DEVELOPMENT AND ASSESSMENT
OF
AN APPROACH FOR
URBAN RIPARIAN RESTORATION

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Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Masters of Applied Science

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Urban waterways are highly degraded; recent research indicates that management by planting riverbanks can reduce water pollution and increase wildlife habitat. There are ecological, social, economic and legal reasons for restoring riparian zones (areas of land adjacent to waterways) in and near cities. Christchurch, New Zealand, was used as a case-study to develop an approach for selecting riparian plant species, and ascertaining their environmental ranges, to enhance planting success. The approach involved choosing relevant environmental variables, simple field sampling methods, and data analysis and presentation methods suitable for use by non-specialist restoration practitioners. Environmental data for self-established and planted individuals of several riparian species were collected from semi-natural riparian areas in the Low Plains Ecological District. The environmental variables measured in the field included soil moisture, elevation and distance from water, broadly defined riparian class (eg., river, backswamp), and specifically defined riparian class (eg., lower bank, mid-bank), slope and slope shape (as indications of drainage), aspect, frost, and soil pH and conductivity.

Between species t-tests were performed to ascertain the most important environmental variables for each species. Within species t-tests were done for species where both self-established and planted data was recorded. Ordination assisted in identifying duplicate environmental variables. Species ranges were compared in Tukey boxplots.

Comparison of self-established and planted data for several tree species and *Phormium tenax* indicated that planted individuals were found in significantly higher, drier and more frosty sites than their self-established counterparts (most p-values >0.05).

Soil moisture, riparian class, canopy and slope were the most distinguishing environmental variables. Species responded to different combinations of these variables and were within the expected ranges for the Christchurch area. With refinement, frost and aspect may also be useful variables. Variables not fully captured but considered important are water level fluctuation and soil texture. It was concluded that the methods were most applicable in areas where little information on species ranges exists, or for monitoring species in modified urban restoration projects.

Several variables could be summarised into a graph and table, however the development of a simple species database is suggested for inputting, analysing, and updating complex data. GIS is considered to be a useful tool for mapping, planning and monitoring riparian restoration projects in large scale or sensitive projects.

One future direction for research is the development of an interactive database, compiling information on species attributes and riparian function (eg., for erosion control), to support the riparian management decision process.

In conclusion, the approach developed will assist in selecting suitable species for the environmental gradients at a riparian restoration site, and should lead to a more rigorous and successful approach to riparian planting and monitoring.

Key Words

Restoration ecology, riparian management, riparian vegetation, environmental variables, indigenous, waterway, Christchurch.

Nomenclature

Nomenclature follows Poole and Adams (1994) for tree and shrub species, Johnson and Brooke (1989) for sedge, rush and other riparian herb species, and Brownsey and Smith-Dodsworth (1989) for fern species (except *Phymatosorus pustulatus*[1] in Large and Braggins, 1992).

Glossary of Terms and Abbreviations

CCC :Christchurch City Council

Decision support system: a systematic approach to providing an appropriate synthesis of information gathered from many sources and sectors.

GIS: Geographical information system. Hardware and software combinations that include collection, storage, analysis, and output of spatially referenced data (Malanson, 1993).

GPS: Global positioning system. A mapping tool using satellite positioning.

PCA: Principal Component Analysis. An ordination technique.

Restoration ecology: Variously defined. "Ecological restoration is the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems" (Jackson et al., 1995). This process is viewed as a continuum in this thesis.

[1] Erratum in New Zealand Journal of Botany. 1992. **30:**372.

Riparian zone: Riparian zones are three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems (Gregory et al., 1991). "The boundaries of riparian zones, when defined from this perspective, extend outward from the channel to the limits of flooding and upward into the canopy of streamside vegetation" (Sedell et al., 1991).

RMA: Resource Management Act

Significance levels are indicated in the text in the following style: * (p-value=0.05); ** (p-value=0.01); *** (p-value=0.001).

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Lowland areas in New Zealand are highly modified through farming and urban development. The waterways dispersed through this lowland landscape have been affected by plant and animal introductions, drainage of over 90% of New Zealand's wetlands (Collier, 1994), engineering works on rivers for flood control, urbanisation, and industrial development. These factors have contributed to a decline in water quality, and damage to aquatic and riparian (land on the edge of rivers) habitats from degradation due to the use and abuse of surrounding land. Extant remnant vegetation is often disturbed by city and rural maintenance practices that seek to optimise drainage and reduce flooding, and through farming management practices that require water abstraction and stock access.

Several studies have indicated that vegetated riparian zones (land near rivers) mitigate the influences of surrounding land use (Collier et al.,1995). Councils and other landowners are revegetating riparian zones to improve waterway quality. However, the improvement of riparian zones through planting has often proceeded on a site by site basis with little theory or methodology supporting successive projects. Increasing commitment of financial and human resources requires a systematic approach to riparian planting. The science of restoration ecology can offer an ecological basis for planting riparian zones to aid in effectively meeting a wide range of riparian management objectives. The focus of this research is to develop an approach for choosing appropriate plant species and for understanding their environmental ranges, as one component of a restoration ecology framework for riparian management. Christchurch, New Zealand (Fig. 1.1), was used as a case-study to develop the approach. A future goal is to apply the approach in urban and/or rural areas in other parts of New Zealand.

This chapter introduces the following:

- a definition of the riparian zone;
- the legal requirements for sustainable riparian management;
- an ecological basis for riparian management;
- the development of urban restoration ecology as a mitigative, scientific, and social goal for cities;
- the past and present natural, human, and heritage values of riparian areas in Christchurch;
- the present riparian management approach in Christchurch; and,
- the objectives and scope of the thesis.

1.2 What are Riparian Zones?

Riparian zones are three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems (Gregory et al., 1991). "The boundaries of riparian zones, when defined from this perspective, extend outward from the channel to the limits of flooding and upward into the canopy of streamside vegetation" (Sedell et al., 1991). A refinement of this definition might be to define the vertical limits of the riparian zone as 'up to the potential canopy of streamside vegetation'. Figure 1.2 highlights the relationship between a stream and its riparian area, and the various influences of the riparian area on the stream.

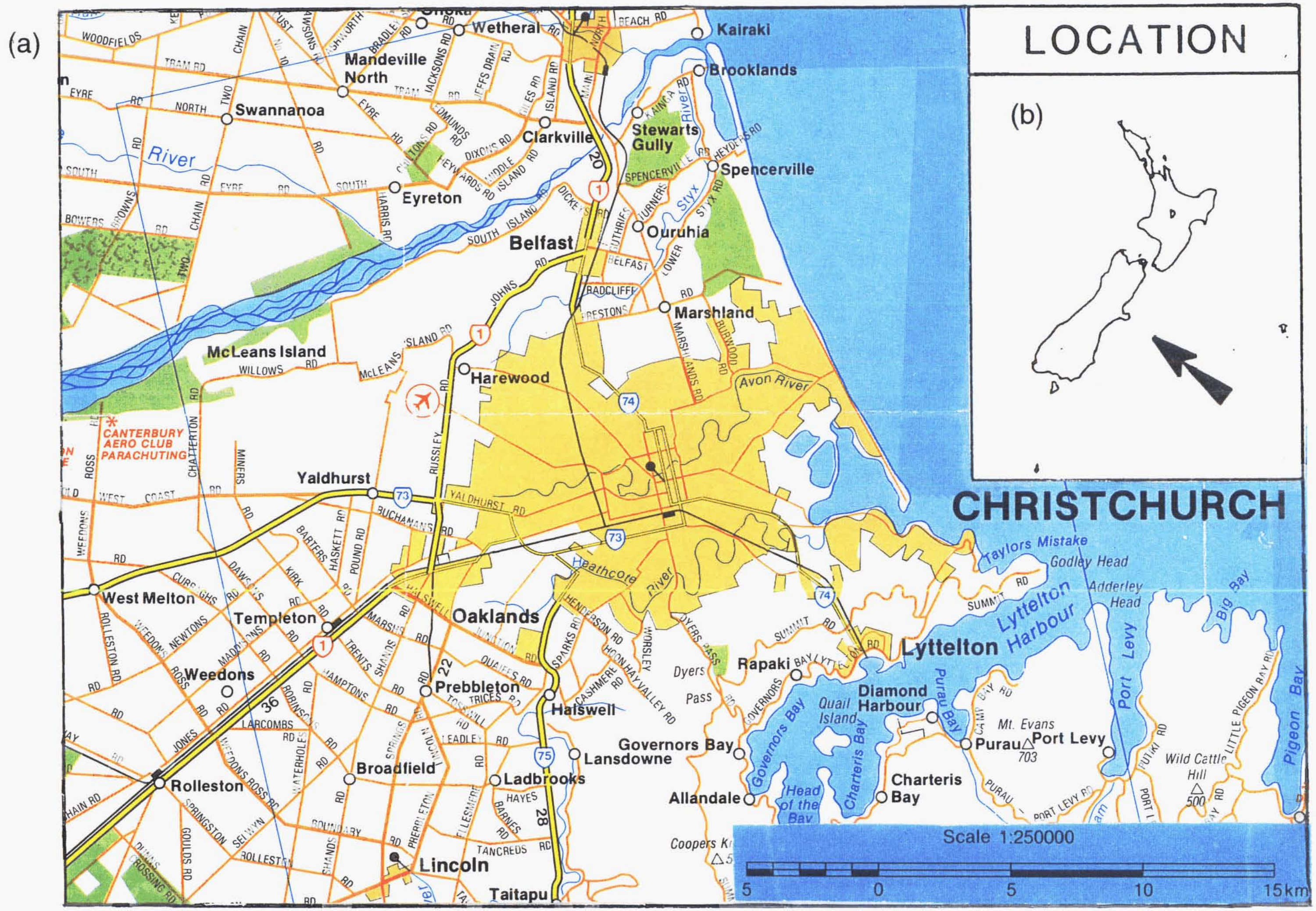


Figure 1.1: Christchurch (a), on the east coast of the South Island in New Zealand (b) was the location of the research. (Sited between latitude 43 and 44, and at longitude 173).

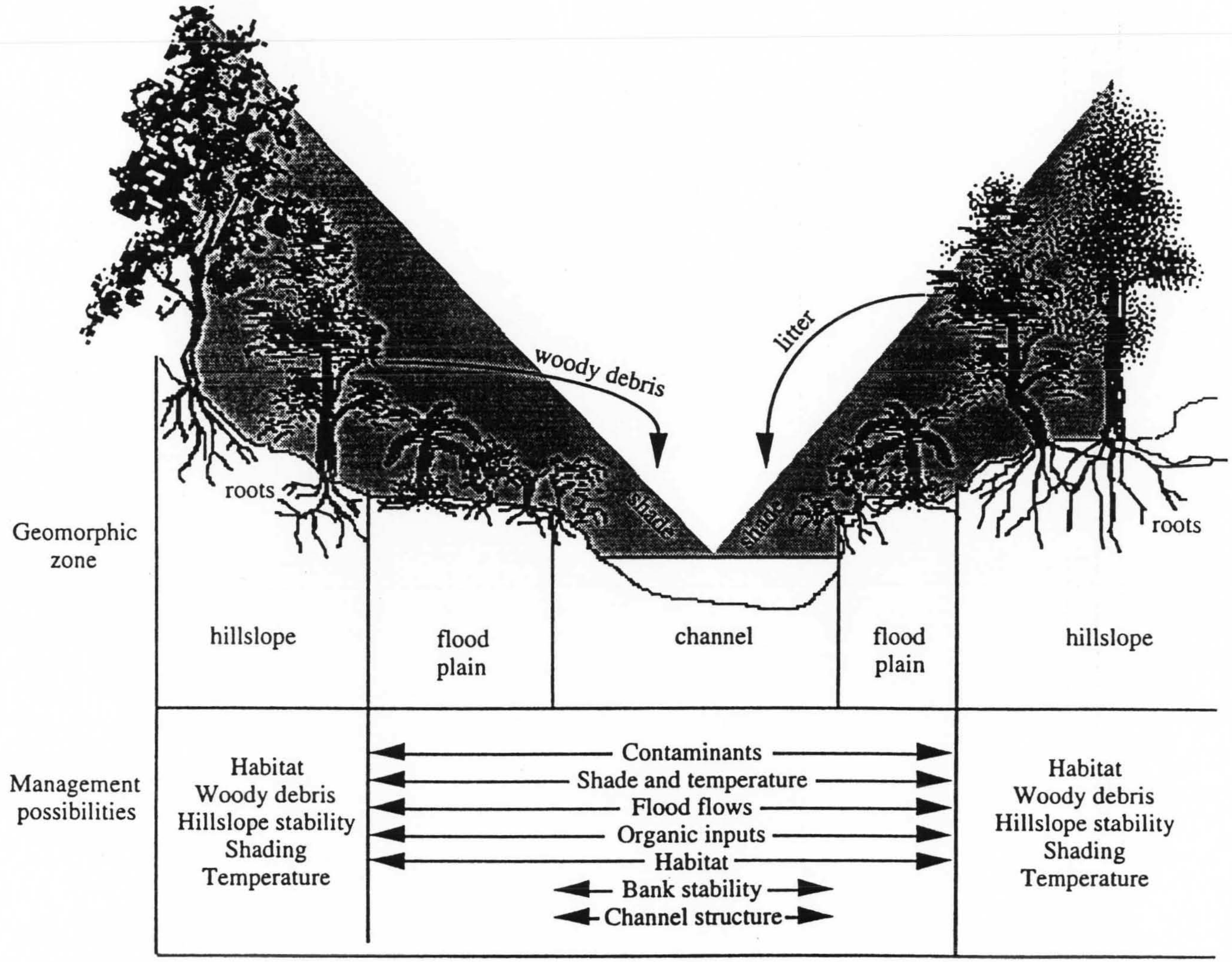


Figure 1.2: Conceptual diagram of a stream and its riparian area showing geomorphic zones and management possibilities (Collier, et al., 1995).

