Ecology of Restored Gully Forest Patches in Hamilton Ecological District

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Abstract

Attempts to protect and restore gully and bush remnants began about 20 years ago in the Hamilton Ecological District especially near Hamilton City. Research was carried out to evaluate the restoration efforts. Factors affecting the ecological failure or success of the restoration plantings were investigated.

Sixty-six experimental plots were set up in both public and privately owned areas within Hamilton City and adjacent gully systems. The plots were assessed to compare vegetation change in patches planted in native species with naturally regenerating patches and mature native forest. A range of variables measured key ecosystem functional, structural and compositional attributes. Different planting and maintenance regimes and environmental factors likely to be implicated in the success of plantings were also evaluated. Analysis included ANOVA comparisons between experimental blocks and ordination and classification of the plots using principal components and dendrogram clustering.

Vegetation change in the most significant variables, towards the reference mature forest ecological state was found to be more rapid in four of the experimental blocks comprised of twenty plots. Three of the experimental blocks, comprised of 12 plots, are deteriorating. The presence and increase with age in the number of lianas and epiphytes in restoration plots was generally poor. In the deteriorating blocks, native species recruitment and species diversity of regeneration were low, and exotic liana species were increasing.

Treatments that generally appeared beneficial for patch ecological condition included good quality maintenance and low level of human disturbance. Planting a diverse range of species and enrichment planting appeared more beneficial if they were linked to good maintenance. Close proximity of seed sources was also indicated as a factor in good ecological condition of patches. Use of exotic canopy species as a nurse for restoration appeared to reduce success of the restoration. However, the canopy effect may be due to soil condition (compaction) or allelopathic effects of canopy species.

In the cluster and principal components analysis, the plots clustered into three distinct groups, based on soil texture: one with heavier soils and two with lighter soils. Within each group, there was a trend towards more advanced ecological condition with age. The signature species associations identified with each cluster reflected the likely soil water availability. Species composition was shown to be related to age but less related to the functional and structural condition of restoration patches.

In terms of the theoretical aspects of restoration, the findings suggest that restoration in isolated urban restoration patches, requires assistance in the form of enrichment within or peripheral plantings in the neighbourhood of the patches. The research emphasizes the importance of the human and alien species context and in particular the value of controlling human disturbance. It supports the concept of multiple restoration pathways and the concept of restoration as a means to speed up vegetation change if accompanied by appropriate management.

However, the research does not support the idea of a closely defined assembly order for the vegetation community. Attending to the structure and function, particularly the regeneration and dispersal functions, of restoration patches appears to be more important for successful restoration. Composition appears to follow from appropriate structure and function.

Recommendations include the following: The community should set clear goals for restoration. Species should be selected for initial establishment and future seed sources and combined with careful site-species matching. Soil conditioning should be considered on difficult sites. The choice of methods should balance rapid cover needs with the need to maintain species diversity. Maintenance should be minimally disturbing but of a high quality. Human disturbance should be actively managed. Planting within the vicinity of restoration patches, should be designed to enhance native and minimise alien species seed sources.

Further exploration of the effects of exotic nurse species on restoration would be useful in order to reach conclusions that are more definite. Further research into low disturbance methods of enrichment would be valuable. Attempting restoration by enrichment of weed-dominated sites would also be an interesting trial.

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Chapter 1 · Introduction

1.1 General Background to Research

Urban areas often create the most intractable problems for sustaining indigenous ecosystems. High levels of disturbance, exotic plant invasion, ecosystem fragmentation or modification, and habitat destruction are factors that tend to degrade urban ecosystems (Douglas, 1983; Heywood, 1996; Hobbs and Norton, 1996; Jenks et al., 1996). Recently attention has turned to restoring indigenous biodiversity in urban areas worldwide and in New Zealand (Cook and van Lier, 1994; Office of the Parliamentary Commissioner for the Environment, 1998; Platt et al., 1994; Stewart and Ignatieva, 2000).

This study is focussed on the urban and periurban area of Hamilton, a small city (9427ha, urban area population 156,000) in the North Island of New Zealand (Statistics New Zealand: http://www.stats.govt.nz/). The urban and periurban areas of Hamilton are some of the most modified in New Zealand. The remaining native vegetation in the Hamilton Ecological District is about 1.6% of that in 1840 and in Hamilton is 0.1% (Leathwick et al., 1995). Remnants survive in isolated gullies, wetlands and fragments of lowland bush.

Urbanisation puts pressure on such remnants and Hamilton has not been immune to this pressure. Claudelands Bush lost about one third of 125 species between 1933 and 1997 (Boase, 1985; Gudex, 1955; Whaley et al., 1977). Hillcrest Bush was fragmented by a public walkway and cleared of undergrowth in the 1960s for public safety of walkway users (Bill Featherstone, pers. comm., Hamilton City Council, 1995).

Gullies and wetlands have been radically modified by development and then by residents use. Some of the problems were recognised as early as 1975 (Waikato Valley Authority, 1976). There have been continued impacts on gullies and remnants even recently. These include silt discharge from St James' Park subdivision (Robin Holdsworth, resident and submitter to resource consent application, pers. comm., 2005); Hammond Bush walkway construction damage in 1999 (B. MacKay, pers. obs.); and piping and partial filling of Hudson Street gully in 2001 (Barry Barton, lawyer and submitter to resource consent application, pers. comm., 2006).

However, gullies have also been the focus of efforts to bring back native forest vegetation into Hamilton City and the periurban environment. Hamilton City Council's gully planting occurred intermittently from about 1975 (Hamilton City Council internal unpublished plan records). A more consciously programmed approach was adopted from about 1987 and from the early 1990s, it was informed with a better understanding of ecological processes (pers. obs.). The publication of the 'Indigenous Vegetation Types of Hamilton City' (Clarkson and Clarkson, 1997) was a stimulus to this. From 2001, the city actively promoted gully restoration by private individuals through the production of the 'Gully Restoration Guide' (Wall and Clarkson, 2001). As at 2003, some 187 ha of land within Hamilton City were under restoration of some form, including 142 ha on public land and 45 ha on private land. The City Council's gully database of nearly 500 properties where owners are interested in restoration shows there is now an impetus within the community towards restoration. (Clarkson and McQueen, 2004).

Recently, substantial surveys of Hamilton City vegetation have been undertaken (Clarkson and Clarkson, 1997; Downs et al., 2000). However, the present study of the gully plantings in the Hamilton area, is the first involving a systematic experimental design. Its purpose is to assess the success of and investigate the factors affecting vegetation change in the gully restoration attempts within the Hamilton Ecological District. It assesses plantings over the last 30 years by private individuals and the staff of Hamilton City Council. It analyses the implications for management of future plantings. It also relates the analysis to the conceptual framework of restoration ecology, which is still in flux (Ehrenfeld, 2000; Webb, 1997).

1.2 Restoration Ecology

This section deals with the relationship of the study to theoretical concepts (succession and restoration ecology) that are the basis for restoration assessments.

1.2.1 Definitions of restoration

All definitions of ecological restoration depend on an understanding of ecological change. Restoration has been defined either as a response to degradation or as a process mimicking succession.

Bradshaw defines restoration as returning an ecosystem to an original healthy or 'perfect' state (Bradshaw, 1987, 1997). Cairns also defines it as 'management to return a damaged ecosystem to its pre-disturbance condition' (Cairns, 1993). Aronson and co-workers defined restoration as an endeavour that seeks to halt degradation and redirect a disturbed ecosystem (Aronson et al., 1993).

Parker and Pickett (Parker and Pickett, 1997), see restoration as primarily an ecosystem process involving management of succession to re-establish functioning and self-sustaining dynamic systems.

Hobbs and Norton (Hobbs and Norton, 1996), suggest that restoration occurs along a continuum and that differentiated terminology simply reflects different forms of restoration and different types of situation for restoration.

For the purposes of the present study, the following definition of restoration (based on a summary of the above) will be used:

> *Restoration is a directed or managed process of ecosystem change along a trajectory towards a stable, healthy pre-disturbance state (i.e. where the function, dynamics, structure, physical and biological characteristics correspond to this pre-disturbance state).*

1.2.2 Succession

The following section reviews successional theory as it relates to restoration. Succession or ecosystem change is a basic concept in ecology. The theoretical basis of restoration is closely aligned with successional theory. Parker and Pickett see restoration as a process of managing succession (Parker and Pickett, 1997). Walker and co-workers specifically advocates examining restoration in the light of succession (Walker et al., 2005).

In classical Clementsian succession, vegetation change is a temporal linear series of stages, each replacing the previous, from a point of disturbance or bare substrate to a climax stage of mature forest (Clements, 1916). The ecosystem as a whole is seen as a closed system in balance and self-sustaining. As each stage is unique and irreplaceable in the sequence, climax species cannot be expected to flourish in earlier stages. Within this model, competition, facilitation, inhibition and tolerance relationships between species are seen as possible mechanisms for the process (Connell and Slatyer, 1977).

However, the concept of succession has changed radically from the classical Clementsian model. The review by Pickett and others of succession mechanisms (Pickett et al., 1987), advanced a non-deterministic, open ecosystem concept with a ‘hierarchy of causes’ of vegetation change. The concept was further developed in Burrows’ theory of vegetation change (Burrows, 1990). More recently Parker and Pickett described it in this way: “[Eco]systems are open to important controlling factors, often externally regulated, frequently probabilistic in their dynamics, subject to natural disturbances and episodic events, not necessarily in short-term or fine-scale equilibrium and contain humans” (Parker and Pickett, 1997).

In the new ecosystem concept, multiple successional pathways and equilibria are possible. The ecosystem is subject to flux in interaction with its specific spatial, scale and temporal landscape context. Vegetation change may not involve a linear or sequential replacement series. The concepts of facilitation, inhibition and tolerance still have validity e.g. Antecedent vegetation often does influence the environmental conditions or the growth of species. However, classical theory predictions do not always hold e.g. late successional species will not always fail in open or disturbed sites (Ashby, 1987). Factors such as seed dispersal, competition, adventive species invasion, environmental change and stochastic events are more recognised as critical to successional dynamics (Ashby, 1987).

Restoration theory depends on such an open ecosystem concept. Besides the need to reverse degradation or improve the viability of remnants, a fundamental rationale for restoration is that it accelerates succession or manipulates it to bypass stages or circumvent bottlenecks (Bradshaw, 1987; Hobbs and Mooney, 1993;

Walker et al., 2005). E.g. planting can bypass slow colonisation processes; techniques may manipulate the 'regeneration niche' for the desired species (Ashby, 1987; MacMahon, 1987). This is particularly relevant in an urban context where successional processes are substantially modified by human disturbance and require ongoing intervention as a consequence (Parker and Pickett, 1997; Webb, 1997).

1.2.3 Key aspects of restoration theory

Current restoration theory applies the open ecosystem and succession concepts (Hobbs and Mooney, 1993; Hobbs and Norton, 1996; Luken, 1990; Parker and Pickett, 1997). Besides succession theory, restoration theory draws on landscape ecology, species autecology and conservation biology. Conservation biology deals with minimum viable populations (Gilpin, 1987; Gilpin and Soulé, 1986), population dynamics (Ashby, 1987) and keystone species (Angelstam and Arnold, 1993; Handel, 1997; Lambeck and Saunders, 1993; Miller, 1987). It is the least relevant to the present study and will not be further discussed. The following sections describe the basic concepts relevant to restoration and the present study.

1.2.3.1 Restoration Processes

Luken applied the hierarchical approach of Pickett and others to restoration, deriving a framework of three primary restoration processes (Pickett et al., 1987). These are: designed disturbance, controlled colonisation and controlled species performance (Luken, 1990). The processes relate to a number of other lower level attributes that can be directly manipulated: populations, resource availability, propagule or coloniser availability, vegetation composition, animal (and human) behaviour, patch area, patch distribution and patch connectivity (Luken, 1990). These processes are directly relevant to the present study.

However, Hobbs and Norton (Hobbs and Norton, 1996), suggest the Luken processes do not address alternate pathways, thresholds, possible assembly rules, non-plant species involvement and aspects other than structure and composition. They also suggest that the Luken framework applies best for individual sites but that guidelines that are more explicit are required for restoration at the landscape scale. General principles that prevent ad hoc approaches are essential. They therefore describe additional processes:

a) Forcing of transitions or ‘thresholds’ between intermediate, stable states along a restoration trajectory. Hobbs and Norton see this as the fundamental restoration process (Hobbs and Norton, 1996).

b) ‘Assembly rules’ for adding species in alternate pathways which determine the final character of the intermediate states (Drake et al., 1993; Gilpin, 1987).

c) Managing landscape scale processes (Luken, 1990; Merriam and Saunders, 1993; Recher, 1993; Webb, 1997).

The next three sections describe some of the restoration processes in more detail.

1.2.3.2 Disturbance

Disturbance is recognised as a normal but important dynamic and selective factor in vegetation change. Understanding disturbance is also fundamental to restoration of mine waste or disturbances such as urbanisation (Cairns, 1993; Smale and Meurk, 1997).

The size, location and timing of disturbance events influence the species that colonise sites (Gross, 1987). Invasion by colonising or adventive species depends on disturbance (Hobbs and Mooney, 1993). In a set of combined data from around the world, it was found that the degree of disturbance explains 55% of the total variation in the proportion of naturalised species at a landscape scale (Rapaport, 2000).

1.2.3.3 Thresholds and assembly rules

Full restoration to self–sustainability may not be possible. Ecosystem processes are dynamic and multi-dimensional and each ecosystem is the result of a unique sequence of events (Aronson et al., 1993; Cairns, 1993; Drake et al., 1993; Gilpin, 1987).

The concept of thresholds follows from Aronson’s definition of restoration and the ‘state and transition’ concept of ecosystem response to management. Partial restoration may occur when the pre-disturbance state is unattainable, a threshold needs to be crossed to reach it, or to reach an alternative stable, sustainable state (transition or metastable state) is induced (e.g. because of site history).

The threshold concept is closely linked to the idea of ‘assembly rules’ for species. The idea is that the ‘assembly order’ of components may affect the structure and composition of reconstituted communities. Introduction of species in different orders can result in different communities. To restore a community successfully, the appropriate species introduction sequence needs to be followed (Diamond, 1975; Drake et al., 1993; Gilpin, 1987). The present study may have implications for this concept.

1.2.3.4 Landscape ecological processes

Landscape ecology is based on modified island biogeography theory and metapopulation principles (MacArthur and Wilson, 1967). In a landscape ecology approach to restoration, the landscape is viewed as an assemblage of patches and corridors in a matrix. The application of the theory in restoration focuses attention on the following issues:

a) Species selection and dynamics: This deals with the choice of species and interactions between them. Species selection is important to achieve representativeness in relation to the target biotope. For indigenous restoration it may also affect restoration success (Meurk, 1997). Issues in New Zealand restoration are the use of exotic species in restoration, the relative balance with indigenous species and the affects on ecological processes in the restored community. Exotic species may facilitate or inhibit natural processes of vegetation change and therefore restoration (Burrows, 1990; Given and Meurk, 2000; Meurk, 1997). The present study will explore use of exotic nurse species (as a canopy) for planting.

b) Arrangement of patches (metapopulation dynamics): This concerns size, shape, connectivity and proximity of patches, (Lambeck and Saunders, 1993; Luken, 1990; Merriam and Saunders, 1993; Webb, 1997). For example, populations of plants need to be large and unfragmented enough to attract pollinators, and diverse enough to maintain the attraction. Seed dispersion is interdependent on the proximity of suitable species for the agents of dispersal

(Handel, 1997). The main aspect explored in the present study will be dispersal in relation to patch proximity.

c) Scale effects: Scale refers to the size of the (restoration) patches relative to the size of surrounding patches and the vegetation matrix. Restoration needs to address the scale of patches relative to the viability of the restored community. The minimal sustainable cover of indigenous vegetation is important (Meurk, 1997). Recently, Drinnan suggested that to maintain plant species richness in urban areas, minimum viable remnant sizes may be about 2ha (Drinnan, 2005). Restoration must integrate individual restoration projects and provide additional habitat or buffer zones in the best locations (Hobbs and Norton, 1996). The present study will not explore patch size directly but may have implications for it.

d) Edge effects: These relate to ecosystem fragmentation and patch dynamics and affect the approach taken to ecosystem restoration. (Diamond, 1975; Pickett and Thompson, 1978; Scougall et al., 1993; Simberloff, 1993; Sisk and Margules, 1993). The present study will not explore this aspect in detail.

e) Landscape management: This deals with the conditions for sustaining and enhancing species populations or biotopes (vegetation types) (Webb, 1997). The present study will explore maintenance issues.

1.2.3.5 Ecosystem structure, function and composition

Restoration involves re-establishing pre-disturbance ecological structural and functional attributes and related physical and biological characteristics (Cairns, 1993). However, the relationship of ecosystem structure, function and composition is not well understood. Webb points out the need for theory linking activities of individual organisms, population dynamics and community assemblages to ecosystem structure and function (Webb, 1997). ‘Even with all the species we may be unable to reassemble communities’ (Luh and Pimm, 1993).

Not all species contribute equally to community structure and function – some species are essential and some species may be functionally unnecessary to an ecosystem. However, species that are apparently functionally equivalent, may have distinguishing attributes that produce environmental resilience in the long-term (Armstrong, 1993).

Stabilising the ecosystem function may have priority over species composition in the early stages of restoration (Armstrong, 1993). It may also be easier to achieve (Edwards et al., 1997). Restoring community structure rather than species composition may be a priority where sustainability is the objective (Recher, 1993).

Risser suggests that most ecosystems are structure by a few dominant functional processes. One could therefore attempt to relate these processes to selected functional attributes of species and so to the species composition (Risser, 1999; Walker, 1999).

The study will explore composition, structure, function of the restoration patches, and attempt to understand better their relationship.

1.2.3.6 Species autecology

Nutrient, moisture, light and thermal conditions are factors critical to individual species' survival and ability to increase in a plant community. However, physiological tolerances of species do not necessarily match or determine the community location of the species in the field, due to competitive effects that interact with the physiological tolerances. The way individual plants allocate resources early in life affects the competitive outcomes on species distributions (Werner, 1987).

Utility of species for restoration depends on their ability to survive and reproduce, create suitable site conditions for other species on the site or induce vegetation change in the desired direction for restoration. Management techniques to manipulate environmental conditions can be used to direct vegetation change (Luken, 1990; Smale and Meurk, 1997). Such techniques include mulching and spraying for moisture and weed control, soil cultivation, modifying germination conditions, and controlling species competition and persistence (Gross, 1987; Simcock and Ross, 1997). The study will explore these techniques.

1.3 Restoration planning processes

A number of researchers see planning as critical to any restoration attempt and propose some sort of comprehensive management plan that sets goals and has funding, policy and monitoring objectives. The following sections will discuss the planning requirements most relevant to the present study. The range of suggested requirements include (Atkinson, 2001; Hobbs and Norton, 1996; Luken, 1990; Saunders et al., 1993):

a) Determining community involvement.
b) Setting specific goals.
c) Describing the site history, conditions and processes.
d) Identifying processes that lead to degradation (ecological, social or economic).
e) Identifying ecosystem processes that need restoring, and assessing habitat and movement requirements of species.
f) Developing methods to reverse degradation processes and manage restoration.
g) Developing cost effective, practical techniques to implement the goals.
h) Developing measures of success.
i) Communicating techniques to planners and managers and results to the community and researchers.
j) Monitoring and adjusting management appropriately.

1.3.1 Goals

Assessing the success of restoration efforts assumes certain goals. Goals need to be realistic about what restoration can actually accomplish. If full restoration is unattainable modest goals may be more appropriate.

Restoration will often be less than replication or replacement of natural systems. It may be dynamic rather than stable. And it may be affected by social, economic and cultural barriers to implementation (Ehrenfeld, 2000; Hobbs and Norton, 1996; Luken, 1990). Parker and Pickett suggest that any goal of self-sustainability is flawed as it fails to recognise the dynamic and multi-dimensional processes creating the ecosystem, or the human and landscape contexts (Parker and Pickett, 1997). Cairns suggests that ecological community reconstruction rather than replication is a more realistic goal (Cairns, 1993).

Atkinson suggests that in New Zealand restoration of ecological function or processes is of less value as a goal than restoration of the evolutionary context of species including animals (Atkinson, 2001).

1.3.2 Identifying degradation processes

There are many processes of ecological degradation and reduced resilience (Burrows, 1997; Cook and van Lier, 1994; Luniak, 1996; Meurk, 1997; Platt et al., 1994; Smith and Hellmund, 1993). The key ones for urban and periurban Hamilton gullies include:

a) Habitat fragmentation and habitat disturbance.

   In an urban context, the severity of fragmentation is greatest. Besides the natural disturbance regime, it is determined by the similarity of the anthropogenic matrix to the natural matrix and by the persistence of anthropogenic change. A landscape approach is helpful for restoration in this context by treating fragmented areas as patches (Marzluff and Ewing, 2001; Meurk and Hall, 2000).

b) Modified relief, hydrology, soil quality and nutrient cycling.

   In extremely degraded sites, restoration will aim to restore and maintain basic ecosystem processes such as soil structure, nutrient status and hydrologic regimes (Ehrenfeld, 2000). In urban gullies, landform modification and fill soils are likely factors that affect the basic processes. However, in less degraded sites, so long as there are living organisms present, these processes will be functioning in some form of ecosystem (Atkinson, 2001).

c) Invasion of adventive species.

   The human and alien species context of restoration is critical to success (Parker and Pickett, 1997). Urban situations have high levels of alien species, relative to indigenous species. They can dominate seed banks (Given and Meurk, 2000). In New Zealand restoration attempts, exotic species appear to have a role, but it is not clear what effect they may have on the processes of vegetation change and long-term compositional status of the restoration (Burrows, 1990; Given and Meurk, 2000; Meurk, 1997; Smale and Meurk, 1997).

1.3.3 Key ecosystem attributes and processes for restoration

Besides the key attributes of structure, function, and composition, other attributes are also important for sustainability of re-established ecosystems (Armstrong, 1993; Aronson et al., 1993; Batcheler and Craib, 1985; Cairns, 1993; Ehrenfeld, 2000; Hobbs and Norton, 1996; Luken, 1990; Majer, 1997; Stephens, 1999; Wilson et al., 1995). The range of attributes to attend to includes:

a) Function: as the performance of basic ecological processes including (as most significant for this study) decomposition, mutualistic interactions, regeneration and propagule dispersal.
b) Composition: as the makeup of faunal and floral species and their abundances.
c) Structure: as the vertical arrangement of soil and species components.
d) Pattern: as the horizontal or spatial arrangement of system components.
e) Heterogeneity: as the compositional, structural or pattern diversity.
f) Productivity: as the plant and animal biomass.
g) Dynamics and resilience: as the response of successional processes to disturbance and stress.

1.3.4 Restoration methodologies

The key restoration processes and attributes indicate principles, methods and techniques for restoration. Ehrenfeld suggests looking for sets of conditions that mandate particular methods (Ehrenfeld, 2000).

Luken's and Hobbs and Norton's vegetation change processes suggest specific methods (Hobbs and Norton, 1996; Luken, 1990):

a) *Disturbance* can be used to prepare a site, eliminate competing species or promote germination of specific species. Soil surface characteristics affect seed entrapment, seed retention, seed germination, seedling emergence, growth and survival. Soil temperature, nutrient status and water retention is affected by disturbance. Control of human disturbance is critical also.

b) *Colonisation* involves establishment of propagules from the seed bank, surrounding areas or by artificial introduction. Controlling germination cues and seedbeds is also important. Establishment and persistence of plants depends on type of propagules, seed production, seed viability, seed size and seed morphology.

c) *Species performance* involves controlling competition, herbivory, predation or invasion.

d) *Landscape ecology methods* to reverse degrading processes include the following [with the focal ecosystem attributes in brackets] (Burrows, 1997; Marzluff and Ewing, 2001; Meurk, 1997; Recher, 1993):

- Manage the whole matrix not just the patches – make the matrix more like the native remnants [function, pattern, composition]
- Integrate planning for the whole matrix e.g. manage urbanisation and other human activities to reduce fragmentation and modification of vegetation and reduce pollution, increase native habitat, manage habitat collectively, incorporate parks into the framework of patches [function, pattern, heterogeneity]
- Establish corridors and discourage movement barriers for native animals [function]
- Minimise edges [function]
- Exclude exotic organisms – e.g. design buffers to reduce penetration of undesirable agents to patches, manage animal populations [pattern, dynamics and resilience]
- Reduce [artificial] disturbance e.g. reduce human activity from interior of patches [dynamics and resilience]
- Protect remote areas [function, heterogeneity]
- Reduce modification of hydrology, protect water courses and small or large wetland complexes [function, heterogeneity]
- Protect high and low nutrient sites [function, heterogeneity]
- Establish diverse composition, multiple vegetation layers and manage patches for different successional stages [composition, structure, dynamics and resilience]

e) *Thresholds and assembly rules* do not suggest specific methods but rather suggest attention to the above methods to ensure likely thresholds do not become obstacles. Research may be required to determine specific threshold conditions linked to specific project sites. Examples include ensuring that site fertility and ground conditions are adequate and that species are introduced appropriately.

The methods suggested above involve manipulating a range of variables. The most relevant to the present study include (Atkinson, 2001; Bradshaw, 1987; Norton, 1997):

a) Propagule composition e.g. pioneer or nurse species; the mix of species from different successional stages; and use of non-indigenous species (to replace extinct animal guilds).
b) Propagule type i.e. seeds, cuttings, plants; imported litter and soil from undisturbed sites (mycorrhizae).
c) Propagule sizes e.g. plant grades.
d) Planting or sowing patterns and spacings.
e) Soil structure, moisture, hydrology and nutrient status e.g. by cultivation, compaction, mulches, drainage, fertiliser, planting nitrogen fixers.
f) Conditions for weed species invasion e.g. planting density, sprays, manual maintenance and gap creation.
g) Pest species herbivory and predation e.g. trapping, poisons.
h) Habitat conditions e.g. deadwood, litter, nesting structures

1.3.5 Developing measures of success

Restoration success assessment is fundamentally assessing goal achievement. Depending on goals, successful restoration will be characterised by the following (Bradshaw, 1987; Cairns, 1993; Clark, 1997; Ewel, 1987; Norton, 1997):

a) A lack of observable adverse effects in the larger landscape.
b) Identity. Species composition, structural and functional attributes vary within predictable limits and species composition is representative.
c) Correspondence. The restored community has comparative similarity to undisturbed ecosystems within the region.
d) Self-regulation or sustainability for an appropriate period. Structural and functional attributes persist without ongoing management inputs; regeneration requirements of species are met. This criterion depends on a goal of full restoration.
e) Elasticity or resilience. The restored community can recover after normal episodic events or anthropogenic events.

f) A high level of invasion resistance. This depends on the presence of key species and complete utilisation of resources - light, water and nutrients - within the system.
g) Productivity similar to the pre-disturbance or reference system. This requires efficient resource use and integration of ecosystem processes.
h) Effective nutrient retention. This is related to sustainability and efficient resource use.
i) Functioning biotic interactions. The critical ones are pollination, microbial interactions and key species interactions.
j) High habitat values for fauna.
k) The time scale for reestablishment of the target ecosystem is reduced compared to natural processes.

To assess success, these criteria require specific measurement of performance against pre-disturbance conditions or reference [indigenous] ecosystems. They require measurement of key functional, structural and compositional attributes of ecosystem health against the natural range of variability (Aronson et al., 1993; Cairns, 1993; Ehrenfeld, 2000; Hobbs and Mooney, 1993; Luken, 1990). In practice, key ecosystem attributes (section 1.3.3) provide measures of correspondence, ecological function (in terms of propagule dispersal) and productivity (Bradshaw, 1987; Cairns, 1993; Clark, 1997; Ewel, 1987). The 'vital ecosystem attributes' (Aronson et al., 1993), include such measures as species richness, phytomass, life-form spectrum and soil organic matter.

Hobbs and Norton outline two other methods of measurement (Hobbs and Norton, 1996):
a) Similarity indices between a reference state and the restored system using indicator taxa and ecosystem reference templates.
b) Current ecosystem health assessed by functional, structural and compositional measures such as density of dominant species or presence of pollinators.

1.4 Relevant New Zealand Restoration Research

Reay and Norton assessed restoration success from plantings dominated by *Olearia paniculata* on the Canterbury Port Hills (Reay and Norton, 1999). They focussed on facilitation of change and species composition in recolonisation. The restoration sites were in close proximity to the likely seed sources for regeneration and this was suggested as a significant factor. Existing vegetation cover was identified as a possible problem in initiation of regeneration.

