et al.* (1990).

Soil replacement treatments are:

- topsoil (0-30 cm) replaced over subsoil (30-60 cm);
- mixed soil materials.

Revegetation methods comprise:

- no artificial revegetation (material replacement by an hydraulic excavator);
- slices of surface vegetation and topsoil on surface (incomplete cover);
- mat of stripped vegetation and topsoil replaced ('instant pakihi').

The first vegetation monitoring in November 1994, eight months after the earthworks, gave inconclusive results because there was very little regeneration of plants at that time. There were some differences in surface appearance between the treatments, however. Disintegration of exposed granite boulders and depositions of very fine sand and silt quartz in hollows were prevalent on the plots with no artificial revegetation. Poor soil drainage had demonstrably been restored!

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Photo 1

Photo 2

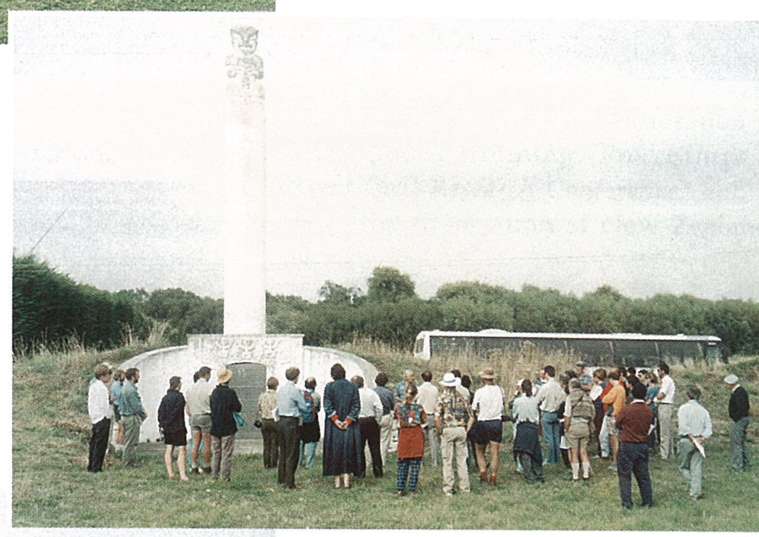

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

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Rehabilitation of lowland indigenous forest after mining in Westland

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Introduction

There are many alluvial gold and open-cast coal mining operations in Westland, and a number are in indigenous forest on Crown land administered by the Department of Conservation (DoC). In the past there has been no planned or managed restoration of indigenous forest on mined sites, but this is changing under DoC management and as a consequence of the requirements of the Resource Management Act 1991. Information on appropriate rehabilitation techniques is needed to set conditions for mining licences, and to advise miners how to restore disturbed land to indigenous forest similar to that present before mining. Rehabilitation techniques for indigenous forest are being investigated at an open-cast coal mine site on alluvial river terraces at Giles Creek near Reefton, Westland.

The forest and soils before mining

The forest on the main terrace at the Giles Creek mine site had been cut over in the early 1980s for red beech (*Nothofagus fusca*), podocarps – principally rimu (*Dacrydium cupressinum*) and miro (*Prumnopitys ferruginea*) – and some silver beech (*Nothofagus menziesii*). However, a forest structure was still present before mining. Beech species dominated the canopy and subcanopy tiers, with silver beech dominant and red beech and mountain beech (*N. solandri* var. *cliffortioides*) also prominent. In adjoining unlogged terrace forest, red and silver beech were codominant and mountain beech was much less abundant. Prominent species in the lower tiers of both forest types included lancewood (*Pseudopanax crassifolius*), wineberry (*Aristotelia serrata*), pepperwood (*Pseudowintera colorata*), small-leaved *Coprosma* species, mountain toatoa (*Phyllocladus alpinus*), and Hall's totara (*Podocarpus hallii*). Soils on the alluvial terraces are predominantly Allophanic Brown Soils (Hewitt 1992) of the Ahaura series, with Acid Brown Soils of the Ikamatua series on younger terraces and Acid Gley Soils of the Maimai series on poorly drained sites. The soils overly varying thicknesses of alluvial gravels which in turn overly the coal seams.

Pilot field trials

Rehabilitation studies began in 1990 when two pilot field trials were established on an existing overburden dump formed by the mining operation. The material capping the dump was composed mainly of finely weathered granitic gravels overlying the coal seam, but included forest soil horizon and sandstone interburden material.

One of the trials used nursery stock that was available when the project was initiated to provide an early indication of the mine rehabilitation potential of a range of indigenous tree and shrub species, to compare bare-rooted and container-grown stock, and to provide information on the need for wild animal control measures for plantings of indigenous species at Giles Creek. This trial was characterised by high mortality in most species, and slow growth rates in surviving plants of all species. The high mortality and slow growth rates are attributed to a combination of factors, including poor drainage, soil infertility, and browsing by hares. The results illustrated the difficulty of establishing native tree and shrub species on unmodified mine spoil, and indicated the necessity of appropriate site preparation techniques to overcome such factors as poor drainage and substrate infertility. Survival was highest in kahikatea (*Dacrycarpus dacrydioides*), reflecting its tolerance of poorly drained substrates. Broadleaf (*Griselinia littoralis*) and karamu (*Coprosma robusta*) survived well in a plot fenced to exclude hares, but were severely browsed in an unfenced plot. Where possible, use of palatable species such as these should be avoided in rehabilitation programmes unless adequate animal control is possible. Severe browsing of both species did not occur until the third year of the trial, indicating that, to be successful, animal control work must be maintained over a long time period. Survival of beech species (mountain, red, and silver) was extremely poor, confirming the difficulties that other workers have experienced with establishment of beech (Wardle 1984). This may reflect a lack of mycorrhizas in nursery grown stock. Further work is necessary to determine causes of failure and appropriate establishment methods for the beeches. For most species bare-rooted plants performed as well as container-grown plants. This result is considered useful, since bare-rooted plants are normally less expensive to purchase and plant than container stock, and have logistic advantages in terms of transport and handling on the planting site.

The second field trial examined the effect of nitrogen (N) and phosphorus (P) fertiliser on the growth of the pioneer shrub karamu. This species responded to treatments containing urea and blood and bone (mainly N), but not to superphosphate (P). The response to the fertilisers containing nitrogen was smaller than anticipated, possibly because of nitrogen fixation by lotus (*Lotus pedunculatus*), which was present before the establishment of the trial. The lack of response to P may be due to high quantities of apatite-P in the material capping the overburden dump.

Glasshouse nutrition study

A glasshouse trial was conducted to determine the potential requirements of karamu and red beech for a range of nutrients when grown in both soil and gravel overburden materials collected from stockpiles at Giles Creek. 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 overburden gravels consisted of a mixture of greywacke, granite, and schist materials. Potential deficiencies of nitrogen, phosphorus, sulphur (S), potassium (K), magnesium (Mg), boron (B), and lime (soil only) were sought by applying a series of complete nutrient supplements which omitted one of the above elements at a time.

In this experiment the growth of both karamu and red beech was severely limited on both soil and gravel when N and P were omitted from otherwise complete nutrient solution applications. Red beech showed much more pronounced yield reductions (>90%) than karamu (~50%) when P was omitted from the nutrient solutions. Small yield reductions occurred in karamu – but not in red beech – when Mg and lime were omitted from the soil (but not from the gravel), but there were no yield reductions when S, K, or B were omitted from either material. In the treatments where N was omitted the leaves of both species exhibited deficiency symptoms; in karamu older leaves were yellow, while in red beech older leaves were red. For equivalent nutrient treatments mean yields of both species on gravel were between 18% and 74% of those on soil, the differences being most marked where N was omitted. This shows the value – particularly for site N levels – of stripping soil separately and respreading it on top of overburden materials.

Seeding trials

Seeding trials with indigenous woody species were established in spring 1991 on an overburden fill site at Giles Creek. Despite low strike rates (0.5-14%), first season establishment of karamu, tree tutu (*Coriaria arborea*), and manuka (*Leptospermum scoparium*) was good (29-189 seedlings/m^2), but subsequent mortality has been high (30-100%) because of summer desiccation, possible frosting, and severe N deficiency. Seedlings surviving the first winter responded strongly to fertiliser applied in spring 1992, but the fertiliser also stimulated competition from herbaceous weed species. Despite the mortality, high seedling numbers were still present in some species at the end of the third growing season, i.e., 9 seedlings m^{-2} (90 000/ha) of karamu, and 14 seedlings/m^2 of manuka.

To date seeding trials have been established only on highly N-deficient gravel overburden. Where soil has been replaced, seeding – perhaps in combination with planting – could be a relatively cheap, viable technique and needs to be investigated further. On substrates with low N availability only N-fixing species will succeed in the absence of fertiliser. Gorse (*Ulex europaeus*) normally occupies this niche in Westland.

Soil replacement trial

A trial was initiated in 1992 to examine the impact of soil stripping and replacement on overburden materials on the survival and growth of indigenous tree and shrub species. Three soil replacement treatments are being compared at Giles Creek:

(1) gravels to surface with no soil replacement (control);

(2) gravels overlain by mixed soil horizons (i.e., mixed organic, topsoil, and subsoil horizons) stripped from the forest before mining; and

(3) gravels overlain with stripped soil, which was replaced by horizon (i.e., mixed organic layers and mineral topsoil over subsoil).

The effects on the gravels of compaction by earthmoving machinery are being tested by ripping; half the plot area in each treatment was deep-ripped before soil placement. The construction of the soil replacement treatments has been outlined by Mew & Ross (1992). Twelve indigenous forest tree and seral shrub species – red beech, mountain beech, kahikatea, totara (*Podocarpus totara*), kamahi (*Weinmannia racemosa*), marbleleaf (*Carpodetus serratus*), karamu, tree tutu, koromiko (*Hebe salicifolia*), manuka, fuchsia (*Fuchsia excorticata*), and wineberry – were planted on the three substrates. Survival and height growth are being measured annually. A fertiliser trial with four species (red beech, kahikatea, karamu, and marbleleaf) was established on the mixed soil treatment to determine whether the N and P deficiencies observed in the glasshouse trial were apparent in the field. In addition, twenty 0.25 m^2 plots were established along transects located in each of the three major treatments to examine natural regeneration of native and exotic species.

Initial results from the trial show that for most of the species planted, soil replacement by horizon is superior to replacement of mixed soil, while the latter, as expected, is in turn superior to no soil replacement at all. However, the beech species are an exception to this trend. Mortality of the beeches has been very high in both soil replacement treatments, probably because of the presence of root rots in forest soil associated with imperfect drainage and poor oxygen supply. The poor performance of the beeches is of concern as they were the dominant species before mining, and studies are needed to investigate the problem with a view to developing techniques that allow their successful establishment. Plant survival to date has been good on gravels, but plant vigour is poor in all species (except for the N-fixer tutu) because of lack of N, and it is possible that ultimately only tutu will survive on this substrate. For situations where it is not feasible to strip and replace soil horizons over gravels, there is a need to develop techniques using N-fixing plants to increase substrate N levels sufficiently to allow subsequent establishment of non-N-fixing native species. Ripping appears to have improved plant survival slightly in the mixed soil treatment, but has had no beneficial effect in the other treatments.

In the fertiliser trial on the mixed soil horizon treatment, vigour responses to N were apparent in karamu and marbleleaf during the first growing season, but not in the second growing season, and there has been little height growth response to N. There has been no response to P in either growing season. The lack of response to fertiliser following the second growing season indicates that the better vigour of plants in the horizon replacement treatment in comparison with the mixed soil treatment, is more likely to be due to better drainage/aeration of the soil than better nutrition. The poor drainage and aeration characteristics of subsoil horizons raises the question as to whether there are any advantages to be gained by retaining and replacing subsoil horizons, particularly in high-rainfall environments.

Natural regeneration of self-sown exotic and indigenous species is proceeding faster in the horizon replacement treatment (mean ground cover 20% at the end of the second growing season) than in the mixed soil (5%) and gravel (<1%) treatments. A total of 15 species were recorded in each of the two soil replacement treatments, while only three were recorded in the gravel treatment. Ground cover in the horizon replacement treatment is dominated by the trailing herb *Nertera depressa*, while cover in the mixed soil treatment is dominated by rushes (*Juncus* spp.), reflecting the poorer drainage and aeration there. However, rushes and sedges (*Carex* spp.) are also common in the horizon replacement treatment.