1.3 Benefits of Riparian Zone Management

The recent publication, "Managing Riparian Zones" (Collier et al., 1995), which brought much of the relevant research together for rural land managers in New Zealand, suggests that riparian vegetation is one of the easiest riparian attributes to manage. The document offers the following vision for riparian management:

> ....appropriate riparian management would reduce bank erosion, nutrient inputs and maximum summer water temperatures. The dappled light filtering through riparian vegetation would deter algae and aquatic weeds from proliferating. A biological community would develop in which thin algal layers on stones and leaves from riparian plantings provide food for a diverse community of aquatic insects which, in turn, provide food for fish and birds. Wood, fallen from riparian trees and retained in stream channels, would reduce substrate movement and increase the habitat available for fish. A diverse terrestrial fauna would colonise planted riparian areas, utilising the foods supplied by streams and rivers, and using the riparian zones as corridors for movement up and down catchments. Plantings of appropriate native species would provide habitat and lead to an increase in native biodiversity. (P. 5, Collier et al., 1995).

The field of restoration ecology offers a comprehensive set of theories that are applicable for riparian planting. In cities, the issue of ecological restoration of riparian areas to optimise riparian management is complex. There are overlapping or conflicting goals of good water quality and controlled quantity, ecosystem health, drainage, habitat creation, and cultural use and aesthetics. Issues of competition for space, and public perception of native versus exotic plants and safety, add to the complexity of decision making.

The potential environmental benefits of maintaining riparian zone function are summarised in Table 1.1.

Table 1.1: Summary of riparian zone functions that potentially buffer streams from various land use effects (modified from Quinn et al., 1993, by Collier et al., 1995).

Riparian Zone Function	Potential In-stream Effects
• Buffers banks from erosion • Buffers channels from localised changes in morphology • Buffers input of nutrients, soil, microbes and pesticides in overland flow • Denitrifies groundwater • Buffers energy inputs • Provides in-stream food supplies and habitat • Buffers floodflows • Maintains microclimate • Provides habitat for terrestrial species • Maintains dispersal corridors	• Reduces fine sediment levels • Maintains water clarity • Reduces contaminant loads • Prevents nuisance plant growths • Encourages growth of bryophytes and thin periphyton films • Maintains lower summer maximum temperatures • Increases in-stream habitat features and terrestrial carbon inputs • Maintains food webs • Reduces floodflow effects • Increases biodiversity

In addition to the environmental benefits of planting riparian zones, there are social, cultural and economic benefits. These benefits include educational, aesthetic, sense of place and heritage, cultural use, and riparian designs that are economically more viable, and socially more acceptable in the long-term. Waterways have a multitude of values, necessitating a multi-disciplinary approach to riparian zone management, especially in the urban context.

1.4 The Legal Framework

Three main legal documents require the sustainable management of riparian zones: The Resource Management Act 1991, Conservation Act 1987 and Amendments, and the Convention on Biological Diversity 1992.

The purpose of the Resource Management Act is to promote the sustainable management of natural and physical resources (Section 5(1) (Part II), RMA

1991). Sustainable management is the management of resources so that they provide for the well-being (in a broad sense) of people now and in the foreseeable future within environmental limits, and while

> "Avoiding, remedying, or mitigating any adverse effects on the environment."
> (Subsection 5(2)(c) RMA)

In section 6 (a) (Part II) of the RMA, the preservation of the natural character of wetlands and lakes and rivers and their margins is stated to be a matter of national importance. Sections 6 (c) and Section 7 have implications for riparian zone management. Section 7 requires that functionaries consider maintaining and enhancing the environment when making decisions about the use, development, and protection of resources.

The Conservation Act 1987 promotes the conservation of New Zealand's natural and historic resources. The Convention on Biological Diversity 1992 advocates setting policies that preserve and enhance biological diversity.

1.5 Restoration Ecology: The Science

This thesis proposes that the science of restoration ecology is an ideal approach to improving the functioning of urban riparian zones. While it focuses on developing methods for measuring the environmental ranges of species, the research fits into the larger restoration ecology framework discussed below.

1.5.1 Definitions, Principles and Goals

Various definitions of restoration ecology have been explored in the literature in recent years. Examples of these definitions are summarised in Table 1.2.

Table 1.2: Definitions of restoration ecology.

Source	Definition
Jackson et al. (1995)	"Ecological restoration is the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems". p.71.
Atkinson (1988)	".... active intervention and management to restore or partially restore biotic communities, both their plants and animals, as fully functioning system". p.1.
Meurk (in prep.)	"Habitat restoration is the indigenous revegetation (and animal repopulation) of more or less natural landform-soil systems in accord with environmental gradients (biotope planting); it could in its least intrusive form include merely removing a destructive element (pest, weed, logging activity, drain, etc) and allowing natural regeneration to occur". p.2.
Hobbs and Norton (1996)	Hobbs and Norton emphasise the idea that "...restoration occurs along a continuum, and that different activities are simply different forms of restoration". p.94.

There has been a tendency to view restoration ecology as distinct from activities termed as rehabilitation, revegetation, recovery of species, enhancement, ecological engineering, naturalistic rehabilitation, and gardenesque rehabilitation (Meurk, in prep; Atkinson, 1994). The definitions presented by Meurk (in prep.) and Atkinson (1994) are important for accurate scientific definition of a project's aims depending on the context. The view presented in this thesis agrees with Hobbs and Norton (1996) that "restoration ecology occurs along a continuum, and that different activities are simply different forms of restoration". In whatever context restoration ecology is occurring, restoration aims to restore the degraded system to some form of cover which is protective, productive, aesthetically pleasing, or valuable in the long term (Hobbs and Norton, 1996). Furthermore, a restoration aim important for urban riparian zones, is to develop a system which is sustainable in the long term (Hobbs and Norton, 1996), ie., with ecological, social and economic benefits. If the reader accepts the theory that restoration ecology is a social construct, then any actions taken to restore an ecosystem are important for their educational and experiential value. To overdefine the terms may be to exclude the human population that will ultimately support the approach of ecological restoration.

The six principles outlined in Table 1.3, are generally applicable to urban restoration ecology. Principle 3 states that ecological restoration is most needed where natural ecosystems are severely degraded. Urban areas are predominantly in lowland New Zealand and are highly degraded. For both ecological and social reasons ecological restoration is important in and near cities. Principle 5 suggests that the ultimate goal is to minimise human input. This is acceptable in terms of the sustainability of the restoration project. However, for successful urban restoration ecology people need to be involved at all stages. This may include the planning stages of the project, in the recreational enjoyment and education that the restored area may offer, and in the monitoring and maintenance phases.

In a review of Department of Conservation restoration projects, Atkinson (1994) found that restoration goals were seldom clearly identified. Many definitions of restoration ecology for conservation purposes focus on the idea of re-establishing what might have occurred on a site before disturbance (Hobbs and Norton, 1996). In highly modified urban areas it is difficult to assess exactly what was here before, and it is unlikely that present social conditions would allow a complete return to a past state. Reinstating the wetlands on which the city of Christchurch is built is unlikely to be popular! While planting indigenous vegetation along environmental gradients will be appropriate, the available riparian areas in which to plant have been modified, and riparian management goals may dictate the plant assemblages in the restoration project. In or near cities, riparian management goals might include areas for conservation of species, recreation, education, science, cultural use, wildlife corridors, water quality protection, erosion control or property improvement, in addition to the specific restoration goals of recreating ecosystem processes. This necessarily entails setting out the goals with the client/community at the beginning and directing the structure of the restoration ecology project towards achieving the stated goals. Ideally, several goals would be achieved in the design of the restoration project. Restoration ecology is appropriate for urban riparian management so long as ecosystems are perceived as dynamic entities and restoration ecologists are willing to work with the challenges that the urban environment imposes. The success criteria used to evaluate restoration projects will depend on the stated goals and objectives of the project.

Table 1.3: Six principles of restoration ecology in New Zealand suggested by Barker and Simpson (1995).

Principles Of Restoration Ecology In New Zealand
1) Ecological restoration is active intervention, primarily to restore ecological processes in order to enhance ecological viability and the conservation of indigenous biological diversity;
2) Ecological restoration can focus on a species (for example, a threatened species), an ecosystem (for example, representativeness), or a place (for example, an island) but it is ultimately process-orientated;
3) Ecological restoration is most needed where natural ecosystems are severely degraded, and these often coincide with land developed for production, under private ownership;
4) Because ecological restoration often involves private land, the support of the local community is essential;
5) Ecological restoration involves human intervention but this should catalyse natural processes in order to minimise on-going human input;
6) Ecological restoration goes "hand in hand" with other conservation activities which aim to minimise the trend towards disruption of ecological processes and the loss of biodiversity.

1.5.2 Benefits of Restoration Ecology in Urban Areas

While much of the restoration ecology in New Zealand has focused on islands, there are plant protection and social benefits to applying similar approaches in urban areas. Cities are often in lowland areas and lowland habitats are generally not represented in New Zealand's protected areas. Urban riparian zones also offer the potential to create or re-create linear habitats or wildlife corridors (Spellerberg and Gaywood, 1993) in lowland New Zealand. Riparian corridors can link fragments of natural habitat across diverse environments. The use of local species in restoration of plant provenance, is widely recognised as important to maintain genetic biological diversity. Corridors planted with local genetic stock can provide proximity and sites for pollen and seed dispersal, thereby strengthening the populations of local species.

Restoration ecology also provides a scientific challenge by providing experimental situations in which unanswered questions about flora and fauna may be addressed (Atkinson, 1988).

1.5.3 Levels of Restoration Ecology

There are various levels of restoration ecology. The first level, and the one explored in this thesis, is an understanding of species distribution in relation to environmental gradients. Grime et al., (1988) used a wide range of environmental variables, including altitude, slope, hydrological class, aspect and soil pH to quantify the distribution of British flora.

In relation to environmental gradients in riparian zones, Howard-Williams (1991) wrote:

> The land-water ecotone is often characterised by sharp environmental gradients relative to adjacent ecosystems, and high biological diversity frequently occurs at this interface with marked species zonations associated with these gradients. (p.87).

Standard measurement procedures for riparian vegetation often include recording data on slope, elevation, soil and hydrology (Kondolf and Micheli, 1995). For riparian restoration, soil moisture is often a particularly important variable for defining plant site; riparian areas include sites that range from extremely dry to saturated conditions (Malanson, 1993). The environmental variables chosen for study will be more or less important depending on the topography, geology, hydrology, the climate and weather, and the present or potential ecosystems at the restoration site. However, understanding the environmental variables that influence plant success is only one aspect of restoration ecology; Table 1.4 gives examples of other ecological components of restoration not fully explored in this thesis.

Table 1.4: Ecological components of a restoration project (adapted from Meurk, in prep.)

Components of a Restoration Project
1) ***An understanding of the regional flora.*** Information on flora may be compiled from a range of sources including: pollen and subfossil records, and reconstructions of plant assemblages from these records; early surveyor reports; botanist notes from early colonisation; and archival photographs and drawings.
2) ***The land unit to be restored***, eg., riparian zones which support known assemblages of plants and animals. Assemblages of plants and animals can be assembled from Step One. Exact location of plants in relation to environmental variables requires observation and/or ecological research.
3) ***The individual species*** individualistically fitted to the environmental gradient with the land unit. This information is gathered from Step Two, and tested through monitoring.
4) ***Organisms must then be added to the system in the right order***, and at the right time. Seral, matrix or keystone species of the intended community should play a role from the beginning. This includes species with functional purposes, such as plants that offer fruit or nectar for birds, or shelter for fish and invertebrates.
5) ***Management and maintenance***, including control of plant and animal pests, and management for specific riparian management, ecosystem or social objectives.
6) ***Monitoring*** of the success or failure of the plantings and of restoration impacts, eg., evaluation of social, hydrological, and economic objectives.

1.6 Restoration Ecology: A Social Construct

The hands-off approach to conservation in New Zealand, and the fact that most 'natural' areas are quite some distance from cities, has alienated people from their responsibility for environmental protection and restoration. Restoration ecology aims to bring culture and nature much closer together, physically, functionally and spiritually (Barker and Simpson, 1995).

Restoration ecology comes from a human need to positively influence nature, a counteraction to the destruction of natural ecosystems, both intentional and unintentional. The whole concept of restoration ecology is a socially created, human value centred approach to relating to the Earth. It is a critical approach to rehabilitating and mitigating our destructive influences through the action of restoration (the process of involving people) and the outcomes of restoration (the ultimate goal of creating functioning ecosystems).

1.6.1 Societal Support for Restoration

Engendering societal support through active participation and consultation in the process of planning and implementation of restoration projects will be more socially sustainable in the long-term. Proximity and affinity with nature, the sense of pride in involvement in restoration (Cairns, 1993), and the enhancement of the immediate environment are key social benefits. Restoration provides one of the most accessible ways in which local communities can become involved in nature conservation and see positive outcomes as restoration develops through time (Norton, 1995). Public participation and education are often suggested as ways of ensuring the long-term success of restoration projects (Saunders, 1990; Craig, 1990; Bellingham, 1990). Funds for restoration will only become available if the science is socially acceptable and if the results of the science are easily interpreted by society.

1.6.2 Restoration Ecology is Multi-Disciplinary

Restoration ecology in the city has ecological, social and economic benefits, necessitating a multi-disciplinary approach. The landscape itself is not a single phenomenon and cannot be studied adequately from only one approach. Restoration requires the participation of ecologists, botanists, educationalists and residents, and can engender therapeutic, cultural, heritage, aesthetic and community values (Atkinson, 1988).