Sullivan and co-workers, investigated exotic invasion of New Zealand native forest near urban centres (Sullivan et al., 2005a). They found that proximity and size of settlements are the dominant factors controlling the number of exotic plant species in these forest areas. In about 45% of the forest samples that were within 250m of houses the source of invasions was dumping of garden waste. Sullivan and co-workers' findings also have implications for restoration patches. Proximity of exotic species is critical to their establishment. This suggests some options to reduce proximity of weed species, e.g. by neighbourhood efforts, responsible gardening and the control of disturbance effects on planted patches. In the same way, proximity of native species may be critical and would confirm the value of increasing the proximity of native species by enrichment.

Sullivan and co-workers, in a separate paper investigated urban restoration in Auckland (Sullivan et al., 2005b). They researched techniques of successful plant establishment and growth (spacing, soil preparation or mulch use and species mixes). They also assessed the influence of soil compaction and moisture and the rate and diversity of weed colonisation in relation to bird dispersal mechanisms and patch isolation. Bird dispersed species showed no difference to other species, but mulched, sparse (1.5m spaced) planting was less effective than soil-ripped (i.e. cultivated), close (0.75m spaced) planting. Early weed control and canopy closure with closer planting, promoted better weed suppression. Major seed dispersal and establishment occurred within 100m of parent plants. This again implies that enrichment planting of native species within or near patches and eliminating nearby weed sources benefits restoration.

1.5 Gully Ecology of the Hamilton Ecological District

The Hamilton Ecological District (HED) is an inland area with boundaries largely defined by the Hamilton Basin extending from Taupiri in the north (Latitude 37°31′ S), to Maungatautari in the south (Latitude 38°03′ S) and from Pirongia and the Hakarimata in the west (Longitude 175°05′ E), to Te Miro (Longitude 175°33′

E) and Hapuakohe in the east (Figure 1.1). It covers an area of 159,376 hectares (Leathwick et al., 1995).

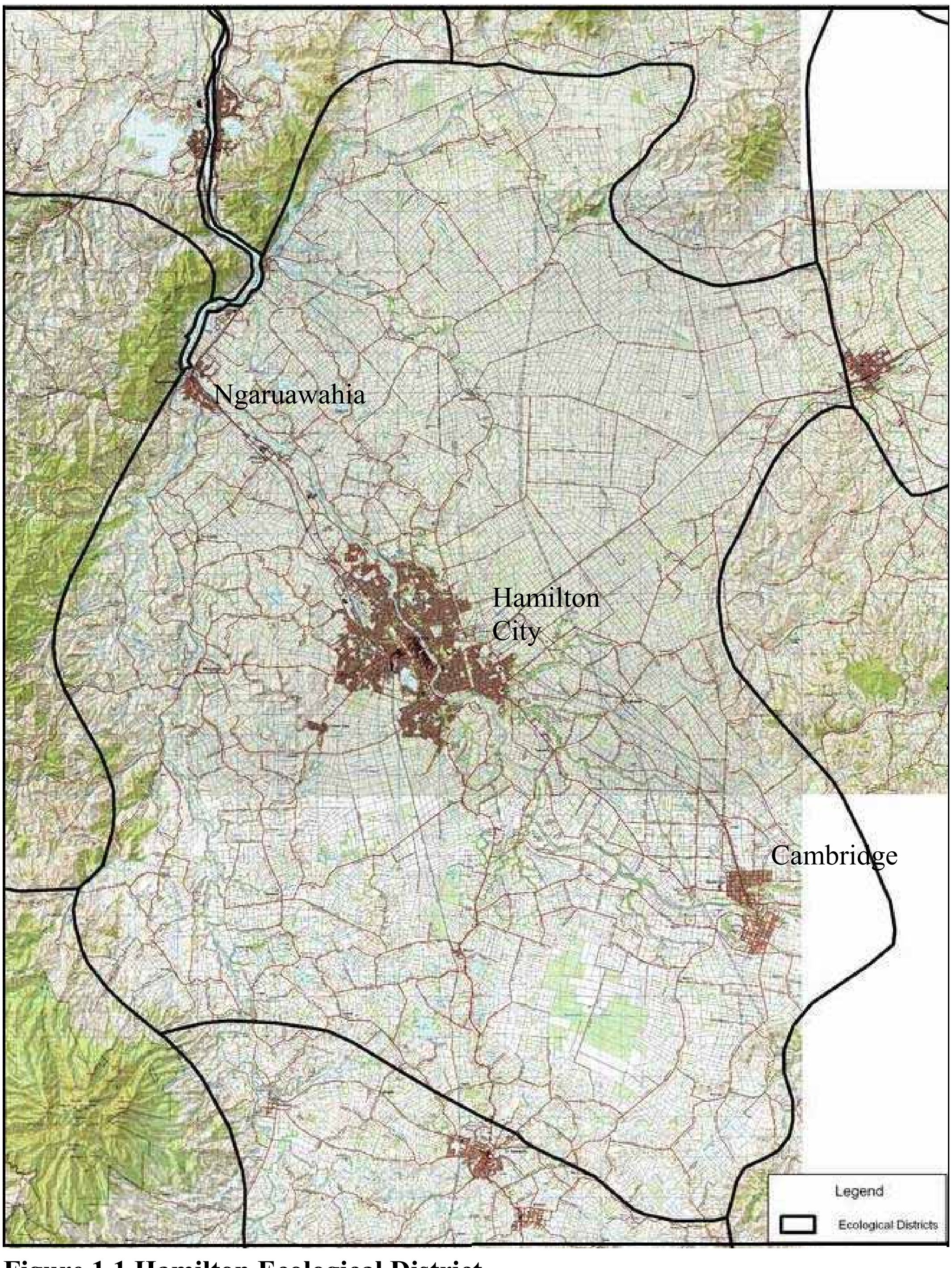


Figure 1.1 Hamilton Ecological District
(Adapted from DOC)

The HED is now comprised largely of rural pastoral landscape, with areas of higher country in exotic and native forests. Urban areas are comprised of Hamilton City and townships servicing the rural land users. Growth of urban areas is generally at the expense of existing farming land use.

The average elevation of the HED is around 30m above sea level. It has a temperate humid climate (warm humid summers and mild winters). Mean annual rainfall (for 1971-2000) is 1190 mm and varies from 71mm/month in February to 126 mm/month in July. Mean annual temperature is 13.7^{o}C and ranges from 18.7^{o}C (February) to 8.7^{o}C (July). The prevailing wind is west to southwest but the basin is relatively sheltered with a mean wind speed of 12 kph. Occasional storms from south, west, north or east do occur (NIWA: www.niwascience.co.nz/edu/resources/climate).

The underlying geology of the Hamilton Basin comprises tephra and alluvial material from ancient and recent Taupo eruptions. Hamilton's gullies are the result of gradual erosion from seepages through this eruption tephra and alluvial material. The gullies, which are the main focus of this research, typically comprise steep slopes with well-drained, rhyolitic sands and gravels and flat gully bottoms that have poorly drained, rhyolitic sands, silts and organic (peaty) soils (Craw, 1967; Harding, 1997; Selby and Lowe, 1992). These characteristics often make the gully sides highly erodable and vulnerable to impacts from runoff.

In rural areas, the covering forests have been replaced by pasture, scrub or woodlots and in urban areas exotic scrub, 'forests' and gardens dominate the vegetation and the banks have been modified by retaining walls, steep tracks and filling (pers. obs). Gully floors typically supported lowland swamp forest in the past, with habitat suitable for a wide range of forest birds and fish. In rural and urban conditions, willow and exotic wetland species have largely replaced native swamp forests (Leathwick et al., 1995).

The natural hydrology has been modified by drainage of wetlands and swamps and by stormwater discharges (Waikato Valley Authority, 1976). In urban areas streams have been channelised, piped or controlled by weirs and are regularly 'maintained' with habitat destructive vegetation clearance activities (pers.obs.).

However, the remnant gully communities with their relatively high species diversity are valuable populations of species that are either rare or highly localised in the Hamilton Basin. The relative isolation and moisture availability assist their function as important refugia of the local flora. (Clarkson and Clarkson, 1999; de Lange, 1986, 1987, 1994).

Several characteristic indigenous vegetation types probably occurred in gullies in the HED (Clarkson and Clarkson, 2000). The two main types were:

- Kahikatea-Pukatea-Swamp Maire forest in the gully bottoms
- Totara-Matai-Kowhai forest on the gully sides

Other successional vegetation types and subtypes of the main two included:

- Kanuka forest (gully slopes and crest)
- Mahoe forest (colluvial footslopes)
- Kahikatea-Pukatea-Swamp Maire forest (poorly drained colluvium)
- Kowhai-Manatu-TiKouka forest (levees)
- Manuka forest (terrace peats)
- Carex-Harakeke wetland (backswamps)

In the modified, exotic ecosystems of many of the HED's gully systems the typical vegetation is dominated by grey willow, alder, hawthorn and tree ferns with other less common species including privet, barberry, acacia, false acacia, Japanese walnut, pine, and *Tetrapanax* (Clarkson and Downs, 2002).

1.6 Gully Restoration in Hamilton ED

In Hamilton City, attempts to protect or restore gully and other bush remnants began 25-30 years ago with projects such as 'Arbour Day' (Hamilton City Council internal unpublished plan records) and by fencing and replanting remnants. A few private restoration projects such as Seeley's gully were also underway in the city and periurban gullies (A. Seeley, P Morris, pers. comms., 2005).

Hamilton City Council now plants over 50,000 native plants annually in such projects (W. Bleaken, Nursery Foreman, Hamilton City Council, pers. comm., 2005). However, revegetation project goals have often been unclear. Many plantings aimed primarily to provide amenity value without close prescription of restoration objectives. With others, the presumption has been that these will somehow re-establish native bush, protect remnants from degradation, and enhance habitat values for native birds (pers. obs.).

Current theory of vegetation change and restoration is unknown to City Council parks staff. Concepts such as an ecosystem in flux, human and landscape contexts, arrangement of patches, edge effects and minimum viable remnant sizes have been insufficiently understood or coarsely applied. For example, the scale of many early Hamilton plantings has been small (Hamilton City Council unpublished plan records).

Survival and persistence of the city's plantings has been mixed with some early total failures and high rates of loss. Preliminary assessment of a range of sites has indicated that older plantings around 20 years old are beginning to degrade again with canopy opening and weed invasion rather than proceeding towards functional indigenous forest ecology (pers. obs.).

Over the last 20 years, in response to some project failures and increased ecological awareness, City Council techniques for establishment planting have been modified e.g. use of mulches. The overall sophistication of revegetation projects has increased (pers. obs.). Changes have occurred in some of the following areas:

a) Plant mixes. These have moved from random mixes including exotic species to 'eco-sourced' mixes.

b) Site preparation techniques. These varied from major clearing to no clearing and from 'blanket-spraying' to mown grass with no other preparation. Site preparation still varies depending on the site conditions.

c) Post-planting maintenance techniques. These have moved from low maintenance to more intensive spray weed control and/or mulching.

d) Approach to long-term diversity enhancement. The approach has changed from laissez-faire to one of post-establishment species enrichment, but is still rather ad hoc.

Some of these factors may have an impact on the success or otherwise of the plantings.

There has been no previous study undertaken of the Hamilton City restoration plantings over the last 30 years or of their success or failure. This study will provide a first assessment. It will attempt to investigate factors in the successes and failures. It will help to guide future planting.

1.7 Objectives of this Investigation

Current restoration theory and concepts and the state of Hamilton's gully plantings suggest several research questions relevant to the restoration projects in urban areas. These include:

a) The rate of change of restoration vs natural regeneration. In light of the apparent decline of some patches, a fundamental question is 'Are restoration plantings generally progressing towards an ecological state similar to mature undisturbed forest?'

b) The effects of maintenance on degradation influences and on species performance. Maintenance is clearly important to initial establishment of plantings. What is not so clear is 'Does ongoing maintenance contribute to advancement or deterioration of plantings?'

c) The effects of human disturbance on the success of restoration. The question is 'Does human disturbance affect the ecological state of the plantings?'

d) Species composition and order of species introduction by enrichment planting. It is not clear if or how the initial structural composition and enrichment of plantings is affecting their functional success. Suitable questions are 'How does species composition relate to ecological state of restoration patches?' and 'Does initial composition diversity or later enrichment help improve the final composition and ecological state of restoration?

e) The patchy distribution of restoration sites in Hamilton City. This is likely to have had an effect on the success of restoration. 'What effects do patchy distribution of restoration plantings have on their ecological state and in particular regeneration and dispersal?'

f) The effects of canopy cover retention on the success of restoration and the role of exotic species (as nurse species). This could be clarified by exploring the questions ‘Does an existing canopy act as a nurse for restoration purposes?’ and ‘How do exotic nurse species (as canopy or otherwise) affect restoration success?’

The specific objectives for this study, based on these questions are:

a) To assess the ecological state and trends in indigenous restoration plantings relative to controls and to reference states of a functioning mature forest by comparing:
   - vegetation change in restoration plantings with naturally regenerating forest patches;
   - the composition, structure, productive value and regeneration components of ecological state.

b) To assess the effects of various factors on the success of plantings. The factors include:
   - Canopy cover regime (in young (0-10 year old) restoration patches);
   - Different maintenance regimes from nil (controls) to high levels of maintenance;
   - Enrichment planting (in patches older than 10 years);
   - Depauperate versus diverse initial planting;
   - Different ages of patches;
   - Environmental context of patches (proximity of other patches or seed sources and independent site variables).

c) To develop restoration recommendations. The results from the previous objectives will be used to develop recommendations for restoration planting in Hamilton Ecological District.

Because no formal goal was set for the restorations being investigated, a restoration goal has been adopted to enable an adequate common basis for assessment:

Restoration to an indigenous ecological community similar in function, structure and composition to a set of local indigenous reference communities (that are relatively undisturbed).

The correspondence of species richness, diversity, composition, forest structure (e.g. life-form spectrum), productivity (biomass), regeneration, and propagule dispersal relative to natural succession in an undisturbed forest community will provide an assessment of outcomes against the adopted goal.

1.8 Study site locations

Sixty-six study plots were surveyed within the Hamilton Ecological District (Figures 1.2 and 1.3). Fifty-three were within Hamilton City and the remainder (13) were within the Waikato District. The plots fall within some 50 distinct sites, mainly individual parks or individual properties (Appendix C).

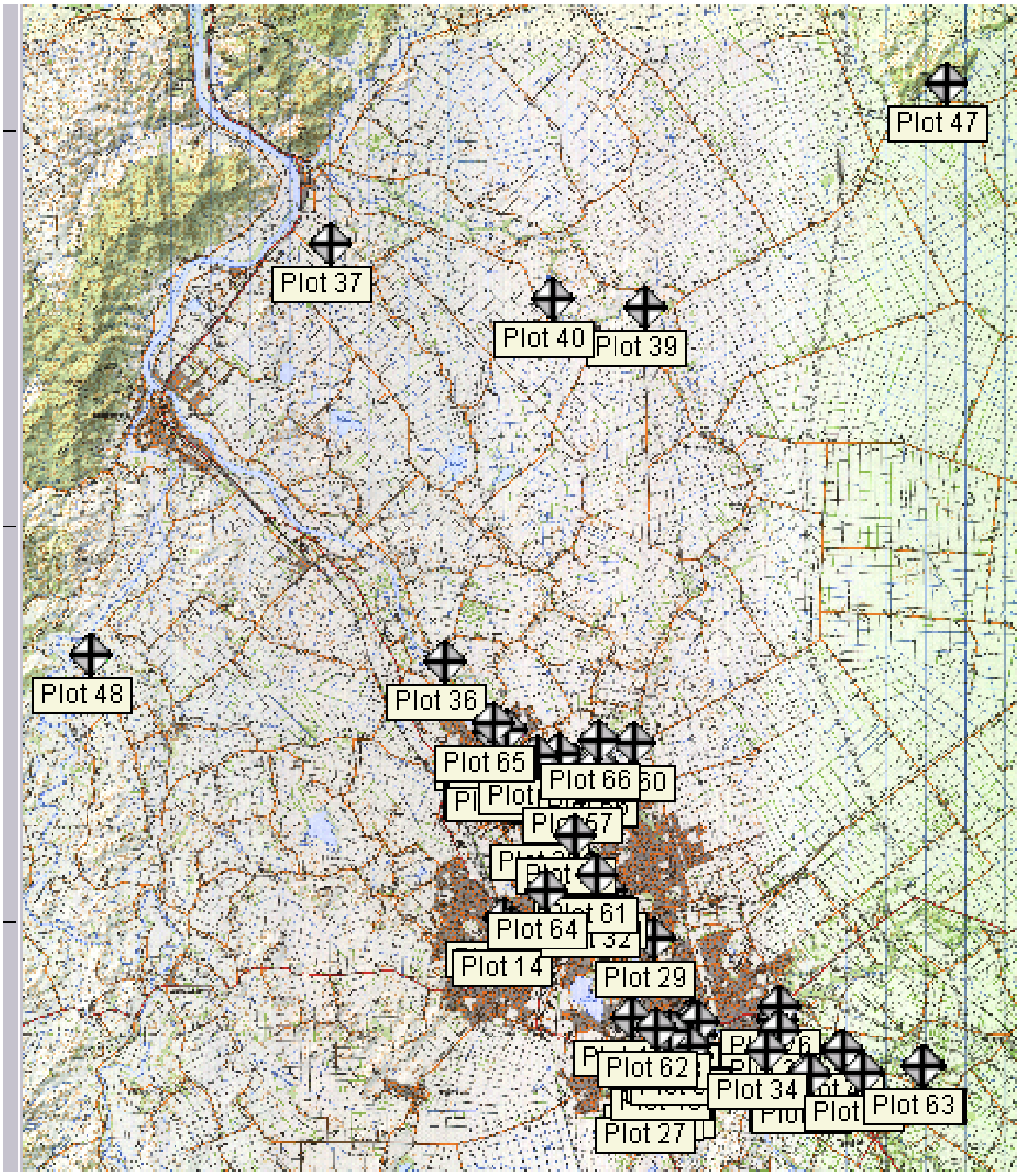


Figure 1.2 All Plot Locations

(Source: LINZ)

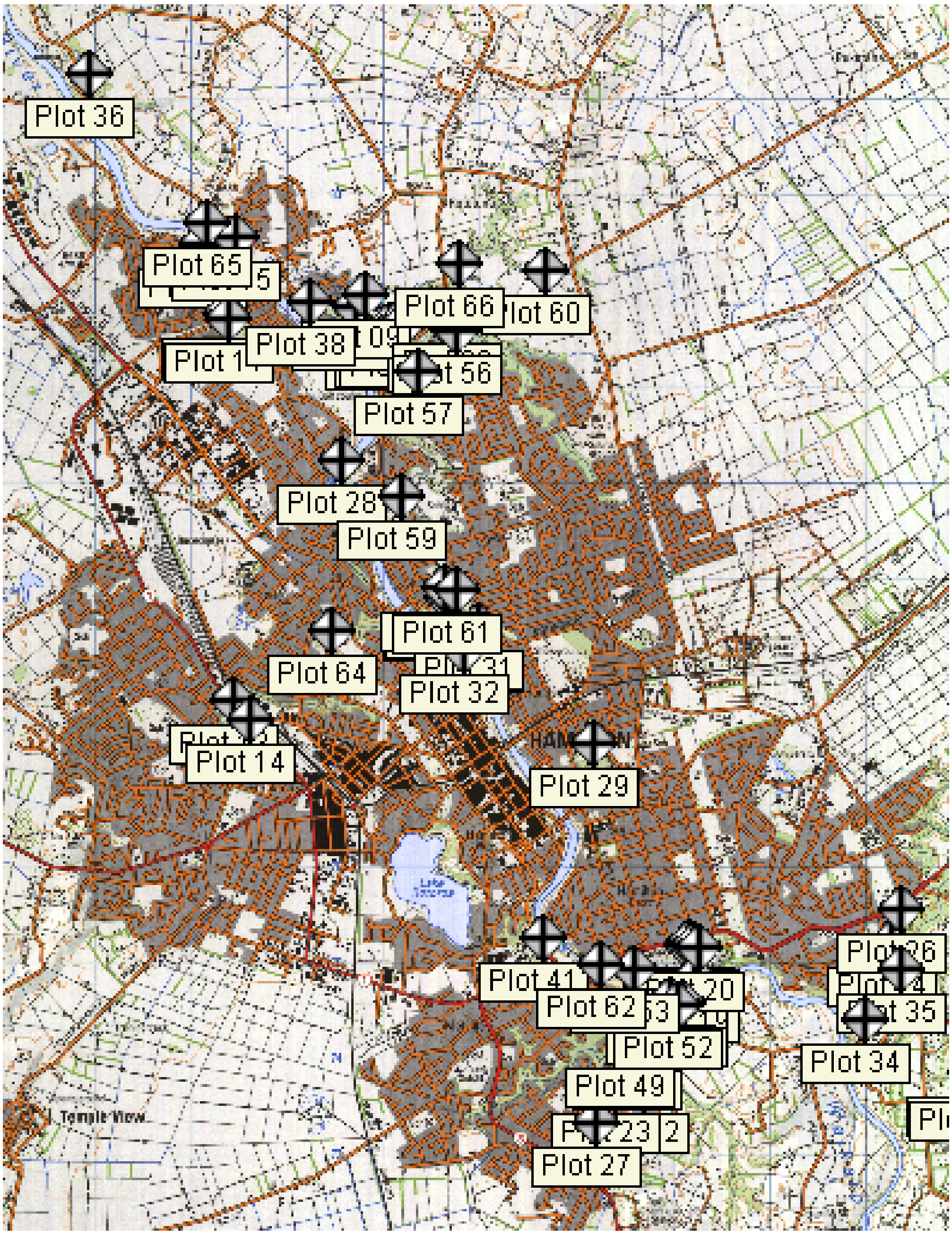


Figure 1.3 Plot Locations in Hamilton City

(Source: LINZ)

1.9 Thesis layout

This research is presented in five chapters. The objectives for each of the next four chapters are set out as follows:

Chapter 1: Introduction

This chapter reviews the theoretical aspects of restoration ecology including relevant New Zealand research. It introduces the study area and study site locations. The ecology of the Hamilton Gully systems, their formation and vegetation are described. The thesis objectives are explained.

Chapter 2: Methodology

This chapter describes the experimental design. It describes the general methodology for the thesis including site selection, plot definition and measurement. It discusses the rationale for the computer statistical software used in the thesis.

Chapter 3: Results: Characteristics of the Experimental Blocks

The chapter describes the results for the experimental blocks. The physical characteristics and significant dependent variables data are described. The chapter also analyses the similarity of experimental blocks to the control blocks across the range of variables. It assesses the effects of planting and maintenance regimes and environmental factors on the success of plantings.

Chapter 4: Results of Cluster and Principal Components Analysis

This chapter describes the cluster analysis and principal components analysis of the plots and species. It describes the species compositions in relation to the independent variables that are responsible for most of the variance between the plot ordination scores. It describes the physical characteristics and values of other variables for the clusters insofar as they add to the analysis of chapter 3.

Chapter 5 Discussion and Recommendations

The last chapter summarises the evidence with respect to the overall ecological state of the planted plots relative to the controls and reference plots. It reviews and summarises the main reasons for the ecological state of the plots. The implications for relevant theoretical restoration issues are discussed. Finally, recommendations for Hamilton Ecological District gully restoration practice are developed.

Chapter 2 · Methodology

2.1 Experimental Design

At the outset of the research, an experimental sampling design was developed (Table 2.1). It consisted of 60 plots in 15 treatments with four replicates each. Age range (column) and maintenance regime (row) treatments divided the plots at the most basic level.

Within the high maintenance treatment level, other treatments were 'nested'. The canopy treatment divided the 0-10 year old high maintenance treatment into two. Enrichment and diversity treatments divided the 10–20 year old high-level maintenance treatment into four combinations and the 20-30 year old high-level maintenance treatment into two combinations. The lowest maintenance treatments are thus the controls for each age range set (each column).

Secondary controls for each of the nested treatments are in A3 (canopy), in B3a (10-20 years, enrichment and diversity) and in C3 (20-30 years, enrichment and diversity). D1 indicates the oldest and most mature forest control block and was therefore designed to be the main 'reference' community used to compare progress or success of planted sites.

The scale of the restoration can affect validity of the data analysis (Rosenzweig, 1987). While the experimental design will use multiple sites and replicates, which may overcome this to some extent, the small-scale nature of the plantings and attendant edge effects are accepted as being consistent factors. The investigation is thus by nature an assessment of success of this scale of planting.

Initial stratification (see below) of the available sites informed the selection of treatments based on the likely number of available plots.

Table 2.1: Experimental sampling design replicates

A1: 4 plots 0 - 10 YRS Revegetation Control	**B1: 4 plots** 10 - 20 YRS Revegetation Control		**C1: 4 plots** 20 - 30 YRS Revegetation Control	**D1: 4 plots** Mature forest Control (reference)
A2: 4 plots 0 - 10 YRS Low level maintenance	**B2: 4 plots** 10 - 20 YRS Low level maintenance		**C2: 4 plots** 20 - 30 YRS Low level maintenance	**Note:** Experimental treatment block codes refer to the respective treatments of each. Capital letters indicate age, numbers indicate maintenance treatment and lower case letters indicate other treatments within the high maintenance blocks.
A3: 4 plots 0 - 10 YRS High level maintenance No canopy at planting	**B3a: 4 plots** 10 - 20 YRS High level maintenance Depauperate initial planting, not enriched	**B3b: 4 plots** 10 - 20 YRS High level maintenance Diverse initial planting, not enriched	**C3: 4 plots** 20 - 30 YRS High level maintenance Depauperate initial planting, not enriched	
A4: 4 plots 0 - 10 YRS High level maintenance Canopy at planting	**B4a: 4 plots** 10 - 20 YRS High level maintenance Depauperate initial planting, and enriched	**B4b: 4 plots** 10 - 20 YRS High level maintenance Diverse initial planting, and enriched	**C4: 4 plots** 20 - 30 YRS High level maintenance Diverse initial planting, and enriched	

2.2 Site Selection

Most planted patches were selected from Hamilton City Council reserves (internal unpublished plan records). Other planted sites were selected from a gully restoration database (unpublished), set up by Hamilton City and Tui 2000.

Control sites were set up as baselines of natural regeneration and mature forest to compare the effects of planting and human activities. They included both urban locations similar to the planting sites and some more remote sites. Some of the control site patches were selected from the Indigenous Vegetation Types of Hamilton City report (Clarkson and Clarkson, 2000) and Hamilton City key ecological sites reports (Downs et al., 2000). Others were selected from QEII trust covenants sites, by searching aerial photos and topographic maps, or from local knowledge.

The initial assessment of sites used a stratified sampling technique (Eberhardt and Thomas, 1991). Initial sample stratification was by:

a) Estimated age of patch (confirmed during survey by tree coring or from extant planting plans)
b) Maintenance regimes or treatments
c) Initial cover type (canopy cover vs. open)
d) Planting treatments - enrichment planting or absence of it
e) Type of site (control vs. planted)
f) Gully slope position (top of bank, crest of slope, mid-slope, foot slope, gully bottom)
g) Main aspect (by compass points not degrees)
h) Preliminary condition assessment (visual correspondence with natural forest)

Final experimental plot sites were selected from the master list of possible sites after initial site visits and preliminary visual assessment of their status in terms of the stratification criteria (Appendix A). To minimise the number of variable options in the experimental design and because of the availability of suitable plots, gully mid-slope was selected as the locus for plot placement. The possible range of actual sites selected was reduced after preliminary site visits to secure sites where restoration planting was of a sufficient scale to meet the requirements of plot size. The experimental design was initially set up as in Table 2.1 but the final number of plots deviated from this to suit the available sites. This resulted in 66 plots in total: 17 controls and 49 planted plots.

Of the 49 planted plots, 13 were planted by private individuals and are mostly on private land. Of the 17 control plots, 8 are on private land, two others are on land that was in private hands until recently, and one is on school land (and thus accessible to the public).