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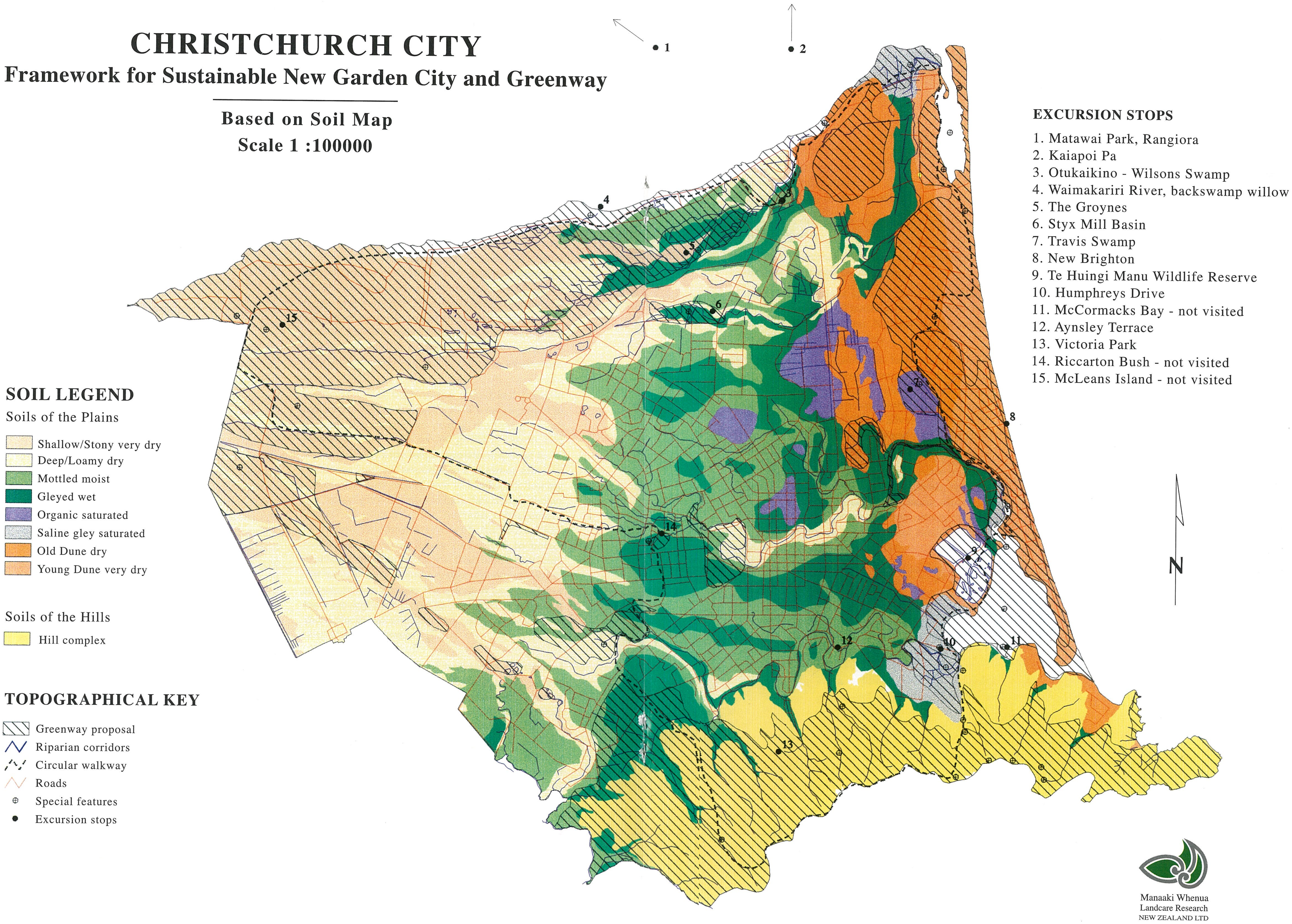
Scale 1 :100000



Preliminary implications for rehabilitation of mining sites

- Good site drainage is essential for most woody native species.
- Adequate animal control is vital for successful indigenous forest rehabilitation.
- Most native plant species grow best where organic and topsoil materials are placed on the surface of overburden. Nursery-grown beech seedlings are an exception.
- Replacement of soils as layered horizons provides better results and overcomes the drainage and aeration problems which occur where subsoils are mixed with organic/topsoil materials. There may be no advantage in saving and replacing subsoil horizons, particularly in high-rainfall environments.
- For situations where it is not feasible to strip and replace soil horizons over gravels, there is a need to develop techniques using nitrogen-fixing plants to increase substrate nitrogen levels sufficiently to allow subsequent establishment of non-N-fixing native species.
- Seeding may be used for establishing pioneer species to supplement plantings.

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Hydroseeding with New Zealand native species

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Introduction

Hydroseeding or hydraulic seeding, developed in the United States and Europe in the 1950s to stabilise and revegetate disturbed areas (Schiechtl 1980), is the application of seed and fertiliser as a water-based slurry from a slow-moving or stationary tanker. Usually fertiliser, adhesives or stabilisers (PVA, PAM, latex, cellulose), and/or a protective mulch (plant litter, peat, paper, bark, wood pulp, or chopped straw) are added to the slurry (Roberts & Bradshaw 1985). Asphaltic bitumen may be separately applied as a stabiliser. Organic polymers like PVA are easier to use than bitumen because they can be added directly to hydroseeding mixtures, are not a hazard to traffic, and do not require cleaning solvents (Armstrong & Watt 1987). Hydroseeding with grass species also provides a filter for stormwater runoff, reducing sedimentation of waterways (Carr & Ballard 1980). It is particularly suited to inaccessible sites and slopes such as road and rail embankments which cannot be traversed by vehicles (Nebauer & Good 1971).

First used in New Zealand in 1966 (Lambrechtsen 1986), hydroseeding is now employed throughout the country, primarily to revegetate highway cuttings. Current hydroseeding practices generally focus on short-term establishment of plant cover. Typical hydroseed mixes used in New Zealand comprise high rates of annual and perennial exotic grasses and legumes (80-165 kg/ha) with inorganic fertiliser (700-1000 kg/ha 12:10:10 N:P:K) in a newsprint mulch (1000 kg/ha) with an adhesive slurry. Sewage sludge, bentonite, and a rhizobium inoculum specific to the legumes being applied may also be included in a hydroseeding mix (Lambrechtsen 1986).

Hydroseeding with native species

Application

Hydroseeding with native species has the potential to enhance roadsides, subdivision cuttings, and railway cuttings which abut predominantly native communities, especially in forested areas, by creating a 'blended' surface. Hydroseeded faces should form a more natural vegetation pattern than planted areas owing to the random distribution of seeds and germination of some species over a number of years. Clunie (1986) states: "Although the area beside roads is small, aesthetically it is highly significant in determining quality of the forest scenery because many viewers are restricted to the road."

Hydroseeding native plants reduces or avoids costly plantings of containerised seedlings. Also, under the National Parks legislation, 'new' exotic species may not be used in national parks without approval.

Vegetation can only be established on sites which are stabilised before or during the establishment period. Mulches and a rough, scarified surface help stabilise the soil, keep seed in place, reduce extremes of surface temperature, and improve retention of soil moisture (Lambrechtsen 1986).

History in New Zealand

Most hydroseeding of native species has been carried out on Crown lands in, or close to, National Parks and Scenic Reserves in conjunction with large-scale road, rail, and hydro-electric dam development (MacGibbon 1994). Native toetoe grasses (*Cortaderia* spp.) and silver tussock (*Poa cita*) were successfully hydroseeded in the Tongariro Power Scheme and Makatote Viaduct access road in the central North Island. The hydroseeded areas were later either planted or left to be colonised naturally by indigenous species (Scheltus 1983). Brown (1986) reported that seeding native plants by hand-broadcasting and hydroseeding had limited, variable success, the best results occurring with large volumes of ripe, viable seed, a fine seed bed in favourable soil, and presence of an uncompetitive cover. Nicholls (1986) and Scheltus (1990) reported that including browntop (*Agrostis capillaris*) at 2.5 kg/ha in a hydroseed mix was successful because the open nature of the sward allowed natural regeneration of koromiko (*Hebe stricta*), broadleaf (*Griselinia littoralis*), and tree tutu (*Coriaria arborea*).

Lambrechtsen (1986) stressed the importance of applying native seeds to a stable surface, and advocated applying only native seeds or adding a non-competitive nurse crop such as *Lotus pedunculatus* cv. 'Maku' at 1 kg/ha. As an alternative, he suggested planting seedlings of native species into hydroseeded areas. As the hydroseeded plants thinned out, seeds from the planted species would establish.

Research findings

Limiting characteristics of native species

There are five main limitations to the widespread use of native species in hydroseeding.

- Gathering large volumes of ripe, viable seeds is expensive (Lambrechtsen 1986), and may require long lead times, especially where treatments to break dormancy are needed. Wheras seed of some native species (e.g., *Hebe*) ripens continuously over several or many months, many native trees seed only infrequently in 'mast' years, requiring multiple visits to collect seed. Native seeds are not widely available commercially and viability may be low: only 16% for manuka (*Leptospermum scoparium*) used in an Upper Hutt trial. Stratification or other treatment is required to increase the rate and evenness of germination of many species. Most New Zealand beech species have seeds which are viable for only 8-12 months (Wardle 1984).
- Native seeds used in recent Landcare Research hydroseeding trials have been slow to germinate. A long germination time (>1 month) requires hydroseeded material (including seed) to be kept moist for extended periods. Traditional hydroseed mixes form a crust on drying which is probably a barrier to shoot and/or root extension.
- Some or many native species are associated with obligate or facultative symbiont mycorrhizae. Malaysian forest research suggests that contact with living ectomycorrhizal tissue from hyphal and root fragments, rather than spores, is much more important for early infection of seedlings (Alexander *et al.* 1992). However, introducing organic matter to supply sources of these fungi also has the potential to introduce propagules of invasive exotic plants.
- Most native species are poor early competitors. Relatively slow growth rates increase the risk of smothering by exotic herbaceous species (Lambrechtsen 1986).
- Relatively few native dicotyledonous woody plants are colonisers or pioneers capable of growing on exposed mineral soil (Pollock 1986). Native nitrogen-fixers are tutu (*Coriaria* spp.), broom (*Carmichaelia* spp.), and matagouri (*Discaria toumatou*). Tutu is a natural coloniser of new volcanic surfaces on Mounts Tarawera and Egmont/Taranaki (Clarkson 1991), but can be poisonous to stock and is disliked by apiarists. Manuka is the dominant pioneer species of eroded sites in Fiordland (Mark *et al.* 1989), burnt areas in Otago (Allen 1988), and elsewhere. However, the original forest re-established much faster where seedlings of the canopy and understorey were present without manuka. Manuka is a particularly adaptable (plastic) species, tolerant of low fertility, low pH, and exposed sites, and has been recommended for revegetating waterlogged sites (Clunie 1989). It has been used extensively by the Department of Conservation for fascining (Scheltus 1983), and was the most successful species hand-broadcast in a recent West Coast trial (L. Langer, pers. comm.).

Clarkson (1991) identified *Metrosideros* species and kamahi (*Weinmannia racemosa*), as tall forest trees able to quickly occupy bare areas from wind-blown seed sources. The most successful native colonisers of mudstone and tephra batters near Ohakune in Tongariro National Park were coprosmas (*C. grandifolia* and *C. robusta*), koromiko, tutu, and toetoe (*Cortaderia fulvida*) (R.E. Simcock unpubl. data). Although toetoe has high root weights, Follet & Dunbar (1985) found that it had few fibrous roots and was thus less likely to effectively hold erodible material than koromiko, *Olearia* spp., and *Cassinia leptophylla*. Clunie (1989) suggested the following species as being suitable for revegetation of exposed sites in Waipoua Forest:

manuka, kanuka (*Kunzea ericoides*), coprosma species (*C. lucida*, *C. robusta*, *C. repens*), northern rata (*Metrosideros robusta*), *Olearia* spp., broadleaf, akeake (*Dodonaea viscosa*), *Corokia* spp., native grasses (toetoe, *Microlaena stipoides*), and the fern *Blechnum* 'black spot'.

Beech germination and establishment

Beech (*Nothofagus*) species are natural colonisers of bare sites such as erosion scars, exposed glacial surfaces, and road cuttings, and thus have potential for hydroseeding despite being poor early competitors. The relatively heavy weight of beech seeds means that natural dispersal (excluding water-carried seed) is limited to areas within 40 m of existing trees. Beech nuts of most species require at least 60 to 90 days of stratification in cool, moist conditions to improve germination percentages and shorten germination time. Germinating beech seedlings are easily killed by desiccation because development of an extensive root system is limited by small seed food reserves (Wardle 1984). Moisture, light intensity, and substrate control the success of germination and establishment of beech seedlings (Wardle 1984, Poole 1987). Shade influences moisture, light, and predator relations. Germination of beech is poor in very shady conditions, e.g., on sites with a dense cover of ferns, herbaceous grasses, or sedges. About 35% of full light is optimum for survival of seedlings through their first summer. This level reduces desiccation and predation by grasshoppers and other insects which feed in bright sunlight, and implies adequate shelter. The small food reserves necessitate a short distance between the seed and a suitable substrate. Scarified, loose mineral soil, fine shingle, or topsoil are most suitable substrates (Wardle 1984). A thin litter or moss layer also aids germination, probably acting as a mulch to conserve water. Where forest duff is thick, establishment of seedlings is poor. Continued growth of beech seedlings depends on early establishment of a symbiotic ectrophic relationship with mycorrhizal fungi (Wardle 1984). Water fern (*Histiopteris incisa*) can smother seedlings up to 60 cm high, especially where soils are damp and have a high humic content.