1.6.3 Restoration as a Multi-Cultural Discipline

In addition to being multi-disciplinary, restoration is multi-cultural. Different cultures view the environment from different perspective's (Puia, 1990; James, 1990) necessitating clear goal definition, and multi-cultural input into science, research and restoration planning. Restoration goals from the Maori cultural perspective may include sustainable use of riparian resources for food, art, and ritual, while from a European perspective may include aesthetics or preservation. As New Zealand is a multi-cultural society, a planning strategy that focuses on understanding the spectrum of riparian restoration values and goals is a key component of restoration.

1.6.4 Integrating the Social and Ecological

Inherent in the concept of restoration ecology proposed here is the premise that social influences impact, and ultimately direct both our desire to research and understand the world around us, and to restore or recreate nature in our proximate environment.

Jackson et al., (1995) suggest that restoration is governed by four interrelated social and biological conditions: how nature is valued by society; the extent of social commitment to ecological restoration; the ecological circumstances under which restoration is attempted; and the quality of ecological judgements about how to accomplish restoration (Fig. 1.3). The weighting on each of these factors in an urban riparian project will dictate its placement along the continuum of restoration ecology goals.

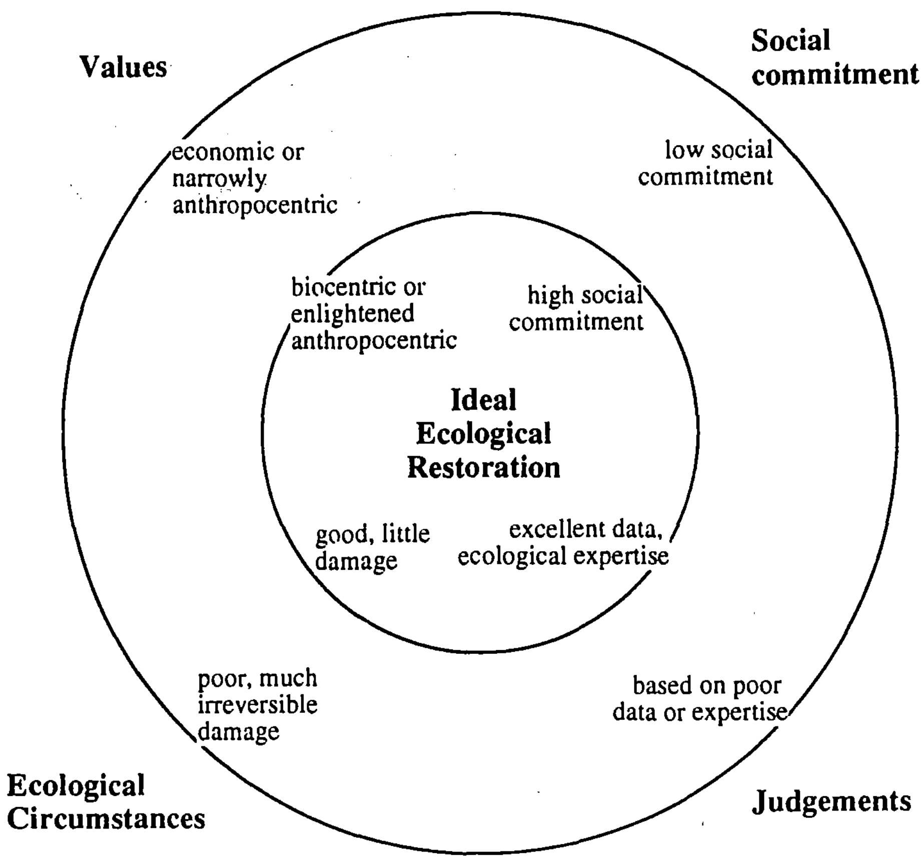


Figure 1.3: The success of restoration ecology projects are limited by several factors: social values and commitment to the project; the ecological circumstances under which restoration occurs; and the ecological judgements on how to restore the site. (Figure from Jackson, et al., 1995).

1.7 Restoration of Christchurch Riparian Areas: A Case Study

The Christchurch office of Boffa Miskell Ltd (landscape architects, environmental planners and ecologists), for whom this research has been undertaken, recognised both ecological and decision making gaps in the process of riparian zone restoration, and proposed research and development in this area. Christchurch was a logical case study choice in terms of proximity.

Christchurch's natural and human history is summarised, and the state of Christchurch's riparian margins and policy directions in the 1990s reviewed. This section provides the background for the case study component of the thesis.

1.7.1 Natural History of Christchurch: Setting the Scene

Geography and Geology

Christchurch is situated on the east coast of the South Island of New Zealand, between latitude 43 and 44, and at longitude 173 (Fig. 1.1).

Geological research indicates the successive disturbance effects of glaciation, fluctuation of sea levels, and the accumulation of outwash sediments from the mountains (deposited by major Waimakariri River flood events), created the present day Canterbury Plains and the site of Christchurch city (Brown and Weeber, 1995).

Forests and other vegetation, destroyed by major flood events, were found buried under various depths of alluvium (Molloy and Brown, 1995). With the settlement of Christchurch city, and control of the rivers, the dynamic nature of the flood disturbed ecology on the lower Plains was curtailed.

Weather

The climate is one of low rainfall, cool frosty winters and warm, dry summers (Molloy and Brown, 1995). The Christchurch area is relatively windy with frequent hot, dry, Northwesterly winds effecting strong evaporation (Ryan, 1995). Extensive flooding is associated with long-duration rainfalls (Ryan, 1995). Although rainfall is evenly distributed throughout the year, its effectiveness for plant growth varies seasonally due to changes in temperature and evaporation (Ryan, 1995).

1.7.2 History of the Vegetation of Christchurch

Evidence of Early Vegetation

Geological evidence indicates that one of the few remaining bush remnants in Christchurch city, Riccarton Bush, and other forest remnants were relics of once greater forests which had been replaced by secondary vegetation of various kinds.

Many large roots, trunks of trees and stumps were found on the Plains by early settlers, leading Torlesse, Deans and Godley to comment on the probability of previous forests on the Plains (Molloy and Brown, 1995). Other evidence today, such as charcoal from burnt trees or shrubs in drier areas, or the peaty remains of former forest on poorly drained land, leads to the conclusion that forest once existed widely in Christchurch. Radiocarbon ages of charcoal indicate a series of fires throughout the postglacial period (Molloy and Brown, 1995). Radiocarbon dates of less than 1000 years ago were most likely derived from fires lit during the Maori period of occupation. These results were determined independently on archaeological remains like moa bone, marine and freshwater shells, wood artefacts and oven charcoals (Molloy and Brown, 1995).

Plant species recorded from post-glacial wood and charcoal remains are similar to those recorded in forest remnants in early European times (Molloy and Brown, 1995). Totara (*Podocarpus totara*), matai (*Prumnopitys taxifolia*), kahikatea (*Dacrycarpus dacrydioides*), kanuka (*Kunzea ericoides*), and ribbonwood (*Plagianthus regius*) figure predominantly. Other species like miro (*Prumnopitys ferruginea*), manuka (*Leptospernum scoparium*), lacebark (*Hoheria angustifolia*), mahoe (*Melicytus ramiflorus*), and Coprosmas are also often found. Pollen, seeds, leaves and twigs recovered from buried post-glacial peats in different parts of Christchurch tell the same story. They appear to be dominated by the remains of totara, matai, kahikatea, manuka, sedges, grasses and other herbs (Molloy and Brown, 1995).

Evidence points to a mosaic of forest, scrub, grassland and wetland during the postglacial period. It is unlikely that forest formed a continuous cover at any one time due to the relatively high frequency of fires, floods and ponding (Molloy and Brown, 1995). From the city area, tall forests extended across the Plains to the foothills on all younger deeper soils flanking the rivers, giving way in between to scrub of kanuka and manuka on older surfaces with shallow, droughty soils (Molloy and Brown, 1995).

Early Observations of Vegetation in Christchurch

In 1836, the first, although brief, description of Christchurch was noted by Captain William Rhodes of the "Australian"...

> .....saw the Plains and two pieces of bush. All the land that I saw was swamp and mostly occurred in water. (In Molloy and Brown, 1995).

On most of the Plains the vegetation was low growing tussock sedges, 'toi toi' (*Cortaderia spp.*), raupo (*Typha orientalis*), flax (*Phormium tenax*), *Carex* spp., and cabbage trees (*Cordyline australis*). The Black Maps (from surveys in 1856) documented wetlands of raupo swamp; raupo and flax swamps; tussocks and raupo; flax swamps and toi toi; and, flax and raupo. While some pictorial archives indicate swamp vegetation (Fig. 1.4), wetland vegetation, along with grassland and sand dune vegetation, are poorly represented in the pictorial record (Molloy and Brown, 1995).

By 1870 little remained of the forest remnants of Christchurch. The timber demand for buildings and firewood left little more than a few stumps in most places. The active and accidental arrival of exotic species further stressed the habitat left after drainage and clearing. John Armstrong (1872), a long time gardener in charge of the Botanic Gardens, wrote:

> ....So completely have these introduced plants established themselves in the neighbourhood of Christchurch, that they nearly equal the native plants in the number of species, and by far out number them in the abundance of each kind...it must be quite evident to every observer that the introduction of these European plants will certainly result in the extermination of the indigenous flora, and that at no very distant period of time. (In Molloy and Brown, 1995).

1.7.3 Human History Of Christchurch

There was a long history of Maori occupation of the area in and around Christchurch before the arrival of European settlers. Various villages and kaikas (an unfortified settlement or a seasonal camp) were established in the Christchurch area as places of food gathering and as rest places.

Water was the centre of all activity within Maori society (Tau et al., 1990). The swamps and rivers of Christchurch provided a wealth of highly valued plant and animal resources for the Maori, and the preferred means of transport. Restrictions and special management practices were, and are still, enforced to protect water and the resources obtained from water.

When the European immigrants arrived, there were few Maori living in the area due to ship-borne diseases and inter-tribal sieges. Various "agreements" between the Europeans and the Maoris had the impact of barring Maori from their traditional resources. From having been the most richly endowed with land and natural food resources, the Ngai Tahu people of Canterbury became the most landless and impoverished tribe in the country, exiled on small reserves, and pauperised in their own homeland (Owen, 1992).

When the European settlers arrived in the early nineteenth century they were met with 50,000 hectares of plains with a maze of swamps, waterways and lagoons stretching between Lake Ellesmere in the south to the tidal reaches of the Waimakariri (Owen, 1992). The major rivers of Christchurch were important to the European colonists for trade and transport. Industries were developed alongside them, riparian vegetation was used in the construction of cob cottages and for roof thatching, and raupo was used for barrel making. Water wheels were set for mills, and industry waste discharged into the rivers. However, two major problems existed for the Europeans - too much water causing flooding, and too little water due to contamination of shallow wells. Drainage of the swampy land became a primary goal.

1.7.4 Christchurch in the 1990s

Present Hydrology

The hydrology of Christchurch has been markedly altered since European settlement. Of the extensive swamps that sustained the Maori, and met the early colonists, the remnants remaining amount to less than 2% (Meurk, in prep.). The dramatic and regenerating influence of the Waimakariri River in flood is prevented by stopbanks from passing through Christchurch. Urban and rural water use seasonally affects the confined and unconfined aquifers that spring-feed Christchurch's streams and rivers, causing water level fluctuations. Streams and rivers have been channelised, banks oversteepened, flows controlled with weirs, and in-stream and bank substrates altered through maintenance practices.

Figure 1.4: Swamp vegetation existed in Christchurch at the time of European arrival. Pictorial records can assist restorationists in building an image of past vegetation. ("The Church and Parsonage, Christchurch, New Zealand." A.C.Barker drawing, Canterbury Museum, Ref: ACB13).

State of Riparian Margins in the City

The state of Christchurch's riparian zones in the 1990s is best described in the words of Meurk et al., (1993):

> The original profile of Christchurch riparian areas have mostly been altered. The lower, flat, soggy terraces have been filled with domestic rubbish and the surface covered over and compacted from material scraped off the scarp and leading edge of the next terrace. This has resulted in an oversteepened and unstable bank, a rather indifferent and poorly structured substrate at the crest of the bank and a flattened scarp and upper terrace with the topsoil removed. In some cases the better growth is found on the upper sunnier slopes, perhaps where the structure has not been seriously truncated, rather than on the heterogeneous and compacted lower flats - the reverse of expectations. p.36.

Christchurch City Council Waterway Policy

While efficient drainage was the pre-eminent consideration for early settlers (Couling, 1992), local council amalgamation (1989), legislation changes, environmental awareness, and a number of independent factors, have led to an acceleration of changes in drainage philosophy that were beginning in the decade before amalgamation. In some areas, changes in riparian zone maintenance have led to improved wildlife habitat, a more diversified riparian ecosystem, greater bank protection, a lower impact maintenance requirement, and a more natural river landscape (Couling, 1992). Revegetated streams have a higher capacity, more storage, more meandering, a lower velocity due to more turbulence, more habitat variety and more pool/riffle sequences than piped waterways - all of which contribute to improved waterway quality if suitable riparian vegetation is used. In addition, the cost of establishing and maintaining a vegetated riparian margin is approximately one third the cost of installing and maintaining rigid structures. With these benefits in mind, the Water Services Unit began developing the multi-disciplinary Waterway Enhancement Programme in 1994, with an emphasis on revegetating versus piping targeted urban streams.

Present Vegetation in Christchurch

The "Natural Areas of Christchurch" report (Meurk et al., 1993) describes, by use of a vegetation/landform survey and general discussion, the basic physiognomic-ecologic types of vegetation presently existing in Christchurch. Waterways and their riparian areas are one vegetation type in a much larger mosaic of dryland/wetland vegetation types. A broad view of "natural" is pertinent to the Christchurch city cultural landscape.