The control sites included a range of vegetation types. They are as follows, (g) to (j) being mature forest types:

a) mainly exotic shrubland (privet, gorse, barberry, hawthorn)
b) Tree fernland
c) Mahoe forest
d) Sycamore/Mahoe forest
e) Willow/Fuchsia forest
f) Kanuka/tree fern forest
g) Blackwood/Mahoe forest
h) Totara forest
i) Kahikatea forest
j) Tawa forest

2.3 Plot and Measurement Randomisation

The patch area was selected for suitable mid-slope. The centre of the plot was a randomly selected point away from the edge of the patch. This involved establishing the approximate centre of the selected patch and the diameter of the patch. A practical minimum distance (15m) of the centre point from the edge was found by preliminary sampling. The area available for centring the plot was calculated by deducting the 15m minimum distance from the total patch radius. North was then identified by compass bearing. A (diameter) line through the area available for centring the plot was established with a random bearing derived from a 1-100 random number chart combined with 100th divisions of the compass. To determine the actual plot centre, a random distance was established along the line using 10th divisions of the line with a 1-10 random number chart.

If the minimum 15m distance was not obtainable for the whole plot, a line was established at about 90^o to the least diameter of the patch. The minimum 15m was deducted from the radii in both directions along the patch diameter to establish a line on which to centre the plot. The random compass bearing was then used only to generate a left or right direction of movement along this line for a random distance selection as 10th divisions of the line with a 1-10 random number chart.

At each selected site, five small seedling subplots also were established within the main plot. Randomisation of the subplots was as follows: The random bearing used to establish the plot centre was projected to the perimeter of the plot once the perimeter was found by the variable area plot method (described below). Using 10^{th} divisions of the diameter of the projected line (i.e. of the plot diameter) with a 1-10 random number chart, a first subplot centre was identified. Successive subplots were found in a similar fashion but using bearings 90^o, 180^o and 270^o from the first. The fifth subplot was placed at the centre.

Two transects for the 'point intercept' measurement of groundcover, were placed through each plot, one approximately directly up the slope and the other at approximately 90^o to the slope. Groundcover type was recorded at 1m intervals along each transect.

2.4 Plot Measurement

Materials used for plot measurement were:

- Diameter tapes
- 30 m tapes
- Flagging tape
- Plant identification guides
- Spade
- Compass
- GPS (Global positioning system)
- Record sheets (Appendix B)
- Tree corer
- Camera
- Clinometer (slope measurement)

The variable area plot method (Batcheler and Craib, 1985; Jane, 1982) was used to measure the plots. The variable area plot method involves recording and measuring stems in a spiral sequence from the centre of the plot until 30 canopy trees (>2 cm diameter breast height; >2 m tall) are counted. The adequacy of the count number was verified for plot sampling in the development of the method.

All patches sampled were relatively small and therefore likely to be affected by edge effects. The technique was modified to reduce these effects, i.e. the plot count of stems was stopped at patch edges, if encountered, but continued on re-entry to the patch in the spiral movement from the centre until the required stem count was achieved. The average distance (measured in two directions at right angles) to stems furthermost from the centre of the plot was used as the plot radius.

Recorded plot data included (see Appendix B - sample plot sheet):

a) Plot location description including GPS of plot centre, corrected where necessary due to offset readings being required on some sites.
b) Date, time and weather during the recording.
c) Interior and exterior photographs of each patch.
d) Plot average diameter.
e) Environmental data (sampled at stand centre) of aspect, slope, soil moisture (or drainage – assessed on a seven-point scale) and soil sand composition (texture – assessed as percentage of sand). Soil texture is a predictor of available water (Peterson et al., 1968).
f) Species of plants present in all layers (Canopy, subcanopy, saplings, seedlings, ferns, lianas and epiphytes, and groundcover). Planted and dead species were identified and measured as separate species.
g) Species numbers, in the diameter sizes and height classes selected.
h) Groundcover by point intercepts in the following classes: ferns, moss, other vegetation, roots, soil, dead wood and rubbish.
i) Seedling regeneration by subplot counts or by percentage of the intercepts along the groundcover transects.
j) Stand age estimated by evaluating increment cores from up to 3 trees in each plot (Norton et al., 1987; Stokes and Smiley, 1968). Where possible Hamilton City plan records (unpublished) were used to verify planting dates for plots.
k) Proximity to nearest possible seed sources for recorded indigenous propagules.
l) Visual assessment of levels of maintenance and human disturbance and any special features of the site. Human disturbance was defined as evidence of vandalism, tracking and other ad hoc activities. Maintenance was defined as

evidence of pruning, thinning removal of dead wood and weed control (spraying). Maintenance and disturbance assessments were graded on a 0-3 scale with 0 (generally the controls), being no disturbance or maintenance.

m) Initial planting diversity for selected plots. This was assessed from either City Council (unpublished planting plans) or visual assessment of the likely range of original species planted.

The ecological state of revegetation patches based on the plot data, was assessed using species richness, diversity and composition, forest structure, productivity (biomass), regeneration, and propagule dispersal distances for each of the plots.

2.5 Statistical Methods and Procedures

The data collected for 66 plots was initially tabulated in 'MS Excel' format for each plot and then collated for all plots. Species data for each plot was tabulated (by dependent variables) separately from data for the overall plot such as physical plot characteristics (independent variables) and 'point-intercept' data. The multivariate statistical tool 'Statistica' was used to enable appropriate analyses of plot data imported from Excel for relevant variables.

Data analyses included derivation of preliminary descriptive statistics, analysis of variance (ANOVA) of the experimental blocks data, multivariate analysis using Principal Components Analysis (PCA) and dendrogram analysis.

The preliminary descriptive tests for normality (Shapiro-Wilk W Test) showed that most data variables were generally not normally distributed nor were the variances homogenous (Levene's or Brown-Forsythe Tests). So parametric methods were not used for analyses.

Analysis of variance was carried out using Kruskall-Wallace ANOVA. This is a non-parametric alternative to one-way (between-groups) ANOVA and is used to compare multiple samples (block or cluster groups). It analyses variance for each continuous (dependent or predictor) variable, from the codes in a single categorical predictor variable (i.e. experimental block codes). It tests the null hypothesis that the different blocks or clusters in the comparison were drawn from the same distribution or from distributions with the same median. Thus, the interpretation of the Kruskal-Wallis test is basically similar to that of the parametric one-way ANOVA, except that it is based on ranks rather than means. (‘Statistica’ Help notes: ‘Kruskall-Wallis test’).

Multivariate analysis is useful for exploring data sets and providing concise summaries. More importantly, it can clarify the complex interactions that occur between species and treatments in studies of ecological communities. It enables identification of similarities in overall species response among the different treatments as well as associations among the different species themselves. In such ecological studies, the standard procedures of statistical estimation and hypothesis testing may be inappropriate (Digby and Kempton, 1987).

Multivariate ordination using PCA and classification using dendrogram cluster analysis with non–normal data cannot use parametric Pearson Correlation (to assess the correlations between variables in the data). However, the Spearman correlation is appropriate since it can use data without a normal distribution though the data must be in at least ordinal form. It is also viewed as having a wider validity (Altman, 1991). Spearman correlation also avoids the need to standardise the data for PCA. Accordingly Spearman Correlation matrices for a number of variables were developed initially as the data input for the analyses.

Data were edited by culling to reduce the data set to the most dominant or key species for each variable. The culled data enabled easier analysis than would have been possible with full data sets, in particular for the production of the Spearman matrices.

Spearman matrices of the plots and of the dominant species were derived for the specific variables. The matrices for both species and plots were completed by using first a species by plot data table and then inverting this to a plot by species table. Multivariate PCA ordination and cluster analysis dendrograms were then used to identify clusters of associated species and associated plots, with the Spearman matrices as inputs.

Chapter 3 · Results: Characteristics of Experimental Blocks

3.1 Introduction

This chapter will describe the physical characteristics of the experimental blocks (mainly independent variables) and the results in terms of the dependent variables measuring key attributes.

3.1.1 Physical characteristics

Physical characteristics illustrate aspects of the ecological community's functional processes such as decomposition, nutrient relationships, hydrology, habitat development and soil structure. Groundcover intercepts may indicate invertebrate habitat values.

3.1.2 Species richness, diversity and composition

Species composition and frequency indicate the species diversity of a patch of forest. In general, one would expect the number of species to increase, at least initially, with age and development of the patch towards a mature state, due to recruitment of new species from the early stages of vegetation change (Smith and Smith, 2001). The species frequencies will change with the type of vegetation so that pioneer species will initially be dominant but their dominance will reduce as species characteristic of mature forest increase in frequency.

3.1.3 Forest structure

Forest structure indicates the vertical and horizontal diversity of a patch of forest and is one of the key attributes for restoration. In general, one would expect structural diversity to increase with age and development of the patch (Smith and Smith, 2001), i.e. a gradual development of multiple understorey layers, replacement of short-lived species and the introduction of shade tolerant species and epiphytes and lianas.

3.1.4 Productivity

Basal areas and biomass are an indication of the productivity of a plot. In general, one would expect plot productivity to increase with diversity and to increase initially with age followed by a decline (Smith and Smith, 2001). This is due to rapid growth of pioneer species, then self-thinning as the stand matures and a second increase as the thinned stand trees are released from the competitive impacts of initial high density.

3.1.5 Regeneration and dispersal

Composition and frequency of regenerating species indicates the trend of the forest patch towards a fully functioning healthy ecological community able to maintain itself in time and space and its potential to become more or less diverse. The proximity of seed sources indicates the available seed resource for regeneration and the ability of a forest patch to develop.

3.2 Data Analysis

For each experimental block of plots, descriptive statistics were calculated for environmental variables. The 'Statistica' Basic Statistics/Breakdown option was used to calculate descriptive statistics: means, standard deviations, range and other statistics by experimental block.

Dependent variables representative of the range of key attributes were analysed. Relevant variables were standardised to a unit plot size of $100m^2$. Analysis of variance (Kruskal-Wallis ANOVA) was computed to significant levels of $p<0.05$ and $p<0.01$.

3.2.1 Physical characteristics

The specific independent variables used to describe the physical characteristics included average age, aspect (degrees east of north), slope angle, soil moisture assessed on a graduated scale, soil texture as estimated percentage of sand content, maintenance regime (assessing pruning, thinning, deadwood clearance and weed control) and estimated level of human disturbance (assessing vandalism, tracking and other activities). Dependent variables that also described physical characteristics included the various types of groundcover as intercepts/$100m^2$.

3.2.2 Species richness, diversity and composition

The assessment of progress towards the target community diversity and representative composition was assessed by measures of species richness (number of species present) and α - a measure or index of diversity. Alpha uses both number of individuals and number of species by means of the log series pattern of species abundances in the form:

$$\alpha x,\ \alpha x^2/2,\ \alpha x^3/3, \ldots\ \alpha x^n/n$$

where αx is the number of species with 1 individual, $\alpha x^2/2$ those with two and so on (Magurran, 1988). Alpha is obtained by:

$$\alpha = N(1-x)/x$$

(x is a parameter that can be estimated if the number of individuals (N) and the number of species, are known)

For species richness, the measures included:

- overall number of species and the native plants subset,
- number of species in canopy to seedling layers,
- number of liana and epiphyte species with native and exotic species subsets,
- and specific composition of native species.

For species composition, the means of *number of species present* were compared between experimental blocks. All native vascular species typical of the control plots, with means greater than 0.30 individuals per block (i.e. generally occurring in more than one plot per block), were tabulated.

3.2.3 Forest structure

The measures used to assess the structural diversity of the plots include canopy heights, density, number of diameter classes, number of structural tiers, number of regeneration classes and population structure.

Mean canopy heights were assessed for all plots in each block by summing the cumulative heights and dividing by total number of canopy individuals. Density was recorded as stems/100m^2 in eight diameter classes and total relative density was calculated. Canopy and subcanopy data were combined to determine the number of diameter classes present. Canopy, subcanopy, sapling, seedling, young fern and groundcover data were combined to determine number of structural tiers present. Unplanted species up to 2m height were assessed to determine the number of regeneration classes present.

3.2.4 Productivity

Basal area ($cm^2/100m^2$) and biomass ($m^3/100m^2$) were used to calculate the mean total productivity of each block and the exotic and native species subsets for each measure were also calculated.

3.2.5 Regeneration and dispersal

Regeneration and dispersal were assessed by the:

- Total counts of regenerating plants in the 5 subplots in each plot and the native and exotic subsets of this and their relative proportions
- Number of unplanted (i.e. naturally regenerating) species in the whole plot and the native and exotic species subsets of the total
- Regenerating species' proportion of canopy species and the native and exotic species subsets of this
- Estimated average proximity to a seed source of the recorded species. (A broader scale assessment would be desirable to assess the proximity of other remnant native vegetation patches in the locale of the sites but this was not possible for this study).

3.3 Results

In the following results only discrete variables (i.e. non-overlapping in what they measured), that were significant to $p<0.05$ and $p<0.01$ (Kruskal-Wallis ANOVA) were tabulated (Tables 3.1-3.3 and Tables 3.5-3.8). Several other percentage measures were also included if they showed clear trends or differences between the blocks.

3.3.1 Physical characteristics

3.3.1.1 Independent variables (Table 3.1)

The age and maintenance variables confirmed patterns of increasing average age and maintenance levels consistent with the experimental design. All the planted plots generally have a lower average age than their equivalent control plots. For the 0-10 year blocks, the lowest average age was of block A3 and for the 10-20 year blocks it was block B3b. The average ages for the 20-30 year old planted blocks only vary marginally. The highest level of maintenance for planted blocks was in block B4b.

Human disturbance decreased from unenriched blocks to enriched blocks but increased from depauperate blocks to diversely planted blocks. The highest overall disturbance level was in Block B3b, marginally greater than that for A4. Disturbance was positively correlated with maintenance and negatively correlated with slope (significant at $p<0.05$, Spearman, see also Appendix E).

Slope increased from unenriched blocks to enriched blocks and decreased from depauperate blocks to diversely planted blocks.

There were no strong patterns with aspect, soil moisture or soil sand content except that B1 had moister plots than all other experimental blocks, A4 had a markedly more northerly mean aspect (32^o) than all the other blocks (between 124^o and 260^o) and A4 was also least sandy.

3.3.1.2 Dependent variables (Table 3.2)

The only dependent variable with significant differences between the experimental block means at $p<0.01$ was *litter intercepts.* Variables assessed but not significantly different between blocks at these levels included other *intercepts* for deadwood, moss, roots, rubbish and bare soil.

Numbers of *litter intercepts* decreased with increasing age across the control blocks. In all blocks *litter intercepts* also had a significant negative correlation with slope (at $p<0.05$, Spearman, see also Appendix E).

With the planted blocks the effects of age, maintenance, enrichment, diversity, and canopy at planting were as follows:

a) *Litter intercepts* decreased with increasing age except for B3a and B4a (depauperate). Values decreased with maintenance in the 0-10 year blocks, stayed the same or decreased in the 10-20 year blocks and increased with maintenance in the 20-30 year old blocks. Values decreased with higher initial species diversity.

Table 3.1: Experimental blocks - mean values for selected independent variables

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS	Mature forest
Controls	**Variable**	A1	B1		C1	D1
	** Average Age (p =.0000)	12.0 ± 4.4	22.4 ± 1.3		32.1 ± 5.2	69.0 ± 54.3
	** Maintenance (p =.0000)	0.3 ± 0.5	0.5 ± 0.6		0.00	0.5 ± 1.0
	** Overall Disturbance (p =.0001)	0.50 ± 0.58	1.75 ± 0.50		0.20 ± 0.45	1.00 ± 0.82
	* Slope (p =.0163)	34.8 ± 3.1	27.3 ± 9.0		28.2 ± 9.6	30.3 ± 6.2
	* Estimated %Sand (p =.0265)	80 ± 14	63 ± 13		64 ± 17	53 ± 39
Low level maintenance		A2	B2		C2	
	** Average Age (p =.0000)	9.3 ± 4.2	17.7 ± 6.4		24.5 ± 5.9	
	** Maintenance (p =.0000)	1.0 ± 0.0	1.6 ± 0.6		1.3 ± 0.5	
	** Overall Disturbance (p =.0001)	***1.00 ± 0.00***	1.80 ± 0.84		2.25 ± 0.96	
	* Slope (p =.0163)	23.4 ± 4.4	***27.9 ± 8.9***		34.8 ± 4.6	
	* Estimated %Sand (p =.0265)	***56 ± 35***	76 ± 15		***60 ± 14***	
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting diverse initially & not enriched	C3: Planting initially depauperate & not enriched	
	** Average Age (p =.0000)	8.8 ± 1.3	20.8 ± 1.7	14.1 ± 3.5	24.7 ± 2.8	
	** Maintenance (p =.0000)	2.0 ± 0.8	1.8 ± 0.5	2.4 ± 0.6	2.3 ± 0.6	
	** Overall Disturbance (p =.0001)	1.50 ± 0.58	2.00 ± 0.00	2.80 ± 0.45	2.33 ± 0.58	
	* Slope (p =.0163)	23.4 ± 11.0	***26.5 ± 7.9***	22.5 ± 5.1	***27.0 ± 6.1***	
	* Estimated %Sand (p =.0265)	***64 ± 35***	85 ± 6	88 ± 4	42 ± 24	
		A4: Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched	
	** Average Age (p =.0000)	10.0 ± 2.1	17.8 ± 5.3	18.8 ± 4.8	24.1 ± 2.7	
	** Maintenance (p =.0000)	2.5 ± 0.6	2.6 ± 0.9	3.0 ± 0.0	2.6 ± 0.5	
	** Overall Disturbance (p =.0001)	2.75 ± 0.50	1.20 ± 0.45	2.25 ± 0.50	2.00 ± 0.58	
	* Slope (p =.0163)	18.5 ± 3.1	39.8 ± 5.9	33.4 ± 8.3	***30.4 ± 7.6***	
	* Estimated %Sand (p =.0265)	33 ± 26	75 ± 34	68 ± 15	66 ± 10	

Note: All variables standardised to a $100m^2$ plot size and listed in order of significance

All p values are derived from Kruskall-Wallace ANOVA.

** variables significant at $p<0.01$
 * variables significant at $p<0.05$.
Means are ± SD

Bold italic values are in the range of the control values C1–D1.

Table 3.2: Experimental blocks – groundcover variables

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS	Mature forest
Controls	**VARIABLE**	A1	B1		C1	D1
	* Litter Intercepts/100m^2 (p =.0106)	27.8 ± 7.1	18.1 ± 6.0		17.6 ± 8.9	13.2 ± 3.3
Low level maintenance		A2	B2		C2	
	* Litter Intercepts/100m^2 (p =.0106)	19.8 ± 10.8	5.5 ± 4.4		9.7 ± 4.6	
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting initially diverse & not enriched	C3: Planting initially depauperate & not enriched	
	* Litter Intercepts/100m^2 (p =.0106)	17.3 ± 9.5	18.4 ± 5.8	***13.8 ± 8.1***	*10.1 ± 3.8*	
		A4: Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched	
	* Litter Intercepts/100m^2 (p =.0106)	16.6 ± 2.7	19.5 ± 6.9	*11.7 ± 3.5*	*12.3 ± 4.4*	

Note: * Variable significant at p<0.05. P values are derived from Kruskall-Wallace ANOVA. Means are ± SD.
Bold italic values (dark shading) are in the range of the control values D1. Italic values (lighter shading) are next closest to these controls.

3.3.2 Species richness, diversity and composition

The variables with significant differences between the experimental block means included at $p<0.01$ *overall number of native species*, *number of native lianas and epiphytes* and *alpha diversity of canopy to seedling plants;* and at $p<0.05$ *number of exotic lianas only* (Table3.3). Variables assessed but not significantly different between blocks at these levels included *alpha diversity of regenerating plants, overall number of exotic species* and *number of native lianas only.* In addition, species composition by experimental block was included (Table 3.4).

In the control blocks, the native species richness variables increased in value with age while the exotic species richness variables decreased in value with age. With the diversity variables, *alpha diversity for canopy to seedling species* increased gradually across the controls with increasing age. For composition, component species and their changing relative dominance consistently progressed from younger to older blocks.

For the species composition, over all the plots, 141 live vascular indigenous taxa and 112 live vascular exotic taxa were recorded (Appendix D). No single indigenous species was recorded at every plot but the 10 most common vascular species were *Melicytus ramiflorus* (65% of plots), *Coprosma robusta* (64%), *Cyathea dealbata* (64%), *Podocarpus totara* (61%), *Hoheria populnea* (53%), *Kunzea ericoides* (51.5%), *Dicksonia squarrosa* (48%), *Pittosporum eugenioides* and *Pittosporum tenuifolium* (both 45.5%) and *Cordyline australis* (39%).

With the planted blocks, the effects of age, maintenance, enrichment, diversity, and canopy at planting for the significant variables were as follows:

a) For *overall number of native species,* initial (0-10 year old) values were about the same as the controls. Values increased generally with age but C3 and C4 (20-30 years) values decreased compared to the younger, high maintenance B3a and B4b blocks respectively. Values increased with enrichment and decreased with higher diversity in unenriched blocks. There were exceptionally high values for B4a, B4b and C4. Values increased with maintenance except in A4 (canopy at time of planting), B3b (diverse, unenriched) and C3 (unenriched).

b) For *number of native lianas and epiphytes,* values generally *increased* with age but C4 decreased compared with the younger B4b. Values increased modestly with maintenance after year 10, except for B3b and C4. There were no clear effects related to enrichment, diversity or canopy at planting.

c) For *number of exotic lianas,* values increased with age with the exception of C2, which declined compared to B2. Values decreased with higher maintenance and with enrichment, except in C3. However, there was no clear relationship with higher diversity or canopy at planting.

d) For *alpha canopy to seedling diversity,* there was a general increase with age and maintenance. Plots B4b (enriched), C4 (enriched), and C3 have exceptionally high values. There was an increase in value with canopy at planting. However, there was no clear relationship with diversity at planting.

e) For composition (Table 3.4), the component species and their changing relative occurrence in the plots was most consistent in the A2/B2/C2 sequence. The compositions and species occurrence indicated that B3b had the species profile of a young block, while C2, C3 and B4b have profiles closest to the C1 and D1 controls. There were no clear relationships with maintenance, diversity, enrichment or canopy. Most planted blocks had more late-control species present at or above the level of 0.3 mean species occurrence than did their control counterparts. However, some late-control species were not represented above the 0.3 mean in any planted blocks: *Blechnum filiforme, Microsorum pustulatum* and *Asplenium polyodon* were represented in the B1 and C1 controls and *Asplenium bulbiferum, Hymenophyllum* species, *Oplismenus imbecillis, Parsonsia heterophylla, Pneumatopteris pennigera* and *Rhopalostylis sapida* were represented in the D1 control.

Table 3.3: Block results for species richness and diversity

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS	Mature forest
Controls	**VARIABLE**	A1	B1		C1	D1
	** Overall no. of native species (p =0.0000)	8.5 ± 4.0	14.3 ± 5.8		18.0 ± 6.5	23.0 ± 6.0
	** No. of native liana/ epiphyte species (p=0.003)	0.5 ± 0.6	2.5 ± 3.0		3.8 ± 2.7	6.5 ± 3.1
	* No. of exotic liana species only (p=0.0284)	0.75 ± 0.96	0.75 ± 0.50		0	0
	** Alpha diversity - canopy to seedlings (p=0.0004)	1.4 ± 0.9	3.0 ± 0.9		3.5 ± 1.5	5.0 ± 1.2
Low level maintenance		**A2**	**B2**		**C2**	
	** Overall no. of native species (p =0.0000)	8.3 ± 2.8	15.0 ± 2.0		*17.8 ± 5.9*	
	** No. of native liana/ epiphyte species (p=0.003)	0.3 ± 0.5	0.2 ± 0.4		*1.3 ± 1.0*	
	* No. of exotic liana species only (p=0.0284)	0.75 ± 1.50	1.40 ± 1.67		1.25 ± 0.96	
	** Alpha diversity - canopy to seedlings (p=0.0004)	*4.1 ± 3.7*	***6.6 ± 4.4***		***6.2 ± 2.5***	
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting initially diverse & not enriched	C3: Planting initially depauperate & not enriched	
	** Overall no. of native species (p =0.0000)	10.0 ± 3.6	*18.3 ± 1.7*	11.6 ± 1.1	16.7 ± 7.5	
	** No. of native liana/ epiphyte species (p=0.003)	0	1.0 ± 1.2	0	*1.7 ± 2.1*	
	* No. of exotic liana species only (p=0.0284)	***0***	***0***	0.80 ± 1.10	1.33 ± 1.15	
	** Alpha diversity - canopy to seedlings (p=0.0004)	***4.5 ± 1.8***	*7.3 ± 4.5*	***4.8 ± 1.6***	13.8 ± 13.8	
		A4:Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched	
	** Overall no. of native species (p =0.0000)	7.8 ± 1.7	***20.6 ± 3.9***	***28.3 ± 3.9***	***25.9 ± 7.9***	
	** No. of native liana/ epiphyte species (p=0.003)	0	0.6 ± 0.9	*1.3 ± 1.3*	0.9 ± 1.5	
	* No. of exotic liana species only (p=0.0284)	***0***	***0***	***0***	0.29 ± 0.49	
	** Alpha diversity - canopy to seedlings (p=0.0004)	7.6 ± 2.2	***6.5 ± 3.9***	12.0 ± 3.4	17.8 ± 9.6	

Note:
** variables are significant at p<0.01
* Variables are significant at p<0.05.
All p values are derived from Kruskall-Wallace ANOVA. Means are ± SD.
Bold italic values (dark shading) are in the range of the control values D1.
Italic values (lighter shading) are next closest to the controls.