Recent research findings

Hydroseeding trials in Upper Hutt and Coromandel tested the hypothesis that placement of native species in a typical hydroseed mix would result in native woody species suppressing short-lived exotic grasses and herbs after an initial period, with faster secondary succession compensating for the reduced diversity of species initially present. For the Hutt Valley trial, native seeds of manuka, kamahi, snowberry (*Gaultheria antipoda*), karamu (*Coprosma robusta*), and koromiko were included in a typical paper and PVA-based hydroseeding mix of legumes, perennial and/or annual grasses, and 12:10:10 fertiliser. Gorse (*Ulex europaeus*) and adventitious weed seedlings germinated within 10-15 days at the two sites, which had a topsoil base. Manuka and kanuka seedlings were visible after 20 weeks; at this time gorse seedlings were about 50 mm tall. On the non-topsoiled site karamu, snowberry, and koromiko seedlings germinated, but no manuka or kamahi. After 18 months the topsoiled sites were dominated by metre-high broom (*Cytisus scoparius*) and gorse, and the trial was judged to have failed to establish native seedlings (Campbell 1994).

In the Coromandel trial no seedlings of native woody plants were recorded in topsoiled areas, including areas where only native plants were hydroseeded, as a dense sward of exotic grasses 40-80 cm high had smothered any native plants (Smale 1995). Manuka, karamu, tutu, and koromiko established successfully on andesitic overburden where natives alone, and natives plus exotic annuals but no fertiliser, were hydroseeded. Despite large numbers of seedlings however, these areas were predominantly bare, and would have been susceptible to erosion if the site were sloping. Kamahi had failed to germinate 18 months after hydroseeding (Smale 1995). In both the Upper Hutt and Coromandel trials, topsoil was the major source of the exotic smothering species.

Ross *et al.* (1990) reported that native plants had failed to establish in dense pasture which was established to stabilise sediments exposed by the decommissioning of the Morton Reservoir near Wainuiomata. Grazing by feral animals had

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

Photo 14

maintained the dense sward. Recent trials at a West Coast site where native seeds were hand-broadcast onto mixed soil and gravel overburden spread with forest trash showed high mortality of native seedlings after germination (L. Langer, pers. comm.).

Requirements for successful hydroseeding of native species

Results of recent trials and a review of the literature on the establishment of native plants from seed, forest duff, and transplanted seedlings indicate that establishment and growth of native species on exposed sites is best achieved by creating successional 'windows' in time or space. The hydroseeding method which achieves this will probably have the following features.

- A moist, sheltered environment for optimum seed germination:
  - Use a topsoil replacement and/or mulch. American researchers have tested several solid municipal and industrial wastes as a source of moisture-retaining organic material without weed burdens. A mulch should be selected on its ability to cover seed, retain moisture without forming a crust, and reduce erosion.
  - Roughen the soil surface to create microclimates.
  - Maintain a stable surface by using a mulch and/or 'nurse' crop.
- Minimal sources of propagules of invasive, smothering weeds and other exotic species:
  - Herbicide weeds (e.g., gorse, broom, lotus, kikuyu – *Pennisetum clandestinum*) which may be seed sources on and around the site before soil disturbance and, if necessary, before hydroseeding (Clunie 1986, 1989).
  - Do not spread topsoil on most sites, because farmland and roadside batters usually have large seedbanks of pasture species and other weeds and moderate to high fertility.
  - Minimise the length of time that bare and disturbed soil is exposed before hydroseeding.
- Maximum growth of native seedlings and competitiveness against herbaceous weeds:
  - Avoid fertiliser applications which promote growth of herbaceous competitive vegetation. Possibly slit-fertilise natives when they reach 30-50 cm height (Note: high levels of fertilisation may be wasteful when applied to plants which have mycorrhizal associations that enhance uptake of phosphorus, e.g., karamu, broadleaf, southern rata (*Metrosideros umbellata*), and probably totara (*Podocarpus totara*) and kahikatea (*Dacrycarpus dacrydioides*), which have nodules and lack root hairs – provided mycorrhizae are added to mix).
  - Exploit all available niches by hydroseeding 4-6 species adapted to the site characteristics. This increases aesthetic value and site stability by increasing tolerance of site vegetation to adverse conditions (Godt & Hadley 1993).
  - Avoid/relieve compaction, so that roots can extend deep into the soil. Note: engineering requirements may limit potential for amelioration of compaction.
  - Supply moisture (see above).
  - Supply mycorrhizae, or inoculate seeds where possible.
  - Keep subsequent disturbance to a minimum, e.g., contour roadside banks to allow sufficient space for native communities to grow without the need for maintenance such as slashing (Clunie 1986).
- Provide conditions which promote additional colonisation by native plants via natural vectors:
  - Confine disturbance to a mosaic, where possible.
  - Minimise the size of open spaces, and keep nuclei of biotic activity where possible.
  - Clump plantings as seed sources.
  - Include at least one species attractive to birds (especially large birds like pigeons which disperse seeds of large-fruited native trees) in the hydroseeding mix.

Future research needs

Current Department of Conservation policy requiring reclamation of indigenous forest where it existed before mining has exposed a dearth of knowledge and information on appropriate techniques for reclamation of indigenous forest (Davis & Crozier 1991, Metcalfe & Godfrey 1990, Ross & Mew 1991). Research on reclamation of indigenous ecosystems is needed in five main areas:

- Ecology of indigenous plants. Experimental studies are needed to quantify the optimal environmental conditions of exposure (temperature, light, and moisture) and compaction for seedling survival and growth. Seed production and dispersal characteristics, techniques to increase viability of seeds, and mycorrhizal relationships are unknown for a wide range of indigenous taxa (Norton 1991).
- Effective techniques and timing for establishment of native plants (Timmins *et al.* 1987, Parker 1991). Most reclamation trials to date have used expensive container-grown plants and/or laying of manuka slash containing viable seed capsules. Specific recommendations are needed for direct seeding and use of native species in hydroseeding (Crawley *et al.* 1991). The methods and benefits of using forest/scrub materials, including forest duff, as mulches, cuttings, or organic amendments also need to be researched.
- The impact and role of fast-growing, exotic, herbaceous, and woody species (barley/oats, grasses, tree lupin – *Lupinus arboreus*, lotus, tree lucerne – *Chamaecytisus palmensis*) at low rates (1-5 kg/ha) as soil stabilisers and non-competitive nurse crops (Brown 1986, Parker 1991).
- Indigenous successions on disturbed, revegetated sites. This is required to determine effective monitoring techniques and criteria which can be used to assess the long-term success of rehabilitated sites, e.g., site productivity, species diversity, nutrient cycling, soil stability, and development (Godt & Hadley 1993). Standards of reclamation and/or specific endpoints are required for consent conditions and for release of bonds.
- Fertiliser requirements and responses of native plants (Davis 1990).

Understand the factors controlling and limiting seed/seedling establishment and growth, and ***design substrates and surfaces accordingly*** *to create hospitable surfaces, substrates, and climates* (after Skaller 1981).

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Revegetation of dredgings on banks of the lower Heathcote River

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In May 1989 the Drainage and Waste Management Unit of Christchurch City Council invited the New Zealand Forest Research Institute, Rangiora to establish a trial to evaluate planting methods and species suitable for revegetation and landscaping on the south bank of the lower Heathcote River. The soils on this section of the riverbank have been dredged from the river; they contain heavy metals and have a high soluble salt content and an acid pH (<4.0). Previous efforts at planting trees and shrubs here have not been successful.

The objectives of the trial were:

- To evaluate plant survival and growth on modified saline soils;
- To test various site treatments and planting methods.

A total of 1000 native plant seedlings was planted in two adjacent areas in 1989 and 1991. The 22 native species used were selected for their ability to tolerate exposed coastal conditions and saline soils. Three treatments were tested:

- Ripping the soil to 60 cm depth and incorporating lime into the rip;
- A 40 cm layer of imported topsoil placed over the river bank soil;

		Treatments					
Species	Height at planting (cm)	Topsoil survival	Height (cm)	Planting survival (%)	Hole height (cm)	Control survival (%)	Height (cm)
Carex litorosa	25	-	-	-	-	30	25
Carex secta	55	100	80	75	65	100	55
Carmichaelia robusta	30	25	80	100	60	100	65
Cassinia leptophylla	45	44	70	-	-	-	-
Coprosma propinqua	50	100	70	100	80	100	85
Cordyline australis	40	100	120	100	90	83	125
Griselinia littoralis	35	87	60	66	55	100	60
Leptocarpus similis	80	-	-	-	-	80	80
Leptospermum scoparium	35	33	130	-	-	-	-
Olearia paniculata	90	55	100	50	80	50	130
Olearia solandri	50	100	80	100	50	100	95
Olearia traversii	45	73	140	100	140	83	145
Olearia lineata 'Dartonii'	80	100	170	44	180	83	170
Phormium cookianum	50	83	75	50	95	-	-
Phormium tenax	20	100	140	83	160	100	140
Pittosporum tenuifolium	20	16	60	50	90	0	-
Plagianthus divaricatus	50	100	80	100	85	77	65
Plagianthus regius	50	100	160	100	140	100	180
Podocarpus totara	30	70	60	-	-	-	-
Isolepis nodosa	70	-	-	-	-	50	60
Sophora microphylla	30	42	40	60	50	100	40

Table 1: *Species, survival, and height after two growing seasons.*

	Common name
1. *Plagianthus regius*	lowland ribbonwood
2. *Phormium tenax*	NZ flax
3. *Cordyline australis*	cabbage tree
4. *Olearia lineata* 'Dartonii'	'Dartonii'
5. *Olearia solandri*	-
6. *Plagianthus divaricatus*	shore ribbonwood
7. *Olearia traversii*	Chatham Island akeake
8. *Coprosma propinqua*	Mikimiki

Table 2: *Species ranking by survival and height growth after two growing seasons. Includes all treatments.*

- Planting holes dug to 50 cm depth and filled with imported topsoil;
- Control – no treatment.

All treatments received a topdressing of lime (10 tonnes/ha) and individual seedlings were given 50 g of NPK fertiliser at the time of planting. Weeds were controlled with a pine bark mulch and herbicide sprays. The trial areas were fenced for animal protection. Plant survival and growth were measured after the second growing season (Table 1) and species were ranked for survival and height growth (Table 2). Height growth was measured after the fourth growing season (Table 3).

Key findings were as follows:

- The top-ranked species for survival and growth after two growing seasons included several species indigenous to the local area (Table 2).
- There were no differences in survival and growth between the imported topsoil, deep ripping, and planting holes filled with topsoil treatments after two growing seasons.
- Seedlings survived and grew better on the treated areas than on the control area after four growing seasons.
- Deep ripping and liming treatment has certain advantages:
  - shattering the compacted soils to allow improved root growth;
  - incorporating lime in the rip assists in countering the heavy metals and saline soil;
  - being the cheapest of the treatments tested.
- Pine bark mulch gave good weed control and moisture retention but was three times more expensive than herbicide sprays.
- Netting fencing was essential for control of rabbits, cattle, and horses.
- Container-grown seedlings (30-50 cm height growth) with large root collar diameters (>6 mm) which had been hardened before planting gave the best survival and growth.

	Height (cm)
Olearia traversii	300
Olearia lineata 'Dartonii'	295
Plagianthus regius	270
Phormium tenax	256
Cordyline australis	237
Olearia paniculata	180
Pittosporum tenuifolium	176
Griselinia littoralis	141
Coprosma propinqua	136
Cassinia leptophylla	134
Podocarpus totara	112
Sophora microphylla	107
Carmichaelia robusta	106
Carex secta	80
Isolepis nodosa	51

Table 3: *Species ranking by height growth after four growing seasons.*

Recommendations resulting from this work are as follows:

- Species indigenous to the local area survive and grow well on the modified saline soils of this exposed river bank. Therefore it is recommended that these species be included in future landscape plantings.
- Because there were no differences in treatments after two growing seasons, deep ripping and liming are the recommended site treatment.
- Future plantings should be of large container-grown seedlings, using chemicals for weed control and netting fencing for animal control.

Restoration of coastal sand dunes using indigenous species – integration of research, management, and community

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Introduction

The widespread problem of sand dune erosion in some regions in New Zealand has been recognised since last century with guidelines on the use of both exotic and indigenous sand binding species to achieve stability (e.g., Whitcombe 1873; Kirk 1873). There are numerous descriptions of sand dune vegetation from earlier this century (e.g., Cockayne 1911) and more recently, ecological studies of coastal dunes (e.g., Esler 1970). Dune stabilisation techniques have often involved planting the exotic marram grass (*Ammophila arenaria*) or erecting solid barriers with considerable success in the use of marram grass in stabilising substantial areas of degraded sand country in many areas. However, there has been little work on large-scale restoration of sand dunes using indigenous species. This is due to a lack of knowledge of techniques for re-establishing indigenous species or for enhancing existing indigenous vegetation.

The Resource Management Act 1991 places an obligation on land managers to protect and preserve the natural character of the coastal environment, including areas of significant native vegetation. Consequently, there is keen interest by managing agencies for information on rehabilitation of coastal dunelands using indigenous plant species for coastal management plans. Local authorities, including Environment Waikato, also recognise the vital role that sand dunes have in protecting coastal development from hazards such as storms and erosion.

In collaboration with Environment Waikato, and to a smaller extent other land-managing agencies, including other local authorities and the Department of Conservation, staff of the New Zealand Forest Research Institute (NZFRI) have been investigating large-scale restoration techniques for sand dunes using indigenous species for several years. Initial emphasis was on establishment of the indigenous sand-binding species, but the programme now includes a wide range of coastal plant communities from foredune to coastal forest. An integral part of the NZFRI-Environment Waikato sand dune research and management programme has been the incorporation of community-based Beach Care groups into the programme.