Meurk et al. (1993) defined a 'natural area' in Christchurch as:

> .....a site of any dimension that retains some character of, or continuity with, its pre-1840s indigenous ecosystem or landscape. This may be recognised in the flora, fauna, soil or landform. (Meurk et al., 1993, p.1)

Meurk et al. (1993) recommended considering the systems, not the fragments, when assessing the general importance of natural areas in Christchurch.

> Freshwater wetlands and their interconnecting rivers, streams and water races are together significant to our heritage. (Meurk et al., 1993, p.25)

In order to study riparian vegetation in Christchurch for this research, it was necessary to locate extant riparian remnants. Riparian environments are an especially prominent, and therefore characteristic element, of the Christchurch landscape, however, "indigenous nature has largely been subsumed by English parkland concepts" (Meurk et al., 1993, p.29). Habitat diversity for riparian flora was reduced last century with the realignment and modification of river banks and margins, reducing the variability in the structure of waterways and their riparian zones. Maintenance practices have further reduced habitat.

In 1992, Baird surveyed the freshwater stretches of the Avon and Heathcote Rivers.

> At no point is there a natural community gradient, for example, from water side sedges to kahikatea (*Dacrycarpus dacrydioides*) swamp forest to drier terrace forest. Nor is there any example of an intact freshwater community - like the broad zones of raupo (*Typha orientalis*) and flax (*Phormium tenax*) that once occurred along the Avon. Plants natural to the rivers at best form small groups of several individuals, which may be composed of one or two species. The groups typically comprise native fern, sedges and rushes. (Baird, 1992, pp.3,4).

Riparian vegetation alongside waterraces offer some examples of where particular species will grow. Meurk et al. (1993) note:

> New Zealand flax-toetoe/sedge-kiokio-rush/forb fern tussock mires of waterraces criss-cross the plains, transcending local soil constraints, and are quite prominent along some road verges. They are significant in that they represent the only repository of the original wetland and riparian biota of the Lower Plains, maintain an albeit tenuous link between core wetlands, and, with the hedgerows and scattered cabbage trees, provide the only glimpse of indigenous nature in the landscape. Some water races have quite long stretches of continuous native vegetation and support a surprising species diversity, including a number of uncommon forbs such as willowherbs, pratia, orchids, turfy rushes, sedges and reeds. (pp. 29, 30).

The report "Natural Areas of Christchurch" (Meurk et al., 1993) served as a source for location of riparian remnants. As indicated above, Christchurch riparian areas are very modified and these remnants are few and far between.

1.8 Aims of the Study

The aim of this research was to develop a process and methodology (using ecological information) for the restoration of urban riparian zones.

The objectives of this study were:

- To use riverside locations in Christchurch city as a case study for developing an approach to selecting suitable riparian species, and ascertaining their distribution on environmental gradients, to assist riparian restoration.
- To collect and analyse data on a range of provenant riparian species in the Low Plains Ecological District (McEwen, 1987) to ascertain plant success under a range of environmental conditions in the Christchurch area.
- To investigate which environmental variables could be of importance in plant establishment and success in restoration projects.
- To develop methods for effectively communicating the ecological results and approach to restoration decision-makers and practitioners.
- To set the research on species ranges in context with other ecological components of riparian restoration and management decision making.

1.9 Scope of the Research

This thesis uses Christchurch as a case study to explore the possibility of developing an approach to urban riparian restoration ecology. In New Zealand there has been a lack of ecological research in the area of riparian flora. Chapters Two and Three develop an approach to increase our ecological knowledge about native plant species for use in restoration projects.
A variety of riparian species were chosen, including shrubs, trees, sedges, rushes, and ferns - all known to naturally occur in Christchurch. Field methods and environmental variables were chosen based on the literature and the particular situation in Christchurch (Chapter Two). Remnants of riparian vegetation in the Low Plains Ecological District were identified and used as a

template. Species were sampled for a range of environmental variables at the remnant locations.

The data was compiled and analysed. Duplicate environmental variables were identified and eliminated, and plant species were presented in boxplots for the remaining environmental variables. This information was summarised in a figure and table combining key environmental variables for all of the species in the study, as a visual guide for landscape architects and restoration practitioners (Chapter Three).

The species results from this study are compared with the literature (Chapter Four). The relevance of each environmental variable for understanding species requirements and tolerances is discussed, and the overall methodology evaluated.

Chapter Five sets the present research in its larger functional context. Ecological data management options are discussed. The ecological approach is simplified and an example of its application illustrated in flow-charts. Other components of restoration ecology and riparian management are introduced and future directions explored. Chapter Six highlights the main conclusions. Fig. 1.5 shows the overall organisation of the thesis.

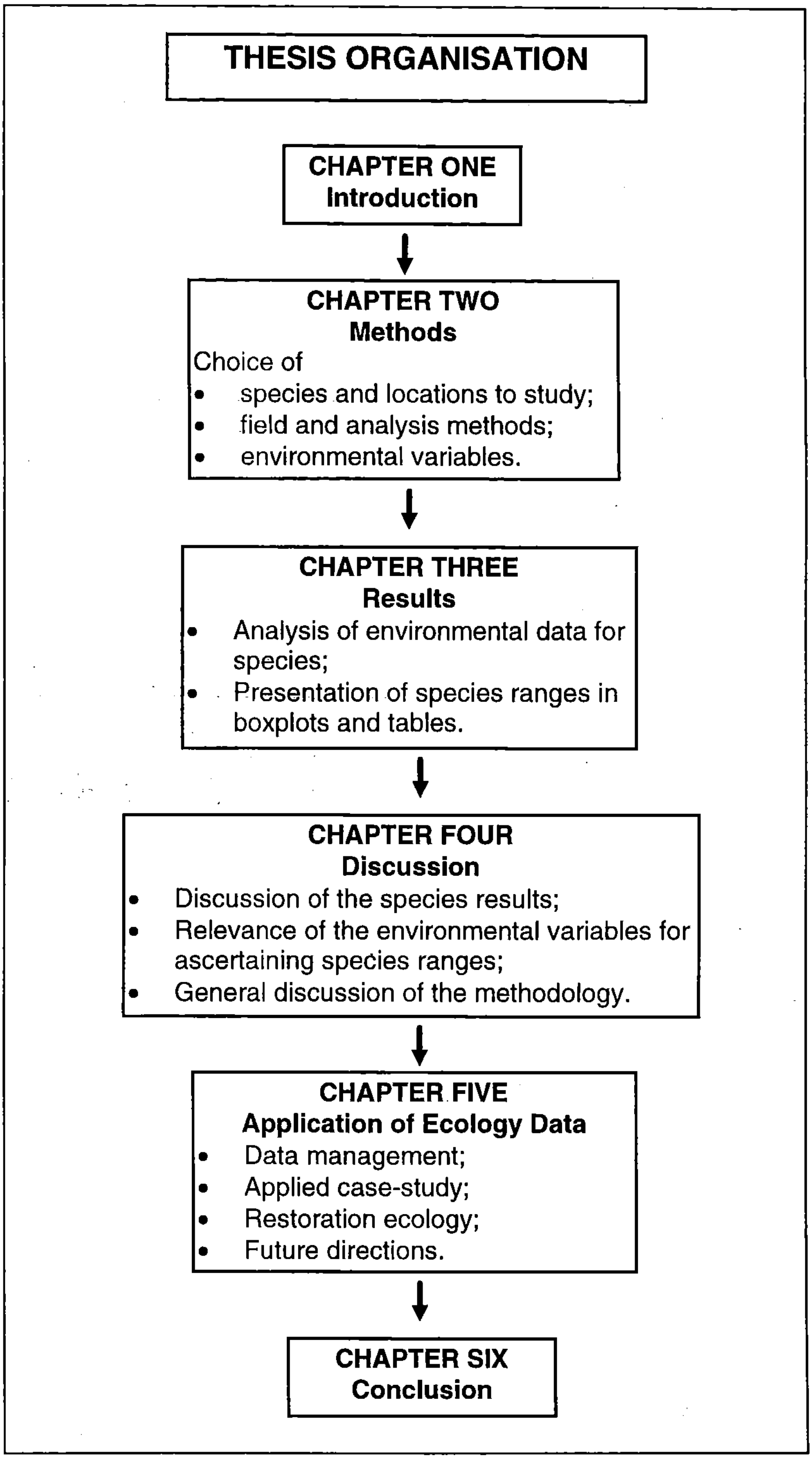


Figure 1.5: Thesis organisation.

CHAPTER TWO
METHODS

2.1 Introduction

The primary objective of this thesis was to design a simple and practical way of collecting environmental information on plant species, to assist in making informed decisions for riparian restoration projects.

A study by Allen and Wilson (1991) outlined a methodology for determining the indigenous vegetation of a particular site for replication in restoration projects. They found that the method would be useful for restoration in circumstances where:

- a strong relationship exists between the physical environment and existing vegetation;
- the physical environment can be characterised by easily obtainable factors;
- the sampled remnants are not highly modified or predominantly secondary vegetation;
- indigenous remnants are surviving on sites that represent the range of environments present in the area.

Allen and Wilson (1991) also found that their approach was 60% successful for predicting vegetation structure using environmental variables in relatively unmodified forest remnants. However, they noted that this approach was not useful where remnants were highly modified or predominantly of secondary vegetation.

There are relatively few places in lowland New Zealand in which intact, unmodified vegetation remnants exist. A methodology for species choice for restoration in modified areas is needed. Christchurch riparian zones, as with those of urban areas in general, are highly modified. A similar approach to that of Allen and Wilson (1991) could be useful for restoration in these areas. Due to disturbance, remnants that provide vegetation structure for sampling are no longer available in Christchurch. Plant communities cannot be reassembled from the present template. However, there may be a chance to quantify the remaining indigenous vegetation in relation to environmental variables, to provide a basis for re-creating riparian zone ecosystems. It may not be possible to accurately predict vegetation structure, but an understanding of species tolerances in a modified environment may improve the success of restoration plantings.

The information needed to restore a riparian site may be collected by landscape architects, community groups and other non-specialist restoration planners who have little time, funding, scientific knowledge or access to complex equipment and analysis techniques. Data collection techniques must necessarily be easy to use and may be subjective. Ideally, the environmental variables selected for measurement should not require complex sampling or analysis methods.

This chapter is divided as follows:

1) Selection of species in the study;
2) Choice of sampling locations;
3) Sampling approach;
4) Selection of environmental variables;
5) Description of methods for collecting information about environmental variables and species attributes; and,
6) Data analysis methods.

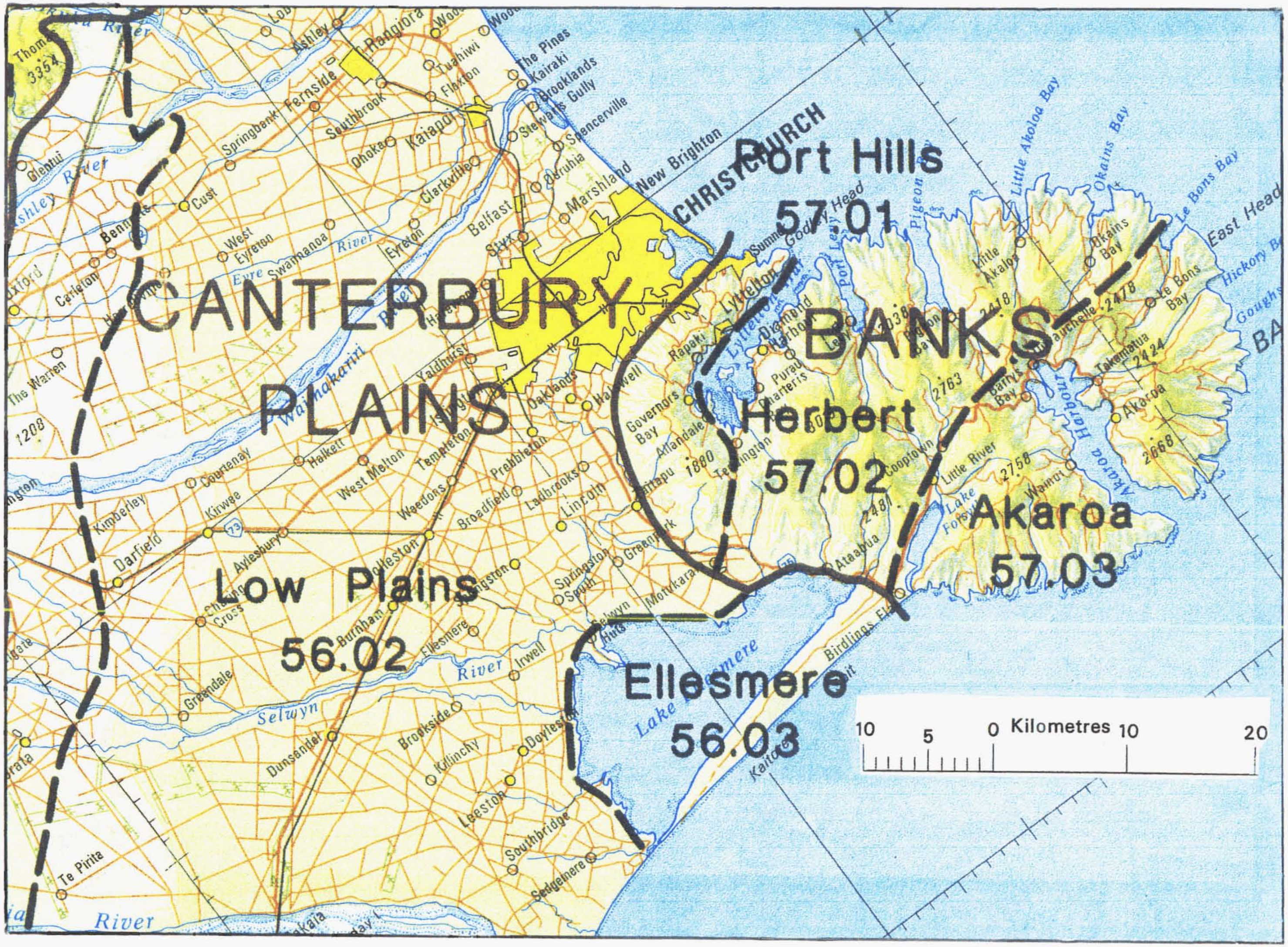


Figure 2.1: Map of the Low Plains Ecological District, New Zealand (NZMS 242, Sheet 3, 1:500,000).