Table 3.4: Block results for mean occurrence of native species (present in the controls)

Maintenance	AGE: 0 - 10 YRS	10 – 20 YRS	20 - 30 YRS	Mature forest
Controls	A1	B1	C1	D1
	Dicksonia squarrosa (0.75)*	*Cyathea dealbata* (1)	*Cyathea dealbata* (0.8)	*Cyathea dealbata* (1)
	Cyathea dealbata (0.5)	*Coprosma robusta* (1)	*Melicytus ramiflorus* (0.8)	*Asplenium bulbiferum* (0.75)
	Blechnum novae-zelandiae (0.5)	*Dicksonia squarrosa* (0.75)	*Coprosma robusta* (0.8)	*Asplenium polyodon* (0.75)
	Coprosma robusta (0.5)	*Melicytus ramiflorus* (0.75)	*Blechnum filiforme* (0.6)	*Blechnum filiforme* (0.75)
	Cyathea medullaris (0.5)	*Cyathea medullaris* (0.75)	*Doodia australis* (0.6)	*Dacrycarpus dacrydioides* (0.75)
	Lastreopsis glabella (0.5)	*Lastreopsis glabella* (0.75)	*Schefflera digitata* (0.6)	*Schefflera digitata* (0.75)
	Muehlenbeckia australis(0.5)	*Blechnum novae-zelandiae* (0.75)	*Dicksonia squarrosa* (0.6)	*Dicksonia squarrosa* (0.75)
	Pteridium esculentum (0.5)	*Cordyline australis* (0.5)	*Blechnum novae-zelandiae* (0.6)	*Melicytus ramiflorus* (0.75)
		Asplenium flaccidum (0.5)	*Muehlenbeckia australis*(0.6)	*Asplenium oblongifolium* (0.5)
		Blechnum filiforme (0.5)	*Asplenium flaccidum* (0.4)	*Hymenophyllum* sp. (0.5)
		Microsorum pustulatum (0.5)	*Asplenium polyodon* (0.4)	*Macropiper excelsum* (0.5)
		Schefflera digitata (0.5)	*Cordyline australis* (0.4)	*Oplismenus imbecillis* (0.5)
			Diplazium australe (0.4)	*Parsonsia heterophylla* (0.5)
			Dacrycarpus dacrydioides (0.4)	*Pneumatopteris pennigera* (0.5)
			Microsorum pustulatum (0.4)	*Pteris macilenta* (0.5)
			Podocarpus totara (0.4)	*Pyrrosia eleagnifolia* (0.5)
			Cyathea medullaris (0.4)	*Rhopalostylis sapida* (0.5)
			Lastreopsis glabella (0.4)	*Uncinia uncinata* (0.5)
				Podocarpus totara (0.5)
				Diplazium australe (0.5)
				Cordyline australis (0.5)
				Asplenium flaccidum (0.5)
				Doodia australis (0.5)

Maintenance	AGE: 0 - 10 YRS	10 – 20 YRS		20 - 30 YRS
Low level maintenance	A2	B2		C2
	Coprosma robusta (1)*	*Cordyline australis* (0.6)		*Podocarpus totara* (1)
	Cordyline australis (0.5)	*Dacrycarpus dacrydioides* (0.6)		*Cyathea dealbata* (1)
	Podocarpus totara (0.5)	*Cyathea dealbata* (0.6)		*Dicksonia squarrosa* (0.75)
	Melicytus ramiflorus (0.5)	*Melicytus ramiflorus* (0.6)		*Melicytus ramiflorus* (0.75)
		***Asplenium oblongifolium* (0.4)**		***Asplenium oblongifolium* (0.5)**
		***Pteris macilenta* (0.4)**		***Pteris macilenta* (0.5)**
		Asplenium flaccidum (0.4)		*Asplenium flaccidum* (0.5)
		Doodia australis (0.4)		*Blechnum filiforme* (0.5)
		Podocarpus totara (0.4)		*Doodia australis* (0.5)
		Coprosma robusta (0.4)		*Coprosma robusta* (0.5)
				Blechnum novae-zelandiae (0.5)
				Cyathea medullaris (0.5)
High level maintenance	A3: No canopy at Planting	B3a: Planting initially depauperate & not enriched	B3b: Planting initially diverse & not enriched	C3: Planting initially diverse & not enriched
	Podocarpus totara (1)	*Melicytus ramiflorus* (1)	*Coprosma robusta* (1)	*Cordyline australis* (0.67)
	Coprosma robusta (0.75)	*Podocarpus totara* (0.75)	*Cyathea dealbata* (0.8)	*Doodia australis* (0.67)
	Cordyline australis (0.5)	*Cyathea dealbata* (0.75)	*Dicksonia squarrosa* (0.8)	*Podocarpus totara* (0.67)
		Muehlenbeckia australis(0.75)	*Cordyline australis* (0.4)	*Coprosma robusta* (0.67)
		***Pyrrosia eleagnifolia* (0.5)**	*Podocarpus totara* (0.4)	***Asplenium oblongifolium* (0.33)**
		Dicksonia squarrosa (0.5)	*Melicytus ramiflorus* (0.4)	***Macropiper excelsum* (0.33)**
		Cyathea medullaris (0.5)		***Pyrrosia eleagnifolia* (0.33)**
		Pteridium esculentum (0.5)		***Uncinia uncinata* (0.33)**
				Asplenium flaccidum (0.33)
				Blechnum filiforme (0.33)
				Diplazium australe (0.33)
				Schefflera digitata (0.33)
				Cyathea dealbata (0.33)
				Dicksonia squarrosa (0.33)
				Melicytus ramiflorus (0.33)

Maintenance	AGE: 0 - 10 YRS	10 – 20 YRS		20 - 30 YRS
				Cyathea medullaris (0.33)
				Blechnum novae-zelandiae (0.33)
				Muehlenbeckia australis(0.33)
				Lastreopsis glabella (0.33)
				Pteridium esculentum (0.33)
	A4: Canopy at planting	B4a : Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched
	Coprosma robusta (1)	*Melicytus ramiflorus* (1)	*Podocarpus totara* (1)	*Cyathea dealbata* (1)
	Melicytus ramiflorus (0.75)	*Cyathea dealbata* (0.8)	*Melicytus ramiflorus* (1)	*Podocarpus totara* (0.86)
	Podocarpus totara (0.75)	***Macropiper excelsum* (0.6)**	*Coprosma robusta* (0.75)	*Cordyline australis* (0.71)
		Dicksonia squarrosa (0.6)	***Macropiper excelsum* (0.5)**	*Melicytus ramiflorus* (0.71)
		Blechnum novae-zelandiae (0.6)	*Asplenium flaccidum* (0.5)	*Dacrycarpus dacrydioides* (0.57)
		Asplenium flaccidum (0.4)	*Cordyline australis* (0.5)	*Dicksonia squarrosa* (0.57)
		Dacrycarpus dacrydioides (0.4)	*Diplazium australe* (0.5)	***Macropiper excelsum* (0.43)**
		Podocarpus totara (0.4)	*Doodia australis* (0.5)	*Diplazium australe* (0.43)
		Cyathea medullaris (0.4)	*Schefflera digitata* (0.5)	*Coprosma robusta* (0.43)
		Lastreopsis glabella (0.4)	*Dicksonia squarrosa* (0.5)	*Cyathea medullaris* (0.43)
				Lastreopsis glabella (0.43)

* **Note:** Species included are those with block mean occurrence of >0.3. Bracketed numbers are the mean species occurrence in the block. Species occurring in the oldest controls have been highlighted.

Species only in youngest controls	Species universal in controls	Species in late controls		Species only in oldest controls	
Pteridium esculentum	*Cyathea dealbata* *Dicksonia squarrosa* *Melicytus ramiflorus*	*Asplenium flaccidum* *Asplenium polyodon* *Blechnum filiforme* *Cordyline australis* *Dacrycarpus dacrydioides* *Diplazium australe*	*Doodia australis* *Microsorum pustulatum* *Podocarpus totara* *Schefflera digitata*	***Asplenium bulbiferum*** ***Asplenium oblongifolium*** ***Macropiper excelsum*** ***Oplismenus imbecillis*** ***Parsonsia heterophylla***	***Pneumatopteris pennigera*** ***Pteris macilenta*** ***Pyrrosia eleagnifolia*** ***Rhopalostylis sapida*** ***Uncinia uncinata*** ***Hymenophyllum* sp.**
Species in early controls					
Blechnum novae-zelandiae *Coprosma robusta* *Cyathea medullaris* *Lastreopsis glabella* *Muehlenbeckia australis*					

3.3.3 Forest structure

The variables with significant differences between the experimental block means included at $p<0.01$ *number of diameter classes, density (number/100m^2) of canopy-seedling individuals* and *number of regeneration classes;* and at $p<0.05$ *number of structural layers* (Table 3.5). Variables assessed but not significantly different between blocks at these levels included *density* (*number/100m^2) of native stems.* Proportion variables of interest included *native proportion of total stem density (stems/100m^2).*

The *number of diameter classes* and *average canopy height* generally increased across the controls with age. *Density* decreased with age and *proportion of native stems* peaked at C1 (20-30 years). The *number of regeneration classes* peaked at B1 (10-20 years) and the *number of structural layers* peaked at B1 (10-20 years) and D1 (maturity).

In the planted blocks, the effects of age, maintenance, enrichment, diversity, and canopy at planting were as follows:

a) *Number of diameter classes* generally increased with age and maintenance although the effect of maintenance was modest. There was an increase with canopy at planting (A4) but no clear effects with diversity and enrichment.

b) *Number of regeneration classes* peaked at 10-20 years, except that B3a and B4a (depauperate) had reduced values (but actually close to the D1 mature forest values). Values increased with enrichment and decreased with canopy at planting (A4). Maintenance effects were not clear.

c) For *density* initial values (years 0-10) were generally very low followed by a large boost in years 10-20 and then followed by a decrease after year 20. Values decreased with maintenance (except B3b) and canopy at planting. Enrichment and planting diversity effects were not clear. Density was significantly correlated with other structural diversity measures ($p<0.05$, Spearman).

d) *Average canopy heights* increased with age for the A2-C2 blocks (low maintenance) and the A3-C3 blocks, but reduced with age for the A4-C4 blocks (high maintenance, canopied or enriched). A4 (canopied) and B4a had higher than expected values (close to the D1 control) but B4b had a slightly lower than expected value.

e) *Structural layers* peaked at the 10-20 year blocks except B4a (depauperate, enriched) and both B3a and B4a had unexpectedly low values. There was a modest increase in values with enrichment and diversity of planting. Values decreased or stayed the same with maintenance.

f) The *proportion of native stems* was generally much higher than in the controls but decreased with age in A2 to C2, peaked at the B4 (enriched) blocks and at C3 (unenriched). Values increased with maintenance excepting A4 and B3b. The C2 (low maintenance) value was unexpectedly low. Values decreased modestly with diversity of planting. The B3 (unenriched) values (especially B3b) were lower than both A3 and C3, but the B4 (enriched) values were higher than A4 and C4. Values decreased with canopy at planting (A4).

3.3.4 Productivity

The only variable with significant differences between the experimental block means at $p<0.05$ was *basal area* (Table 3.6). Variables assessed but not significantly different between blocks at these levels included *biomass.* However, biomass is include in the results for comparison.

In the control blocks, both biomass and basal area increased with age but with a double peak in values at B1 and D1.

In the planted blocks, the effects of age, maintenance, enrichment, diversity, and canopy at planting were as follows:

a) For *basal areas*, values increased with age and with maintenance except for B3a and C3. Values increased with enrichment and with canopy at planting.

b) For *biomass*, values increased with age across the blocks. Values increased with maintenance level. There is no clear relationship of biomass with diversity at planting or with enrichment. Biomass increased with canopy at planting.

Table 3.5: Block results for structure variables

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS	20 - 30 YRS	Mature forest
Controls	**VARIABLE**	A1	B1	C1	D1
	** Average canopy height /Block (p=.0000)	4.5 ± 1.3	6.0 ± 1.3	7.0 ± 2.0	8.3 ± 1.7
	** No. of diameter classes (p =.0010)	3.5 ± 0.6	5.5 ± 0.6	5.8 ± 0.8	6.0 ± 0.8
	** No. of regeneration classes (p =.0082)	4.5 ± 1.9	5.3 ± 0.5	4.8 ± 1.1	3.1 ± 1.0
	** Density: No. stems /100m^2 (p=.0097)	434 ± 216	225 ± 108	160 ± 67	93 ± 22
	*No. of structural layers (p =.0215)	5.75 ± 0.50	6.00 ± 0.00	5.80 ± 0.45	6.00 ± 0.00
	Native proportion of total stem density (stems/100m^2) (%)	21.7%	74.9%	93.8%	91.1%
Low level maintenance		A2	B2	C2	
	** Average canopy height /Block (p=.0000)	4.3 ± 0.8	6.1 ± 1.5	***7.5 ± 2.9***	
	** No. of diameter classes (p =.0010)	3.8 ± 0.5	*5.2 ± 0.48*	*5.8 ± 1.0*	
	** No. of regeneration classes (p =.0082)	1.3 ± 1.0	*4.6 ± 1.3*	***3.3 ± 1.5***	
	** Density: No. stems /100m^2 (p=.0097)	***132 ± 71***	337 ± 290	238 ± 204	
	*No. of structural layers (p =.0215)	5.00 ± 0.82	***6.00 ± 0.00***	*5.75 ± 0.50*	
	Native proportion of total stem density (stems/100m^2) (%)	***99.1%***	*90.1%*	32.6%	

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting initially diverse & not enriched	C3: Planting initially depauperate & not enriched
	** Average canopy height /Block (p=.0000)	5.3 ± 1.9	*6.7 ± 1.7*	*6.6 ± 1.5*	*7.3 ± 2.1*
	** No. of diameter classes (p =.0010)	4.0 ± 0	*5.8 ± 0.5*	*5.8 ± 0.8*	***6.0 ± 1.0***
	** No. of regeneration classes (p =.0082)	*2.8 ± 2.5*	***3.0 ± 1.2***	*4.6 ± 1.7*	*2.7 ± 0.6*
	** Density: No. stems /100m^2 (p=.0097)	***126 ± 50***	***137 ± 93***	283 ± 168	***119 ± 72***
	*No. of structural layers (p =.0215)	4.50 ± 2.38	*5.50 ± 0.58*	*5.80 ± 0.45*	*5.33 ± 0.58*
	Native proportion of total stem density (stems/100m^2) (%)	***96.9%***	*90.3%*	*81.1%*	***96.2%***
		A4: Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched
	** Average canopy height /Block (p=.0000)	***8.7 ± 3.1***	*7.4 ± 2.4*	5.6 ± 1.6	*7.2 ± 1.6*
	** No. of diameter classes (p =.0010)	***6.3 ± 0.5***	*4.8 ± 0.8*	***5.8 ± 1.5***	***5.9 ± 0.9***
	** No. of regeneration classes (p =.0082)	1.3 ± 1.0	***3.4 ± 1.3***	*4.3 ± 1.5*	***3.0 ± 1.5***
	** Density: No. stems /100m^2 (p=.0097)	51 ± 14	*149 ± 71*	***135 ± 40***	***109 ± 54***
	*No. of structural layers (p =.0215)	4.25 ± 0.50	*5.40 ± 0.89*	***6.00 ± 0.00***	*5.71 ± 0.49*
	Native proportion of total stem density (stems/100m^2) (%)	75.7%	***98.5%***	***96.8%***	***91.6%***

Note: All variables standardised to a 100m^2 plot size and listed in order of significance except the proportionate and averaged variables.
** Variables are significant at p<0.01; * variables are significant at p<0.05.All p values are derived from Kruskall-Wallace ANOVA. Means are ± SD.
Bold italic values (dark shading) are in the range of the control values D1.Italic values (lighter shading) are next closest to the controls.

Table 3.6: Block results for biomass and basal area

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS	Mature forest
Controls	**VARIABLE**	A1	B1		C1	D1
	* Total Basal Area ($cm^2/100m^2$) (p =.0197)	7330 ± 6470	7800 ± 2550		6880 ± 1900	7010 ± 3980
	Total biomass estimate ($m^3/100m^2$) (p =.0627)	2.2 ± 2.0	3.3 ± 1.7		3.2 ± 1.2	3.9 ± 2.9
Low level maintenance		A2	B2		C2	
	* Total Basal Area ($cm^2/100m^2$) (p =.0197)	2200 ± 1430	5090 ± 1440		5610 ± 1890	
	Total biomass estimate ($m^3/100m^2$) (p =.0627)	0.8 ± 0.5	2.2 ± 0.8		*3.0 ± 1.6*	
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting diverse initially & not enriched	C3: Planting initially depauperate & not enriched	
	* Total Basal Area ($cm^2/100m^2$) (p =.0197)	2680 ± 650	4700 ± 2980	5200 ± 780	5520 ± 1990	
	Total biomass estimate ($m^3/100m^2$) (p =.0627)	1.3 ± 0.8	2.4 ± 1.6	2.6 ± 0.5	2.8 ± 0.8	
High level maintenance		A4: Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched	
	* Total Basal Area ($cm^2/100m^2$) (p =.0197)	3510 ± 1690	*6550 ± 4400*	5390 ± 3480	***7240 ± 1410***	
	Total biomass estimate ($m^3/100m^2$) (p =.0627)	1.8 ± 0.9	*3.2 ± 2.2*	2.1 ± 1.4	*3.2 ± 0.8*	

Note: * Variables significant at $p<0.05$; note that biomass is not significant but is included to complete the picture. All p values are derived from Kruskall-Wallace ANOVA. Means are ± SD.
Bold italic values (dark shading) are in the range of the control values D1. Italic values (lighter shading) are next closest to the controls.

3.3.5 Regeneration and dispersal

The variables with significant differences between the experimental block means included at $p<0.01$ *number of regenerating native species* and *average distance to seed source* (Tables 3.7-3.8). Variables assessed but not significantly different between blocks at these levels included *number of regenerating exotic species* and *the regenerating native plants count.* Proportion variables of interest included *native species regeneration proportion of canopy species number,* and *native regeneration plant count - proportion of total count.*

In the controls, the *number of regenerating native species* decreased generally with age except that B1was slightly lower than expected. The *regenerating native species proportion of canopy species* decreased with age. The *regenerating native plant proportion of total count* increased with age. *Average distance to seed source* peaked (i.e. seed sources were furthest) at years 10-20 and then reduced slightly.

In the planted blocks, the effects of age, maintenance, enrichment, diversity and canopy at planting were as follows:

a) For *number of regenerating native species* initial values (years 0-10) were generally low compared with the controls. However, at 10-20 years a boost in species occurred followed by a decrease after year 20 in some blocks (C3 compared to B3a, C4 compared to B4b) but a further increase in block C2. Values increased with maintenance, except in A4 (canopied) and B3b. However, there were no clear relationships with diverse planting and enrichment.

b) For *proportion of native canopy species regenerating* values generally increased with age, but the maximum proportion reached was no more than 25% (about the minimum in the controls). Values decreased with enrichment and increased with initial diverse planting. There was a major decrease to 0% with canopy at planting.

c) For *regenerating native plant proportion of total count* initial values (years 0-10) were higher than in the controls and peaked at years 10-20 for A2-C2 and A3-C3, but not for A4-C4, where C4 was the highest value. Values increased with maintenance only in the depauperate 10-20 year blocks and the 20-30 year blocks. Values decreased with enrichment, with initial diverse planting and with canopy at planting.

d) For *average distance to seed source* values decreased (i.e. seed sources were closest) with increased age. Distance decreased with maintenance in the 0-10 year blocks and the 20-30 year blocks but only in the depauperate 10-20 year blocks. Distance decreased with enrichment but increased with diverse planting and canopied plots.

Table 3.7: Block results for species regeneration

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS	Mature forest Control
Controls	**VARIABLE**	A1	B1		C1	D1
	* No. of regenerating native species (p=0.0168)	4.5 ± 3.0	5.5 ± 4.0		7.6 ± 1.5	5.3 ± 1.7
	Proportion of native canopy species regenerating	50.0%	46.2%		33.3%	25.0%
	Native plant count - proportion of total count	12.7%	69.9%		69.3%	85.7%
Low level maintenance		A2	B2		C2	**Note:** Count proportions are based on the regeneration in the 5 subplots ** Variable is significant at p<0.01. P values are derived from Kruskall-Wallace ANOVA. Means are ± SD. Bold italic values (dark shading) are in the range of the control value D1. Italic values (lighter shading) are next closest to the controls.
	* No. of regenerating native species (p=0.0168)	1.5 ± 1.7	3.8 ± 1.3		4.0 ± 2.2	
	Proportion of native canopy species regenerating	11.8%	13.0%		13.3%	
	Native plant count - proportion of total count	*70.7%*	*74.4%*		34.3%	
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting initially diverse & not enriched	C3: Planting initially depauperate & not enriched	
	* No. of regenerating native species (p=0.0168)	2.5 ± 1.9	*5.8 ± 2.8*	2.8 ± 2.7	4.3 ± 1.5	
	Proportion of native canopy species regenerating	15.4%	*20.0%*	***25.0%***	*20.0%*	
	Native plant count - proportion of total count	48.9%	***95.6%***	*69.8%*	***82.7%***	
High level maintenance		A4: Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched	
	* No. of regenerating native species (p=0.0168)	0.5 ± 0.6	4.0 ± 2.4	*5.8 ± 2.1*	*5.1 ± 3.2*	
	Proportion of native canopy species regenerating	0.0%	15.4%	*20.7%*	*20.0%*	
	Native plant count - proportion of total count	44.4%	***81.0%***	47.1%	***85.9%***	

Table 3.8: Block results for seed source proximity

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS	Mature forest Control
Controls	**VARIABLE**	A1	B1		C1	D1
	**Average distance to seed source (m) (p =.0077)	21.3 ± 12.5	25.0 ± 7.1		18.0 ± 4.5	17.5 ± 2.9
Low level maintenance		A2	B2		C2	
	**Average distance to seed source (m) (p =.0077)	63.8 ± 29.6	*19.0 ± 4.2*		25.0 ± 7.1	
High level maintenance		A3: No canopy at planting	B3a: Planting initially depauperate & not enriched	B3b: Planting initially diverse & not enriched	C3: Planting initially depauperate & not enriched	
	**Average distance to seed source (m) (p =.0077)	26.3 ± 11.1	***17.5 ± 2.9***	31.0 ± 7.4	*20.0 ± 5.0*	
High level maintenance		A4: Canopy at planting	B4a: Planting initially depauperate & enriched	B4b: Planting initially diverse & enriched	C4: Planting initially diverse & enriched	
	**Average distance to seed source (m) (p =.0077)	40.0 ± 37.0	***16.0 ± 2.2***	*20.0 ± 4.1*	***17.1 ± 3.9***	

Note: **Variable significant at p<0.01. P values are derived from Kruskall-Wallace ANOVA. Means are ± SD.
Bold italic values (dark shading) are in the range of the control values D1. Italic values (lighter shading) are next closest to the controls.

3.4 Discussion

3.4.1 Ecological condition and trends in relation to dependent variables

Generally, condition of the restoration plots is improving (see also Table 3.10). Comparison of the restoration blocks with the controls blocks shows that some dependent variables values were in the same range as the controls, some had generally higher values and some had lower values. In addition, with increasing age, certain trends in the results are evident.

The following sections discuss both the trends and the condition of the plots relative to the dependent variables:

3.4.1.1 Physical characteristics

a) *Litter intercepts*: The possible explanation for the lower values in the low maintenance and older blocks could be the higher vegetative groundcover values. Groundcover was negatively correlated with litter ($p<0.05$, Spearman, see also Appendix E) so generally where litter values were low, vegetation groundcover values were high. Furthermore, only in the low maintenance and older blocks where litter values dropped below the mature forest level (B2, B4b, C2, C3 and C4), *Tradescantia* (as an example of the sort of groundcover vegetation likely) was present in at least one plot of each block and in B2, C2 and C4 it was present in 2 or more plots.

3.4.1.2 Species richness, diversity and composition

a) *Overall number of native species*: The values for the 0-10 year old blocks were similar to the controls and there were high values in the enriched blocks. Possible explanation is in the initial planting density, attrition and the standard of care. Restoration patches planted by Hamilton City Council typically included up to 20 species. However, selected plan records (unpublished), compared with the species recorded on site, show surviving species are typically less than 60% of the species originally planned for planting, even in high maintenance plots. A reason could be that selection of species not suited to a pioneering role, or poor site location, results in attrition followed by increased recruitment to the gaps left (noting that density increases greatly in 10-20yr old blocks B3a, B4a and B4b).

The explanation for the enriched blocks' high values is perhaps the 'pressure cooker effect' of enrichment and perhaps the fact that these blocks had some plots in private ownership or with a high standard of care (e.g. Hamilton Gardens).

The decline of native species numbers in B3b and C3 (compared with most high maintenance blocks), possibly relates to increasing seed source distances resulting in reduced native species recruitment and ongoing recruitment of exotic species in these blocks.

b) *Number of native lianas and epiphyte species:* The generally low values for the native lianas and epiphytes may be understandable because they are specialised, but possibly relates to the regeneration issue of lack of close seed sources. While all planted blocks were below control values, some more advanced individual plots had values greater than the B1 control, i.e. B4b (plot 27), C3 (plot 28) and C4 (plot 23). These are all privately owned plots.

c) *Number of exotic lianas:* This variable had an inverse relationship to ecological state. The highest values occurred with low maintenance, enriched blocks or in blocks older than 20 years. The possible reasons for increased values are similar to those for decline in *number of native species* with age and enrichment i.e. seed source distances, standard of care and attrition of planted species creating a vulnerability to exotic species (weed) invasion.

d) *Overall alpha diversity*: The explanation for these values being generally greater than the equivalent aged control values could be the combination of the (non-local) range of species planted and the local volunteer species producing a larger than normal range. The values were even greater with some enrichment plantings, where this effect is likely to have been increased (i.e. the 'pressure cooker effect' as described above).

e) *Species composition:* In the control blocks, earliest introductions were ferns at 10-20 years, followed by bird-transported species at 20-30 years, and then finally forest grasses and lianas. With the restoration plots, *Uncinia, Macropiper, Pyrrosia, Pteris macilenta* and *Asplenium oblongifolium* appeared earlier than in the controls, but (as mentioned in 3.3.2) nine late-control species were not represented above the 0.3 species mean in any planted blocks.

C3, C2, B4b and C4 in that order, were closest to the controls in their composition of the species occurring at greater than the 0.3 mean, but not necessarily in the other measures so far discussed.

Some of the species not occurring at high frequency in the planted plots (ferns and lianas) may be possible candidates for indicator species for gully restoration in the Hamilton Ecological District.

3.4.1.3 Forest structure

a) *Number of diameter classes:* Higher values than in the controls are general except in A2, A3 and B4a. An explanation could be that the lower densities for the 0-10 year blocks and use of relatively large plants (plus existing trees in the case of the canopied block), promote a wider range of diameters than are found in the high-density early control blocks and that the effect has persisted into the older blocks. Enrichment would tend to counteract this trend explaining B4a.

b) *Structural layers*: Some of the restoration block values were lower than even the 0-10 year control value. The highest values were for B2 and C2 (unmaintained), and B3b and B4b (initially diversely planted) blocks so these factors are important (see 3.4.2).

   The number of structural layers tended to decline at the 20-30 year period in all blocks and C3 had the greatest decline. It is possible that this was simply a dip in the general trend as occurred in the controls. The likely explanation for the declines is self-thinning which allows surviving stems to develop and new recruitment to the gaps.

c) *Native proportion of total stems:* The most obvious explanation for the values being generally elevated above the controls, but their reduction in low maintenance blocks, is that the values are an artefact of planting 100% native species and the recruitment of more exotic species under a low maintenance regime.

d) *Canopy Height:* Most of the blocks older than 10 years reached control values comparable with control blocks older than 20 years. However, B4b had average canopy height comparable to a 10-year control. The unusually low value may be the result of removal of mature specimens for new planting (as certainly happened at some Hamilton Gardens sites in this block), consequent decreased density of plants and reduced height growth.

e) *Density:* Blocks B2, C2 and B3b had density profiles of control blocks of less than 20 years. Low values for the younger blocks and the high values for blocks B2 and C2 (low maintenance), indicate the impact of low planting densities (relative to the controls) and attrition as mentioned above for native species numbers. Initial plantings were generally at 1-1.5m centres giving a density of 45-100 plants (or stems)/100m^2.

   However, in the case of the high B3b value, comparison of the mean ages of the four high maintenance 10-20 year blocks shows a progression of density with age (B3a and B4b are the oldest and have the lowest density, B3b is youngest and has the highest).

   Low level of maintenance seems to have been a factor in the densities of unmaintained blocks (B2 and C2) being close to their relative control levels. The densities of the other blocks (except A4) are between the 30-year and mature forest controls levels.

3.4.1.4 Productivity

a) *Basal area* and *Biomass*: Only B4a and C4 have values higher than the controls. B2, B3a, B3b, and B4b values would be typical of a control block around 10 years age. This could partly reflect the fact that the average age for each control block was higher than their restoration counterpart blocks but other possible reasons are a combination of removal of trees (B4b), high density (B2 and B3b) and no enrichment (B3a and B3b). Concerning the last factor, enrichment also accounts at least partly for the high values for B4a and C4.

3.4.1.5 Regeneration and dispersal

a) *Number of regeneration classes, proportion of native canopy species regenerating* and *number of regenerating species, native regeneration count proportion of the total:* There was a general decrease in the regeneration classes at 20-30 years and especially in C3. The level of canopy species regeneration was below 15% for A2, A4, B2 and C2. With proportion of counts, most blocks are in the range of the controls. However, the unusual aspect is that though the values in the younger blocks are relatively high, in the remaining blocks there are notable exceptions (C2 and B4b), which are at the level of about a 10-15 year old control.

Native species regeneration processes generally do not seem to be operating as well as in the controls except for improvement with age. The regeneration results, the exotic species numbers in the older blocks, the low level of native lianas and epiphytes and of native species discussed above, all support the idea of recruitment of exotics competing with native species recruitment.

Possible causes of poor native regeneration are the lack of diversity in the canopy species and possibly the seed source distances already discussed above, allowing exotic species to increase at the expense of native species. (*Overall native species* were low in A4, B3b and C3; *exotic liana species* numbers were relatively high in B2, C2 and C3). There are unfortunately few signs yet of the enrichment planting having an impact – the *number of regenerating species* was better in B4b and C4 but *proportion of canopy species regenerating* was not better than other blocks and in B4a was less.

b) *Seed source proximity:* A possible explanation of the lower values for the younger plots could be the relative isolation of new plantings or particular gullies from other native areas, followed by improved proximity as the city has grown and supportive private or public plantings increased. Low values for B3b and C2 could indicate that these plots have remained more isolated from other suitable mature native species. Limited suitable seed sources may make some restoration patches vulnerable to exotic invasion.