This paper gives an outline of the NZFRI sand dune research programme, the rationale for managing the coastal environment, and the role of Environment Waikato as a regional managing agency. The role of the community in ecological restoration of sand dunes is also discussed.

The presentation at the workshop also considered the research and management of sand dunes in relation to two themes that are relevant to ecological restoration in a wider context. *'Rebuilding the tricky ones...'* and *'Monitoring success – knowing when we've arrived'* provided an opportunity to examine some of the philosophical issues in relation to ecological restoration.

NZFRI sand dune research programme

Previous work

A substantial amount of research has been carried out on the natural vegetation of coastal dunes in New Zealand (e.g., Esler 1970). However, there has been little work on restoration of sand dunes using indigenous species. Dune stabilisation techniques have involved planting exotic marram grass or erecting solid barriers. In part this has been because of a lack of knowledge of the role of indigenous species in sand stabilisation processes and a lack of research techniques to help re-establish indigenous species or enhance existing indigenous vegetation.

Aims of restoration research

NZFRI has an 8-year-old duneland research programme evaluating the role of native species in stabilising and protecting coastal sand dunes. Objectives are:

- At an applied level, to evaluate establishment techniques for a range of coastal species and to provide managers with choices for rehabilitating dunes where use of indigenous plant species is the preferred option. The long-term goal is to produce practical guidelines for managers and beach users on the role and management of vegetation communities on sand dunes.

- At a more fundamental level, to increase our understanding of sand dune dynamics in relation to vegetation cover, of the ecology of the species, and of the population dynamics of the plant communities that are being established experimentally.

Sand-binding species

Initial research concentrated on two of our most important native sand-binding species, spinifex (*Spinifex sericeus*) and pingao (*Desmoschoenus spiralis*).

Establishment of pingao

The most effective method of establishing pingao is to plant nursery-raised seedlings on dunes. Seed collection and nursery techniques for raising large numbers of pingao seedlings are well proven. Planting trials have consistently indicated that pingao is very site specific. Eighteen-month-old seedlings planted on exposed unstable foredunes with sparse vegetation consistently outperform seedlings on vegetated stable dunes. Results suggest that mobile dunes with small to moderate rates of sand accumulation are the preferred habitat for this species. However, excessive accumulations of storm-driven sand or dune degradation will reduce survival.

Application of slow-release NPKMg fertiliser (Magamp®) at 30 g per plant, incorporated in the sand at planting, significantly boosted early growth and health. In all trials where Magamp® has been applied, the outstanding feature is the improvement in colour and vigour of fertilised plants.

Pingao provenance differences

Variation in size, plant habit, and leaf colour has been observed in pingao collected from different parts of the country. Seedlings of 34 provenances, representing many of the main populations from Northland to Southland as well as collections from Great Barrier Island and the Chatham Islands, were raised at the NZFRI nursery, Rotorua. Seedlings have been evaluated for a range of growth and weaving characteristics. Preliminary results indicate two major forms: one is initially taller and more erect, but collapsing to a sprawling rhizomatous form, often associated with provenances from beaches with wind-blown fine sand; the other is shorter, tufted and erect with multiple basal divisions, and is often associated with coarse sand or shingle beaches.

Pingao harvesting

In many areas inappropriate methods of harvesting fibre are contributing to the decline of natural stands of pingao. The effects of different harvesting methods on plants and the quantity of useful fibre produced are being evaluated in field and garden trials. Results will be used to recommend harvesting methods that are most appropriate for a supply of good-quality fibre and a sustained resource.

Establishment of spinifex

Trials to date have shown that establishing spinifex on dunes using a range of methods is difficult. However, spinifex has been used extensively in Australia to improve degraded dune systems using a range of techniques. On the basis of Australian experience, trials have been set up in New Zealand to determine appropriate strategies for local conditions. Some field germination of spinifex has been achieved by sowing seed to a depth of 100 mm, but low viability of seed is a recurring problem. Placement of runners 600 mm long in trenches 200 mm deep with the runner tips exposed has been partially successful. Trials are continuing, to determine the best sowing season, feasibility of establishment from cuttings, and the effect and optimal timing of fertiliser application. Raising large quantities of seedlings in the nursery is also difficult, with slow and poor germination of seed and high mortality of seedlings at all stages. However, as for pingao, dune planting trials using small numbers of seedlings show high survival, and have responded positively to application of slow-release fertiliser at planting.

Australian experience indicates that fertiliser treatment of existing colonies is an efficient way of improving their vigour and extent. A series of fertiliser trials has been established at two

Coromandel sites and at Port Waikato, where areas up to 30x5 m have been treated with a range of fertiliser types and application rates. Changes in vegetation cover are being monitored. Preliminary results indicate that spinifex responds vigorously to heavy applications of nitrogenous fertiliser. Research is continuing into the most cost-effective fertiliser option, including the timing of applications. The effects of increased fertility on composition of dune vegetation, including the response of weed species, is also being evaluated.

Coastal plant communities

Recent publications stress the importance and vulnerability of coastal ecosystems (e.g., Department of Conservation 1994) and the importance of restoring ecosystems and communities rather than individual species (UNCED 1992). Further, the Resource Management Act 1991 requires that coastal management and research should be holistic in approach and based on the community model. In recent years the NZFRI sand dune research programme has been refocused into a plant-community model rather than a single-species approach. This community-based research aims to provide managers with guidelines for establishing and maintaining an ecologically sound suite of native duneland species that provide diversity and enhance the natural character of our dunes.

Indigenous species now under study include sand fescue (*Austrofestuca littoralis*), the third significant native sand-binding species (Cockayne 1911). Shrub and tree species under investigation include pohuehue (*Muehlenbeckia complexa*), sand coprosma (*Coprosma brunnea*), pohutukawa (*Metrosideros excelsa*), coastal fivefinger (*Pseudopanax lessonii*), karo (*Pittosporum crassifolium*), kanuka (*Kunzea ericoides*), and ngaio (*Myoporum laetum*). Future research will also include now rare sand dune species such as *Pimelea arenaria* and *Euphorbia glauca*. Initial planting trials will test seedling quality and size, dune habitat, shelter, and fertiliser requirements. Screening trials of indigenous species have been recently established on stable dunes at two Coromandel beaches and two at Christchurch to evaluate the performance of over 20 species.

Monitoring sand dune transects

Sand movement is being monitored on a regular basis using transects set up on coastal dunes by several Regional Councils to provide long-term trends for land-use planning and hazard mitigation purposes. In dune profile surveys along the Christchurch beaches by the Canterbury Regional Council and on beaches in the Waikato region by Environment Waikato, there has been no systematic recording of vegetation cover in relation to sand movement. The influence of vegetation cover and the effects different species on dune stability and shape has long been recognised (e.g., Esler 1970). NZ FRI have developed a method for incorporating a vegetation component into existing sand dune transect monitoring programmes for the Christchurch beaches where 45 transects are regularly surveyed using a global positioning system (GPS).

Transect data is being entered in to a geographical information system (GIS) to identify the effect of vegetation cover on dune shape, sand volumes and sand movement over time. Interpolation between transects with the aid of aerial photography will allow for understanding of dune dynamics in relation to vegetation cover and also the comparative effects of beach utilisation and modification between well used beaches and remote sections of the coast. Intensive contour and vegetation mapping is also underway on selected recently recontoured sites along the Christchurch coast where reshaped sand dunes are being replanted with exotic and indigenous coastal species to enable long-term monitoring of dune processes and revegetation strategies.

Collaborative Research Programme

A major feature of the sand dune research programme is that it is integrated with coastal management agencies; most planting trials have been established and maintained with the full participation of local communities via Beach Care groups.

Besides NZFRI in a research role, the main participating agencies include the Department of Conservation (Science & Research Division and Conservancies), Regional Councils (Environment Waikato, Environment Bay of Plenty, Auckland

Regional Council, Canterbury Regional Council), and district or city councils (e.g., Christchurch City Council, Franklin District Council, Tairua District Council). Other participants include Maori trusts and incorporations, polytechnics, sand dune forest owners, and coastal estate developers, as well as local Beach Care groups at each site.

Research is jointly funded by the New Zealand Foundation for Research, Science and Technology, the Department of Conservation, the New Zealand Lottery Grants Board, and local authorities.

Duneland Research and Management Working Group

Preliminary discussions between NZFRI duneland researchers and management agencies including Environment Waikato, Auckland Regional Council, Canterbury Regional Council, and the Department of Conservation suggest that a duneland working group would be useful in advancing research and management. We anticipate the formation of an informal Duneland Research and Management Working Group, with the aim of:

- encouraging contact between managers, Beach Care co-ordinators and researchers of key agencies (e.g., regional councils, NZFRI, Department of Conservation);
- effective transfer of information on Beach Care activities, research results, and beach management;
- organising annual field trips and workshops focusing on dune problems, research trials, and community-based activities in a particular region;
- providing input into a co-ordinated research programme and determining appropriate funding strategies;
- co-ordinate and collaborate in publication of pamphlets and guidelines.

We suggest that the Working Group be kept small and focus on technical and practical aspects of coastal dune management and research, including community participation and revegetation. It is not intended that it compete with the newly formed Coastal Society.

Managing agencies' perspective – Environment Waikato

Environment Waikato is placing increasing emphasis on the management of coastal dune systems, especially where they lie between coastal development and the sea. The reasons for this are:

- protecting coastal development from hazards;
- preserving the natural character of the coastline;
- protecting and enhancing amenity values;
- protecting and enhancing ecological values;
- protecting and enhancing cultural and historical values.

Coastal hazard management

Coastal dune systems provide a vital role in protecting coastal development from hazards such as erosion and flooding. Once such buffer zones are lost (or where they are inadequate) and hazards impinge directly on development, serious and complex management problems arise. These are costly and can be difficult to resolve in a manner that adequately protects the natural and amenity values of the beaches. The major aim in coastal hazard management is to maintain the sand volumes in dune systems and their natural repair mechanisms. Where feasible and appropriate, efforts are also being made to enhance the volume of sand in dune systems by dune nourishment, particularly at sites where the existing systems are potentially inadequate. Maintaining and enhancing an appropriate cover of native coastal species is critical to dune management for hazard protection.

Natural character of the coastline

This is a Matter of National Importance in the Resource Management Act, and is likely to become one of the major coastal issues in New Zealand over the next decade. Natural character is primarily related to the natural (cf. man-made) elements of the coastal environment; coastal vegetation is a critical element. Council staff believe that protection and enhancement of native vegetation cover on dunes offers one of the major opportunities for both protection and enhancement of natural character.

Amenity values

This is a matter for which agencies exercising functions under the Resource Management Act are required to have particular regard (Section 7, Resource Management Act 1991). At present most New Zealand beaches are relatively devoid of trees and shrubs, particularly of native species, and improving this aspect has considerable potential to enhance their amenity value. For example, providing increased shade and wind shelter are critical issues at many beaches. The potential impact of trees and shrubs on the views from coastal development is one of the major impediments to extensive plantings for the purposes of enhancing amenity and ecological values and natural character.

Ecological values

The vegetation sequences found along dune coastlines – commonly a progression from sand-binding grasses to shrubs and trees – is very distinctive, but is now rarely found in New Zealand. There are probably few, if any, such sequences in a virgin state anywhere in the North Island. Re-establishment of such sequences, either by allowing natural succession to proceed or by accelerating the process, is a major priority for ecological restoration in the North Island. Environment Waikato is currently involved in re-establishing a native coastal vegetation sequence at Whitianga, and has found strong community support for the proposal. At this early stage the work is focusing on testing a number of coastal species (see below). Later it is planned to move towards re-establishment of a fuller native coastal sequence. At this stage it is not clear how this process is best facilitated; whether by allowing natural succession to proceed without interference, or by managing the process – perhaps by establishing an appropriate ground-cover or shrub nurse, or (more quickly, but more artificially) by attempting to plant the succession.

Other purposes

Many dunes have a range of intrinsic and human values additional to those discussed above. Some contain important archaeological sites; for example, a large number of *urupa* are located on dune systems. Maintaining and establishing appropriate coastal vegetation can be of considerable significance in such instances. Environment Waikato and NZFRI have been allowed to establish trial plantings on an *urupa* site at Whiritoa Beach on the Coromandel peninsula because of the importance of re-establishment of native coastal vegetation to the local *hapu*. The *urupa* is otherwise closed to public use, being fenced along its landward margin to prevent pedestrian access. The landowners also take an active part in the trials, participating in trial design, establishment, and monitoring, and take considerable pride in the work. There is considerable, and virtually untapped, potential for such partnerships around the New Zealand coast.

Management considerations

Establishing a good cover of appropriate coastal vegetation is critical to effective dune management for the above purposes. In terms of appropriate vegetation, Council staff place a strong emphasis on the use of native species and have serious reservations about the use of exotics for dune management. Issues of concern with exotics include the weed potential of some of these species (e.g., golden wattle – *Acacia sophorae*) and the incompatibility of such species with important management aspirations, including preservation of natural character, and protection and enhancement of ecological values. Staff also believe that species such as marram are – for a number of reasons – markedly inferior to native sand-binding grasses in terms of managing the seaward face of dunes, a critical area for coastal dune management.

Community Participation

Rationale

There is little question that the major threat to dune systems and their associated values arises from inappropriate human use and development. Similarly, some of the major impediments to the protection and enhancement of dune systems lie in community attitudes and practices. Thus, significant attitudinal and behavioural changes are required if our coastal dune systems are to be sustainably managed.