2.2 Selection Of Species

2.2.1 Plant Selection Criteria and Method

The following criteria were used to select an appropriate Christchurch riparian species list for use in the study:

1) **Provenance:** The geology and geography of Christchurch was described in Chapter One. It was considered critical that the species were of local origin (ie., provenant to Canterbury) as far as could be assured. Riparian areas in the Low Plains Ecological District (McEwen, 1987) (Fig. 2.1) were defined as the range for "local" plants, and as the restriction for field site choice. Norton (1988) set this precedent in his Pyramid Valley restoration plan.
2) **Riparian zone:** The species selected were all growing between the riparian margin (lower bank or just into the water) and up to the upper terrace zone, where these sites existed at the locations sampled (Fig. 2:2).

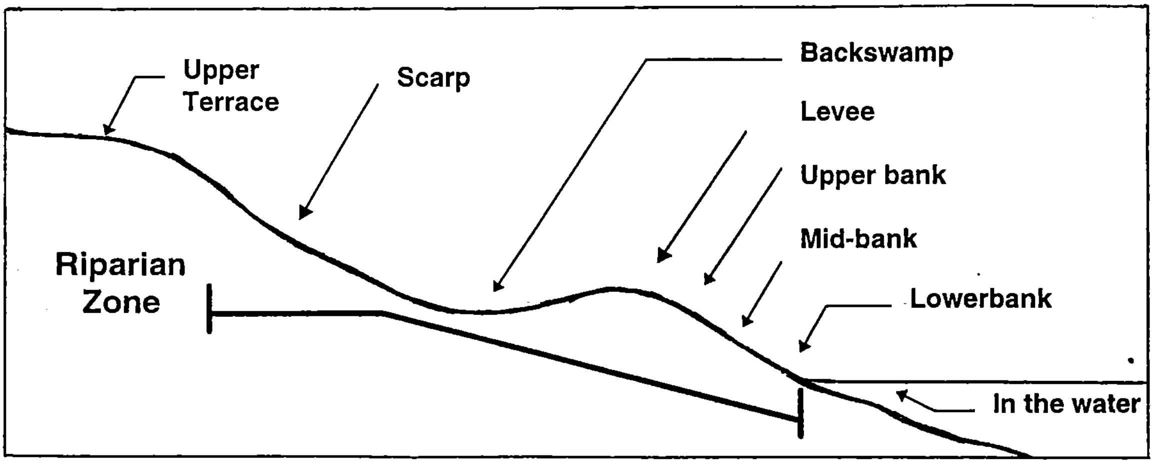


Figure 2:2: Riparian zone classifications developed for field data collection.

3) **Local knowledge:** Local botanists and ecologists were consulted regarding appropriate plant species for Christchurch based on the provenance and existence of, or past existence of, species in riparian zones in the area.

4) **Archaeological and historical information:** Pollen records and subfossil records recorded in the literature (in particular information from Molloy, 1995), and pictorial records (eg., Fig. 1.3) were of use in plant choice.
5) **Species availability for sampling:** Where it was thought that there would be enough samples for a species (ie., above 25), data for that species were collected. However, in many cases it proved difficult, without a large increase in sampling effort, to collect sufficient data from the few remaining remnant locations or planted locations near waterways in the Christchurch area. The species studied included sedges, rushes, ferns, shrubs and trees.
6) **Availability of sites in which to sample a particular species:** Some species were only found to be in some locations. For example, two *Blechnum* species were only recorded on the banks of a channelised waterway within the stop-banks of the Waimakariri River (Fig. 2.3a). For other species only planted individuals could be found. Figures 2.3b-d are examples of the range of sampling locations.
7) **Landscape potential:** In urban areas aesthetics often require using plant species that can be easily seen. In addition, some species offer ecological functions (eg., a food source for birds) and are considered an important part of the restoration project. However, where a species was considered both difficult to sample, and of little landscape value (eg., some low herbs), it was not pursued. While low herbs may have potential as low ground cover for restoration sites, they are not generally used in restoration plantings.

2.3 Choice Of Sampling Locations

In choosing sampling sites, the aim was to find the widest range of possible environmental/site conditions for each species to be surveyed in the study.

The database entitled "Natural Areas of Christchurch" (Meurk et al., 1993) was used to identify potential study sites. With the permission of the authors, the database was manipulated to highlight species found in particular areas around

Christchurch, to find the areas with the highest number of species, and to assess the degree of abundance of each species at each location.

Where possible, locations with a range of riparian habitats were chosen for sampling to ensure that a species was sampled in all possible riparian sites. Descriptions of sampling locations are presented in Appendix 1a.

As mentioned above, the lack of sampling locations was limiting. Pre-1800s remnant vegetation near rivers and streams is practically non existent, and there are only limited and highly modified areas from which to sample plants. This affected the study in two ways:

1) Most self-established species in the study were successional; and,
2) Extant natural plant associations are too highly modified to be of use as templates for ecological communities. Another research project would be needed to understand plant associations, possibly extrapolating from rural or less disturbed riparian remnants in other parts of the South Island.

2.3.1 The Sampling Method

Sampling methods were trialed in a pilot study. Randomly spaced transects were found to be inefficient for two reasons:

1) Riparian areas have a diverse assortment of environmental gradients. These cannot be accurately duplicated by delineated transects on the ground (Malanson, 1993).
2) The vegetation patches available for sampling were scattered throughout Christchurch and were often discontinuous at each sampling location.

The highly modified nature of the locations and the difficulty of assessing environmental gradients using transects, meant that a sampling method which focused on individual plants would be the most efficient.

Figure 2.3a: ***Blechnum chambersii* and *B. fluviatile* at a small, semi-shaded, steep-sided stream near the Waimakariri River.**

Figure 2.3b: ***Typha orientalis*, *Juncus gregiflorus* and exotic grasses at Taumutu, south of Lake Ellesmere.**

Figure 2.3c: ***Carex geminata*** **(to the left of the photograph) growing in dense swards on the banks of the Avon River in Christchurch.**

Figure 2.3d: Springfed and fenced Blackwater Creek, had dense, primarily indigenous, riparian vegetation. ***Phormium tenax, Carex secta, Blechnum minus, Eleocharis acuta*** **and** ***Typha orientalis*** **were found here.**

The sampling method chosen was one of random plant selection. An area of riparian vegetation was divided into semi-randomly placed 10 metre square plots. There seemed no scientifically valid way, given reasonable time constraints, of randomly choosing the 10 metre plots if plants were widely scattered in the environment. Within the 10 metre plots every native plant was sampled for a range of environmental parameters at the site of the individual plant. To mitigate pseudo-replication, individuals of the same species were not sampled within a one metre radius of each other for small species and within two metres for trees. Soil was taken seven centimetres from the plant, on a plane parallel to the water. As far as possible, measures were taken to avoid pseudo-replication by not over-sampling a site for any given species.

One important characteristic of the species data gathered in this research was that plants were noted for their presence only. In the urban context, species growing in one site may be missing from another because of a human induced reason and not because they cannot physically grow in that site. For this reason the plants were noted where they were growing but not where they were absent as this information would have been misleading (ie., they were not present in most places). The data analysis was therefore restricted by not having binomial data. To address this, the variance and median of one species was tested against the variances and medians of the other self-established species in the study. The assumption made was that the individual plants of a species could have grown in any of the sites occupied by other species.

2.4 The Environmental Parameters

2.4.1 Choice of Environmental Variables

Allen and Wilson (1991) used broad scale environmental variables in their study of Otago forest remnants, South Island, New Zealand. These factors included rainfall, minimum and maximum altitude, slope, distance from the sea, exposure to winds, soil type and fertility, and the main rock type. Grime et al. (1988) in their study of British flora used a wide range of environmental variables to assess plant species habitat. Altitude, slope, soil pH, aspect, hydrology were some of the environmental variables included as part of the extensive primary and secondary information collected on each species (Grime et al., 1988).

A primary consideration in the choice of environmental variables for this study was that they were easy to collect in the field. From a review of the literature, and from information from local ecologists, the environmental variables that appeared to be most important to sample in the field for riparian species in Christchurch included: hydrology (eg., soil moisture and placement in the riparian zone); slope and slope shape (drainage); elevation and distance from water; soil pH and conductivity; aspect; and canopy (shade). Soil was collected from each plant site and brought back to the laboratory for pH and conductivity testing. A frost index was developed using elevation, slope, aspect and canopy cover. The field datasheet is included in Appendix 1b. Environmental variables and plant attributes were sampled at the site of each individual plant.

The plant attributes recorded were: whether or not the plant was reproducing; its growth style; age class; abundance at the site; whether it was self-established or was planted; and most importantly, the degree of plant vigour.

2.4.2 Soil Moisture

Moisture availability has been considered one of the principal environmental factors in plant ecology research (Scott and Groves, 1989). In the riparian area tolerance of very wet soil may be equally important, therefore soil moisture was considered an important variable to measure. Several laboratory based analyses of soil moisture are available (Scott and Groves, 1989; Bannister, 1986). However, in this study, soil moisture was measured on a subjective scale for two practical reasons. Firstly, laboratory soil analysis methods to assess water content were considered too time consuming and therefore too costly for the methodology being developed. Secondly, practitioners in the field will be more likely to assess the soil moisture by a subjective rank class than by detailed soil analysis (Table 2.1).

The wetness state of soil, when it is being described in the field, is usually noted simply as dry, moist or wet (Ball, 1986). In order to ascertain if soil moisture gradients were important for riparian species, a wider soil moisture rank class (from 1=wettest, to 7=driest soil) was developed for the riparian zone.

The soil moisture classes were taken as a winter/spring measure. Care was taken to wait at least 3 days after rain before sampling soil moisture. Soil moisture was remeasured in summer at each riparian class at each location.

Table 2.1: Soil moisture rank class.

Soil Moisture	Rank Class
Plants are growing in the water in very fine sediment or pure root mass	1
Saturated - soil is very wet and loose	2
Saturated -soil is thick and wet	3
Wet but not dripping	4
Damp	5
Dry	6
Very dry	7

2.4.3 Distance

Distance from and into the water was measured in centimetres using a tape on a horizontal plane.

2.4.4 Elevation

Elevation above and into the water was measured in centimetres, from the average winter water level, using a metre rule, tape and clinometer (to assure horizontal angle).

2.4.5 Canopy Cover

Canopy cover was assessed using a rank (Table 2.2) based on the Braun-Blanquet method of cover-abundance. The measure was taken looking straight up from the plant and in a 10 metre square area above the plant.

Table 2.2: Canopy cover (shade rank class).

Canopy Cover	Rank Class
No shade	0
Partial shade/summer	1
Partial shade/all year	2
Full shade/summer	3
Full shade/all year	4

2.4.6 Slope

Slope degree was measured using a clinometer laid on a ruler on the slope immediately adjacent to the plant. The degree of the slope was recorded. Slope shape was observed when slope degree measurements were taken (Table 2.3). The slope (rank class) was assigned based on the area surrounding the particular plant site.

Table 2.3: Slope shape rank class.

Slope Shape	Rank Class
Flat	0
Concave	1
Convex	2
Straight	3

2.4.7 Aspect

The data was collected using compass points, and then all values were scaled from North (0-180°).

2.4.8 Broad Riparian Class

Broad riparian classes (Table 2.4) were developed as a method of summarising the broad reach in which individual plants of a species were recorded, therefore the rank class is not linear. Most of the rank classes were developed based on Christchurch conditions, and the backswamp classification was adapted from Salo (1990).

Table 2.4: Rank for broad riparian class.

Classification	Abbreviation	Rank
Stream: running water of less than 3m wide.	s	1
Backswamp (stream): area of permanently or frequently wet soil adjacent to a stream, often separated from the channel by a levee (Salo, 1990).	bs (s)	2
Backwash (stream): area of slow water, away from the main current of the stream.	bw (s)	3
River: running water, more than 3m wide.	r	4
Backswamp (river): area of permanently or frequently wet soil adjacent to a river, often separated from the channel by a levee (Salo, 1990).	bs (r)	5
Backwash (river): area of slow water, away from the main current of the river.	bw (r)	6
Waterrace: artificial, usually channelised, waterway for transporting water for farming purposes. Water is usually abstracted from major rivers.	wr	7

2.4.9 Specific Riparian Class

The specific riparian class (Table 2.5) was noted when plant information was collected. This riparian classification has been used in the data analysis. Figure 2.2 (shown earlier) illustrates the classifications.

Table 2.5: Rank for specific riparian class.

Classification	Abbreviation	Rank
In water	in	1
Lower bank	lb	2
Mid bank	mb	3
Upper bank	ub	4
Levee	l	5
Scarp	s	6
Terrace	t	7

2.4.10 Frost Index

A frost index (range=0-40 from least to most "frostiness") was developed from a combination of other variables. It comprises four variables each coded 1-10 according to their likely impact on frostiness of a site. The variables are:

- Slope - less slope, more frost;
- Aspect - more degrees from direction of most sun potential, more frost;
- Canopy (ie. shade) - less canopy, more frost; and,
- Elevation above water - closer to the water, less frost.