Table 3.9: Age Trends and Effects of Independent Variables

Ecosystem Attribute	Variable	Effects of Increasing Age	Effects of Increasing Maintenance	Effects of Increasing Planting Diversity	Effects of Increasing Enrichment	Effects of Canopy at Planting
Physical	Litter Intercepts/100m^2	+	- (A3, A4)	- (low B4b)	- (C4)	-
Species composition	Overall no. of native species	+ (B3b, C3, C4)	+ (A4, B3b,C3)	+ (B3b)	+	-
	No. of native liana/ epiphyte species	+ (B2,C4)	+ (A3, A4, B3b, C4)	+ (B3b)	- (B4b)	nil
	No. of exotic liana species	-	+ (C3)	- (B4b)	+	nil
Species Diversity	Alpha diversity - canopy to seedlings	+ (C2, B4a)	+ (B3b, B4a)	- (B4b)	+ (B4a)	+
Structure	No. diameter classes	+	+ (B4a)	+ (B3b[0 change])	- (B4b [0 change])	+
	No. regeneration classes	+ >10 yr (B3b, B4b; low C3)	+ (B3b, C3)	-	+	-
	No. structural layers	+ (C2, C3, C4?)	- (B4b)	+	+ (B4a)	-
	Average canopy height	+ (high B4a)	+ (B4b)	-	- (B4a)	+
Density	Density: No stems /100m^2	+ >yr 10 (B3b)	+ (very low A4)	+ (B3b)	+ (B4a)	-
	Native proportion of total (stems/100m^2) (%)	+ (A4, B3b)	+ (A4, B3b)	-	+ (C4)	-
Productivity	Total basal area (cm^2/100m^2)	+ (low B4b)	+ (C3)	+ (B4b)	+	+
Regeneration	No. of regenerating native species	+ (C3, C4)	+ (A4, B3b)	+ (B3b)	+	-
	Proportion of native canopy species regenerating	+	+ (A4)	+	- (C4)	-
	Regeneration native plant count - proportion of total	+ (C2; low B3b, B4b)	+ (A3, A4, B3b, B4b)	-	- (C4)	-
Proximity	Average distance to seed source (m)	+ (B3b, C2)	+ (B3b, B4b)	-	+	-
Note:	The notations are: '-' for negative effects; '+' for positive effects on ecological condition; ( ) brackets indicate exceptions and caveats					

3.4.2 Independent variables (experimental design)

The following sections assess the main effects of the independent variables that form the basis of the experimental design and discuss the possible explanations (Table 3.9).

3.4.2.1 Maintenance effects

The results support the idea that maintenance is beneficial across a range of compositional, functional, structural and productivity attributes. High maintenance is associated with best ecological condition particularly in blocks older than 10 years and with poor condition in blocks younger than 10 years or blocks planted with a more diverse range of species, particularly B3b.

Maintenance is not beneficial for litter accumulation tending to reduce the amount of litter (except in A3 and A4) and for the number of structural layers, which it also tends to reduce (except in B4b). The litter level in A3 and A4 are high probably due to mulching of at least two out of the four plots in each block. In B4b, removal of some plants and enrichment may have improved the number of layers.

The younger and more diversely planted blocks (A3, A4 and B4b) are characterised by several factors: low average age (9-14), high levels of human disturbance (about 2.8 for both A4 and B3b) and comparatively shallow slopes (18-23^{o}) relative to other blocks. (The levels of disturbance are inversely correlated with slope, significant at $p < .05$, Spearman, see also Appendix E). It may be that human disturbance is a driving factor of ecological condition in younger sites, so it is compromising the benefits of maintenance. Maintenance may contribute to the disturbance and slow or prevent the advent of appropriate ecological processes in these sites as implied by the effects on litter and structural layers.

One other factor that may be of interest is the level of private ownership. All high maintenance blocks except A3, A4 and B3b have at least one plot in private ownership. This could have an effect on both disturbance and level of maintenance care.

3.4.2.2 Diversity effects

For the significant variables measuring ecological condition, the evidence suggests that initial planting of a diverse range of species is neutral in its effects (Table 3.9). There is a positive effect with increasing diversity in half of the 16 variables.

Higher initial planting diversity is associated with poorer ecological condition mostly in functional attributes: litter, diversity, regeneration classes, number of regenerating species, regeneration counts and distance to seed source. It is associated with better ecological condition mostly in structural and species richness attributes: overall number of native species, number of native lianas and epiphytes, number of diameter classes, number of structural layers, density, total basal area, number of regenerating native species and proportion of native canopy species regenerating.

However, comparison of the data for blocks B3a, B3b, B4a and B4b shows that the diversity effects are relatively more positive in the enriched blocks for eleven of the 16 variables.

B3b did more poorly than B4b in number of native species, numbers of native lianas and epiphytes and exotic lianas, alpha diversity, diameter classes, regeneration classes, structural layers, density, native species regenerating and distance to seed source. The unique factors for B3b include it having the highest level of disturbance, the highest percentage of sand in the soils and the youngest average age for the 10-20 year old blocks. Age and human disturbance could affect most of these variables negatively and disturbance could affect establishment of native lianas and facilitate establishment of exotic lianas. Sandy soil may exacerbate disturbance effects. Distance to seed sources could be a factor in regeneration performance.

B4b did more poorly than B3b in litter, canopy height, basal area, and native regeneration counts. Unique factors for B4b include it having the highest level of maintenance and a relatively steep slope. Of these, slope affects litter accumulation and high maintenance affects the productivity (see 3.4.1 canopy height note) and regeneration.

These results suggest that planting diversity has an interactive effect with enrichment but this may be affected by maintenance and disturbance. The diverse blocks have higher maintenance and disturbance levels than the depauperate blocks, and the enriched blocks have higher maintenance but lower disturbance than the unenriched counterparts do. This may explain the effect of more positive results in the enriched blocks.

3.4.2.3 Enrichment effects

For the variables measuring ecological condition, the evidence supports species enrichment being generally beneficial. There is a positive effect with increasing enrichment in ten of the 16 variables.

However, enrichment is associated with poorer ecological condition for levels of litter, number of native lianas and epiphytes species, canopy height, native regeneration count proportion and native canopy species regeneration. Overall, enrichment results in good compositional, moderate structural, moderate functional and good productivity attributes.

Comparison of the data for blocks B3a, B3b, B4a, B4b, C3 and C4 shows that the enrichment effects are relatively more positive in the diverse blocks (B4b and C4) for ten of the 16 variables.

Species enrichment seems less beneficial for B4a in number of native lianas and epiphytes, alpha diversity, number of diameter classes, number of structural layers, density and proportion of native canopy regeneration but more beneficial in canopy height. B4a is characterised by steep slopes, the lowest level of disturbance and youngest age of the enriched blocks. Of these, younger age could affect the structural layers and density negatively. The effect of the density progression with age (see 3.4.1) appears to be masking any density effect of enrichment.

Species enrichment seems less beneficial for B4b in canopy height, native regeneration count proportion, but more beneficial in native lianas and epiphytes and number of diameter classes. B4b has the highest level of maintenance. The removal of trees in several plots probably explains the low canopy height. The high maintenance could also be affecting native regeneration by human disturbance.

Species enrichment seems less beneficial for C4 in native proportion of stems, but more beneficial in proportion of native canopy species regeneration and native regeneration count proportion. C4 is exceptional only for being older. This could help explain the better canopy species regeneration and counts.

These results support the idea that planting diversity has an interactive effect with enrichment as suggested above. The diverse blocks have higher maintenance and disturbance levels than the depauperate blocks, and the enriched blocks have higher maintenance but lower disturbance than the unenriched counterparts do. Enrichment effects could thus be linked to low disturbance but the positive effect of diverse planting may be masked by the higher disturbance level.

3.4.2.4 Effects of canopy at planting

For the variables measuring ecological condition, the evidence provides little support for an existing evergreen *canopy at time of planting* being generally beneficial. Besides block A4, only three other older plots, 43 and 44 (controls) and 26 had existing canopy content, and in the controls, this was sparse.

A canopy at time of planting is associated with poorer ecological condition for levels of litter accumulation, overall native species, alpha diversity regeneration, regeneration classes, structural layers, density, native proportion of stems, number of regenerating species, regeneration counts, proportion of native canopy species regenerating and distance to seed source. These are predominantly functional (regeneration) attributes.

3.4.3 Conclusions

3.4.3.1 Ecological state of restoration plots - trends and condition

Ten selected variables (mainly those with significant differences between the experimental block means at $p<0.01$) provide insight into the overall ecological state of the plots (Table 3.10). However, alpha *regeneration diversity* was substituted for *canopy to seedling diversity*. This is because *regeneration diversity* reflects a functional state of the treatment blocks more than does the canopy to seedling diversity, which is weighted by the planted species.

Condition of the restoration plots is improving, the main exceptions being blocks C2 and B3b, which had similar or lower values than B2. Several blocks had five or more variables equal to or more advanced than the equivalently aged controls. The same blocks had two or more variables in the range of the D1 control values. The blocks in question in decreasing order of ecological state are C4, B3a, B4a and B4b. While the young blocks A2, A3 and A4 had one or two variables in the control range, for A4 they are explicable by the presence of mature tree canopy and for A2 and A3 they are explicable in terms of low initial values (i.e. prior to peaking and then decreasing towards maturity).

3.4.3.2 Deterioration of plots

Plots are deteriorating after a period even in well-maintained blocks (B3b, C2 especially and C3). Native species were not recruiting to restoration plots as well as in the controls and even at the 20-30 year period there was some ongoing recruitment of exotic species. Exotic species were also recruiting. Regeneration diversity was below controls in general, especially in A4, B3b, C2 and C3.

3.4.3.3 Regeneration and dispersal

Regeneration is not functioning as well as in the controls even though native proportions of regeneration are higher than controls. Two essential factors seem to be involved: the seed source availability is lacking - either in terms of appropriate canopy species or in terms of proximity of alternate source vegetation; patches are vulnerable to exotic invasion under these conditions and exotics need to be well controlled.

Planting a suite of species to provide future seed sources, adding seed directly or enrichment planting within or near the patches are all possible options to improve the regeneration function and the viability of restoration patches.

3.4.3.4 Composition versus structure, function and productivity

The species compositions compared with the other attributes (functional, structural, productive) support the hypothesis that composition is no guarantee of ecological function. The blocks most advanced in other measures including species richness, structure and regeneration (C4 and B4a) had a composition less like the controls than did C2, C3 and B4b. Productivity (measured in part by basal area and canopy height) was less consistent with the other measures.

3.4.3.5 Maintenance and human disturbance

Maintenance is generally beneficial for restoration but with several caveats:

a) Young restoration patches should be managed for early exclusion of human disturbance.
b) Early selective thinning of some species may help maintain diversity provided it does not increase level of disturbance.
c) Low maintenance may assist density increase and structural layer development and high maintenance may prevent rarer species introduction.
d) Private restoration demonstrates the value of detailed maintenance attention especially in older patches but this level of maintenance may also enhance the recruitment of exotics.
e) Therefore, high maintenance can only be justified for and should be limited to good control of exotic species and enrichment for diversity enhancement, where it has the greatest value.
f) Control of disturbance of restoration sites is a necessary adjunct to low maintenance especially in young sites. Structures such as boardwalks and fences that control public access would help reduce disturbance.

Table 3.10: Overall ecological state of restoration plots

Maintenance	AGE	0 - 10 YRS	10 – 20 YRS		20 - 30 YRS
Low level maintenance	**VARIABLE**	**A2**	**B2**		**C2**
	Overall no. of native spp.				
	No. of native liana/epiphyte spp.				
	α diversity - regeneration				
	No. of diameter classes				
	No. of regeneration classes				
	Density (stems/$100m^2$)				
	Average canopy height (m)				
	Basal area ($cm^2/100m^2$)				
	No. of regenerating native spp.				
	Distance to seed source (m)				
High level maintenance		**A3: No canopy at Planting**	**B3a: Planting initially depauperate & not enriched**	**B3b: Planting initially diverse & not enriched**	**C3: Planting initially depauperate & not enriched**
	Overall no. of native spp.				
	No. of native liana/epiphyte spp.				
	α diversity - regeneration				
	No. of diameter classes				
	No. of regeneration classes				
	Density (stems/$100m^2$)				
	Average canopy height (m)				
	Basal area ($cm^2/100m^2$)				
	No. of regenerating native spp.				
	Distance to seed source (m)				
		A4: Canopy at planting	**B4a: Planting initially depauperate & enriched**	**B4b: Planting initially diverse & enriched**	**C4: Planting initially diverse & enriched**
	Overall no. of native spp.				
	No. of native liana/epiphyte spp.				
	α diversity - regeneration				
	No. of diameter classes				
	No. of regeneration classes				
	Density (stems/$100m^2$)				
	Average canopy height (m)				
	Basal area ($cm^2/100m^2$)				
	No. of regenerating native spp.				
	Distance to seed source (m)				
Note: cell coding in the cells to the right is based on values in Tables 3.1-3.9		**Values in the range of the controls D1**		**Values next closest to controls D1**	

3.4.3.7 Initial planting diversity and species selection

Planting diversity appears to interact with enrichment in a generally positive way. However, any positive effect of planting diversity appears to be masked by the higher disturbance level. Diversity benefits may thus be greater if disturbance levels are also reduced. Therefore, initial species diversity may still be of value, e.g. it may improve structural diversity.

Species losses have also compromised initial planting diversity. Species survival in the first 10 years is therefore an important objective. Initial planting diversity should be reconsidered to reduce species losses from attrition. Attention to species site location and species selection is critical. Species selection and management techniques may retain the diversity values while enabling species to 'compete' with pioneer species and survive to provide future seed sources. Techniques could be used, such as variable plant spacing, less diverse planting, a greater proportion of pioneering species that have a wider range of site tolerances, and peripheral planting with seed source species.

3.4.3.8 Enrichment

Enrichment benefits are apparently linked to good maintenance, low disturbance and to older or less dense patches. Because it is important for diversity enhancement, it is therefore essential that good maintenance and low disturbance accompany enrichment operations. This is especially important because highest levels of exotic lianas also occurred with enriched blocks with low maintenance or older than 20 years.

Enrichment with seed rather than plants will reduce disturbance and substitute for scarcity of seed sources. In an urban context, enrichment could also take the form of mature specimen planting in the close neighbourhoods of restoration patches either in public parks, streets or in private residential gardens.

3.4.3.9 Canopy

An evergreen canopy at time of planting is generally not beneficial even though it apparently promotes improvement in some structural and productivity attributes. However, more exploration of canopy effects would be useful, to assess why it is not beneficial (this will be further discussed in chapter 4).

Nevertheless, in restoration, canopy should be limited to initial temporary nurse shelter using species that do not heavily shade or compete with native species or using sparse canopy planting for shelter.

Chapter 4 · Results: Cluster and Principal Components Analyses

4.1 Introduction

Cluster analysis and principal components analysis (PCA) are based on measures of association, similarity (coefficients) or distance and use a similarity matrix. A common similarity matrix enables their use together to compare results from cluster analysis with PCA ordinations. (Digby and Kempton, 1987; Gower, 1971; Magurran, 1988).

As discussed in the methodology, PCA and dendrogram analysis are useful for summarising and synthesizing data to detect patterns and generate new hypotheses. They can clarify the complex interactions that occur between species and treatments in studies of ecological communities (Digby and Kempton, 1987).

This chapter will use the results of the Cluster analysis and PCA to explore species associations and assess the factors that underlie the clustering patterns. It will look to confirm the results presented in Chapter 3 or develop new hypotheses on contributing factors in restoration success. It will present the results in terms of the significant independent variables that contribute to the variance between plots. This will enable analysis of the age, maintenance, human disturbance and environmental variables effects on vegetation change. The physical characteristics, significant dependent variables and species associations of the clusters will be described.

4.2 Data analysis

4.2.1 Cluster analysis

In the cluster analysis, several different clustering methods are possible. Of the various linkage rules, the Complete Linkage method and Ward's method seemed the most appropriate. In the Complete Linkage method 'the distances between clusters are determined by the greatest distance between any two objects in the different clusters (i.e., by the "furthest neighbours"). This method usually performs quite well in cases when the objects actually form naturally distinct "clumps." However, this method is inappropriate if the clusters tend to be somehow elongated or of a "chain" type nature'. Ward's method uses 'an analysis of variance approach to evaluate the distances between clusters' and 'attempts to minimize the Sum of Squares (SS) of any two clusters that can be formed at each step'. ('Statistica' Help notes: 'Joining (Tree Clustering) Introductory Overview – Amalgamation or Linkage Rules').

Of the distance measures available, the Euclidean (measures geometric distance in multidimensional space), the City-Block or Manhattan (measures average difference across dimensions – and thus dampens the effect of outliers) seemed most appropriate. ('Statistica' Help notes: 'Joining (Tree Clustering) Introductory Overview – Distance Measures'). The linkage method and distance measures selected for general use in the analyses were those that gave the most consistent cluster analysis groupings when compared with the PCA.

The statistical analyses were done for separated planted and unplanted data of each species. Because of unexpected clustering results (see 4.3 below), the analyses were then repeated with the data combined for each species (planted and unplanted).

The variable selected for finalising the clusters used in the analyses was that giving the greatest consistency between species and plot groupings when identified by their dominant species. Two variables were assessed – the *total species number present* variable and the *total basal area* (BA) variable. Each plot was described by its three leading dominant canopy and subcanopy species to enable comparison of plot and species clusters.

Initial data was culled for *species number present* based on retaining only the species with a presence in at least five plots. Initial data was also culled separately for *basal area* based on retaining only the species with at least one plot of total *basal area* greater than $500cm^2/100m^2$.

4.2.2 Descriptive statistics analysis

For each cluster of plots, descriptive statistics were calculated for environmental variables. The descriptive statistics were calculated using the 'Statistica' Basic Statistics – Breakdown option to calculate means, standard deviations, range and other statistics by cluster.

The same independent and dependent variables were used as for the experimental plots analysis (see section 3.2). Significant discrete (i.e. non-overlapping) variables significant to $p<0.05$ and $p<0.01$ (Kruskal-Wallis ANOVA) were tabulated (Tables 4.2- 4.3).

In addition, other descriptive factors for each cluster were explored in explaining the data. These included plot ownership, site locality relative to other sites in the same cluster, urban soils and vegetation type. Ownership of the plots in each cluster was analysed using the Chi-squared test (Table 4.2).

4.3 Results

Separate planted and unplanted species data in PCA and cluster analyses indicated a strong division between planted plots or species and unplanted plots or species, which could mask the effects of the independent variables and experimental treatments. To avoid this, the data was reanalysed with combined planted and unplanted data for each species and the results gave a clearly different pattern of clustering.

The initial data culled for *species number present* resulted in data sets of 82 species for the uncombined data and 81 species for the combined data. The initial data culled for *basal area* resulted in culled basal area data sets of 57 species for the uncombined data and 62 species for the combined data.

4.3.1 Cluster analysis

Generally, the *total basal area* variable, with the Manhattan (City–Block) distance measure and the 'Complete Linkage' method of tree clustering enabled the most ecologically sensible and coherent interpretation. The clusters were most consistent for both plot and species and related clearly to the equivalent PCA ordinations of plots and species (See Figures 4.1-4.5).

The resulting ordination separated most of the restoration planted sites from the control sites including the mature forest sites (Figures 4.1 and 4.2). The lower left plots (Figure 4.1) mainly comprise Clusters P3 and P4a. Those in the top right mainly comprise Clusters P1a and P1b and to a lesser degree P2a and P2b. The total variance accounted for by the first two axes was 47%. There were significant correlations (nonparametric, Spearman) between the ordination plot scores and a number of independent variables (Table 4.1). The strongest correlations with factor 1 scores were maintenance (positive), average age (negative), and slope (negative). The strongest correlations with factor 2 scores were average age and slope (both negative). Plots in the bottom left of the ordination diagram (Figure 4.1) were thus older, less well maintained, less disturbed and steeper than those at the top right.

Table 4.1: Summary Statistics for Basal Area Ordination of 66 plots and 62 species.

	Factor 1	Factor 2
Total variance %	37.11	9.84
Total variance cumulative %	37.11	46.95
Spearman Rank Order Correlations*		
Average age	**-0.36**	**-0.44**
Slope	**-0.37**	**-0.40**
Maintenance	**0.47**	0.07
Overall disturbance	**0.36**	0.23
Average proximity (m)	0.22	**0.32**
* **Bold** correlations are significant at **p <0.01**, others are not significant		

Figure 4.1: Ordination of Plots (Basal Area Data)

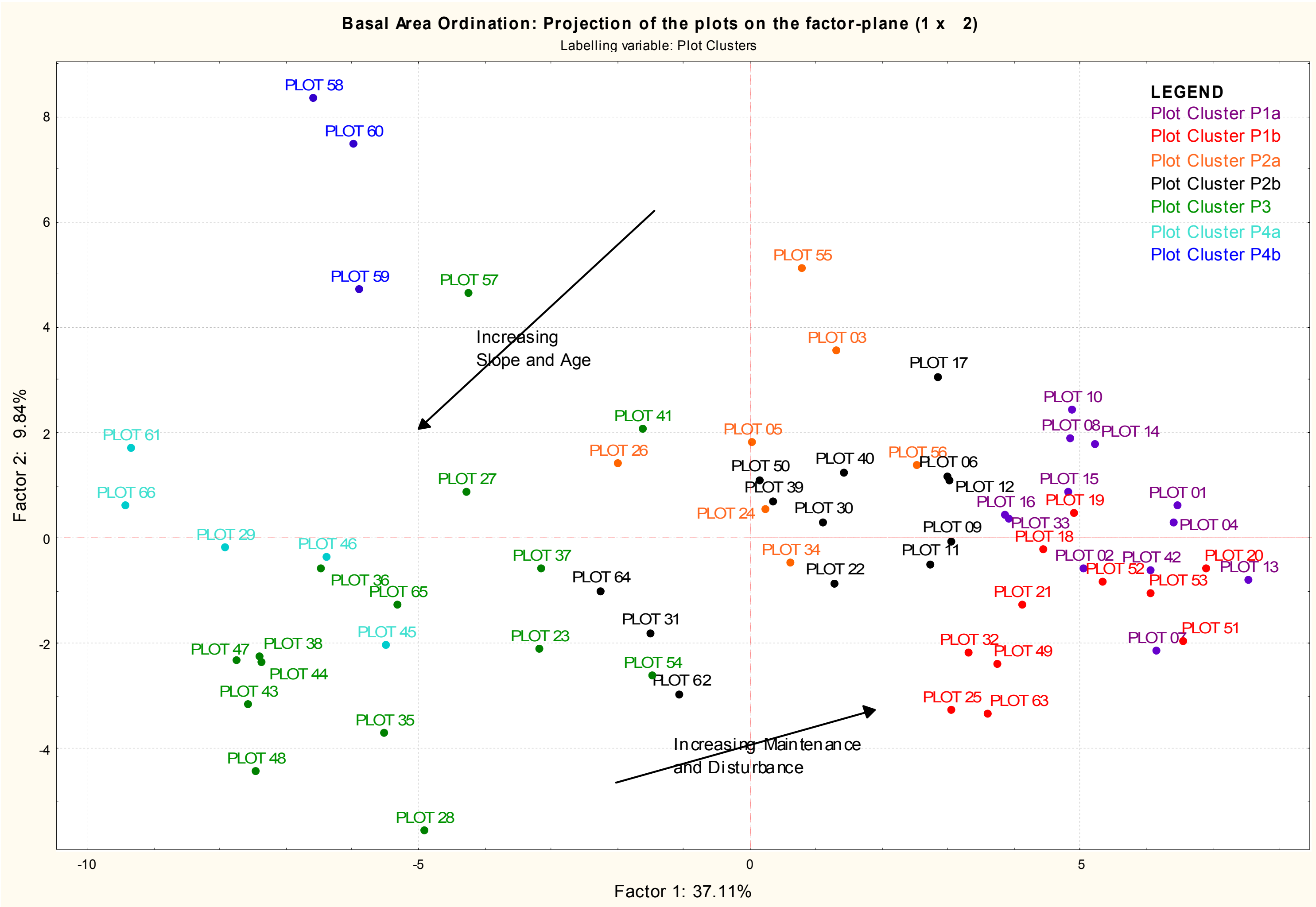
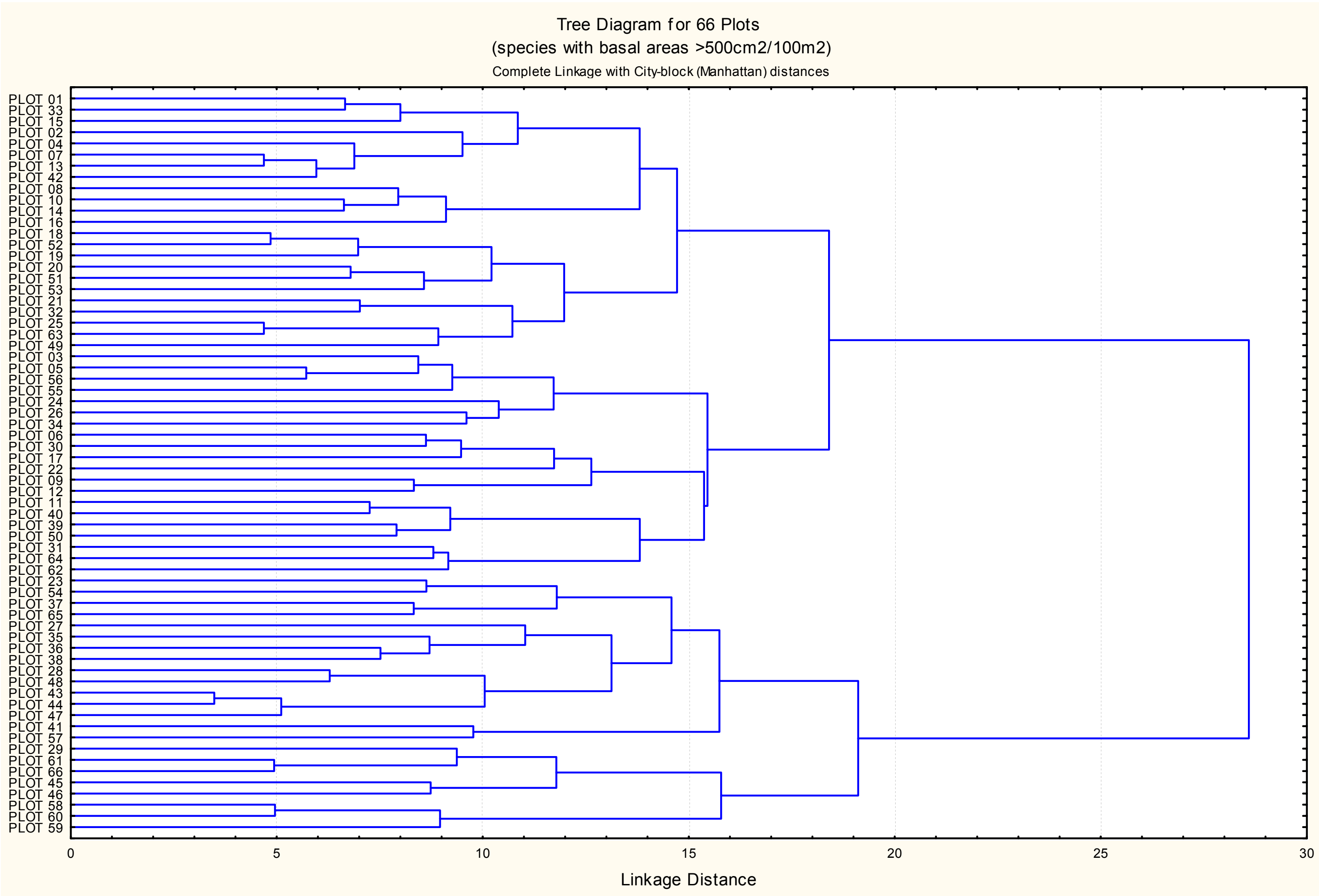


Figure 4.2: Dendrogram of Plots (Basal Area Data)



4.3.2 Cluster description

The following section describes vegetation type, plot locality, plot ages, ownership, and soil conditions for each of the clusters.

Overall most plots were clustered with others from the same locality and in different ways from the experimental block groupings. Most of the control plots segregated into clusters P3, P4a and P4b. Most (7 out of 8) of the planted plots associated with controls were private restoration patches. The exception was the Yendell Park plot (41), which notably was also somewhat of an outlier in the ordination.

4.3.2.1 P1 Clusters

Overall, most of the P1a and P1b plots were less than 20 years old. There were twelve P1a plots and eleven P1b plots.

All P1a plots were in public ownership. P1a age breakdown was as follows: less than 10 years: five plots, 10-20 years: four plots and 20-30 years: three plots. P1a gully system localities that had more than one plot included the Kirikiriroa system (3), the Ranfurly system (3), the Waitewhiriwhiri system (2), and exactly opposite banks of the Waikato (2).