Environment Waikato believes that while other instruments (e.g., policy and regulation) have an important role, community participation in the management of coastal dunes offers one of the more appropriate methods by which community attitudes and practices can be changed. It also offers considerable potential as a means of technology transfer whereby the technical knowledge arising from research can be passed on to communities.

Beach Care programme

Environment Waikato initiated a Beach Care programme in early 1993 to facilitate more active community participation in coastal management, particularly dune and foreshore management. The groups act as a forum where the community can work together with Environment Waikato and the local district council (at some sites Department of Conservation staff also get involved) to develop and implement appropriate dune management programmes. The concept was modelled on the Australian Dune Care programme, and modified to facilitate more community involvement and better integration among government agencies.

The groups are initiated at priority sites for dune management action, normally where there is only a narrow and fragile dune buffer zone between development and the sea. There is usually extensive community consultation and information before a group is launched. As many of the communities are centred on holiday resorts, groups are usually launched with a public presentation over a holiday period.

Ultimately they are likely to be extended to most relevant sites. To date, there are eight groups in the Waikato region: seven on the eastern Coromandel Peninsula and one on the west coast. Most have memberships of 100-200, with activities co-ordinated by a Beach Care committee comprising locals and representatives from statutory agencies. Plans are developed by circulating ideas to all members by way of regular newsletters and by advertisement in the wider community (e.g., through media). Once a plan of action has been developed, working bees are held to organise implementation. Materials for the dune works (e.g., plants, materials for access ways and fences) are usually provided by the statutory agencies, with the community providing labour for implementation.

Effectiveness of community participation

The groups have proved to be very effective in the design and implementation of dune management programmes, activities including dune repair and nourishment, installation of a number of fenced vehicle and/or pedestrian ways, and plantings of several thousand native plants (particularly native sand-binding grasses, but also trees and shrubs at some sites). To date, most of the groups have focused on initial stages of dune management, particularly access management and establishing a good cover of sand grasses on the dune face to ensure natural dune stability and repair. Once these basic areas have been addressed, it is hoped that the groups can move into addressing some of the more complex and controversial issues associated with revegetation of beaches with coastal shrubs and trees.

The groups have also proved to be very enthusiastic with regard to local dune revegetation research, and have played an active role in trial work to date, facilitating technology transfer. This has been particularly notable at Whiritoa and Whitianga. Apart from direct involvement, group newsletters and working bees also provide useful means of technology transfer. To date, technology transfer has proved to be very effective, results from some trials being adopted into local practice even before being written up. It is hoped to reinforce this aspect as the groups develop and as the trials (mostly still in early stages) start generating results.

Though it is still too early to judge the effectiveness of the programme as a means of inculcating a dune care ethic into local communities, the degree of community support and the high profile of the groups is undoubtedly having an impact. Most groups are also moving into community information and education, and this direction will be further encouraged and supported in the future.

Overall, it appears that the model has considerable promise in terms of inculcating a dune care ethic, developing and implementing dune management activities, and facilitating technology transfer. The model has now been adopted in the Bay of Plenty region, and a number of others are also looking closely at it.

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The native plant option for soil conservation

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Introduction

To start, a parable. Once there was a Ministry of Works and Development (MWD) which had a Water and Soil Division and a Soil Conservation Centre. Researchers at the Soil Conservation Centre *c.* 1980 detected a groundswell of interest in using native plants for soil conservation. There were three sources: the catchment authority clientele, to whom the researchers were enjoined to be responsive; the general public at large; and the researchers themselves, who came to soil conservation from native plant science backgrounds. They spoke to their managers in the Water and Soil Division, saying: 'We ought to have a native plant programme for soil conservation.' The managers replied: 'Why should we get involved in the native plant scene? Everyone else is doing it, the New Zealand Forest Service, Forest Research Institute, Department of Lands and Survey, Auckland Regional Authority...'

The business of plant materials for soil conservation is – by and large – about walking over your average paddock-type farmland and establishing trees and shrubs for shelter and erosion control. Who, the researchers asked, were the other researchers dealing with, promoting native plants as direct alternatives to poplars or willows or radiata pine in this situation? The managers conceded that we had a case, and so a native plant programme was born. Responsibility for the programme was given to a New Zealander by adoption, expatriate Canadian Keith Pollock[1].

Southern Ruahine Range revegetation trials

These began in the mid 1970s as part of officialdom's response to widespread concern about accelerated erosion, particularly riparian landslides and screes, and deterioration of native forest, particularly the rata (*Metrosideros umbellata*)-kamahi (*Weinmannia racemosa*) forest at the treeline. The main trial plantings were undertaken in 1976-78. About 54 000 plant 'materials' were planted on 17 sites; over 40 000 were willow stakes, and about 10 000 were container-grown or open-grown plants of other genera. In all, over 70 species and hybrids from 25 genera were included. When Keith and I arrived on the scene, the trials were in the post-early-establishment assessment phase, although we did carry out some further plantings from locally sourced indigenous propagating material. Of particular interest to us was the interaction of native regeneration with planted (and sown) stock, both exotic and native.

Lessons:

Native plants are generally better adapted to a New Zealand mountainland environment than many overseas introductions with otherwise eminent records of usefulness for soil conservation purposes. There were, however, exceptions – radiata pine (*Pinus radiata*) and Tasmanian blackwood (*Acacia melanoxylon*) both outperformed natives on disturbed sites.

Planting native species is of no use until the sites are stabilised; until then the plants are simply not seen again. Initial stability can be achieved by oversowing with fast-growing species such as lotus (*Lotus* spp.), so long as this doesn't interfere with natural herbaceous communities like wetlands, tree lupin (*Lupinus arboreus*) or tagasaste (*Chamaecytisus palmensis*), or planting species adapted to disturbed ground such as willows (*Salix* spp.).

[1] A sequel (from the editors): not only was Keith Pollock made redundant in the 1980s, but the author of this article was also rendered 'surplus to requirements' in 1995.

Browsing animals have to be excluded from revegetating sites.

Planting native species gains 2-5 years over natural regeneration. Where this time gain is not important, planting is most valuable as a means of re-introducing seed sources of species that regenerate freely.

If exotics are used as early stabilisers, there follows a phase where their dominance of the site prevents invasion by natives, until the integrity of the exotic stand starts to disintegrate – a delay of 2-5 years, but conceivably much longer if long-lived nurse species are used.

Soil Conservation Centre (Aokautere) shelter system

When the shelter system at the Soil Conservation Centre (then National Plant Materials Centre, Ministry of Works and Development; now Aokautere Research Centre, HortResearch) was planted, 230 species and clones were included so that the centre could serve as a demonstration of suitable shelter species for the (lowland) lower North Island.

Lessons:

Successful native species (NWASCA 1986) were *Coprosma repens*, *C. robusta*, *Corokia* x *virgata*, *Dodonaea viscosa*, *Hoheria sexstylosa*, *Olearia paniculata*, *O. traversii*, *Phormium tenax*, *Pittosporum crassifolium*, *P. eugenioides*, *P. ralphii*, *P. tenuifolium*, *Plagianthus regius*, and the Tasmanian *Pomaderris apetala*, supposedly conspecific with the New Zealand species. Failures were *Pseudopanax arboreus* and *Quintinia acutifolia*. Undoubtedly, many other scrub and forest margin trees and shrubs would also have been successful had we tried them. Natives proved particularly suitable as lower, evergreen associates of tall, fast-growing deciduous trees such as poplars (*Populus* spp.). As is the general rule for mixed-species belts, the lower-growing associate is best planted on the sunny side of the belt and in a separate row about 1.5 m from the main row of tall trees. I favour using native species in mixtures rather than in single-species rows; this is also a contingency against the tendency of *Hoheria* or *Olearia* spp. to suddenly decline and die. My ideal for a native shelterbelt would look like a narrow strip of native forest with natural regeneration occurring within.

South Wairarapa shelter trials

These trials were connected with flood control schemes in the region and attempts to provide a basis for more intensive land use, and were set up jointly with the former Wairarapa Catchment Board. Species used included exotic conifers, poplars, willows, eucalypts (*Eucalyptus* spp.), wattles (*Acacia* spp.), and 25 species of native trees and shrubs (NWASCA 1986). The native species were planted in 1981 on four principal sites. Species were assigned as far as possible to the sites they were most likely to suit. Limiting environmental factors were different combinations of silt loam soil or stony soil originating from river or lake bed, well drained soil or impeded soil drainage, saline soil, occasional inundation, exposure to frost, salt-laden wind, desiccating north-west winds and strong, cold southerly winds, and damage by hares.

Lessons:

Species tolerant of particular factor combinations and designated 'successful early establishers' were *Myoporum laetum*, *Pittosporum crassifolium*, *Olearia paniculata*, *Nothofagus menziesii*, *Pittosporum colensoi*, *Coprosma robusta*, *Griselinia littoralis*, and *Olearia traversii*. Species intolerant of the environmental factor combinations, and therefore designated 'early failures' (but possibly candidates for later introduction once a stand had been established) were *Corynocarpus laevigatus*, *Knightia excelsa*, *Pseudopanax arboreus*, *Metrosideros robusta*, *Nothofagus fusca*, *Dodonaea viscosa*, *Nothofagus solandri*, *Pittosporum eugenioides*, and *Cordyline australis*. 'Persistent survivors but unimpressive growers' were *Dacrycarpus dacrydioides* and *Podocarpus totara*, probably best also as later introductions.

Possum feeding trials

As part of an annual cycle of evaluating new poplar and willow clones, feeding trials are conducted using caged possums. Palatability of the test foliage is rated on a 0-5 scale which essentially correlates to percentage eaten. The poplar clone 'Tasman' is used as a palatable control, and 'Eridano' is used as the unpalatable control. When other genera are under test, tree lucerne is often used as the palatable control and *Prunus ilicifolia* as the unpalatable control. In 1982, 32 species of native trees and shrubs were included in the possum feeding trials.

Lessons:

Ratings covered the whole gamut from 5 (highly palatable) to 0 (highly unpalatable). In descending order, species rating from 5 to 4 (very palatable) were *Aristotelia serrata*, [*Chamaecytisus palmensis*], *Hoheria sexstylosa*, *Metrosideros excelsa*, *Schefflera digitata*, *Dodonaea viscosa* 'Purpurea', *Pittosporum crassifolium*, *Pseudopanax arboreus*, and *Weinmannia racemosa*. Those rating from 3.5 to 2.5 (average palatability) were *Corokia* x *virgata*, *Knightia excelsa*, *Plagianthus regius*, *Hoheria populnea*, and *Olearia traversii*. From 2 to 1 (below-average palatability) were *Coprosma repens*, *Kunzea ericoides*, *Myoporum laetum*, *Pittosporum ralphii*, and *Brachyglottis repanda*. Below 1 (unpalatable) were *Hebe stricta*, *Myrsine australis*, *Cordyline australis*, *Laurelia novae-zealandiae*, *Melicytus ramiflorus*, *Pittosporum eugenioides*, *P. tenuifolium*, [*Prunus ilicifolia*], *Griselinia littoralis*, *Corynocarpus laevigatus*, *Olearia paniculata*, *Coprosma robusta*, *Olearia albida*, *Phormium tenax*, and *Pomaderris apetala* (Tasmanian origin). While the first principle would seem to be to select the right (low) end of the scale when planting where possums are a problem, hungry possums will eat anything, and pre-planting control of possums is much better.

Native plant establishment trials, Northland

During the early to mid 1980s, native plant establishment trials were set up in conjunction with the 'Beautiful New Zealand' roadside planting scheme (NWASCA 1986). The field officer responsible was Lindsay Wells, based at Whangarei. Performance of 30 species across nine sites was rated for tolerance or response to topsoil, clay, pH in the 5.0-4.0 range, site contour, and exposure to wind, including salt-laden wind. In another series, ten-plant plots of nine native species were compared at a nursery site and two road reconstruction sites. Treatments at the nursery site included releasing (weed control) and no releasing, and fertiliser applications.

Lessons:

Over the nine sites, species which grew consistently well across a range of environmental factors were *Coprosma repens* 'Middlemore', *C. robusta*, *Cordyline australis*, *Dodonaea viscosa*, *Hebe stricta*, *Myoporum laetum*, *Pittosporum crassifolium*, and *P. eugenioides* – prime candidates for early planting in similar situations. Species adapted to some of the factors were *Aristotelia serrata*, *Coprosma grandifolia*, *C.* (prostrata), *C. repens*, *Metrosideros excelsa*, *Olearia traversii*, *Pittosporum colensoi*, *P. tenuifolium*, *Pseudopanax arboreus*, and *P. lessonii*. Species rather site-specific in performance were *Carpodetus serratus*, *Entelea arborescens*, and *Griselinia littoralis*. Species generally performing poorly across the range of factors were *Alectryon excelsus*, *Beilschmiedia tarairi*, *Corynocarpus laevigatus*, *Hoheria populnea*, *Melicope ternata*, *Melicytus ramiflorus*, and *Olearia albida* – possibly candidates for later planting after the initial stand has begun to dominate the site.