This approach was not intended to bias the values for any specific variable. However, more investigation is needed, eg., canopy may be the most critical factor and therefore should be given greater weight (eg., 0-20 not 1-10).

2.4.11 Water Quality

Water quality parameters were tested, with hand-held pH and conductivity meters for each location. Visual clarity of the water in the stream was noted.

2.5 Soil Analysis

2.5.1 Field Collection of Soils

An open faced soil corer was used to obtain a 15cm deep core of soil from around each plant (two cores), approximately seven centimetres from the plant on a horizon parallel to the nearest water. A further seven centimetres of soil was collected as a deeper level. Where evident, the degree of mottling of each level, 0-7.5cm, 7.5-15cm and 15-22.5cm, was noted.

The two cores of soil were placed in a small plastic bag, tied with rubber band, and labelled with plant number, site number and date.

2.5.2 Soil Analysis

Preparation of Soils for Analysis

Soil samples were placed in an oven for air drying at 30-35° degrees Celsius for 24-36 hours depending on soil moisture content. Very wet sediment sometimes needed longer than 36 hours. Dry samples were then crushed using a mortar and pestle and sieved through a 2mm sieve back into containers.

Soil pH Testing in the Laboratory

pH is a measure of the acidity/alkalinity of a soil and is critical for mineral and ion availability and absorption by plants.

Analysis methods are those used by the Soil Science Department at Lincoln University. Ten grams of air dried soil was weighed and placed in 50ml containers with 25ml of deionised/distilled water. These containers were shaken and left overnight at 20° degrees Celsius. Samples were tested with an electronic probe calibrated using pH7 and pH4 buffer solution. pH values were noted after 25 seconds and the probe rinsed and wiped between samples. The pH probe was recalibrated every half hour.

Soil Conductivity Testing in the Laboratory

Conductivity is a measure of the quantity of free ions available in the soil, which can be important for plant nutrition.

The following analysis is that used by the Soil Science Department at Lincoln University. Ten grams of air-dried soil was weighed into 100ml plastic centrifuge test tubes. 50ml of deionised water was added and the samples shaken in an "end over end" shaker for 30 minutes at 20° degrees Celsius. The sample was centrifuged at 2000 rpm for 5 minutes.

Small amounts of samples were measured at one time and the conductivity measured with a conductivity meter as soon as possible after centrifuging to avoid possible changes in ionic content due to microbiological activity. The conductivity meter was set at the default range of 25° degrees Celsius and the room temperature checked throughout the testing period. The probe was washed thoroughly between samples and the rating on the machine returned to a neutral level before the next sample was tested.

The following equations give approximate values for total soluble salts in soils using a soil to water ratio of 1:5: K_{25} (millimho/cm) x 0.35 = Total soluble salts (%).

2.6 Plant Attributes

2.6.1 Health

As a measure of vigour, each plant was ranked from 1 to 3 (poor to excellent vigour).

2.6.2 Naturalness At Site

Whether a plant had self-established or whether it was planted was recorded. For some species, self-established and planted data for the range of environmental variables was compared in the analyses. The divisions used were:

1) Original vegetation;
2) Self-established;
3) Planted and well-established; and
4) Recently planted.

2.6.3 Abundance

The abundance of individuals of each species at a location was measured to assess if plants were establishing naturally at the location. Abundance was measured within a 10 metre square area, using a rank scale adapted from the Braun-Blanquet method.

1) Few (<5);
2) Some (5-10); and
3) Many (>10).

2.6.4 Age Class

This parameter was collected to identify the population being sampled, as different age classes may be influenced by their environment in different ways. This was a comparison rank for within species and gave an indication of species establishment and success at a site. It also indicated the nature of the population upon which some recommendations and limitations are discussed, eg., a population consisting of primarily juveniles may appear to be surviving well but may not have suffered any adverse drought or heavy frost years during establishment. The rank class used was:

1) Seedling;
2) Sapling; and
3) Adult.

2.6.5 Reproducing

This parameter was collected as it may indicate a) adult plants, b) success at a site, and c) potential stress at a site (depending on other variables such as plant vigour). It was simply noted as "Yes" (reproducing) or "No" (not reproducing).

2.6.6 Disease

This parameter was a simple observation of the reason for low plant vigour, was recorded on a Yes/No basis, and any discernible reasons for low vigour noted.

2.6.7 Growth Type

The growth pattern of a species was recorded using a rank class (Table 2.6). This gave information on whether a species was generally found in patches, clumps or growing individually.

Table 2.6: Growth type rank class.

Growth Type	Rank
Individual - growing individually	1
Clump -groups of plants growing closely - generally rhizomatous	2
Patch - a group of plants growing in the same general area - generally growing from self-established seed	3

2.6.8 Plant Association

The Braun-Blanquet scale of cover abundance was adapted for assessing plants growing in a 2X1m plot around the target plant (2m along the bank and 1m up the bank) (Table 2.7). Species and rank were noted on the data sheet.

Table 2.7: Rank class for plant associations.

Percentage Cover of Associated Species	Rank Class
76-100% cover	5
51-75% cover	4
26-50% cover	3
6-25 % cover	2
1-5% cover	1
Less than 1% cover	0

2.7 Data Analysis Methods

2.7.1 T-tests

T-tests were used to ascertain the most significant environmental parameters predicting plant site for each species. The results gave a conservative estimate of likely environmental parameters affecting plant success in restoration projects. The means and standard deviations for each species for each quantitative and some of the qualitative environmental variables were calculated. The significances of the differences between the medians of one self-established species and those of all the other self-established species were tested using the non-parametric Mann-Whitney U test. Probability values were generated from this test in SYSTAT. The significances of the difference between the variances of the target species and the rest of the data was tested using Barletts Test; p-values were again generated in SYSTAT. The significance levels were recorded (NS indicates non-significant values). Variables with a higher than 0.1 significance level were included as indications of possible effect if more data was to be collected.

For some species, both self-established and planted data were recorded. The medians and variances of the self-established dataset and the planted dataset for a species were compared.

2.7.2 Principal Component Analysis

Principal Component Analysis (PCA) was used to separate data relative to the axis of the greatest variation in data. PCA assumes that there is a large amount of duplication or correlation in the variability of the species or environmental variables across the data. It reduces the original dataset to a few components. These components can be regarded as "super-variables", made up of highly correlated combinations of the original environmental variables (Kent and Coker, 1992). While the original environmental variables were almost certainly highly intercorrelated, the new components are completely uncorrelated and are said to be orthogonal and uncorrelated. The analysis removes problems with intercorrelation and duplication within the original variables in the dataset. The PCA is useful for synthesising environmental data, and for producing an ordination of species based on environmental variables alone.

Eigenvectors are sets of scores, each of which represents the weighting of each of the original species or variables on each component. For each component, every species or variable has a corresponding set of eigenvector scores and the nearer the score is to +1.0 or -1.0, that is, the furthest away from zero, the more important that species or variable is in terms of weighting that component (Kent and Coker, 1992).

Eigenvalues represent the relative contribution of each component to the explanation of the total variation in the data. There is one eigenvalue for each component (or factor), and the size of the eigenvalue for a component is a direct indication of the importance of that component in explaining the total variation within the dataset (Kent and Coker, 1992). An eigenvalue of less than 1.0 means that the axis is contributing less to the overall explanation of the variability in the data than any one of the original species or variables.

Correlation was used to determine whether two datasets move together, ie., whether large values of one dataset are associated with large values of the other dataset (positive correlation) or whether small values of one set are associated with large values of the other (negative correlation), or whether values in both sets are unrelated (correlation near zero). Pearsons product-moment correlation coefficient was used with the PCA. Although rank classes were used in the analysis, equal distances between each class were assumed in the PCA and correlations. Care should be taken in the interpretation of correlation coefficients. A significant correlation analysis does not necessarily mean that there is a causal relationship between the variables; it may instead indicate a mutual interaction. It may be more realistic to talk of these variables 'varying together' rather than a one-way causal relationship. It was expected that there would be some degree of correlation between environmental variables measured, eg., soil moisture and elevation above water may represent the same variable for plant success. The most rigorous environmental variables indicating species ranges were further analysed.

2.7.3 Boxplots

Jandel Sigmaplot software was used to calculate and present boxplots to compare species ranges for both the quantitative and qualitative environmental variables. The quantitative variables presented were elevation, soil pH, and degree of slope, and the qualitative environmental variables were soil moisture, canopy cover, and specific riparian class. No statistical methodology was intended for the qualitative environmental variables. In the boxplots, the 25th and 75th percentiles are indicated by the box, the mid-line is the median, the 'whiskers' are at the 10th and 90th percentiles, and outliers are presented as circles. The species were divided into sedges, rushes, ferns, and tree and shrub species to highlight differences in range, particularly for the margin species, that may have been hidden in larger scale graphs.

2.7.4 Histograms

The range of the slope shape rank class was considered to be too narrow to be presented in a boxplot. This data was analysed using histograms and presented as tables of percentages for comparison. As Broad riparian class was not linear, data were also calculated using histograms.

2.8 Summary

The quantitative environmental variables of elevation and distance in relation to water were measured in centimetres. Aspect and slope were measured in degrees. Values for soil pH and soil conductivity were calculated using standard soil analysis methods. Rank classes based on Braun-Blanquet methods were used for collecting information on the qualitative environmental variables of soil moisture, canopy, slope shape, and broad and specific riparian class, and other species attributes such as abundance at site. An index for frost was calculated from four other variables. Plant reproduction, disease, and health were calculated on a binary scale (yes/no). The environmental data was analysed using t-tests and Principal Component Analysis, and presented in boxplots and tables of histogram percentages. The results are presented in Chapter Three and discussed in Chapter Four.

CHAPTER THREE
RESULTS

3.1 Introduction

This chapter presents the results of species data for a range of environmental variables. Such results must be presented in a form that is easily understood for them to be useful to restoration practitioners who often have little time available for data collection and detailed analysis. Consequently the methods and final presentation of results have been chosen with this goal in mind. The species data, environmental variables and overall methodology will be discussed in Chapter Four.

3.1.1 Presentation of Results

The results are presented in relation to the questions highlighted in Figure 3.1. The dataset selected for analysis was tested to ascertain if the environmental variables could be related to particular plant types, if individual species had specific environmental ranges, if there were any within species differences between self-established and planted individuals, and if the environmental variables measured were independent of each other[2]. Data are presented in boxplots to compare species range patterns in relation to the environmental variables. Finally, examples of methods to summarise the key variables for all species are presented.

[2] Significance levels in text: p-value= 0.05*, 0.01**, 0.001***

3.1 Introduction

3.2 Selecting the Dataset for Analysis

3.3 Testing the Significance of the Environmental Variables
Can the environmental variables be summarised for particular plant types?
Do species respond strongly to certain environmental variables?

3.4 Testing the Differences Between Self-Established and Planted Data

3.5 Testing the Independence of the Environmental Variables
Were the environmental variables independent of each other for measuring plant site attributes?

3.6 Species Ranges in Relation to Environmental Variables
What were the patterns of individual species ranges in relation to the environmental variables?

3.7 Summarising the Key Environmental Variables for all Species
How might the species ranges in relation to key environmental variables be efficiently summarised for use by restoration practitioners?

3.8 Summary

Figure 3.1: Structure of Chapter Three: Results. The questions addressed in each section are noted.

3.2 Selecting the Dataset for Analysis

3.2.1 How was the dataset selected for analysis?

Data was collected for a wide range of species with the intention of having a sufficiently large self-established dataset per species for analysis, and having both self-established and planted individuals for within species comparisons. The data collected was divided into those species with more than 50% of self-established individuals (Dataset One), and those with less than 50% (Dataset Two). For the purposes of establishing an approach for selecting species for riparian restoration, only Dataset One was fully analysed and interpreted. Dataset Two (species with primarily planted samples) is available for reference in Appendix 2. It was felt that such data was useful to record so that future studies could more directly compare the environmental ranges of self-established and planted individuals through future monitoring of restoration projects.

A histogram of sample size was generated for the self-established component of Dataset One (Fig. 3.2). This figure indicates that by including species with 15 samples or more, a large proportion of the data collected could be used. Thirty samples is a standard threshold for statistical analyses, however, this number was difficult to attain consistently in Christchurch. In this study, 15 samples are assumed to give an arbitrarily more confident estimate of where plants will grow, than smaller sample sizes. Small sample sizes for some species have been included in the graphs as a means of demonstrating the method, not because the species sample is necessarily representative. In some situations, however, small sample sizes are representative of the populations in Christchurch at this time.

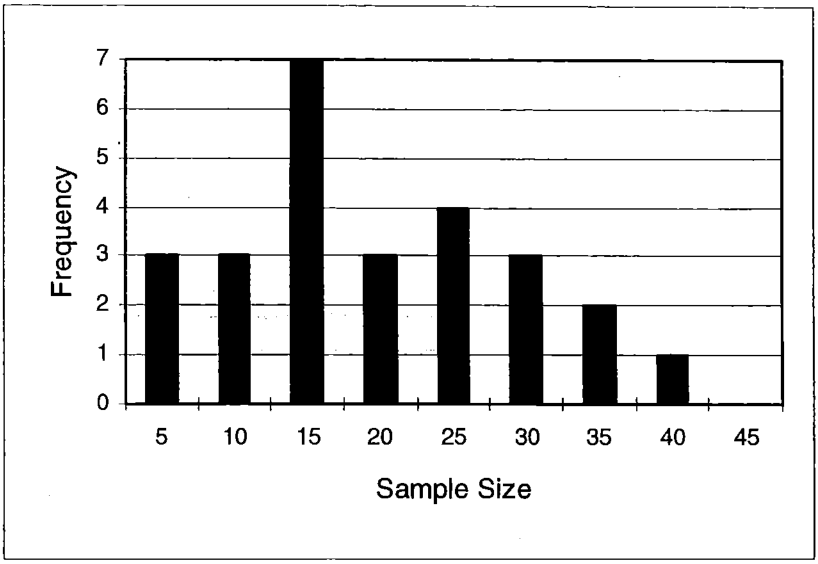


Figure 3.2: Histogram of species sample sizes for the self-established data in Dataset One.