All but two P1b plots were in public ownership. The two in private ownership were in Morris' gully in Matangi (25 and 63). P1b age breakdown was as follows: less than 10 years old: ten plots, 10-20 years: four plots and 20-30 years: three plots. P1a gully system localities that had more than one plot included the Riverbanks (5), the Mangaonua system (2) and the Hamilton gardens system (2).

4.3.2.2 P2 Clusters

Overall, most of the P2a and P2b plots were older than 10 years. There were six P2a plots and fourteen P2b plots.

All P2a plots were in public ownership. P2a age breakdown was as follows: less than 10 years old: four plots, 10-20 years: one plot and 20-30 years: one plot. P2a gully system localities that had more than one plot included only the Kirikiriroa system (4). All the canopy plots (experimental block A4) were in the P2a cluster. At least three and possibly up to five P2a plots had fill soils.

P2b plots included two controls. P2b age breakdown was as follows: less than 10 years old: three plots, 10-20 years: four plots and 20-30 years: seven plots. P2b gully system localities that had more than one plot included the Ranfurly system (3), the riverbanks (2), the Mangakotukutuku (2) and the Komakorau (2, controls). At least two (and possibly up to 6) P2b plots had fill soils. Six plots were in private ownership.

4.3.2.3 P3 Cluster

There were fifteen P3 plots. P3 plots included ten controls. Nine plots were in private ownership. Planted plots in the cluster were Lee's gully in Fitzroy (23), Korving's gully in Glenview (27), Calcott's gully in Pukete (28), Yendell Park riverbank in Melville (41) and one plot in Morris' gully in Matangi (54).

P3 cluster age breakdown was as follows: 10-20 years: 5 plots, 20-30 years: 7 plots and older than 30 years: 3 plots. P3 gully system localities that had more than one plot included the Kirikiriroa (3), the Mangaonua (4), the Mangakotukutuku (2) and the riverbanks (3).

4.3.2.4 P4 Clusters

Overall, most of the P4a and P4b plots were younger than 20 years. There were five P4a plots and three P4b plots.

P4a included two control plots. Three plots were in private ownership and these were the planted plots. They were Seeley's gully in Hamilton East (29) and two plots in Dudley's gully in Tamahere (45 and 46). P4a age breakdown was as follows: less than 10 years old: one plot, 10-20 years: three plots and 20-30 years: one plot. The only P4a gully system locality that had more than one plot was the Mangaonua (2).

All P4b plots were controls and one was in private ownership. P4b age breakdown was as follows: less than 10 years old: three plots. The only P4b gully system locality that had more than one plot was the Kirikiriroa (2).

Table 4.2: Cluster results - means for selected independent variables

Variable	P1a	P1b	P2a	P2b	P3	P4a	P4b	Mature forest Control D1
**Average age (p =.0001)	14.8 ± 7.0	19.7 ± 4.2	12.1 ± 5.8	*22.0 ± 11.6*	*35.4 ± 32.6*	*21.8 ± 3.0*	9.8 ± 0.6	69.0 ± 54.3
**Slope (p =.0007)	20.7 ± 5.0	***32.1 ± 8.8***	*22.9 ± 5.8*	***31.4 ± 7.5***	***29.7 ± 8.6***	36.0 ± 1.9	33.3 ± 1.5	30.3 ± 6.2
* % Sand (p =.0184)	77 ± 15	77 ± 16	***59 ± 25***	***51 ± 28***	***58 ± 25***	78± 16	80 ± 17	53 ± 39
* Maintenance (p =.0299)	2.0 ± 0.7	2.3 ± 0.8	2.0 ± 0.82	1.8 ± 1.0	*1.1 ± 1.3*	*1.0 ± 1.2*	***0.3 ± 0.6***	0.5 ± 1.0
* Overall disturbance (p =.0444)	2.1 ± 0.8	1.8 ± 0.8	2.1 ± 0.9	1.8 ± 0.9	***1.1 ± 0.8***	1.8 ± 1.1	***0.7 ± 0.6***	1.00 ± 0.82
*** Private ownership (Chi-Square = 13.79860; df = 6; p < .031971)	0.00	0.18 ± 0.40	0.00	*0.46 ± 0.52*	***0.67 ± 0.49***	*0.60 ± 0.55*	0.33 ± 0.58	0.75 ± 0.50

Note: P values (derived from Kruskall-Wallace ANOVA or Chi-square) are bracketed after the variable: ** variables significant at p<0.01, * variables significant at p<0.05; *** significant Chi-square at p< 0.05. Means are ± SD
Bold italic values (heavily shaded cells) are in the range of the control value D1 or better. Italic values (shaded cells) are next closest to the controls.

Table 4.3: Cluster results - means for selected dependent variables

Attribute	Variable	P1a	P1b	P2a	P2b	P3	P4a	P4b	Mature forest Control D1
Species Richness	**No. of liana/epiphyte species (p=0.0001)	0.17 ± 0.39	0.64 ± 0.81	0.29 ± 0.49	0.62 ± 1.45	***4.13 ± 2.85***	*1.00 ± 0.71*	0.33 ± 0.58	6.5 ± 3.1
	**Overall no. of native species (p=0.0003)	11.0 ± 3.8	***19.7 ± 5.8***	12.7 ± 7.8	*17.8 ± 6.7*	***21.7 ± 8.5***	*16.8 ± 5.5*	7.3 ± 4.0	23.0 ± 6.0
	**No. of regenerating native species (p=0.0015)	2.4 ± 2.1	*4.5 ± 1.7*	1.7 ± 1.4	*4.5 ± 2.9*	***6.2 ± 2.9***	***5.8 ± 1.9***	3.3 ± 2.3	5.3 ± 1.7
Species Diversity	*Alpha diversity - regeneration (p=0.0327)	8.1 ± 8.1	*7.3 ± 4.5*	9.6 ± 11.9	8.7 ± 4.1	***5.1 ± 3.3***	*7.6 ± 8.7*	1.2 ± 1.0	5.0 ± 1.2
Physical	**Fern Intercepts /100m^2 (p =0.0081)	*1.9 ± 5.4*	*1.4 ± 3.6*	0.0	***2.3 ± 3.5***	***3.3 ± 3.8***	*1.2 ± 1.6*	0.0	2.0 ± 2.4
	*Litter Intercepts /100m^2 ((p =0.0113)	***15.3 ± 10.1***	12.1 ± 6.9	***13.6 ± 6.6***	11.9 ± 3.9	***16.8 ± 6.5***	***21.0 ± 4.0***	28.8 ± 8.3	13.2 ± 3.3
	*Soil Intercepts/100m^2 ((p =0.0191)	***1.7 ± 1.3***	5.6 ± 3.8	***2.3 ± 2.6***	3.4 ± 2.8	*2.6 ± 2.4*	***1.7 ± 1.4***	10.6 ± 5.2	2.5 ± 3.1
Structure	**Canopy height /Block (p=.0000)	6.2 ± 2.1	6.3 ± 1.4	5.9 ± 2.6	*6.6 ± 2.6*	*6.5 ± 2.0*	***7.0 ± 2.0***	4.5 ± 1.3	8.3 ± 1.7
	*No. of diameter classes (p=0.0263)	4.9 ± 1.2	5.1 ± 0.8	*5.7 ± 1.3*	*5.6 ± 0.9*	***5.9 ± 0.9***	5.0 ± 1.2	3.7 ± 0.6	6.0 ± 0.8
	*No. of regeneration classes (p=0.0342)	2.5 ± 1.8	***4.1 ± 1.4***	2.6 ± 1.8	***3.0 ± 1.6***	***4.3 ± 1.4***	***4.2 ± 0.4***	4.7 ± 2.3	3.1 ± 1.0
Density	*Density of native stems (no./100m^2) (p=0.046)	***131.1 ± 63.9***	219.5 ± 199.4	133.1 ± 174.3	***92.8 ± 53.7***	152.9 ± 65.5	***90.4 ± 48.5***	70.1 ± 74.6	85.1 ± 24.9
Productivity	**Total biomass estimate (m^3/100m^2) (p =.0058)	2.18 ± 0.92	1.95 ± 0.68	2.03 ± 1.25	*2.76 ± 2.3*	***3.1 ± 1.21***	***4.38 ± 0.79***	1.27 ± 0.45	3.9 ± 2.9
Regeneration	Proportion of native canopy species regenerating	*20.29%*	15.09%	9.68%	17.78%	***27.45%***	***38.89%***	0.00%	25.0%
Proximity	**Distance to seed source (m) (p =.0008)	35 ± 22.7	***17.27 ± 3.4***	43.6 ± 29.5	*20.0 ± 5.0*	***19.3 ± 5.3***	23.0 ± 10.4	*15.0 ± 0.0*	17.5 ± 2.9
Notes:	P values (derived from Kruskall-Wallace ANOVA) are bracketed after the variable: ** variables significant at p<0.01, * variables significant at p<0.05. All are listed in order of significance. Means are ± SD Bold italic values (heavily shaded cells) are in the range of the control value D1 or better. Italic values (shaded cells) are next closest to the controls.								

4.3.2 Independent variables results

For the clusters, the independent variables that had significantly different means (Kruskall-Wallis ANOVA) were average age, slope, percentage of sand in the soil, maintenance levels and disturbance levels (Table 4.2). Plot ownership in the clusters was significantly different (Chi-squared test) from the expected (i.e. from the 30% private ownership across all plots together). Aspect and soil moisture levels did not have significant between-cluster means.

Mean age was greatest for plot cluster P3 and least for P4b. Slopes were steepest in plot clusters P4a, P4b, and least in P1a. Percentage of sand was the most discontinuous independent variable with two clear groups: between 77% and 80% in clusters P1a, P1b, P4a and P4b and between 51% and 59% in P2a, P2b and P3. Maintenance and human disturbance values were positively correlated ($p<0.05$, Spearman). Both values generally decreased across the clusters. Maintenance was highest in P1b and lowest in P4b. Disturbance was highest in P1a and P2a and lowest in P4b and P3. The disturbance value for P4a was very high compared with maintenance. The disturbance values for P3 and P4b were very low compared with slope (slope negatively correlated with disturbance: $p<0.05$, Spearman). Private ownership was highest in P3 followed by P4a and P2b.

4.3.3 Dependent variables results

In the following results, variables with significant differences between cluster means (Kruskall-Wallis ANOVA) and some proportion variables of interest are included.

Across all clusters, the dependent variables generally showed clusters P3 and P4a to be the closest to the mature forest control (Table 4.3). The variables where P3 and P4a were not comparable with the controls included *number of diameter classes* (P4a low), *density of native stems* (P3 low), and *distance to seed source* (P4a low).

The dependent variables generally showed clusters P4b, P2a and P1a to be least like the mature control. In these three clusters, the variables with values least comparable to the mature forest control values included *number of native species*, *number of native lianas and epiphytes*, *number of native regeneration species*, *number of regeneration classes* and *distance to seed source.* P4b is distinct in having the more extreme-values and had particularly low values for *fern intercepts* and *proportion of native canopy species regenerating*. The P4b extreme values are also at the opposite end of the range from P1a and P2a for *alpha regeneration diversity*, *soil and litter intercepts, number of regeneration classes*, and *distance to seed source* variables. P4b is also notable in being the one cluster comprised entirely of control plots and entirely of exotic vegetation types.

4.3.4 Species composition

Comparison of the species and plot dendrograms (Figures 4.3 and 4.5) enabled the species clusters to be related to the plot clusters. The plot dendrograms were relabelled by vegetation type (using the three dominant (basal area) canopy and subcanopy species) and compared with the species dendrograms. Matches of the clusters were then made but the species dendrogram species have been designated 'signature species' because the matches are not exact.

Table 4.4 identifies plot clusters and the most similar cluster signature species. P1a signature species included mostly native pioneer species or planted species used as nurse species. P1b included other native species typical of lighter soils. P2a included mostly exotic species but was unusual because the range included both typically xerophytic species and mesic species. P2b included mainly native species typical of heavier soils. P3 included mainly shade tolerant native species typical of heavier soils. P4a signature species were ferns typical of drier sites and P4b species were mainly exotic pioneer species of lighter soils.

Species composition was also compared between clusters using the means for *number of species present* (Table 4.5) All native vascular species typical of the control plots and with a mean greater than 0.3 individuals per cluster were grouped in rank order of means.

Figure 4.3: Basal Area Plot Dendrogram – with dominant species labels

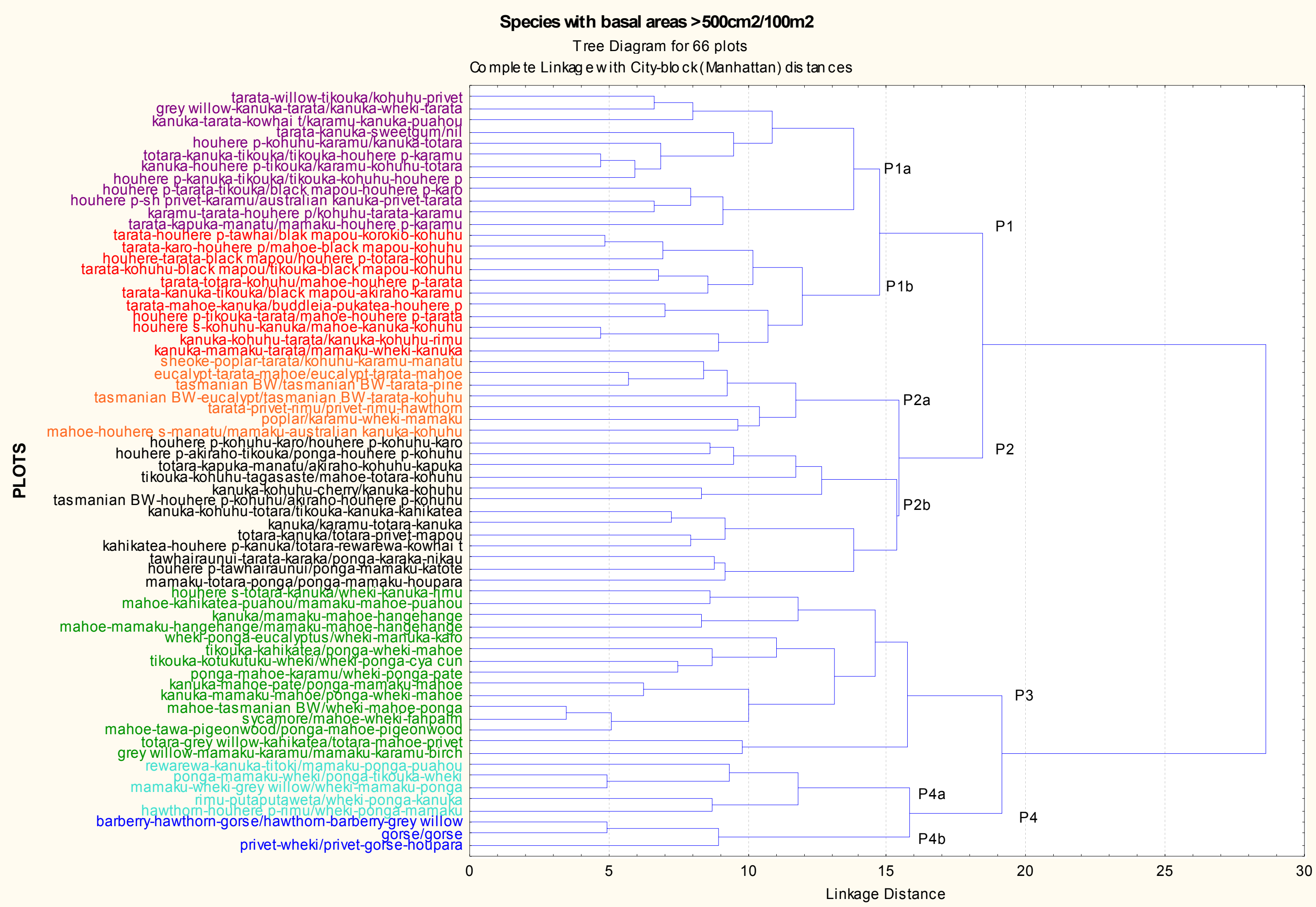


Figure 4.4: Ordination of Species (Basal Area Data)

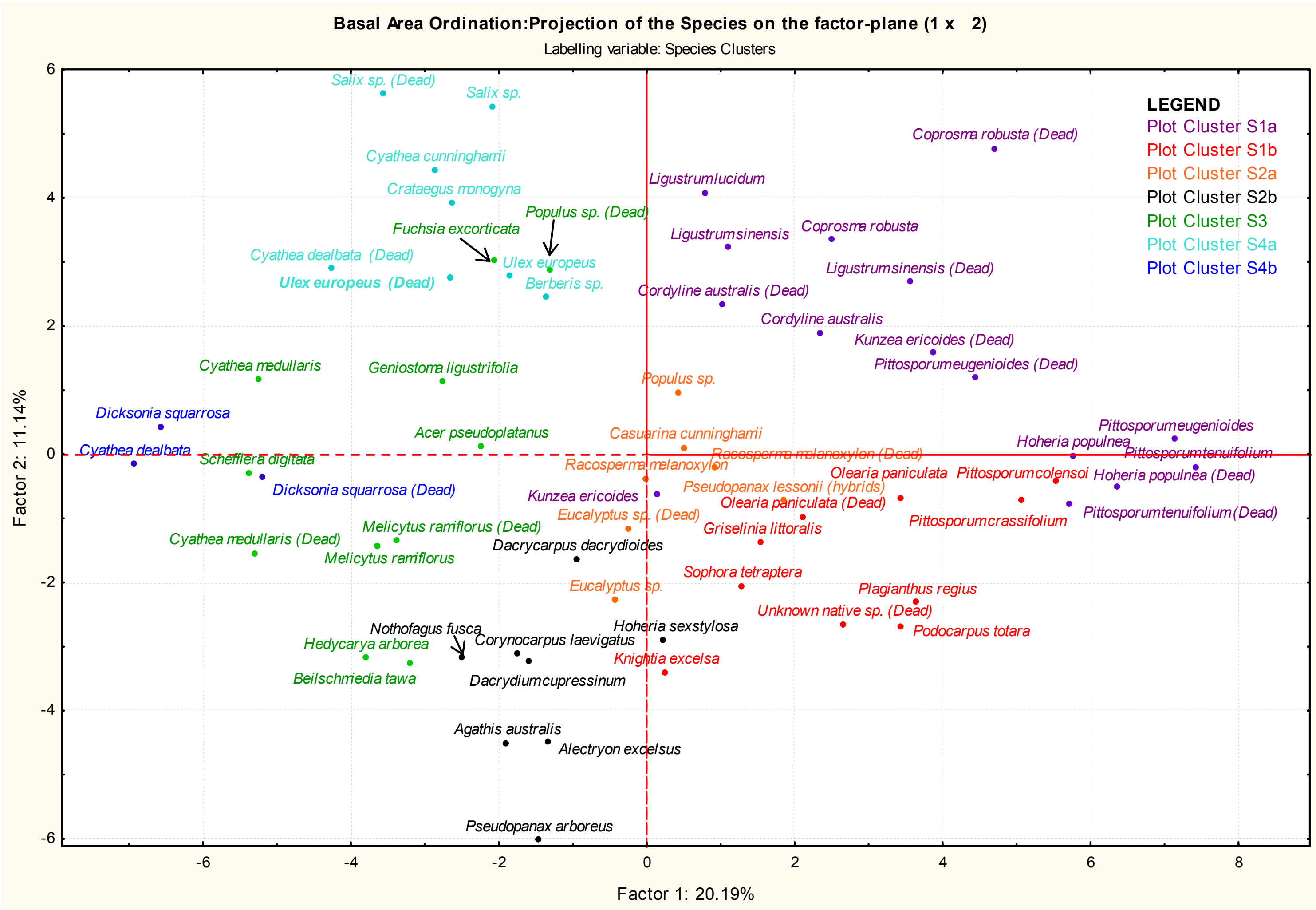


Figure 4.5: Species Dendrogram (Basal Area Data)

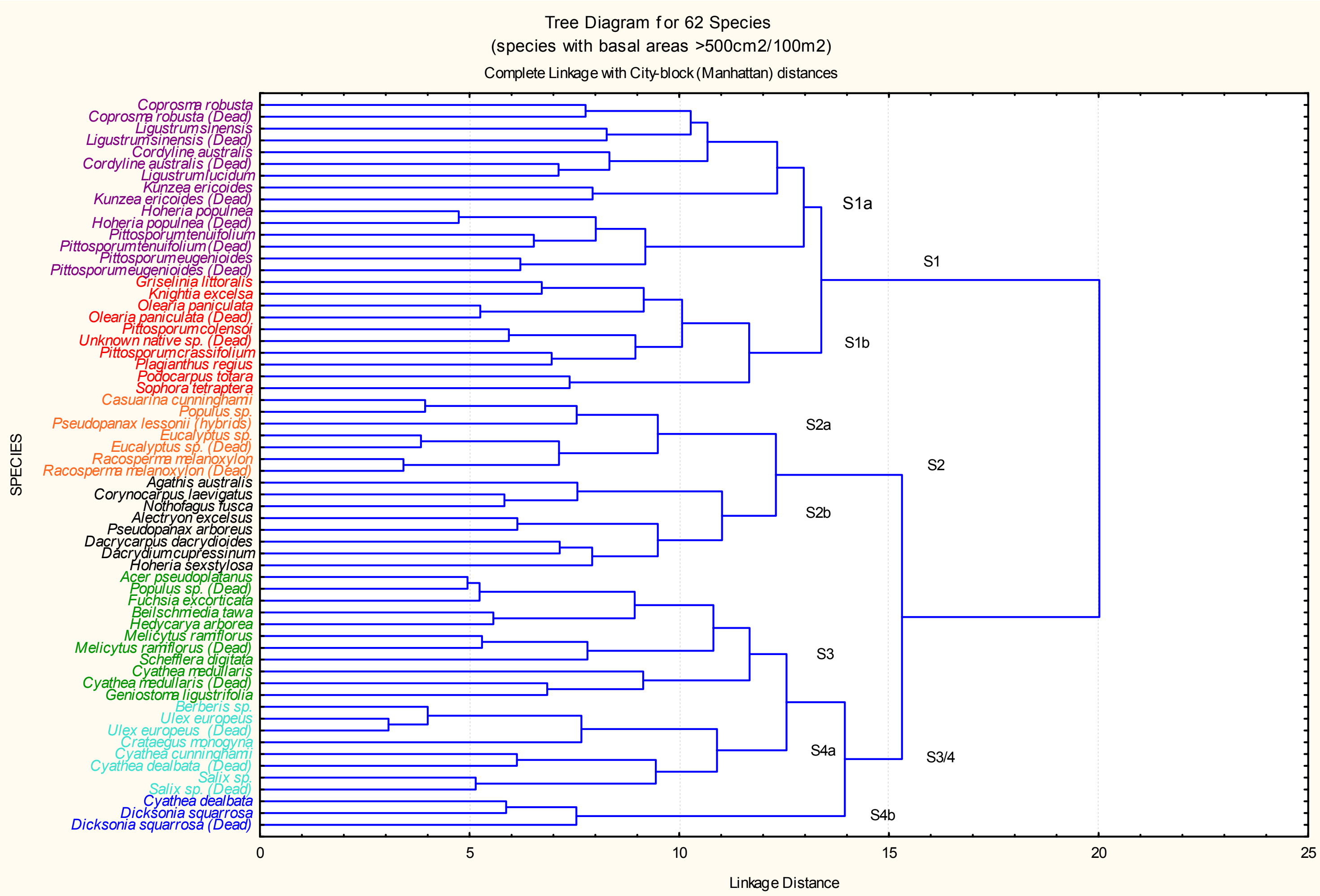


Table 4.4: Plot & Species Clusters

Plot Clusters		Equivalent Species Clusters*			
Cluster label	**Plot numbers**	**Cluster label**	**Signature Species ****		
P1a	01-04, 07-10, 13-16, 33, 42	**S1a**	*Coprosma robusta* *Cordyline australis* *Hoheria populnea*	*Kunzea ericoides* *Ligustrum lucidum* *L. sinensis*	*Pittosporum eugenioides* *P. tenuifolium*
P1b	18-21, 25, 32, 49, 51-53, 63	**S1b**	*Griselinia littoralis* *Knightia excelsa* *Olearia paniculata*	*Pittosporum colensoi* *P. crassifolium* *Plagianthus regius*	*Podocarpus totara* *Sophora tetraptera*
P2a	03, 05, 24, 26, 34, 55, 56	**S2a**	*Casuarina cunninghamii* *Eucalyptus* sp.	*Populus* sp. *Pseudopanax* x *lessonii*	*Racosperma melanoxylon*
P2b	06, 09, 11, 12, 17, 22, 30-31, **39, 40,** 50, 62, 64	**S2b**	*Agathis australis* *Alectryon excelsus* *Corynocarpus laevigatum*	*Dacrydium cupressinum* *Dacrycarpus dacrydioides*	*Hoheria sexstylosa* *Nothofagus fusca* *Pseudopanax arboreus*
P3	23, 27, 28, **35-38**, 41, **43, 44, 47, 48,** 54, **57, 65**	**S3**	*Acer pseudoplatanus* *Beilschmiedia tawa* *Cyathea medullaris*	*Fuchsia excorticata* *Geniostoma ligustrifolium*	*Hedycarya arborea* *Melicytus ramiflorus* *Schefflera digitata*
P4a	29, 45, 46, **61, 66**	**S4a**	*Cyathea dealbata*	*Dicksonia squarrosa*	
P4b	**58-60**	**S4b**	*Berberis sp* *Crataegus monogyna*	*Cyathea cunninghamii*	*Salix cinerea* *Ulex europaeus*

Notes: Bold numbers = controls; **bold underlined** = mature forest controls
* The species listed are from the species dendrogram; but the matches with the vegetation type labelled plot dendrograms are not exact.
** Dead species are excluded from this summary

The overall compositional changes (Table 4.5) between clusters of diversity of species and occurrence of species are consistent with a progression towards maturity. P3 and P4a are the most diverse clusters and have more common occurrence of mature forest species. P1a and P2a are the least diverse and have less common occurrence of mature forest species. P4b has a diversity and occurrence of mature forest species only slightly less than that of P4a but has the greatest occurrence of pioneer species typical of the controls.