In the second series, after a year, plant survival was close to 100% at the nursery site but was down to 60% on the roadside sites. Vigour and growth for all species at the nursery were rated about average (3 on a 0-5 vigour rating scale), considered lower than it should have been because of suboptimal plant quality at planting out. Native species, as with all other plants, should be in peak condition at planting out. Vigour and growth of all species on one roadside site was below average (2 on the 0-5 scale). On the other roadside site, where lime used for basecourse stabilisation had elevated soil pH to 7.3 and calcium content by 'Quick Test' to a value of 42.5 (normal range 6-12), growth and vigour were average in *Coprosma robusta*, *Phormium tenax*, and *Cordyline australis*, but well below average (1.5 on the 0-5 scale) in *Griselinia littoralis*, *Pseudopanax lessonii*, *Dodonaea viscosa*, *Pittosporum tenuifolium*, and *Hebe stricta*; *Aristotelia serrata* died out completely. Releasing (weed control) made no apparent difference at the nursery. This was attributed to suppression by weeds in one treatment, and damage to the plants from herbicides in the other, more or less counterbalancing. Weeds need to be controlled by methods that do more good than harm. While consistent responses to nitrogen fertilisers in fast-release and slow-release forms, with and without lime, were probably masked by the weed control methods and planting stock quality, results implied that slower release and broader-spectrum fertilisers were more likely to be beneficial.

Plant Materials Handbook for Soil Conservation

This three-volume series, published in 1986, codified New Zealand experience with plant materials for soil conservation. One volume – admittedly the slimmest – was devoted to native plants (Pollock 1986).

Lesson:

The native plant volume was out of print before the volume dealing with introduced species. Thus public interest is manifest, but needs to be harnessed and serviced with information. Pollock (1986) is still available in photocopied form (including colour photocopies of colour plates) from Landcare Research, Private Bag 11052, Palmerston North.

Conclusion

Both native and exotic plants enrich our lives. But our native flora is unique. If we are planting an exotic, we should ask ourselves: What is the reason we are not planting a native? If there is no good reason, we should be planting a native plant. In general, using native plants for soil conservation involves an extra cost over conventional exotics, but there is increasing public acceptance that the extra cost is worthwhile. Working towards increasing use of native plants involves practicalities and trade-offs: possibly use of exotics as nurse cover, longer time-frames instead of labour-intensive methods, goals of plant communities dominated by natives rather than exclusively of natives, and guideline compromises on genetic purity. Control animals and weeds, prepare the site properly, select 'early succeeders' to start with, let natural regeneration assist – and may The Force be with you.

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A second generation at Matawai Park

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Introduction

Matawai Park, Rangiora, about 35 km north of Christchurch, is one of the oldest restoration projects in the Canterbury region. A four-hectare site in the south of the town has been progressively planted in New Zealand native plants since the early 1970s. The dumping of spoil had modified the site to such a degree that heavy machinery was needed to mould the heavy clay and debris mounds before planting could begin. Planting began in 1972, after the area was covered in dried sewage sludge and disced. Mortality in the early years was high, but once some shelter developed mortality declined, and now the area is covered in developing forest from 12 m to 15 m tall. Over 70 000 trees and shrubs have been planted since the scheme's inception in 1970. For further details see Franklin & Thompson (1983).

Soon after planting began it was decided to organise some of the more prominent plants to reflect a 'mountains to the sea' theme, with beech (*Nothofagus*) forests in the northwest (the Canterbury mountains and foothills vegetation) and podocarps (Canterbury lowland forest) in the southeast. This was also a form of ecological organisation, since the higher and drier areas were more suited to beech and the lower-lying, wetter areas in the southeast were more suited to podocarps such as kahikatea (*Dacrycarpus dacrydoides*). Lower-tier species were not selected to reflect the mountains to the sea theme, however.

There are now three recognisable broad plant 'communites' at Matawai Park - beech, podocarp, and mixed broadleaved forest (see Table 2 for characteristic canopy species.) Twenty-five years after the establishment of Matawai Park, dramatic changes in the vegetation are taking place. Whilst many of the slower-growing tree species that were planted (e.g., matai – *Prumnopitys taxifolia*) are still a component of the understorey, the broadleaved canopies that developed are thinning out under intense competition. The long period since establishment raises the interesting question of what successional changes are occurring in the developing vegetation.

Methods

We sampled the three different 'communities' using 2 m x 2 m quadrats arranged as belt transects between 22 m and 64 m long. A total of 73, 62, and 74 quadrats were sampled in the beech, podocarp, and broadleaved 'communities' respectively. In each quadrat we recorded:

- Species and diameter of all trees (> 3 cm diameter at 30 cm above ground)
- Numbers of saplings (< 3 cm diameter at 30 cm above ground but > 1.3 m tall)
- Numbers of seedlings (> 10 cm but < 1.3 m tall)

Results and Discussion

Some species that were abundant in the tree canopy were also well represented as seedlings (e.g., lacebark – *Hoheria sextylosa*, and lowland ribbonwood – *Plagianthus regius*, Table 1). Others that were dominant or well represented in the canopy were rare or absent as seedlings (e.g., kohuhu – *Pittosporum tenuifolium*). In the most striking example beeches contributed to 57% of the basal area of the beech 'community', but beech seedlings were totally absent from this community and the two others.

The abundance of seedlings of various woody species also varied among the three 'communities', with seedling density highest in the 'broadleaved' community. Seedlings of some species were more-or-less restricted to the communities in which they were planted (e.g., broadleaf – *Griselinia* in the beech community, Table 1). Others were abundant in all communities, irrespective of whether they were planted there or not (e.g., lowland ribbonwood seedlings were abundant in all communities). A third group (e.g., small-leaved *Coprosma* seedlings) were present as seedlings but had rarely been planted at the outset. Many of the small-leaved *Coprosma* seedlings exhibited leaf forms suggesting hybridisation with larger-leaved *Coprosma* species such as those that were originally planted. It is probable that seeds of small-leaved *Coprosma* species were dispersed by birds into the Park from surrounding suburban gardens.

At this early stage of succession several replacement patterns are evident in the three 'communities'

(Table 2). In the beech 'community' *Coprosma* species and broadleaf dominate the understorey. In the broadleaved 'community' the canopy species lacebark and ribbonwood appear to be replacing themselves, as seedlings of both are abundant. In the podocarp community seedlings of lacebark and ribbonwood also dominate, and the main canopy species – kohuhu – is poorly represented in the understorey. This could indicate that lacebark and ribbonwood may dominate the community for a time, but regeneration of the podocarps may eventually occur when the planted individuals reach reproductive maturity. Similarly, in the beech 'community' the lack of beech seedlings indicates that the planted individuals have yet to reach reproductive maturity.

Many exotic plants have invaded the plantings and may influence the compositional variation that will occur as forest succession proceeds. Although we have no quantitative data on the exotic invaders, we encountered seedlings of bird-dispersed woody trees, shrubs, and vines such as holly (*Ilex aquifolium*), yew (*Taxus baccata*), spindleberry (*Euonymus* sp.), elderberry (*Sambucus nigra*), plum (*Prunus Xdomestica*), hawthorn (*Crataegus monogyna*), and blackberry (*Rubus fruticosus*). These must have been introduced to the park by birds from the surrounding suburban area. A range of other exotic invaders such as ivy (*Hedera helix*), *Iris*, and *Calystegia silvatica* discarded from neighbouring gardens, and a variety of widely dispersed weeds such as dock (*Rumex* sp.) and Scotch thistle (*Cirsium vulgare*), were also encountered.

Reference

Franklin, D.A.; Thompson, S. 1983: Matawai Park. *The Landscape 18*: 7-10.

Species	Beech	Broadleaved	Podocarp
Hoheria sexstylosa	6 (6)	56 (49)	66 (14)
Plagianthus regius	10 (11)	20 (0.2)	15 (18)
Griselinia littoralis	24 (4)	-	(0.1)
Pittosporum tenuifolium s. l.	9 (8)	3 (18)	1 (47)
Small-leaved *Coprosma* spp.	26	20	6
Coprosma robusta	19 (6)	- (2)	6 (3)
All other species	6 (65)	2 (31)	6 (18)
Absolute density (per 100m²)	**97**	**680**	**313**

Table 1. Relative density (%) of the most common indigenous tree seedlings in the three plant 'communities' at Matawai Park. Numbers in brackets are the relative basal areas (%) of canopy trees of the same species.

'Community'	Dominant canopy species	Dominant seedling species
Beech	*Nothofagus solandri* (57)	Small-leaved *Coprosma* spp. (26)
	Plagianthus regius (11)	*Griselinia littoralis* (24)
	Pittosporum tenuifolium s.l. (8)	*Coprosma robusta* (19)
Broadleaved	*Hoheria sexstylosa* (49)	*Hoheria sexstylosa* (56)
	Hoheria angustifolia (28)	*Plagianthus regius* (20)
	Pittosporum tenuifolium (18)	Small-leaved *Coprosma* spp. (20)
Podocarp	*Pittosporum tenuifolium* (47)	*Hoheria sexstylosa* (66)
	Plagianthus regius (18)	*Plagianthus regius* (15)
	Hoheria sexstylosa (14)	*Coprosma robusta* (6)

Table 2. Canopy/understorey relationships of indigenous spp. for the three plant 'communities' at Matawai Park. Numbers in brackets are the relative basal area (% of native trees) or relative density (% of native seedlings) for the three dominant spp. per 'community'.

Revegetation trials on Mangere Island, Chatham Islands

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In November 1992 a trial was established on Mangere Island in the Chathams group to determine the influence of several treatments on the survival, growth, and health of Chatham Island akeake (*Olearia traversii*) seedlings planted in May 1992 and June 1991. Stock was 12-20 cm tall. Planted sites were reassessed in February 1994. At the time the trial was established there was little documentation of other revegetation efforts around the country. What was reported suggested that the recommended root-trainer stocks must be planted carefully. Plants were then left to their own devices. No weeding was undertaken, and it was found that the wind protection afforded by a tall grass sward was advantageous; wind was reported to have uprooted weeded seedlings on Tiritiri Matangi Island.

Suggestions by a local resident, Mr James Moffett, that akeake health and survival were greatly assisted by weeding and fertiliser application were, therefore, investigated.

Three comparisons were made:

(1) no treatment (control);

(2) weeding – approximately 20-30 cm radius, with the pulled grass used as a mulch;

(3) weeding and fertiliser application – using one tablespoon of 'Nitrophoska Blue' slow-release granules.

Site 1.
Eastern end of the island below and south of Mt Mangere. Characterised by grassy slopes, with occasional flax shelter belts, tree groves, and clubrush pockets which adjoin a small forest remnant on the face below the peak.

Site 2.
Douglas Basin. The cover is a thick grass sward with a tightly woven mat 30 cm deep of grass rhizomes and shoots.

Discussion

- Weeding in the second growth season confers little advantage to plants in terms of growth rate, though there is an improvement in vigour (leafier, sturdier, more heavily branched).
- On poorer shallow soils where grass competition is relatively low, fertilising with weeding produced a significant improvement in growth rate of first-year plants. However, the treatment did not increase survival.
- On rich, deep soils with a very dense cover of grass, plants showed a profound response to weeding, reflected in greatly improved survival and growth rates. Addition of fertiliser did not confer any extra benefit.

Quality of the original planting stock is probably a major factor influencing survival and the degree to which weeding and fertiliser confer an advantage. As plants were essentially similar in size at planting, it was not possible to determine the effect of initial size on survival and growth. It is possible that stock 30-40 cm high would perform better in the absence of aftercare on the rich, heavily grassed slopes than the smaller plants used in this trial. The one-year plants in this study were short, averaging 16 cm at planting. Plants that died were not significantly smaller than surviving plants.

Overall, first-year survival appears good in the absence of aftercare where there is little competition, especially smothering, from other plants. In contrast, planting success is poor on rich sites in the absence of aftercare.

With only short planting stock available it is essential that any plantings on the Douglas Basin are weeded and mulched in the spring following planting. At the time the trial was being assessed, every one of the surviving control plants was being smothered by grass, and it is almost certain that most would also have succumbed to competition. In contrast 100% survival occurred for those that were weeded, or fertilised and weeded.

Recommendations

(1) Endeavour to obtain taller planting stocks (30-40 cm) for continuing work on the Douglas Basin; this is not as important for areas alongside the forest remnant.

(2) Weed all plants in spring, and if possible in year two as well.

(3) Apply fertiliser on poor soils.

(4) Test a range of species.

(5) Continue to use seedlings in preference to clones; observation of earlier Wildlife Service plantings suggests that seedlings are hardier and faster growing.

Restoration of ecological communities: potential for farmland sites on the Canterbury Plains, New Zealand

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The Canterbury Plains have few remaining fragments of their original forest ecosystems, which have largely been replaced by pastoral, arable, horticultural, and non-native forest habitats. Ecologically the Plains are degraded, with a virtual absence of native flora and fauna, except in the few sites deliberately or accidentally preserved. In the cultivated areas, non-native crop species and their associated non-native weeds and arthropods now dominate the landscape. Field margins are characterised by post and wire fencelines, with heavy herbicide use at their bases. Woody field margins, where they exist, usually comprise poplars (*Populus* spp.), radiata pine (*Pinus radiata*), macrocarpa (*Cupressus macrocarpa*), and gorse (*Ulex europaeus*), all exotic. Invertebrate communities are also dominated by non-native species: all the earthworms, most of the springtails, and many of the spiders, for example, are of European origin.