The data was divided into plant types as plant type groupings were considered most appropriate for landscape purposes. Based on this logic, plant species were arranged in graphs of the following three main plant types: sedges and rushes; ferns; and trees and shrubs. *Astelia fragrans*, *Phormium tenax*, *Hydrocotyle novae-zeelandiae and H. heteromeria* were also studied, and while they do not represent a specific plant type they were grouped together for presentation purposes. Species names have been abbreviated to six letter codes (Table 3.1) in the tables and figures.

Table 3.1: Species list and abbreviations used in the study. The abbreviations use the first three letters of the genus followed by the first three letters of the species (after New Zealand Forest Service Surveys).

Species	Abbreviation
Sedges and Rushes	
Typha orientalis	Typori
Carex virgata	Carvir
Eleocharis acuta	Eleacu
Juncus pallidus	Junpal
Juncus sarophorus	Junsar
Schoenus pauciflorus	Schpau
Carex secta	Carsec
Carex maorica	Carmao
Juncus gregiflorus	Jungre
Carex geminata	Cargem
Fern Species	
Phymatosorus pustulatus	Phypus
Blechnum penna-marina	Blepen
Blechnum aff. capense	Blecap
Blechnum minus	Blemin
Blechnum fluviatile	Bleflu
Blechnum chambersii	Blecha
Polystichum vestitum	Polves
Trees and Shrubs	
Cordyline australis	Coraus
Coprosma robusta	Coprob
Pittosporum tenuifolium	Pitten
Coriaria arborea	Corarb
Solanum laciniatum	Sollac
Other Species	
Astelia fragrans	Astfra
Phormium tenax	Photen
Hydrocotyle heteromeria	Hydhet
Hydrocotyle novae-zeelandiae	Hydnov

3.2.2 Dataset Summary

Most of the self-established data is not normally distributed as shown in the summary histograms of each environmental variable by sample number (frequency) for all self-established and planted samples in Dataset One (Figs. 3.3a-j). Elevation and distance from surface water were measured in centimetres. Slope and aspect were measured in degrees. Soil pH and conductivity were also measured quantitatively. Some of the data was recorded in rank form. Soil moisture was ranked on a scale of 1 (wettest) to 7 (driest). Riparian class was also measured on a 1-7 scale, with '1' representing 'in the water' and '7' the upper riparian terrace. Canopy was ranked from 0-4 (0=no shade, and 4=full shade). Frost was ranked from 0-40, with low values indicating low frostiness. A table of summary histograms of other attributes (ie., abundance at site, age class, growth type, and reproduction) of the datasets of each of the self-established species is included in Appendix 3.

Dataset One was divided into two groups:

1) The self-established data only; and
2) Those species for which both self-established and planted data were recorded.

Between species t-tests were done for the first group and within species t-tests for the second.

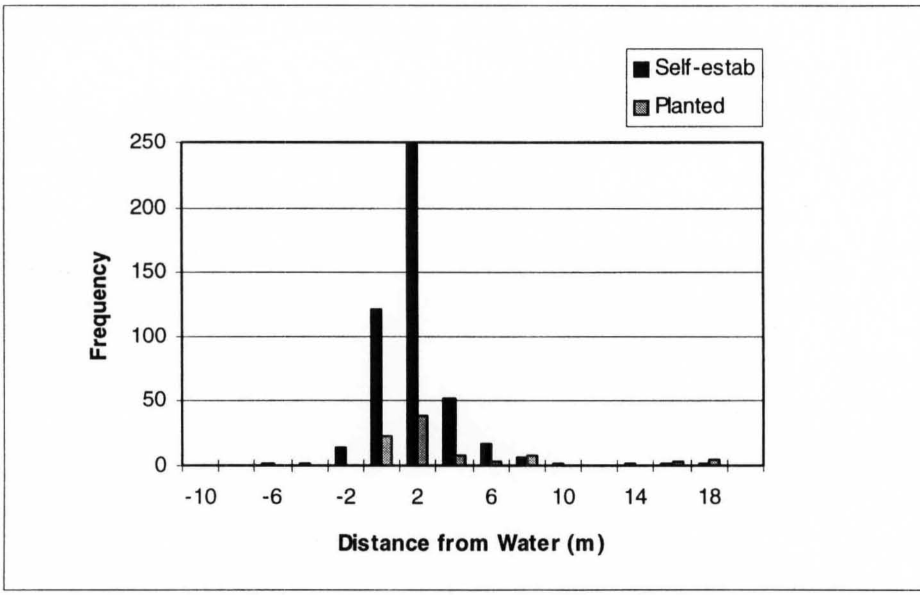


Figure 3.3a: Frequency histogram of distance for self-established and planted samples of Dataset One.

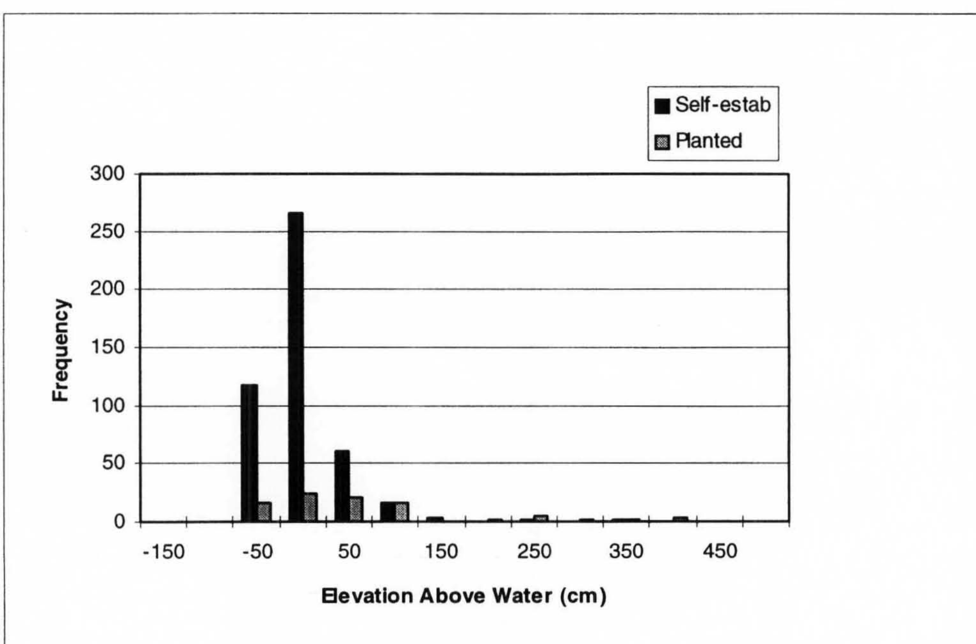


Figure 3.3b: Frequency histogram of elevation for self-established and planted samples of Dataset One.

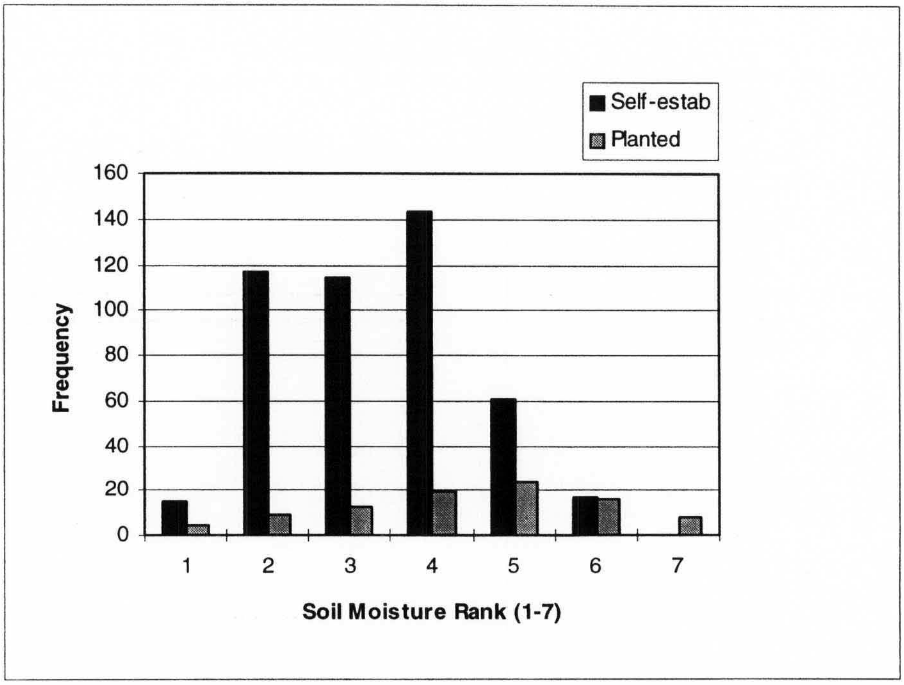


Figure 3.3c: Frequency histogram of soil moisture for self-established and planted samples of Dataset One. Soil moisture is ranked from 1=wettest soil to 7=driest.

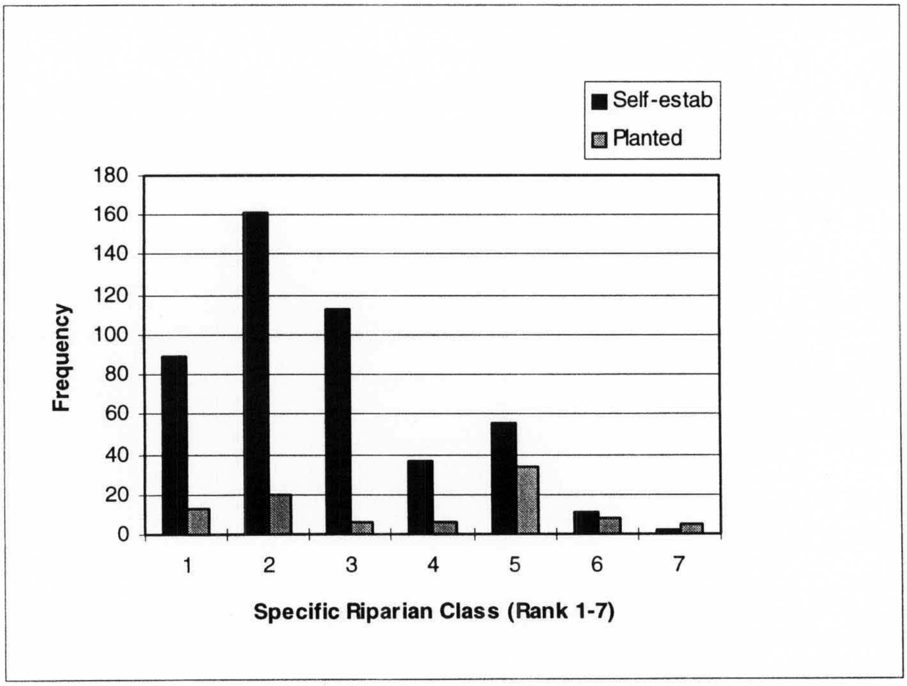


Figure 3.3d: Frequency histogram of specific riparian class for self-established and planted samples of Dataset One. Riparian class divides the riparian zone as follows: 1=in the water, 2=lower bank, 3=mid-bank, 4=upper bank, 5=levee, 6=scarp, and 7=terrace.

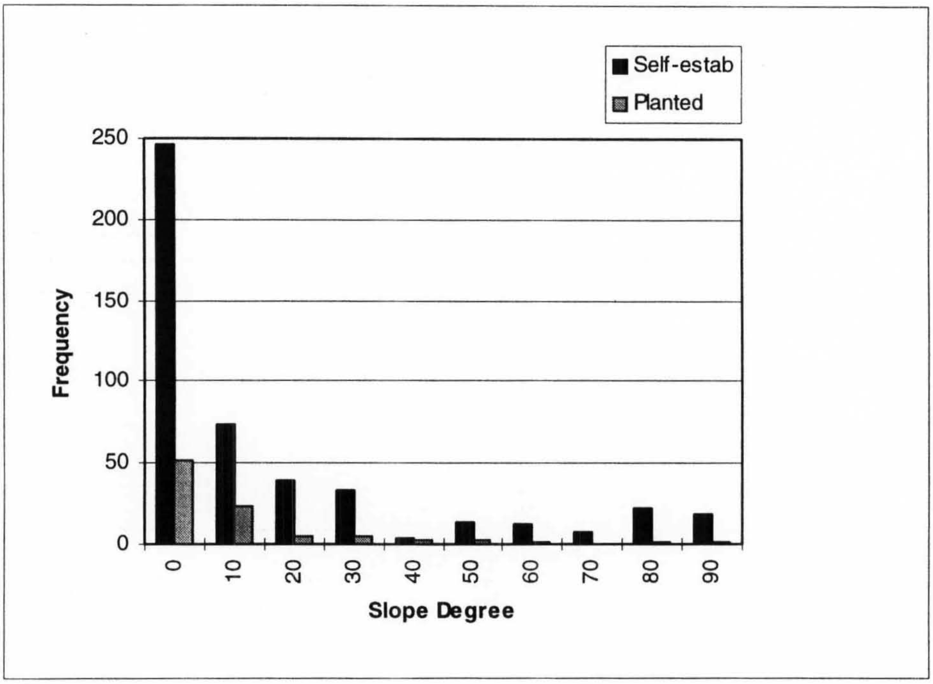


Figure 3.3e: Frequency histogram of slope for self-established and planted samples of Dataset One.