Table 4.5: Cluster results for mean occurrence of native species

P1a	P1b	P2a	P2b	P3	P4a	P4b
Coprosma robusta (0.83)	*Melicytus ramiflorus* (0.82)	*Coprosma robusta* (0.86)	*Podocarpus totara* (0.85)	*Cyathea dealbata* (0.93)	*Cyathea dealbata* (1.0)	*Dicksonia squarrosa* (0.67)
Podocarpus totara (0.75)	*Podocarpus totara* (0.73)	*Podocarpus totara* (0.71)	*Cyathea dealbata* (0.85)	*Melicytus ramiflorus* (0.93)	*Dicksonia squarrosa* (1.0)	*Cyathea dealbata* (0.33)
Cordyline australis (0.42)	*Asplenium flaccidum* (0.55)	*Melicytus ramiflorus* (0.57)	*Coprosma robusta* (0.69)	*Dicksonia squarrosa* (0.67)	*Lastreopsis glabella* (1.0)	*Blechnum novae-zelandiae* (0.33)
Cyathea dealbata (0.42)	*Doodia australis* (0.55)	*Cordyline australis* (0.43)	*Melicytus ramiflorus* (0.69)	*Asplenium flaccidum* (0.67)	*Melicytus ramiflorus* (0.8)	*Coprosma robusta* (0.33)
	Coprosma robusta (0.36)	*Dacrycarpus dacrydioides* (0.43)	*Dicksonia squarrosa* (0.54)	*Schefflera digitata* (0.67)	*Cyathea medullaris* (0.8)	*Cyathea medullaris* (0.33)
	Cordyline australis (0.36)	*Cyathea dealbata* (0.43)	*Cordyline australis* (0.46)	*Coprosma robusta* (0.67)	*Coprosma robusta* (0.4)	*Lastreopsis glabella* (0.33)
	***Asplenium oblongifolium* (0.36)**		*Cyathea medullaris* (0.38)	*Blechnum novae-zelandiae* (0.67)	*Blechnum novae-zelandiae* (0.4)	*Muehlenbeckia australis*(0.33)
			Blechnum filiforme (0.38)	*Diplazium australe* (0.53)	*Asplenium polyodon* (0.4)	*Cordyline australis* (0.33)
			Diplazium australe (0.38)	*Blechnum filiforme* (0.53)	*Blechnum filiforme* (0.4)	*Podocarpus totara* (0.33)
			Muehlenbeckia australis(0.31)	*Dacrycarpus dacrydioides* (0.47)	*Cordyline australis* (0.4)	*Doodia australis* (0.33)
				Microsorum pustulatum (0.47)	*Dacrycarpus dacrydioides* (0.4)	***Oplismenus imbecillis* (0.33)**
				Lastreopsis glabella (0.47)	***Uncinia uncinata* (0.4)**	*Pteridium esculentum* (0.33)
				Cyathea medullaris (0.40)	*Pteridium esculentum* (0.4)	*Cyathea smithii* (0.33)
				Podocarpus totara (0.40)	*Blechnum membranaceum* (0.4)	*Cyathea* sp. (0.33)

P1a	P1b	P2a	P2b	P3	P4a	P4b
				Doodia australis (0.40)		
				***Pneumatopteris pennigera* (0.40)**		
				***Asplenium oblongifolium* (0.40)**		
				***Asplenium bulbiferum* (0.40)**		
				Cordyline australis (0.33)		
				***Pteris macilenta* (0.33)**		
				***Hymenophyllum sp.* (0.33)**		
				Blechnum membranaceum (0.33)		

Coding for species in Table 4.5

Species only in youngest controls	Species universal in controls	Species in late controls		Species only in oldest controls	
Pteridium esculentum	*Cyathea dealbata* *Dicksonia squarrosa* *Melicytus ramiflorus*	*Asplenium flaccidum* *Asplenium polyodon* *Blechnum filiforme* *Cordyline australis* *Dacrycarpus dacrydioides* *Diplazium australe*	*Doodia australis* *Microsorum pustulatum* *Podocarpus totara* *Schefflera digitata*	***Asplenium bulbiferum*** ***Asplenium oblongifolium*** ***Macropiper excelsum*** ***Oplismenus imbecillis*** ***Parsonsia heterophylla***	***Pneumatopteris pennigera*** ***Pteris macilenta*** ***Pyrrosia eleagnifolia*** ***Rhopalostylis sapida*** ***Uncinia uncinata*** ***Hymenophyllum* sp.**
Species in early controls					
Blechnum novae-zelandiae *Coprosma robusta* *Cyathea medullaris* *Lastreopsis glabella* *Muehlenbeckia australis*					

Note: Species included are those with block mean occurrence of >0.3. Bracketed numbers are the mean species occurrence in the block. Species occurring in the oldest controls have been highlighted.

4.4 Discussion

The assumption of cluster analysis is that plots or species cluster, based on their similarity and therefore express a set of factors that are common to and underlie the plots in the cluster. The following sections discuss significant factors and variables that may underlie the clustering patterns.

4.4.1 Independent and cluster descriptive variables

4.4.1.1 Clusters

In terms of ordination plot factors 1 and 2, the variables correlating with them are either explanatory of much of the variation or related with factors that do. Age, slope, human disturbance and maintenance are likely to be important explanatory variables. Slope is likely to decrease both disturbance and litter accumulation. Age is likely to increase growth and the long-term species recruitment process. Maintenance is likely to increase the disturbance level. Proximity of seed source species is likely to improve recruitment.

The correlation of site slope and level of disturbance, and maintenance and disturbance, indicate reasons for the low level of disturbance in clusters P3, P4a and P4b. (These clusters were the least maintained and except P4a the least disturbed).

The correlation of older age with the P3 and P4a clusters is consistent with their advanced ecological state – they have had time to mature.

One other factor may have a bearing on the clustering pattern – the pattern of clustering of plots from similar localities. It is likely to be associated with soil factors.

4.4.1.2 Independent variables

The soil sand content is clearly an important underlying factor indicating heaviness of the soil type and available water (even though the soil moisture variable showed no significant differences between clusters). Soil sand content is a structuring variable that affects the clustering patterns. It may underlie the clustering of plots from similar localities described above. The variation in percentage of sand in the soil, across the clusters, creates three major groupings – P1, P4 and P2 combined with P3.

A second important factor that could explain both the maintenance and disturbance factors (also discussed below) is the level of private ownership of plots. The high private ownership level in P3, P4a and P2b could explain the positive effects of maintenance and low disturbance on ecological condition in these clusters.

Within each of the soil-based groupings described, private ownership tended to increase uniformly with improved condition. Similarly, within each group the age variable is a good indicator of their ecological condition: condition improves with age.

Within the two younger cluster groups (P1 and P4), ecological condition improved with maintenance (P1a to P1b and P4b to P4a). However, in the older cluster group (P2 and P3), improved condition paralleled a maintenance decrease (P2a to P2b to P3).

The trend for disturbance is more complicated. Condition generally improves with disturbance decrease within each cluster group except in P4. The explanation may lie in comparing P1 and P4 groups. From P4b to P4a there is a marked increase in maintenance paired with a minor increase in slope and from P1a to P1b there is an increase in maintenance paired with a large increase in slope.

If both maintenance and slope are factors in human disturbance, then they may also balance each other in their combined effect. In P1, the increase in maintenance paired with a large increase in slope tends to balance the effect of slope and reduce the disturbance level. Conversely, in P4 the large increase in maintenance balances the minor slope increase. The net effect on disturbance is greater in P4. In the same way, the gentle slope and high maintenance values of P1a and P2a could explain the high levels of human disturbance of these clusters and be reasons for their being the least advanced in ecological state.

4.4.1 Ecological condition in relation to variables

P3 and P4a were the clusters most advanced in ecological state. P3 was particularly advanced in species richness and P4a more strongly advanced in the structural and productive variables.

Unique factors in the restoration plots of these two clusters were:

a) Oldest age (not only average age but also all plots except one (in P4a) were older than 10 years).
b) Significant presence of private ownership.
c) High maintenance category in the experimental design (even though the cluster average was low).
d) Low human disturbance.

The next most advanced clusters (P2b and P1b) also have privately owned plots represented in them, had moderate disturbance and had medium age (67% were 10-20 years old). Maintenance levels are about the average for all plots. The clustering of two control plots - mature Totara forest and the much younger Kanuka and fern stand on the same property at Komakorau (plots 39 and 40) is of interest and may suggest that the clustering is also indicating an underlying soil factor.

P4b, P2a and P1a were the least advanced clusters. They were all in public ownership. They had relatively low ages (almost 80% were less than 20 years and 50% were less than 10 years old). All four canopied plots were part of cluster P2a. At least three of the canopied clusters had fill soils and a number of windthrown canopy trees, which may indicate poor root penetration. The species composition of the plot canopies was also exclusively exotic. In one plot, eucalypts were used, in two plots, Tasmanian Blackwood was the canopy species and in one plot, there was a mixture of Sheoke and Poplar. This may suggest some possibility of allelopathic effects from the canopy species used as both *Eucalyptus* and *Racosperma* have been implicated in allelopathic effects (Le Houerou, 2000; May and Ash, 1990).

Of all clusters, P1a was poorest in structural and richness variables: It was least similar to the controls in *native liana and epiphyte species*, *number of* *regeneration classes* and except for P4b was also least similar for *number of native species* and *number of diameter classes*. P2a was least similar to the controls in regeneration and dispersal variables: *number of regenerating native species*, *regeneration diversity, fern intercepts* and *distance to seed source*.

However, P4b was exceptional compared to P2a and P1a particularly in values of several regeneration variables, litter and soil intercepts and density of native stems. Most surprising, because of the exotic signature species, there was in P4b compared with P1a and P2a a higher number of regenerating species. Possible reasons are that P4a had steeper slope and much lower maintenance, a more open canopy, less groundcover weed invasion and possibly less impact from grazing herbivores than P2a and P1a.

Generally, the descriptive variables show that private ownership is beneficial for restoration probably due to better quality maintenance linked to low disturbance. The value of time in the process of vegetation change is also demonstrated in these descriptors. In P2a, the negative effects of canopy at planting run counter to intuitive expectations based on shelter. The dependent variables in P2a indicate that poor conditions for regeneration may exist. A possible explanation is that the fill soils of some of the P2a plots are compacted and an unsuitable medium for good seedling germination or establishment. This idea is also supported by the fact of older canopied plots (26, 43 and 44) being clustered with more advanced clusters.

4.4.2 Species composition

Comparison of signature species with the independent variables shows that the species of each cluster are associated according to heaviness of soil type, and successional status. The species in P2 and P3 clusters are generally typical of heavy soils except for the xerophytic species (*Eucalyptus* and *Racosperma*) in P2a. The dominance of the plots 05, 55 and 56 (being located on a clean fill site) in P2a explain this anomaly.

In P1 and P4, the exotic or native nature and different successional status of the species separate the species associations of each cluster. The P1 and P4 species are more typical of light soils.

In terms of the species occurrences, there are some clear trends. Within the three cluster groups identified from soil heaviness (P1, P4 and P2/P3), a similar pattern of change was observed as for the independent variables. Within each group there was a trend with improved condition to reduced pioneer species, increased shade tolerant species and more diversity. For example, the occurrence of *Coprosma robusta* decreased with improved ecological condition. A shade tolerant species such as *Melicytus ramiflorus* increased with condition. Rarer species from mature forest controls appear in the clusters P1b, P2b, P3 and P4a (*Asplenium oblongifolium, Asplenium flaccidum* and *Blechnum filiforme*).

4.4.3 Overall conclusions

The clusters formed relate to several apparent species distributional factors: phase of vegetation change, species associational status, soil factors and indigenous status.

Soil composition (and possibly soil moisture) is an important factor in the species associations that are clarified in the clustering. That plots from similar localities cluster together, sometimes irrespective of age supports the importance of soil factors as determinants of the clusters and therefore possibly also of the vegetation associations.

Major factors in the condition of the plots are age, slope, maintenance and disturbance. Time is essential in allowing plots to mature so that shortcutting the process of succession has a limit. Slope and maintenance interact to affect the level of disturbance in plots. Younger plots generally benefit most from maintenance and all plots benefit from reduced disturbance. High quality maintenance that does not increase disturbance is valuable in improving ecological condition of plots.

The question of the effects of canopy cover at planting on restoration and particularly regeneration processes is still an open question. Soil factors may be just as important in the canopied plots.

Chapter 5 · Discussion and Recommendations

5.1 Introduction

This chapter summarises the discussion and conclusions of chapters 3 and 4 by way of response to the original research questions. Implications of the conclusions for restoration theory are discussed. Finally, implications for restoration practice are discussed in the form of recommendations.

5.2 Research Questions

5.2.1 Progress in the restoration patches

The question is 'Are restoration plantings generally progressing towards an ecological state similar to mature undisturbed forest?'

The ecological condition of the restoration plots is improving but none is as advanced as the equivalent aged controls or the mature forest control in all of the most significant variables (Table 3.10). However, four experimental blocks (B3a, B4a, B4b and C4) are largely moving more rapidly than controls towards a mature forest state. They are as advanced as or more advanced than their equivalent controls in most variables. They are within the range of the mature forest control in several variables (8 of the 10 variables for C4). Blocks B3a, B4a and B4b are remarkable in terms of their progress relative to the ages of the plots.

In number of lianas and epiphytes all planted plots did poorly compared to the controls. Lianas and epiphytes indicate ecological condition in terms of advanced species diversity, structural diversity and dispersal processes.

In addition, as suspected from the preliminary visual evaluation, three blocks (B3b, C2 and C3) were deteriorating after a period even though they were maintained. Native species were not recruiting as well as in the controls and regeneration diversity was low. There was also ongoing recruitment of exotic species in these blocks.

5.2.2 The effects of maintenance and human disturbance

This involves two questions that will be dealt with together: 'Does ongoing maintenance contribute to advancement or deterioration of plantings?' and 'Does human disturbance affect the ecological state of the plantings?'

Maintenance is important to ecological condition of restoration. Of the four blocks that are closest to the mature forest ecological state B4a, B4b and C4 have a very high level of maintenance and B3a has moderate maintenance level. In the deteriorating blocks the level of maintenance was lower than in B4a, B4b and C4.

Furthermore, the experimental block analysis shows that high maintenance occurs in both older and younger blocks. In the younger high maintenance blocks the level of maintenance was lower than in B4a, B4b and C4. However, maintenance has been particularly beneficial in older plots in private ownership.

In the cluster analysis, high maintenance is associated with poor ecological condition in the clusters P1a, P1b and P2a (but the high maintenance of advanced planted plots is masked by the inclusion of control plots in the clusters - particularly the more advanced ones). However, in the youngest clusters, *increasing* maintenance is linked to *improving* ecological condition.

A possible explanation of the results for the experimental blocks and the cluster analyses is that maintenance quality varies: The proportion of private ownership is highest in C4 and B4a with some private ownership in B3a and B4b also. The high maintenance regime in these blocks implies a qualitative difference between the maintenance in them compared to that in the younger plots and the deteriorating B3b and C3 blocks.

Furthermore, the analyses of both the experimental blocks and the clusters show that maintenance interacts with slope and together they affect overall disturbance.

Human disturbance in the advanced experimental blocks B3a, B4a and C4 is moderate (but in B4b is slightly higher). In the deteriorating blocks disturbance was higher than in the other planted blocks older than 10 years except for A4, which is also in a poor ecological condition.

The conclusion is that human disturbance is a driver of ecological condition not maintenance in itself. Good quality maintenance is particularly valuable in older restoration. In younger restoration, the important link is between disturbance and ecological condition. Maintenance can be beneficial provided it is linked to lower overall disturbance. Controlling human disturbance by improving quality of maintenance and controlling public access will improve success in restoration plantings. The recommendations below will address this.

5.2.3 Species composition in relation to ecological state

The question is: 'How is species composition related to ecological state of restoration patches?'

The data shows that the overall species composition is not a good predictor of ecological state even though it does show trends with time. The older experimental blocks were closer (in the species with a higher mean level of occurrence than 0.3) to the controls in their general composition. However, the occurrence of species typical of advanced control blocks was counterintuitive. It was greater in some blocks that were less advanced (based on the combination of other variables) than in blocks B3a, B4a and C4. Less advanced blocks C2, C3 and B4b have composition profiles closest to the C1 and D1 controls.

Provided the functional and structural factors in restoration are in place and operating satisfactorily, species composition seems to be taking care of itself. This is not to detract from the value of enrichment, which the next section covers.

Nevertheless, some species may be good candidates for indicators of ecological state – particularly those late entry species including *Blechnum filiforme, Microsorum pustulatum, Asplenium polyodon*, *Asplenium bulbiferum, Hymenophyllum* species, *Oplismenus imbecillis, Parsonsia heterophylla, Pneumatopteris pennigera* and *Rhopalostylis sapida*. Many of these are lianas and epiphytes, and in numbers of lianas and epiphytes, the restoration plots did not perform well.

5.2.4 Species diversity and enrichment in relation to ecological state

The question is: 'Does initial composition diversity or later enrichment help improve the final composition and ecological state of restoration?

Generally, planting a diverse range of species does not appear to be beneficial for ecological condition but enrichment of restoration plantings does. However, there also appears to be an interactive effect between initial planting diversity and enrichment. Maintenance and disturbance also complicate matters.

Both enrichment and diverse planting appear to be more beneficial for ecological condition where they occur together. Diversity effects are relatively positive in the enriched block B4b, which also has higher maintenance and lower disturbance than B3b. Enrichment effects are more positive in the diverse blocks B4b and C4, which also have higher levels of disturbance (and maintenance in B4b) than the depauperate B4a. The three privately owned restoration plots that have higher numbers of epiphytes than their respective controls also indicate that enrichment may be linked to maintenance.

The higher level of quality maintenance in enriched and diversely planted blocks suggests that in them there is less loss of initial species diversity and better survival of enrichment plantings. This implies a need to plan specific maintenance tasks targeted at reducing attrition of species from diverse plantings and enrichment plantings. The recommendations below will address maintenance tasks.

5.2.5 Landscape ecological factors

The question is: 'What effects do patchy distribution of restoration plantings have on their ecological state and in particular on regeneration and dispersal?'

There was no assessment of proximity of mature forest patches to the restoration patches within the area of study. However, the proximity of seed sources for species regenerating within the plots was shown to be an important variable in restoration. The data shows that irrespective of species regenerating (whether exotic or native), most regeneration is sourced from species close by. Average estimated distances to seed sources were less than 65m (though individual plots had greater distances recorded).

The *proximity of seed sources* results suggests that a patchy urban distribution of restoration vegetation will not operate effectively as a metapopulation without other assistance since most plantings would be further apart than this.

5.2.6 Canopy as 'nurse' and 'nurse' species

The question is: 'Does an existing canopy act as a nurse for restoration purposes and how do exotic nurse species (as canopy or otherwise) affect restoration success?

The data are not clear on the effects of a canopy on restoration. Canopy was associated with poor regeneration but it was unclear as to whether this was due to the canopy presence or due to other site factors. Soil condition (compaction or poor soil) was a possible factor that could have caused the poor levels of regeneration and structural development of the canopied restoration plots. Allelopathic effects may also have been a factor in some plots as some *Eucalyptus* and *Racosperma* species are known to have such effects (Le Houerou, 2000; May and Ash, 1990). Canopy in older plots had no apparent detrimental effect on regeneration or structure. However, the older plots did show that there is some risk with exotic nurse species as there was regeneration of exotic species (*Acer pseudoplatanus* and *Racosperma melanoxylon*) into two of them.

5.2.7 Other factors

Soils composition was one variable that has an important effect on the restoration plots. Soil sand content was a determinant of the plot and species clustering. It is likely to have an effect on the species associations, regeneration and overall condition of the restoration patches. Furthermore, some of the canopy plots were on clean fill sites with possibly poor and compacted soils. Restoration of these sites may be more akin to restoration of mined or quarried sites. Modification of the soil condition by cultivation, management of groundcover weeds, mulching, maintenance and human disturbance could improve litter accumulation, humus content, and regeneration conditions.

5.3 Implications for Restoration Theory

This section reviews the findings that relate to the theoretical concepts that underlie restoration ecology. It comments on some implications for restoration theory. Other practical implications are covered in the recommendations section.

5.3.1 Conceptual framework: successional pathways, processes and thresholds

The research supports the Parker and Pickett (Parker and Pickett, 1997) hypothesis of multiple possible successional pathways and equilibria and of thresholds in restoration.

The diversity of restoration efforts in the Hamilton Ecological District demonstrates the possibility of multiple pathways. The general change towards the reference forest condition in the restoration plots, albeit with variable success, shows this. Furthermore, none of the restoration pathways observed for this research follows a classic successional pathway.

The results demonstrate a human induced threshold related to chronic disturbance of restoration plantings. They also support the need to control disturbance (Luken, 1990). Disturbance controls seedling establishment processes, so chronic human disturbance, without any action to prevent it, can result in deterioration of the restoration patch. (There are also signs of human induced disturbance affecting mature forest remnants in the same way). Disturbance from maintenance activity or public access needs to be reduced to a level that permits sustainability of the planting.

This research also raises a caution on the expectation that restoration can speed up change (Hobbs and Mooney, 1993). The results support the idea that the length of time for succession to maturity can be reduced by restoration planting. The ages of the more successful plantings are younger relative to the ages of the controls. However, they also show that there is a limit imposed by the time for individual plants to mature so that the older the age of the planting the better chance there is of appropriate processes developing for a sustainable system. The rationale for restoration of reducing time to mature forest development may not be such a useful one in this case because of the expectations it raises within the community.

In this respect, it would also be interesting to attempt some restorations by stocking weed-ridden areas with appropriate forest species as a seed source and simply managing the weeds with minimal interference to prevent over growth of plants.

5.3.2 Composition versus structure and function

The research supports the idea that for effective restoration, emphasis on structure and function of restoration patches is a more important priority than the detailed composition. Luh and Pimm (Luh and Pimm, 1993) stated that 'Even with all the species we may be unable to reassemble communities'. This research shows that even without all the species it is possible to achieve substantial gains in restoration. Vegetation structure and function of the successful restoration patches seems to be close to that of mature forest.

However, it is still unlikely that full function will be restored without the animal and invertebrate community structure and functions in place. Even in the case of urban restoration, this must eventually mean that exotic animal control becomes a priority.

In vegetation restoration, a key community function affected by species composition appears to be regeneration. This applies to the ground conditions (control of litter, accumulation soil composition and groundcover vegetation) for germination. It also applies to proximity of species to supply seed.

Another key function is disturbance - specifically the need to reduce human disturbance. This is less specific to composition but does have implications for the selection of appropriate species to establish rapid cover – pioneer species that cope with a range of poor site conditions and create conditions suitable for enrichment species to thrive. In this respect, the research supports the idea that the human and alien species context of restoration is important (Given and Meurk, 2000; Parker and Pickett, 1997). This research did not find clear support for or against using exotic nurse species. However, it suggests caution in light of the fact that some exotic species may have allelopathic effects and in some sites, exotic canopy species are regenerating with native species.

5.3.3 Landscape ecology

The concept of an assembly order of introduction of community components (Diamond, 1975; Gilpin, 1987) runs somewhat counter to the idea that composition is less important than structure and function. This research suggests that ecological change is not closely tied to exact vegetation compositional authenticity or the order in which species arrive, provided the basic functions are operating such as suitable conditions for more demanding species. The order is likely to be determined by the available seed sources for regeneration. The related issue of representativeness in relation to the reference biotope is important for long-term conservation of representative vegetation types. It is less of a critical issue for urban restoration except that species selection should ideally include the most significant representative species and if other species are used they should ultimately be removed or be short-lived.

This research supports indirectly the concept of metapopulation dynamics (Luken, 1990). The proximity of seed sources is important and therefore proximity of other patches of native vegetation will be beneficial to the health and interaction of all patches. Reay and Norton (Reay and Norton, 1999) and Sullivan and co-workers (Sullivan et al., 2005b; Sullivan et al., 2005a) show that proximity of seed sources affects regeneration. The present research reaches the same conclusion.

Landscape ecology based methods to reverse degradation are also supported by this research. The concept of managing the whole matrix is useful in terms of the significant seed-source proximity issues. Integrated planning is vital to managing human disturbance and reducing the state of fragmentation of the many restoration patches. It is also important for managing exotic organisms that threaten positive change in the whole ecological community.

5.4 Recommendations for Restoration Practice

This section provides practical recommendations for future restoration work based on the findings of the research.

5.4.1 Goals

Lack of clear goals for existing plantings in Hamilton City was clear at the outset of this study. A clear and if possible common goal should be set for all public and private restoration efforts within the city and neighbouring gullies. This would assist the putting in place of means to manage restoration on a more strategic level. Such an approach could more effectively enact the other recommendations here. A possible goal could be:

> *To restore, particularly in gullies and on the riverbanks throughout Hamilton, a matrix of representative lowland Waikato ecological communities. In addition, to restore, structure, function and composition, and some populations of the more typical native animals capable of colonising such communities.*

5.4.2 Species selection

Species should be selected for restoration based on the following criteria:

a) Nurse or pioneer species that are robust, resilient to abuse and tolerant of a range of site conditions including poor and urban soils (see notes below on exotic nurse species)
b) Inclusion of later successional seed source species at the outset where possible
c) Selection of a diverse range of species for enrichment purposes
d) Species based as much as possible on representative vegetation types for the Waikato lowlands

If exotic nurse species are used, the following guidelines will assist selection: Ideal nurse species should have a sympathetic ecology to native species in the restoration. They should provide rapid shelter (growth), be short-lived (to reduce competitive effects), probably be evergreen but not densely so, be weakly competitive for nutrients or water, be non-invasive and leave little seed bank after death or removal from the site.

5.4.3 Site selection

Site selection guidelines apply to the selection of detailed locations or 'microsites' within plantings. Species-site mismatching is a likely cause of high rates of species loss in extant plantings. Site selection should be robust and take more account of localised site conditions and species tolerances than is traditional in such plantings. Because many plantings are community based this can be difficult. The choice of appropriate tolerant pioneer species will assist in reducing the impact of mismatches.

Use of forest canopy species for long-term seed source purposes needs to take account of site exposure and competition. Separate planting such as specimen trees and street plantings should be associated with restoration plantings as an alternative. Less tolerant canopy trees and other species, which can improve the diversity of the restoration, should not be included in early planting but introduced by other means (see regeneration below).

5.4.4 Establishment techniques

Mulching of sites should be standard practice wherever it is possible. However, use of artificial fabric mulches should be avoided. The few restoration plots where these were evident had little regeneration occurring. Soil conditioning should be used where fill sites are being restored. This could include deep ripping or cultivation of the surface to remove compaction from the root zone or deeper.

Sullivan and co-workers (Sullivan et al., 2005b) concluded that the best method was to plant to fill space as rapidly as possible (0.75 m spacing was used) to create a microclimate suitable for invertebrates, reduce establishment of woody weeds and protect plants from vandalism. However, the need to establish rapid cover should be balanced with the need to avoid species (rather than individual plant) losses. If planting is relatively diverse, close planting would increase loss of species unable to tolerate the competition. Alternatively, more effective enrichment management could substitute for initial species diversity.

Managers need to decide either to intensively manage planting that is wider-spaced with diverse species or to use more expensive, close-spaced, plantings and manage long-term enrichment.

5.4.5 Maintenance level and quality

Maintenance regimes should be of high quality and minimal disturbance. It should target eradication of exotic woody and perennial ground-covering weeds. Where necessary it should also control competition where it threatens species diversity.

However, maintenance should be avoided that may have an impact on the patch ecological condition. This includes heavy pruning, thinning, removal of damaged branches or fallen trees, and blanket spraying of margins or within the margins of patches.

Early selective pruning or thinning of some plants should aim to maintain diversity. Maintenance should be reduced with age by limiting it to removal of exotics and enrichment of plantings.

5.4.6 Disturbance management

Early control of human disturbance of restoration sites is critical. This can be achieved by managing young restoration patches with planting techniques as well as by barriers.

Steep sites are less prone to public access and disturbance so little may be necessary to protect them from public access. Protecting gentle slopes from public access is more important.

Older plantings may be more vulnerable because they have a higher canopy layer and are more open and because regeneration processes may be damaged. Low disturbance enrichment may be possible using seed rather than plants, but this needs to be trialled experimentally.

Structures such as boardwalks and fences that control public access help reduce human disturbance. Other barriers not consciously or widely used in Hamilton are natural landforms, watercourses, swamps and buffer zones of barrier vegetation.

5.4.7 Regeneration and dispersal

Enrichment planting of suitable seed source species within the restoration or its locality is essential to successful restoration. If the required species are not tolerant of open sites, it is possible to introduce them by enrichment with seed or planting. The critical thing is that enrichment is part of programmed management rather than an ad hoc process.

The same principle of seed source proximity applies for exotic regeneration as for native regeneration. Therefore, steps to enhance regeneration should also include control of exotic species in the restoration and in the neighbourhood of the patch to prevent their regeneration into the patch.

5.4.8 Landscape effects

Proximity of seed sources findings suggests that separate restoration plantings within individual parks would be worth amalgamating or connecting. Amalgamation of close patches may also enhance their viability and reduce the effects of fragmentation and disturbance. If closed canopy dense native vegetation is not appropriate, using specimen canopy species will still improve the connections.

In an urban context, managing the whole matrix not just the patches is essential. Some native canopy species that can provide seed sources, should be planted in the close neighbourhood of restoration patches, in public parks, in streets or in private residential gardens, to support the native remnants. Conversely, planting exotic species that have potential to act as seed sources in the restoration patches should be avoided in the neighbourhoods. Removing exotic weeds from the immediate vicinity would also be useful in this respect.