The current challenge for the restoration ecologist is to recreate plant and animal communities in forest ecosystems akin to those originally present on the Plains. The principles of ecological succession at all seral stages need to be understood as far as possible. However, such newly created areas are likely to be 'ecological islands', with all the expected problems associated with high edge/area ratios, low rates of natural colonisation from remote 'natural' sources, and interference from adjacent agro-ecosystems. For example, easily achievable restored habitats on the Plains may comprise little more than 'trees in a paddock'. This may be a laudable attempt at restoration, but given the dominance of the plant and animal communities by non-native species, it is difficult to see how such a 'landscape gardening' approach can provide the ecological nucleus for the successional acquisition of new species.

It is also difficult to see how desirable native invertebrates such as some of the estimated 100 or more species of earthworm, the relatively immobile carabid (ground) beetle *Megadromus antarcticus*, and native springtail species could possibly colonise such an 'island' from their nearest sources, which may be many kilometres away.

The farmland restoration work which is about to begin via joint Lincoln University/Forest Research Institute research will be based on the following provisional and partly empirical protocol.

- Accelerate natural succession by planting appropriate woody species. Choose the species according to soil type, water tables, historical plant communities, and sociocultural preferences.
- Retain moisture and control weeds. The use of well rotted forest bark as a mulch is likely, although this may still represent a net nitrogen loss in the initial stages as it decomposes. Some combination of a source of organic nitrogen (e.g., aged chicken manure) incorporated into a slowly biodegrading matrix may enable the plants to establish their rhizospheres at the appropriate depths/nutrient levels.
- Monitor soil pH, organic matter, and microflora before and during the restoration programme.
- Plant herbaceous species at the same time as the woody plants.
- Obtain plants from Canterbury sources as far as possible, for the maintenance of (presumed) genetic integrity/provenances of the plant material.
- Examine experimentally the 'counterintuitive' idea of placing plants in clumps, rather than in a regular arrangement. This may satisfy a desire for a 'natural' appearance, but more importantly may enhance the exchange of mycorrhizal associations.
- Introduce appropriate invertebrate species from 'natural' sites, with Department of Conservation (DoC) approval for such translocations.
- Mark the larger invertebrates (e.g., by mutilation of the hardened forewings of ground beetles) and monitor their movement within and outside the new area, and the appearance of their progeny.
- Monitor the population growth or decline of all introduced species, using appropriate survey/sampling methods. For example, dry pitfall traps with leaf and soil refugia can be used for

live-trapping marked and unmarked beetles; suction samplers are ideal for epigeal (soil-surface) springtails, and electric-shock devices will sample earthworms and show the (predicted) decline in populations of the European species in favour of the re-introduced native ones.

- Where possible, connect discrete areas by planting along existing fence lines. These plantings may act as corridors for invertebrates, and in any event, will provide more shelter for livestock than do post and wire fences.
- Involve specialists whenever possible; soil scientists and plant ecologists together can help make ecologically rational decisions on species choice. DoC will be involved in animal translocation decisions, and the farming and local communities can contribute towards sensible choices in terms of the area of planting the farm can economically support and the sociohistorical context of what to plant where.
- Choose sites with (ideally) wind-powered water pumps for irrigation, and landowners with a familial/historical/proven commitment to the persistence of sustainable farmland.
- Ensure that the site is not a 'private club', by making early restoration attempts 'pilot' schemes, with visitors encouraged and perhaps outbuildings used for displays of the projects' progress/methods.
- Aim for a network of such sites on the Plains, sharing enthusiasms, methods, and ideas.
- Involve the community in the scheme by means of planting programmes/ maintenance/ interpretation and dissemination of knowledge.
- Involve Universities as sources of long-term monitoring/maintenance/research/ dissemination of information.
- Try to replicate sites, or at least maintain unmodified control areas, with monitoring to compare restored and unmanaged Plains habitats.
- Investigate ecological interactions between adjacent ecosystems. Predators of insect pests need refuges or sources of pollen and nectar. The incorporation of plants such as native monocotyledons and deliberately placed branches of native timber on the newly created 'forest' floor will provide the abiotic requirement for invertebrates many years earlier than would waiting for successional processes to provide them. *Hebe* spp. and other plants are a good source of pollen and nectar for such beneficial insect species as hoverflies and parasitoid wasps. Species using these abiotic and biotic resources are likely to exhibit 'metapopulation' characteristics and move into adjacent farmland, where higher levels of 'natural' pest control may be the result.

Practical plans at Lincoln

Some preliminary funding has been obtained from the Robert Bruce Trust, with other applications pending. A farmland site with wind-powered irrigation is ready at 'Winfield', near Leeston, provided by the Osborne family who have farmed the property since the mid-nineteenth century. Lincoln University is funding Post doctoral student Vaughan Keesing to work in this area, so the project is about to begin.

Not all the historical/methodological/ecological/ financial resources are in place, but waiting for all these could mean that the project would never begin. A start needs to be made, admittedly on a partly empirical basis, and without a sound understanding of the ecological successional processes on the Canterbury Plains. As philosopher Karl Popper has said, '... bold ideas, unjustified anticipations and speculative thought are our only means for interpreting nature.' If this philosophy is ignored, scientific progress may increase arithmetically rather than geometrically. Perhaps the Marsden Fund will promote such 'Popperian' approaches to ecology, including adaptation of ecological theory to help restore the depauperate natural communities of the Canterbury Plains.

Creating wetlands for black stilts

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New Zealand's large braided riverbeds, which once contained distinct plant and animal communities, have been dramatically changed by human activities such as water abstraction and the introduction of exotic plants and animals. In the Mackenzie Basin practically all the water that once flowed down the Pukaki, Tekapo, and Ohau rivers has been abstracted for hydroelectric power (HEP) generation. These riverbeds once provided extensive foraging and nesting habitat for several species of wading birds, including the endangered black stilt (*Himantopus novaezelandiae*). In 1991 the Department of Conservation and Electricorp (ECNZ) signed a compensatory funding agreement called 'Project River Recovery' (PRR) which recognises the impact of HEP generation on these braided riverbeds. The agreement provides for management and enhancement of habitat in reparation for habitat lost during the development of the Upper Waitaki HEP scheme (1968-85). One of PRR's aims is to provide alternative foraging and breeding habitat for black stilts.

Black stilts nest near large areas of shallow water surrounded by flat open spaces that are free of tall vegetation. Nest site selection appears to be influenced by the availability of the aquatic invertebrates on which black stilts prey (Pierce 1982). The aim of my research is to develop techniques for manipulating aquatic invertebrate community composition, abundance, and standing crop, so as to enhance foraging and nesting habitat for black stilts. Specifically, I am investigating the effects of adding stones or straw to ponds that have been created by flooding or excavation in the Mackenzie Basin.

Substrate additions have been used successfully elsewhere to increase aquatic invertebrate food supplies for waterfowl (e.g., Street 1982) and salmonid fish (e.g., Raastad *et al.* 1993). A small-scale pilot experiment (Sanders & Maloney 1994) in which pea straw, large or small stones, or topsoil was added to 1 m^2 quadrats in existing wetlands produced very encouraging results. Samples from quadrats to which pea straw had been added contained invertebrate biomass up to 16 times greater, on average, than samples from control quadrats

Treatment	Mick's Lagoon	Irishman's Ponds	Tekapo Delta	Aviary Wetland	Kevin's Diversion	Ben Ohau Seepages
Old	5	5	5	5		5
Excavated		6			5	5
Excavated mud	5		5			
Excavated and raked stones		4	5			
Flooded				5	5	
Flooded mud			5			
Flooded stones			5			
Excavated + stones					5	5
Flooded + stones				5		
Excavated and raked stones + barley straw			5			
Excavated + barley straw	5	5			5	5
Flooded + barley straw				5		
Total (N=125)	15	20	30	20	20	20

Table 1. Summary of experimental treatments (types of substrate) at ponds in Mackenzie Basin.

(nothing added). Stone quadrats contained up to twice the invertebrate biomass, on average, of control quadrats.

To test the feasibility of substrate additions as a wetland enhancement technique, at a realistic scale, replicated field trials are currently underway in the Mackenzie Basin (Sanders 1996). A total of 100 ponds were constructed at six locations in August 1993 (Table 1). Several substrates are being investigated at each location. For example, at Ben Ohau Seepages 15 ponds were excavated; barley straw was added to five of these, large stones to five, and another five received no substrate addition. These 15 ponds, and five control sites in the existing wetland ('Old' in Table 1) were sampled after 3 and 15 months' incubation. Ponds at the other five locations were also sampled after 3 months. Aquatic invertebrate community composition, abundance, and standing crop in samples taken from different substrates and at different locations will be compared.

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Science issues in ecological restoration: a summary

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The discussion today has ranged far more widely than scientific issues alone. It is entirely appropriate that it did so, because the driving forces behind most restoration programmes, both here and overseas, are not those of scientific interest. Rather they are from people at large; that is, the motivation is social. This fact does not deny that often it is scientists who sow the 'seeds' for a particular programme.

The opening session showed how people approach restoration from a variety of viewpoints: aesthetic, cultural, recreational, and utilitarian. Our task today, however, has been to address science issues – including research – that may be needed to make restorations effective. To give this summary some structure, I have listed a few major questions that are asked, or should be asked, in relation to the science input for a restoration programme. The list should not be seen as comprehensive.

Goals and objectives?

With any scientific investigation it is vital to ask 'What is the question to be answered?' It is equally essential to clarify the goal(s) of a restoration project and the specific objectives required to achieve those goals. If it is to be an *ecological* restoration the objective can be expressed in terms of the kind(s) of biotic community, habitat, or, more explicitly, soil-plant-animal system that it is desired to restore. When I use the phrase 'soil-plant-animal system' I mean just that. It helps to focus one's mind on the three major components for which we have some power to manipulate. If we talk of 'restoring ecosystems' we imply that we can restore climatic and geological factors of the past, and that is not realistic.

Both soil and plants received attention today, and Steve Wratten's contribution on invertebrates ensured that the animal part of the system was not neglected. Reconstructing lost biotic communities and habitats, repairing damaged ones, providing habitats for threatened species, conserving genetic variation of both threatened and common species, providing specific educational, scientific and recreational opportunities, or aesthetic benefits, are all widely recognised as legitimate goals for restoration. More obviously utilitarian goals include the restoration of *mahinga kai*, and providing sources for weaving material or specialised forest products. However, I do not think that goals of 'increasing biodiversity' or 'increasing the area of indigenous vegetation or habitat' are specific enough to be helpful. For example, if one looks into the meaning of biodiversity (biological diversity), it is apparent that it is a multi-dimensional concept that includes differences between individual organisms through to the biological diversity that exists between nations and continents. Thus, 'increasing biodiversity' is stating a goal in terms of several, if not many, unspecified goals. It is unlikely to be sufficiently directed to make our restorations effective.

Defining goals and objectives may be rather less crucial for other kinds of restorative action, such as revegetation. Here, the need to establish a plant cover of some kind is often self-evident, as for example on an abandoned mining site. Deciding what kind of cover to establish may have few constraints apart from ensuring that it is compatible with surrounding land use.

Doubts have been expressed today about whether it is necessary to identify a particular time period of the past as part of a restoration goal. It is certainly not realistic to think that we can build exact replicas of past times, especially if times are specified as particular years. All biological systems are in a state of continuous flux, so that time periods expressed in decades at least are more reasonable. But losses of species, and introductions of many more, still leave us knowing that exact replicas of the past are not achievable. Should we therefore relegate such ideas to the waste basket?

The reality is that this is not possible, because people so often value the past and its loss. It is part of the human psyche to wish for things to be as they once were. We see this in the energy devoted to restoring old buildings, furniture, paintings, cars, and steam engines – and it is a major influence in attempts to restore biological communities that are valued. If we ignore this yearning for the past on the grounds of scientific impracticality, we may deny ourselves a vast amount of voluntary help willingly given to restoration work that can have significant scientific value, apart from wider benefits.

To make this point with an example, at Karori, four kilometres from the centre of Wellington, a 252 ha water-supply catchment has largely been decommissioned for safety reasons. The Wellington branch of the Royal Forest and Bird Protection Society has proposed that the catchment be encircled by an 8.5 km fence capable of excluding possums, goats, cats, stoats, ferrets, weasels, rats, and mice. Eradication of pest animals and plants, recovery of vegetation, and reintroduction of some animal species within the fence will create a 'pest-free island' sanctuary on the mainland (Lynch 1995). 'The forest will blossom and the bird song will swell to a level not heard on the mainland for a century.' Emotive perhaps, but the proposal has been judged technically feasible, has the backing of both the regional and city councils of Wellington, and a recent opportunity for public submissions resulted in support from more than 90% of 1750 respondents. The cost? More than $8 million dollars, the fence alone comprising $2 million of that amount (Lynch 1995).

The proposal now has permission from the city council to proceed. It seems likely that the money will be found. Some major problems will be encountered, both expected and unexpected, and initially they will not all be solved. But my expectation is that in overcoming at least some of these problems, they will extend what we now think of as being realistic and achievable in a restoration programme.

Historical information?

If, then, there is a case for attempting to restore ecological systems to a state more like that of specified periods of the past, we may need historical information, particularly if there are no current communities suitable as models. This has not been mentioned today. Even a system of the very recent past may benefit from study of written historical records. When constructing restoration models for earlier communities, several research tools can be used: identifying subfossil bones in cave or dune deposits (Atkinson & Millener 1991); identifying persistent plant fragments such as seeds from suitable deposits; archaeological studies; pollen analysis; phytolith analysis (Kondo *et al.* 1994); and methods, not yet fully developed, for identifying previous vegetation using organic matter components that may persist in the soil for thousands of years. Even when such information is not used to build a detailed model of a former community, it may reveal what has been lost and thus clarify what it is feasible to restore.

Local successional processes?

As was aptly said by one speaker today: 'Restoration is about accelerating natural succession.' (Warwick Harris has reminded me that sometimes we are interested in retarding the natural succession, e.g., restricting entry of native woody plants into grass/herb communities that we are trying to restore.) All ecological restoration programmes should aim to work with an understanding of successional processes, which will always involve both plants and animals. To understand these processes they can be divided into widespread general trends and local trends that reflect local conditions of site, soil, and position in the landscape. This second group of processes are particularly important because most restoration programmes are centred on particular sites or groups of sites.

In attempting to accelerate successional processes it is sometimes possible to replace native plants with exotics of limited life span. I thought the discussion this morning on the use of woody exotics was very useful; too often we seem to discount use of exotics for a restoration merely because they are not native.

Remarks were made, both yesterday and today, that it may not matter what plant species are used to establish a cover in a restoration project. My response to that suggestion is that how much it matters depends on what goals and objectives have been identified for the restoration. For example, in the case of Victoria Park on the Port Hills, which we were shown yesterday, the main plant used as a pioneer was *Olearia paniculata*. It is fully capable of growing on such sites, and is likely to provide a temporary cover through which a more mixed broadleaved forest could develop. But supposing the goal in this instance were to establish a mixed podocarp forest; an *Olearia* would not then be the species I would use. Lacking fleshy fruit, these species cannot act as 'magnets' for attracting birds, particularly pigeons, that have been feeding on podocarp fruit, perhaps at a considerable distance from the restoration site. Without bird dispersal we are forced into labour-intensive planting to restore the podocarps.

Sources for plants and animals?

We have paid more attention to this question since Godley's (1972) pioneering article. But the question is still far from properly researched. With all the plant and animal species we attempt to restore, we do not know the nature of their genetic variation, nor how this variation relates to the ecological performance of the species in question. By using the ecological district/region boundaries from within which to select suitable material for restoration projects, we are adopting a precautionary principle. In so doing, however, we may sometimes be placing unnecessary constraints on what plants (or animals) we can use in a particular restoration. If no source remains within the ecological district, how far beyond the district should we go and in which direction? Without knowing where the significant genetic or ecological variants are, we often have less than adequate data on which to make a choice. I think more research is needed in this area.

Monitoring?

Some attention has been given to this question today, but we seem to be very half-hearted about it. As we were told yesterday, if monitoring features at all in a programme, it is likely to be limited by meagre funds, and in any case is seen as very much a second priority to getting the restoration underway.

There are at least two important considerations relating to monitoring. The first was pointed out by a speaker this afternoon, i.e., unless effort is invested in characterising the *status quo* at the beginning of a restoration programme, there is no effective baseline against which to measure change. The second is that unless there is systematic monitoring there is no means of measuring progress towards achieving objectives and goals. We should never forget this point. Restorations are expensive, and the people providing the money or volunteer effort have every reason to want to know the extent to which a particular objective has been achieved. There is thus a strong argument for expressing objectives (but not goals) quantitatively, e.g., a water-table within certain height limits, a major plant within a certain range of cover, reduction of an alien plant or animal by a certain percentage of its present numbers (Atkinson 1994). It is then possible, provided that the initial levels of each objective have been established, to measure the extent to which each has been achieved at a particular time.

Plant-animal interactions?

For the purpose of restoration, an arbitrary distinction can be made between plant-animal interactions that operated in the past, and the new interactions that have resulted from introduced species. With both groups of processes we are concerned with competitor, plant-herbivore, predator-prey, and parasite-host relationships. Because there is general agreement that 'restoring ecological processes' is a central aim of restoration, there is a need to gain at least some understanding of interactions that formerly operated. The present level of understanding is meagre.

The second group of processes, involving interactions between native and introduced plants and animals, are better understood although practical solutions to the problems now facing us are few (Atkinson & Cameron 1993). From a restoration viewpoint, we are interested in understanding the extent to which the processes formerly operating will be curtailed by introduced species. More explicitly, in a particular restoration, which alien species will have to be controlled (or even eliminated) and which can we tolerate without undue disruption of the processes we wish to maintain or reinstate?

There is a commonly expressed view that restoration programmes – as well as other conservation work – should focus on processes, not species. Whatever the reasons why this particular view has developed, it is unfortunate because processes and species are inseparable. All the processes mentioned above involve interactions between particular species or groups of species. Community composition is defined in terms of particular species. When restoration of habitat for a threatened species is a goal, then that species, as well as those on which it is directly dependent for food and shelter, must be targeted.

An example of the influence of species on physical process is that of southern beeches (*Nothofagus* spp.) in relation to windthrow and soil disturbance in the Tararua and Rimutaka ranges. Windthrow of red beech (*N. fusca*) commonly snaps the trunk, leaving the base of the tree intact. Windthrow of hard beech (*N. truncata*) commonly uproots the tree, lifting soil and rock debris into unconsolidated heaps (A.P. Druce & I.A.E. Atkinson, unpubl.). No measurements are available to determine whether rates of soil loss are greater from hard beech forest as a result of this difference; the generally lower rainfall under which hard beech grows may be a compensating factor. Many more examples could be given of the intimate relationship, both qualitative and quantitative, between species and process. Separating these aspects is not a way forward.

Sustainability

We have to ask: 'Will the goals identified for a particular restoration be sustainable in the long term without a continuing high level of intervention?' The question of sustainability focuses on ecosystem processes, additional to those discussed above, that originate in areas of land or water at varying distances from the restoration site. If we are concerned about sustainability we cannot restrict our thinking to what is going on within the boundaries of the site. We saw an example yesterday (Styx Mill Basin) of the problem of maintaining a low-fertility marshland within a catchment in which there are major sources of plant nutrients. Similarly, restoring low-fertility gumland scrub in hilly North Auckland can be undermined if surrounding pasture slopes, topdressed with phosphate, drain towards the site. Warwick Harris mentioned the possible association *Hieracium*-infested hill country with enhanced fertility; this highlights the processes of fertility transfer by farm stock and by wind-borne soil particles eroded from one place to be deposited in another.

Alien weeds reach a restoration site by air, along streams, with birds or mammals, or on the clothing, footwear, and vehicles of humans. Distances from source to restoration site vary, but unless the source of a weed problem is identified it will be difficult to mitigate or remove it. The manner in which a restored site becomes more attractive to alien rather than native mammals and birds, as its plant cover develops, is another topic that deserves study.

Climatic factors at the restoration site must be taken into account in determining whether a particular restoration will be sustainable. These include aspect (solar radiation), slope (drainage and available moisture), and exposure (to both wind and wind-borne salt).

We have as yet failed to think in a comprehensive manner of the effects of ecosystem processes on the sustainability of the various communities we are attempting to restore.

Trials and experiments

In opening the workshop this morning, Colin Meurk mentioned the need for rigour in our restoration work. This brings to mind the potential of designing restoration projects as controlled experiments. I had to consider this question recently and, with some reluctance, concluded that opportunities for proper experiments with replicated treatments and controls are likely to be the exception, not the rule (Atkinson 1994). They will be most needed in large projects when it is important to establish whether one method is more effective than another, e.g., weed control.

This limitation should not prevent us from doing 'trials' in which the *feasibility* of a new procedure (does it work or not?) is tested against another area where the old method, or nothing, is done. This is no more than a 'single replicate' experiment, which should not then be subject to inappropriate statistics. But it is this trial-and-error approach that has provided us with much of our understanding of how to restore ecological systems. As mentioned under monitoring (above), the value of a trial will depend very much on how well the details are recorded as the trial progresses.

Bradshaw (1987) has remarked on the fact that restoring a disturbed system is an acid test of our understanding of that system. In fact it is uncomfortably revealing for the ecologist who has spent years of his or her life making detailed observations of the 'field situation' to find that we cannot predict reliably what will happen as a restored community develops. For example, can we predict the biological composition of a wetland site subject to a particular water-table regime that we propose to maintain?

It is therefore necessary to approach any restoration programme with humility. For this reason I will close with a statement from Professor Jared Diamond of the University of California. It is both humble and bears directly on the question of the place of experimentation in restoration work:

"There is no doubt that the controlled experiment with preselected perturbations and randomised experimental design is the most powerful tool in ecology, just as it is the most powerful tool of the other sciences. In ecology, however, most of the perturbations that would yield far-reaching insights are either immoral, illegal or impractical. Our field experiments usually run for a very short time – rarely more than a few years – on tiny spots rarely as big as a hectare. Even within these small areas we are confined to those small perturbations, those modest additions or subtractions that we can carry out without being persecuted by our governments, our neighbours, or our consciences." Diamond (1987: 330)

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Key to photographic record

A photographic record, depicting a number of the sites visited and issues discussed, is incorporated through this document.

Photo 1: Group of local government staff, scientists, and managers being addressed by Dudley Franklin (instigator of concept, left) and Miles Giller (management committee) at Matawai Park, Rangiora. Beyond is a 20 year old, recreated swamp forest of harakeke, ti kouka or cabbage tree (including a mountain cabbage tree!), manatu, and kahikatea.

Photo 2: Group at the monument, Kaiapoi Pa.

Photo 3: Rakiihia Tau, of Ngai Tuahuriri, explaining the history of Kaiapoi Pa.

Photo 4: Rakiihia Tau, describing the restoration of waterways at the old canoe launching sites of Kaiapoi Pa. Manatu, ti kouka, and kohuhu have been established around the pukio *(Carex secta)* swamp. Grey willow and blackberry are threatening to invade. A sand ridge beyond with bracken and broom is planted with tauhinu, ti kouka, mikimiki (*Coprosma propinqua*), matagouri, korokio, and olearias.

Photo 5: Moment of reflection for Rob Blakely (Wai-ora Trust) and Robyn Simcock (Manaaki Whenua) on the bridge, Kaiapoi Pa. South Island toetoe seems to be a great success.

Photo 6: Toetoe, ti kouka, houhere (*Hoheria angustifolia*), karamu, manatu, and koromiko *(Hebe salicifolia)* doing well on river terrace at Kaiapoi Pa.

Photo 7: Annette Hamblett and Bruce Arnold (Department of Conservation) explaining their partnership with Lamb & Hayward Ltd in the development of the Otukaikino Living Memorial Park (Mau Mahara) beside the northern motorway. Extensive planting of indigenous swamp forest species under the shelter of crack willow, and construction of walking tracks is in progress. Beyond, grey willow is being cleared and wetland species are being planted.

Photo 8: Swamp forest, riparian, and lake shore species have been extensively planted at the Groynes Park (South Branch, Waimakariri R). Joe Cartman (Christchurch City Council, Linwood Nursery) describes his role in the 'nativising' of parks in the city. A special case of ecological restoration has been practised in the sheep-grazed turfs surrounding the pond. The diminutive, regionally rare herbs of *Utricularia monanthos* and *Mazus pumilio* have been successfully planted into the turfs.

Photo 9: Underplanting of willows at the Groynes about 10 years ago is beginning to dominate in some areas. Joe Cartman points out the well-established pittosporums, karamu, kanuka, manatu, ti kouka, ferns, and podocarps.

Photo 10: Colin Meurk (Manaaki Whenua) enthuses over the 5 year-old coastal bush of native trees (ngaio, akeake, kohuhu, karamu, manuka, kanuka, kowhai) that were planted on New Brighton sand dunes as a 1990s heritage project by community volunteers.

Photo 11: The indigenous, sand-binding *Euphorbia glauca* strutting its stuff in the shifting dunes among the marram grass. This species became extinct in Canterbury early this century and the nearest known population from North Otago has been reintroduced.

Photo 12: The end of a long day. An urban restoration project (1990s heritage) on the banks of the Heathcote River (Aynsley Tce). This site was covered by willow, grass and hemlock six years ago. River bank species (kowhai, koromiko, karamu) on the left, backswamp species on the right, and kanuka established on the landfill beyond with inorganic fertiliser and bark chip mulch.

Photo 13: A sequence of planting in the Aynsley Terrace backswamp from pukio and tall rushes to harakeke, toetoe, mikimiki, and weeping mapou, to ti kouka, manuka, manatu, kahikatea and pokaka (with some alder) in the background, to matai-totara-hardwood species on the terrace scarp beyond. The tussock sedges (pukio) were well established and forming a closed canopy within 2-3 years, but they are an easy target for children who love to roll over and crush them allowing exotic grasses and dock to take over. In Canterbury, manuka suffers badly from the 'blight' – sooty mould growing on the exudate of an Australian scale insect.

Photo 14: The 'wrong' provenance of *Olearia paniculata* planted over 20 years ago at Victoria Park, Port Hills. The canopy is now beginning to collapse and other volunteer native species (also of dubious parentage) are establishing in the light gaps. Stephen Reay, Canterbury University, has shown that native invertebrates and plants are not especially impeded by this 'hard litter' from its initially dense canopy of olearia.