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Appendices

A. Site Stratification Preliminary to Site Selection

No.	Hamilton Gully Revegetation Sites								
		VARIABLES							
		(PLANTED) SITE CONDITIONS				VARIABLES TO CONTROL			
No.	SITE DESCRIPTION	A: PREDOM VEGETATION COVER TYPE	B: TYPE OF SITE	D: PLANTING TREATMENTS	E: EARLY MAINTENANCE TREATMENTS	F: AGE OF PATCH (Yr of Plan)	G: Gully Slope	H: Main Aspect	Preliminary condition assessment
	Controls in Red, Public in bold, Riverbanks Blue	1: NO VEGETATION (Cleared or sprayed) OR vegetation BELOW 1.2m (Grass/ herbaceous) 2: VEGETATION ABOVE 1.2m exotic, decid or evergreen spp 3: Native vegetation above 1.2m	1: Mature forest 2: Natural regeneration 3: Planted site - OLD OR NEW PLANTING	1: NO NEW PLANTING 2: New Planting	1: NO WEED CONTROL or IRREG OR INFQT CONTROL (<6 MTHLY) 2: MOD,REG OR FQT CONTROL CONTROL (>6 MTHLY)	1: 0-10 YRS 2: - 20YRS 3: - 30 YRS 4: -100 YRS 5: >100 YRS	1: Top (0-5%) 2: Crest (-100%, convex) 3:slope (-100%) 4: footslope (-100%, concave) 5: bottom (0-5%)	1: North 2: NorthEast 3: East 4: South East 5: South 6: South West 7: West 8: North West	1: no corresp with nat vegetation type 2: very little corresp 3: little corresp 4: some correp 5: average/medium corresp 6: moderate corresp 7: high corresp 8: very high corresp 9: exact corresp
001	Gibbons Gully - Rod/Nerissa, Grey St	A3	B3	D2	E2?	F1	G3	H4	
004	Gibbons Gully - Seeley, Armagh St?	A1?	B3	D2	E2?	F4?	G3	H8	5
008	**Graham Park - Hockin House**	A1	B2	D1	E1	F1	G3	H7	2
012	**Graham Park - Gills Hill gully - ferns**	A3	B2	D1	E1	F3	G3	H8	3-4
015	**Hamilton Gardens - gully, lower end**	A1	B3	D2	E2	F2	G3	H4	4-5
017	**Hamilton Gardens - gully, older top end**	A1	B3	D2	E2	F3	G3	H1	
018	**Hamilton Gardens - Nursery CP gully**	A1	B3	D2	E2	F3?	G3	H4	4-5
019	**Hamilton Gardens - Nursery CP gully II**	A1	B3	D2	E2	F3?	G3	H4	4-5
020	**Hamilton Gardens - Station masters bank**	A1	B3	D2	E2	F2/3	G3	H1	
021	**Hammond Park - Balfour Gully**	A1	B3	D2	E1	F3	G3	H2	2
023	Hillcrest River - du Chatenier, Silva Cr	A2	B3	D2	E2	F2	G3	H7	
026	Hudson Gully - McDonnell, Howell Ave	A3	B3	D1	E1	F2?	G3	H4	
030	Mangaiti Gully - Johnson/HCC, Helmsdale Ct	A1	B3	D2	E2	F1	G3	H6	
033	**Mangaiti Gully - Te Awa o Katapaki (St James) Park**	A3	B2	D1	E1	F3/4?	G3	H3	4?
037	**Mangakotuku Gully - Fitzroy Park, older (Eucalyptus)**	A2?	B3	D1	E1	F2?	G3	H1	3
041	**Mangakotuku Gully - Fitzroy Park, recent**	A1	B3	D2	E1	F2	G3	H2	3
045	Mangakotuku Gully - Huser, Fitzroy Ave	A1	B3	D1	E1	F1	G3	H2	
048	Mangakotuku Gully - June, Waterford Rd	A1	B3	D2	E1	F2	G3	H6	
052	Mangakotuku Gully - Korving, Splitt Ave	A1	B3	D2	E2	F2	G3	H8	
056	Mangakotuku Gully - Lee, Fitzroy Ave	A1	B3	D2	E2	F3	G3	H6	
060	**Mangakotuku Gully - Te Anau Park**	A1	B3	D2	E1	F3?	G3	H4	3
064	**Mangakotuku Gully -Sandford Park, old bank pltg**	A1	B2	D2	E1	F3	G3	H5	3-4
067	**Mangakotuku Gully -Sandford Park, pines**	A2	B3	D1	E1	F3	G3	H5	2
071	**Mangakotuku Gully -Sandford Park, poplars**	A2	B3	D1	E1	F3	G3	H5	2
072	**Mangakotuku Gully -Sandford Park, recent**	A1	B3	D2	E1?	F1	G3	H5	3
076	Mangaonua Gully - Berkeley	A3	B1	D1	E1?	F5	G3	H3	4
079	**Mangaonua Gully - Chelmsford Park**	A3	B2	D1	E1	F3/4	G3	H4	6
082	Mangaonua Gully - Cuming, Morrinsville Rd	A2	B3	D2	E2	F2	G3	H4	
086	**Mangaonua Gully - Humare Park**	A1	B3	D2	E1	F3	G3	H6	3-4
089	**Munro's Esplanade - Alandale**	A1	B3	D2	E1?	F1?	G3	H3	
092	Onukutara Gully - Clarkson, Lynwood Cr	A1?	B3	D2	E1	F1?/2?	G3	H8?	
094	Onukutara Gully - Clarkson, Lynwood Cr II	A1?	B3	D2	E1	F1?/2?	G3	H8?	
097	Onukutara Gully - Graham, Sharpley Pl	A3	B3	D2	E2	F1	G3	H3	
101	**Onukutara Gully - Hillary Park**	A1	B3	D2	E1	F3/F2	G5	H2	3
103	Onukutara Gully - Hukanui School, Pickering Cr	A1	B3	D2	E2	F1?	G3	H2	
106	Onukutara Gully - Leet, Hooker Ave	A1	B3	D2	E2	F1	G3	H7	
109	Onukutara Gully - Martinson,Montrose Pl	A3	B3	D2	E2	F1	G3	H8	
113	Onukutara Gully - Mortimer, Rutherford St	A2	B3	D2	E2	F1	G3	H2	
118	**Onukutara Gully - Onukutara Park, Road embankment**	A1	B3	D2	E2	F1	G3	H3	3
121	**Onukutara Gully - Onukutara Park, Eucs (88)**	A2	B3	D2	E2	F1	G3	H3	3-4
122	**Onukutara Gully - Onukutara Park, recent embankments**	A1?	B3	D2	E2	F1	G3	H3	2
124	**Onukutara Gully - Porritt Stadium**	A2	B3	D2	E1?	F3	G3	H7	2
125	**Onukutara Gully - East bank regen**	A3	B2	D1	E1	F3/F4	G3	H6	
129	Onukutara Gully - Silvester, Crosby Rd	A2	B3	D2	E1	F2	G3	H7	
132	**Pukete Farm Park - Kauri gully**	A1	B3	D2	E2	F1	G3	H3	3
136	Ranfurly Gully - Harrison, Howden Rd	A1	B3	D2	E2	F1	G3	H7	
141	Ranfurly Gully - Matheson, Boundary Rd	A1	B3	D1	E1	F1	G3	H1	
143	Ranfurly Gully - Matheson, Boundary Rd	A2	B3	D1	E1	F1	G3	H1	
147	**Ranfurly Gully - Park, ridge**	A1	B3	D2	E2	F2	G3	H8?	4
149	Ranfurly Gully - Matheson, Boundary Rd (Top area)	A2?	B3	D2	E2	F1	G3	H1	
150	**Ranfurly Gully - Park, West Bank I**	A1	B3	D2	E2?	F2	G3	H4	
151	**Ranfurly Gully - Park, West Bank II**	A1	B3	D2	E1	F2	G3	H6	3-4
152	**Ranfurly Gully - Park, NW bank I**	A1	B3	D2	E2?	F2	G3	H3	3-4
153	**Ranfurly Gully - Park, ferns NE**	A3	B2	D1	E1	F2/3?	G3	H6	3-4
155	Ranfurly Gully - Sayer, Casey Ave	A2	B3	D2	E1?	F4	G3	H3	
159	Sonning River - Fairhurst, River Rd	A2	B3	D2	E2	F1	G3	H7	
162	Swampy Creek	A2	B2	D1	E1	F4	G3	H6	4?
165	**Tauhara Gully - Chartwell Park**	A1	B3	D2	E1?	F1?	G3?	H2	2
168	**Tauhara Gully - Chartwell Park - old only**	A2	B3	D1	E1?	F1	G3?	H2	3
171	**Tauhara Gully - Tauhara Park, Clements Cres A (old)**	A1	B3	D2	E1	F3	G3	H2	3-4
174	**Tauhara Gully - Tauhara Park, Clements Cres B**	A1	B3	D2	E2	F1	G3	H2	3
177	**Tauhara Gully - Tauhara Park, Clements Cres C**	A2	B3	D2	E2	F1	G3	H2	3
180	**Tauhara Gully - Tauhara Park, Horsehead gully**	A1	B3	D2	E1	F1	G3	H6	3
184	**Tauhara Gully - Tauhara Park, Longwood banks**	A1	B3	D2	E2	F1	G3	H5	3-4
187	**Tauhara Gully - Tauhara Park, Opp River Road**	A3	B2	D2	E1	F4?	G3	H6	4
190	Tauhara Gully - Weeselink, Pulham Cres	A1?	B3	D2	E2?	F4	G3	H3	
194	**Te Hikuwai Gully - Pa**	A1	B3	D2	E1	F1	G3	H6	3-4
197	**Te Inanga Gully - Donny Park, decid, Wymer**	A2	B3	D1	E1	F3	G3	H6	2
203	**Te Inanga Gully - Donny Park, evergreen**	A2	B3	D1	E1	F3	G3	H6	2
205	Te Inanga Gully - Fairfield College	A1?	B2	D1	E1	F3/4	G3	H5	
206	Te Inanga Gully - Rees, McNicol St	A1	B3	D2	E2	F1	G3	H1	
210	**Totara Park**	A2	B2	D1	E1	F4?	G3	H2	4
214	Upper Mangaone Gully - Morris, Fuchsia Ln	A1?	B3	D2	E2	F2	G3	H6	5-6
219	**Wairere Drive - north bank**	A1	B3	D2	E1	F1	G3	H5	4
221	Waitawhiri Gully - Agnew, Maeroa Rd	A2?	B3	D2	E1	F1	G3	H4	
224	**Waitawhiri Gully - Edgecumbe Park, native**	A1?	B3	D2	E1	F2	G3	H1	2
229	**Waitawhiri Gully - Edgecumbe Park, Redwoods**	A2	B3	D1	E1	F3	G3	H1	1
233	**Waitawhiri Gully - Lincoln Street, native**	A1	B3	D2	E2	F1	G3	H8	2
236	**Waitawhiri Gully - Lincoln Street, pines**	A1	B3	D2	E2?	F1	G3	H8	1
239	**Waitawhiri Gully - Rugby Park**	A2	B3	D2	E1	F2	G3	H1	1
242	**River Banks - Andrews Hill Conifers**	A2	B3	D1	E1	F2	G3	H3	
244	**River Banks - Opposite Tauhara Pk**	A2	B3	D1	E1	F3?	G3	H7	
247	**River Banks - Andrews Hill Woodland**	A2	B3	D1	E1	F2	G3	H2	
250	**River Banks - Braithwaite Park - Old Kanuka**	A3	B2	D2	E1	F4	G3	H3	
252	**River Banks - Braithwaite Park - Newer bank**	A1	B3	D2	E1	F1?/2	G3	H2	
254	**River Banks - Ham Golf Course**	A1	B3	D2	E2?	F1	G3	H3	
258	**River Banks - Hays Paddock (bridge end)**	A1?	B3	D2	E1?	F1?/3	G3	H6	
261	**River Banks - New Memorial Park/Memorial Pk**	A1	B3	D1	E1	F4?	G3	H7	
266	**River Banks - nr Days Park**	A2?	B3	D1?	E2?	F4?	G3	H6	
267	**River Banks - Victoria St Esp**	A1	B3	D2	E2?	F1	G3	H3	
270	**River Banks - Yendell Park**	A1	B3	D1	E1	F3	G3	H3	
272	**River Banks - Hamilton Gardens**	A1	B3	D2	E2	F2?	G3	H4	

B. Sample Plot Sheet

PLOT LOCATION

Description	Plot No:	Date:
	Code	Time:
	Grid Ref/ GPS:	Weather:

SITE DESCRIPTION

Slope	Aspect
Plot diameter (canopy)	Plot area
Plot diameter (subcanopy)	Plot area
Proximity of nearest source patch	

Drainage: insignificant ☐ very poor ☐ poor ☐ moderate ☐ good ☐ very good ☐ excessive ☐

Photo: ☐ Cores: ☐ Core species Soil Type: ________________

Location Diagram	
Maintenance and disturbance levels	Special features

DESCRIPTION – Trees (* indicates cored trees)							
No	Species	Type	Stem DBH	Canopy/ subcanopy	No stems	Hgt	Cause of death/ notes
1							
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SEEDLING REGENERATION PLOTS – Numbers OR presence in height classes							
Plot #	Species	<25cm	26 – 49 cm	50 – 99 cm	100 – 149 cm	150 – 199 cm	>200 cm

Groundcover (point intercept) [Classes: F=fern, L=litter, M=moss, R=roots, S=soil, V=vegetation, W=dead wood]			
Point (m)	Species	Class	Notes

C. Plot GPS Coordinates

PLOT	Eastings	Northings	Location and name	Owner
PLOT 01	2710059	6381620	Tauhara Park: Clements Crescent I	Hamilton City Council
PLOT 02	2710150	6381631	Tauhara Park: Clements Crescent II	Hamilton City Council
PLOT 03	2710223	6381664	Tauhara Park: Clements Crescent III	Hamilton City Council
PLOT 04	2709686	6381814	Tauhara Park: Longwood Place I	Hamilton City Council
PLOT 05	2710704	6381565	Onukutara Park: Hukanui Road I	Hamilton City Council
PLOT 06	2710697	6378811	Ranfurly Park: Ranfurly Avenue I	Hamilton City Council
PLOT 07	2708134	6382449	Braithwaite Park: Totara Drive	Hamilton City Council
PLOT 08	2710691	6378791	Ranfurly Park: Ranfurly Avenue II	Hamilton City Council
PLOT 09	2709829	6381936	Tauhara Park: Longwood Place II	Hamilton City Council
PLOT 10	2710601	6378861	Ranfurly Park: Ranfurly Avenue III	Hamilton City Council
PLOT 11	2708404	6381677	Wairere Drive overbridge	Hamilton City Council
PLOT 12	2712696	6373645	Fitzroy Park: Waterford Road	Hamilton City Council
PLOT 13	2708449	6377704	Lincoln Street: Waitiwhiriwhiri Espl.	Hamilton City Council
PLOT 14	2708615	6377498	Lincoln Street/Rifle Range Road Cnr.	Hamilton City Council
PLOT 15	2708473	6382517	Munro's Walkway: River Road	Hamilton City Council
PLOT 16	2713139	6375174	Hamilton Gardens: Hungerford Cres. I	Hamilton City Council
PLOT 17	2713169	6375202	Hamilton Gardens: Hungerford Cres. II	Hamilton City Council
PLOT 18	2713235	6375156	Hamilton Gardens: Hungerford Cres. III	Hamilton City Council
PLOT 19	2713232	6374831	Hamilton Gardens: Riverbank I	Hamilton City Council
PLOT 20	2713279	6375132	Hamilton Gardens: Hungerford Cres. IV	Hamilton City Council
PLOT 21	2710716	6378812	Ranfurly Park: Ranfurly Avenue IV	Hamilton City Council
PLOT 22	2710767	6381696	Onukutara Park: Wairere Drive	Hamilton City Council
PLOT 23	2712420	6373662	Fitzroy Ave: No. 39	D. Lee
PLOT 24	2715269	6375211	Humarie Park: Beverley Cres	Hamilton City Council
PLOT 25	2719028	6374055	Mangaharakeke Stream: Fuchsia Lane, Matangi I	P. Morris
PLOT 26	2715377	6375535	Morrinsville Road: No. 82	R. Cumings
PLOT 27	2712206	6373314	Splitt Avenue: No. 24	R. Korving
PLOT 28	2709575	6380197	Braid Road: No. 46	L. & J. Calcott
PLOT 29	2712209	6377254	Armagh Street: Seeleys Gully	A. Seeley
PLOT 30	2710993	6378472	Casey Avenue: No. 18C; I	D & A Sayers
PLOT 31	2710980	6378491	Casey Avenue: No. 18C: II	D & A Sayers
PLOT 32	2710835	6378259	Pines Beach Reserve: opposite 410 River Road	Hamilton City Council
PLOT 33	2712654	6374091	Sandford Park: Peacockes Road I	Hamilton City Council
PLOT 34	2715003	6374387	Hammond Park: Balfour Street	Hamilton City Council
PLOT 35	2715412	6374887	Berkley Avenue: No 59	J. Slavich
PLOT 36	2706942	6384230	Swampy Creek: River Road	C. Litt
PLOT 37	2704048	6394818	Great South Road, Taupiri: No. 127	L. Button
PLOT 38	2709247	6381869	Tauhara Park: River Road	Hamilton City Council
PLOT 39	2711961	6393175	Gower Road ,Komokarau I	P. Levin
PLOT 40	2709673	6393405	Gower Road ,Komokarau II	P. Levin
PLOT 41	2711659	6375226	Yendell Park: Cobham Drive	Hamilton City Council
PLOT 42	2710648	6378904	Ranfurly Park: Ranfurly Avenue V	Hamilton City Council
PLOT 43	2716906	6374416	'Wartle': Matangi Road I	Flower
PLOT 44	2716952	6374382	'Wartle': Matangi Road II	Flower
PLOT 45	2716114	6373845	Cambridge Road, Tamahere I	J. Dudley
PLOT 46	2716148	6373794	Cambridge Road, Tamahere II	J. Dudley
PLOT 47	2719591	6398839	Pukemokemoke Reserve	David Johnstone Trust
PLOT 48	2697990	6384401	Bedford Road, Te Kowhai	J. Hodge

PLOT	Eastings	Northings	Location and name	Owner
PLOT 49	2712577	6374133	Sandford Park: Peacockes Road II	Hamilton City Council
PLOT 50	2712990	6374587	Water Treatment Station I	Hamilton City Council
PLOT 51	2713107	6374562	Water Treatment Station II	Hamilton City Council
PLOT 52	2713073	6374531	Water Treatment Station III	Hamilton City Council
PLOT 53	2712627	6374927	Hamilton Gardens: Riverbank II	Hamilton City Council
PLOT 54	2719038	6374022	Mangaharakeke Stream: Fuchsia Lane, Matangi II	P Morris
PLOT 55	2710764	6381547	Onukutara Park: Hukanui Road II	Hamilton City Council
PLOT 56	2710758	6381566	Onukutara Park: Hukanui Road III	Hamilton City Council
PLOT 57	2710376	6381130	Chartwell Park: Herbert Road	Hamilton City Council
PLOT 58	2717476	6373863	Windmill Road, Tamahere	R. Ryan
PLOT 59	2710199	6379834	Fairfield College: Bankwood Road	College BOT
PLOT 60	2711697	6382177	Gordonton Pony Club, Gordonton Road	Hamilton City Council
PLOT 61	2710763	6378834	Ranfurly Park: Ranfurly Avenue VI	Hamilton City Council
PLOT 62	2712254	6379560	Dillicar Park: Sillary Street	Hamilton City Council
PLOT 63	2718990	6374018	Mangaharakeke Stream: Fuchsia Lane, Matangi III	P Morris
PLOT 64	2709475	6378446	Darley Street: No 19	J Rumney
PLOT 65	2708169	6382679	Waikato Esplanade: River Road Nth	Hamilton City Council
PLOT 66	2710792	6382262	Mangaiti Walkway: Hukanui Road	Hamilton City Council

D. Native and Adventive Vascular Plant Taxa Recorded in Restoration and Control Plots

Native Species

Adiantum cunninghamii
Adiantum hispidulum
Adiantum viridescens
Agathis australis
Alectryon excelsus
Aristotelia serrata
Arthropodium cirratum
Asplenium bulbiferum bulbiferum
Asplenium bulbiferum gracillimum
Asplenium flaccidum
Asplenium hookerianum
Asplenium oblongifolium
Asplenium polyodon
Astelia chathamica 'Silver Spear'
Astelia grandis
Beilschmiedia tawa
Blechnum chambersii
Blechnum discolor
Blechnum filiforme
Blechnum membranaceum
Blechnum novae-zelandiae
Blechnum sp.
Brachyglottis repanda
Carex dipsacea
Carex geminata
Carex secta
Carex sp.
Carex virgata
Carmichaelia aligera
Carpodetus serratus
Collospermum sp.
Coprosma arborea
Coprosma cv.
Coprosma grandifolia
Coprosma propinqua
Coprosma rhamnoides
Coprosma rigida
Coprosma robusta
Coprosma rotundifolia
Coprosma sp.
Coprosma tenuicaulis
Cordyline australis
Corokia cv.
Corynocarpus laevigatum
Cotula sp.
Cyathea cunninghamii
Cyathea dealbata
Cyathea medullaris
Cyathea smithii
Dacrycarpus dacrydioides
Dacrydium cupressinum
Dianella nigra
Dicksonia fibrosa
Dicksonia squarrosa
Diplazium australe
Doodia australis

Adventive species

Acanthus mollis
Acer negundo
Acer pseudoplatanus
Agapanthus orientalis
Agropyron repens
Allium triquetrum
Alnus glutinosa
Alocasia brisbanensis
Anagallis arvensis
Araujia sericifera
Aucuba japonica
Bambusa sp
Berberis vulgaris
Betula pendula
Buddleia davidii
Calystegia silvatica
Camellia japonica
Cardamine hirsuta
Casuarina cunninghamii
Chamaecytisus proliferus
Chlorophytum comosum
Choisya ternata
Cirsium vulgaris
Conium maculatum
Cortaderia selloana
Cotoneaster sp.
Crataegus monogyna
Crepis capillaris
Crocosmia x *crocosmiiflora*
Cymbalaria muralis
Cyperus sp.
Deparia petersonii
Dryopteris affinis
Duchesnea indica
Eleagnus x *reflexa*
Eriobotrya japonica
Erodium moschatum
Eucalyptus sp.
Euonymus europaeus
Euonymus japonicus
Euphorbia lathyrus
Euphorbia peplus
Fatsia japonica
Ficus pumila
Fumaria muralis
Galeobdolon luteum
Galium aparine
Hedera helix
Hedychium gardnerianum
Hypericum androsaemum
Impatiens sp.
Iris foetidissima
Jasminum polyanthum
Juglans sp.
Kunzea pedunculata
Lamium purpureum

Earina mucronata
Elatostema rugosum
Elaeocarpus dentatus
Entelea arborescens
Freycinetia banksii
Fuchsia excorticata
Geniostoma ligustrifolium
Grammitis sp.
Griselinia littoralis
Hebe sp.
Hebe stricta
Hedycarya arborea
Histiopteris incisa
Hoheria populnea
Hoheria sexstylosa
Hydrocotyle moschata
Hymenophyllum sp.
Juncus sp.
Knightia excelsa
Kunzea ericoides
Lastreopsis glabella
Laurelia novae-zelandiae
Leptopteris hymenophylloides
Leptospermum scoparium
Leucopogon fasciculatus
Libocedrus plumosa
Lophomyrtus cv.
Macropiper excelsum
Marattia salicina
Melicope simplex
Melicytus micranthus
Melicytus ramiflorus
Melicytus ramiflorus x *macrophyllus*
Metrosideros fulgens
Microlaena avenacea
Microsorum pustulatum
Microsorum scandens
Muehlenbeckia australis
Myrsine australis
Nothofagus fusca
Nothofagus menziesii
Nothofagus solandri
Olearia paniculata
Olearia virgata
Oplismenus imbecillis
Paesia scaberula
Parsonsia heterophylla
Passiflora tetrandra
Pellaea rotundifolia
Phormium cv.
Phormium tenax
Phyllocladus trichomanoides
Pittosporum colensoi
Pittosporum crassifolium
Pittosporum eugenioides
Pittosporum ralphii
Pittosporum tenuifolium
Pittosporum tenuifolium cv.
Plagianthus regius
Pneumatopteris pennigera
Podocarpus hallii
Podocarpus totara
Laurus nobilis
Leucanthemum vulgare
Leycesteria formosana
Ligustrum lucidum
Ligustrum sinensis
Liquidambar styraciflua
Lonicera japonica
Lotus pedunculatus
Lunaria annua
Mahonia aquifolium
Malva parviflora
Mentha pulegium
Monstera deliciosa
Myositis scorpioides
Nephrolepis cordifolia
Oxalis sp.
Paulownia tomentosa
Persicaria persicaria
Phytolacca octandra
Pieris japonica
Pinus sp.
Plantanus major
Poa annua
Polystichum sp.
Populus sp.
Prunus sp. (Cherry)
Prunus sp. (Plum/peach)
Pteris cretica
Quercus robur
Racosperma melanoxylon
Ranunculus repens
Raphiolepis umbellata
Rhododendron sp. (Azalea)
Robinia pseudoacacia
Rubus fruticosus
Rumex sagittatus
Rumex sp. (Dock)
Salix cinerea
Selaginella kraussiana
Senecio jacobaea
Solanum mauritianum
Solanum nigrum
Solanum pseudocapsicum
Sonchus oleraceus
Sorbus aucuparia
Stachys sylvatica
Stachyurus praecox
Stellaria media
Taraxacum officinalis
Trachycarpus fortunei
Tradescantia fluminensis
Trifolium pratense
Ulex europaeus
Veronica persica
Viola odorata
Zantedeschia aethiopica

Polystichum richardii
Prumnopitys ferruginea
Prumnopitys taxifolia
Pseudopanax arboreus
Pseudopanax crassifolius
Pseudopanax laetus
Pseudopanax x *lessonii*
Pseudowintera colorata
Pteridium esculentum
Pteris macilenta
Pteris tremula
Pyrrosia eleagnifolia
Raukawa anomala
Rhopalostylis sapida
Ripogonum scandens
Schefflera digitata
Solanum aviculare
Sophora microphylla
Sophora tetraptera
Streblus heterophylla
Tmesipteris sp.
Uncinia uncinata
Vitex lucens

E. Selected Spearman Correlations

	Spearman Rank Order Correlations (Spreadsheet in matrix of 7 variablesv2) MD pairwise deleted Marked correlations are significant at p <.05000 Include cases: 1:66								
Variable	Average Age	Slope	Aspect	Soil moisture	Maintenance	Overall disturbance	Average distance to seed source (m)	Percent sand	Ownership
No of Native lianes/ epiphytes species	0.63	0.19	0.02	0.03	-0.28	-0.23	-0.21	-0.00	0.38
No of exotic lianes species	-0.03	-0.07	0.22	-0.18	-0.13	0.05	0.19	0.06	-0.37
No of Native Canopy Species regen	0.13	-0.01	0.25	-0.13	0.19	-0.04	0.06	0.10	-0.05
alpha (canopy to seedlings)	0.03	-0.01	-0.13	-0.01	0.58	0.44	-0.04	-0.22	0.06
alpha (regen)	0.38	0.20	0.29	-0.14	-0.11	-0.15	-0.19	-0.03	0.36
Fern %GCover	0.38	0.21	0.00	-0.34	-0.18	-0.22	-0.17	-0.10	0.38
Litter %GCover	-0.16	-0.27	-0.02	0.13	0.06	0.05	0.12	0.01	-0.07
No of diameter classes	0.44	-0.20	-0.15	0.15	0.20	0.41	-0.06	-0.30	0.16
No of structural layers	0.32	0.41	-0.08	-0.22	-0.20	-0.22	-0.22	0.03	0.21
No of regen classes	0.20	0.21	0.28	-0.01	-0.24	-0.18	-0.13	0.18	0.20
No of stems /100m2	-0.07	0.16	0.12	-0.04	-0.14	-0.32	-0.08	0.32	-0.05
No of native stems /100m2	0.02	0.11	0.26	-0.14	0.03	-0.30	-0.04	0.27	0.10
Total biomass estimate (m3/100m2)	0.52	0.26	-0.05	-0.04	-0.14	0.05	-0.19	-0.06	0.37
Total Basal Area(cm2 /100m2)	0.54	0.30	-0.07	-0.13	-0.19	-0.11	-0.26	-0.04	0.40
Native regen -Proportion of Canopy Species	0.24	0.00	0.28	-0.13	0.02	-0.14	0.05	0.04	0.02
Total regen - Proportion of Canopy Species	0.11	0.07	0.27	-0.13	-0.12	-0.22	-0.05	0.11	-0.03
Proportion Native regen counts	0.37	0.29	0.06	0.01	-0.07	-0.18	-0.18	-0.06	0.33
Native regen counts	0.40	0.13	0.18	-0.12	0.03	-0.05	-0.17	-0.07	0.16
OVERALL DISTURBANCE	-0.10	-0.25	-0.12	0.05	0.51	1.00			
Average distance to seed source (m)	-0.37	-0.38	0.17	-0.13	-0.03	0.27	1.00		
Ownership	0.41	0.38	-0.01	-0.10	-0.04	-0.34	-0.44	0.02	1.00