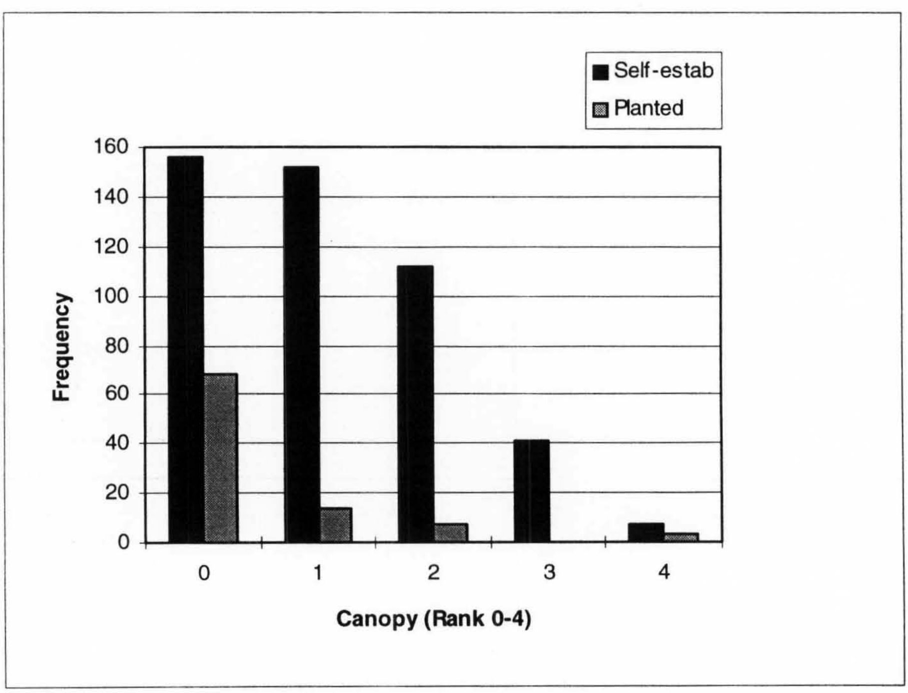


Figure 3.3f: Frequency histogram of canopy for self-established and planted samples of Dataset One. Canopy is ranked from 0-4: 0=no shade and 4=full canopy.

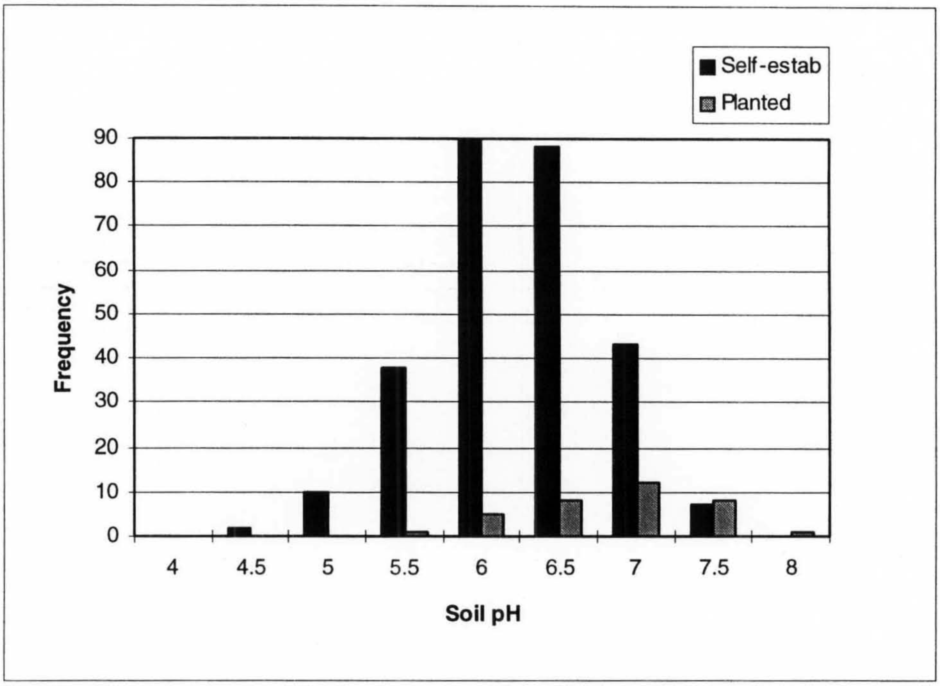


Figure 3.3g: Frequency histogram of soil pH for self-established and planted samples of Dataset One.

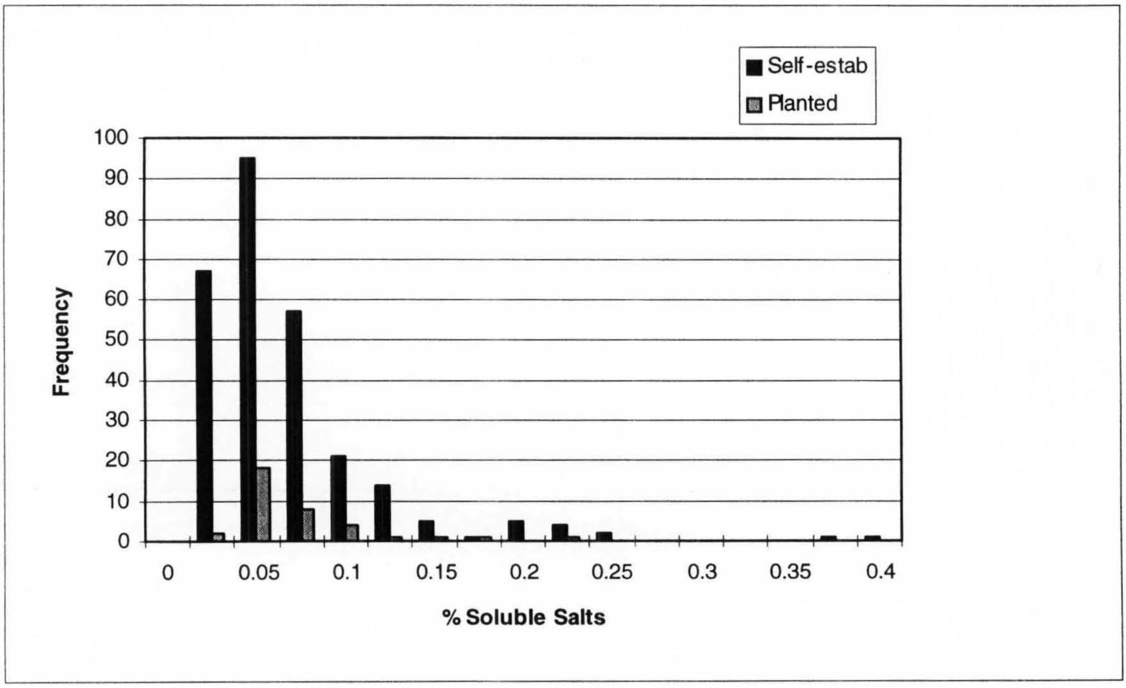


Figure 3.3h: Frequency histogram of soil conductivity (mS cm^{-1}) for self-established and planted samples of Dataset One.

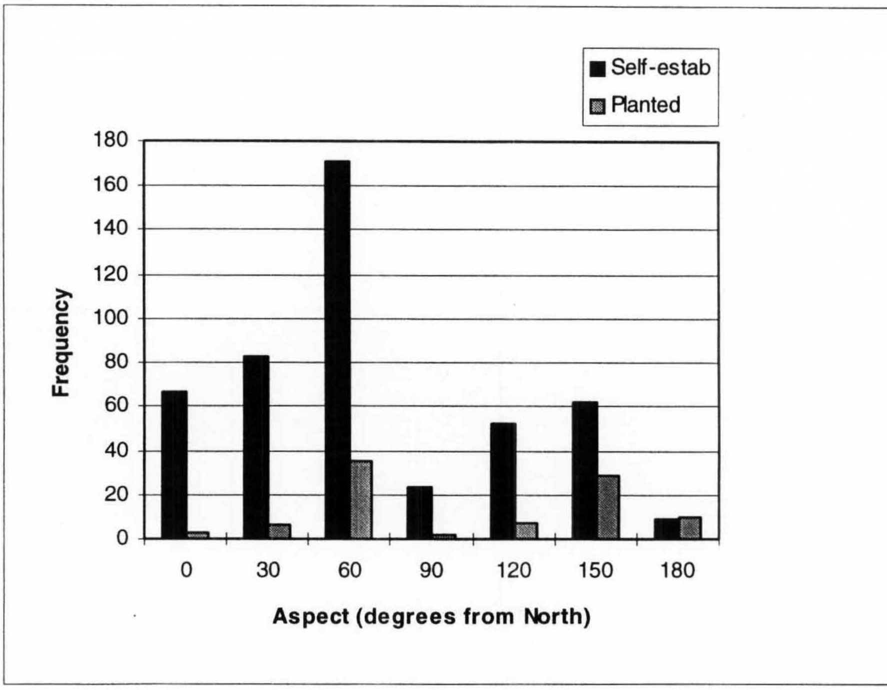


Figure 3.3i: Frequency histogram of aspect (degrees from North) for self-established and planted samples of Dataset One.

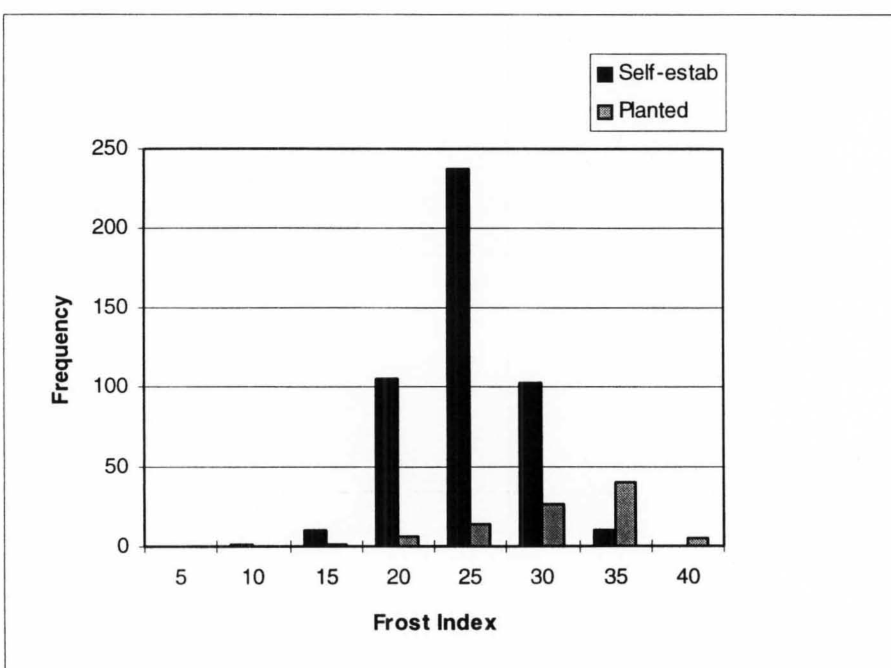


Figure 3.3j: Frequency histogram of frost for self-established and planted samples of Dataset One. Frost was ranked on a scale of 0-40, with low values indicating low frostiness.

3.3 Testing the Significance of Environmental Variables Using T-tests

The self-established data for each species were analysed using non-parametric t-tests to ascertain whether each species was significantly more or less sensitive to an environmental variable than all other self-established species in the dataset (Tables 3.2a-d). For example, *Carex secta* was found in a significantly (median*** and variance**) different soil moisture range than several other species in the dataset. The assumption was made that an individual plant had an equal chance of growing in any of the sites in which other species had self-established. The p-values included in Tables 3.2a-d are from the non-parametric t-tests of medians and variances, and the sample sizes, means and standard deviations have been included to summarise the species datasets. It was not considered necessary to fully state the results of the 26 species in Tables 3.2a-d. Instead, to ascertain the most important variables to measure in the field, these results were summarised by plant type and for all plant types (Table 3.3). The environmental ranges of each species are most easily compared in the boxplots in Section 3.6.

3.3.1 Can the environmental variables be summarised for particular plant types?

Table 3.3 summarises the percentages of species in the plant types of sedges and rushes; ferns; trees and shrubs; and for all species, for which the environmental variables were significantly different to that of all other species in the dataset. If the environmental variables were able to be grouped for each plant type, this would simplify the parameters to measured in the future.

The plant type of sedges and rushes had high numbers of significant levels (medians) for the environmental variables of elevation (90%), soil moisture (80%), distance from water (80%), riparian class (70%), and canopy (70%).

Table 3.2a: Summary of the sample sizes, means and standard deviations of the self-established samples of each sedge and rush species. The p-values are the t-test results from a comparison of the medians and variances of one species against all other self-established species in the dataset. (Refer to Table 3.1 for full species names).

Species *Sample No.*	**Typori** 15	**Carvir** 8	**Eleacu** 25	**Junpal** 15	**Junsar** 3
Distance (cm)					
Mean	-103.33	-86.43	-33.8	-20.33	330
p-value (median)	0.002	0	0	0	0.044
Standard deviation	254.8	106.25	83.81	62.21	115.33
p-value (variance)	0.038	0.002	0	0	0.099
Elevation (cm)					
Mean	-13.33	-3.14	-0.96	3.6	8.33
p-value (median)	0	0.002	0	0	NS
Standard deviation	9.39	6.89	5.76	27.4	2.89
p-value (variance)	0	0	0	0.009	0.004
Soil Moisture (Rank 1-7)					
Mean	2	2.43	2.12	2.8	4
p-value (median)	0	0.011	0	0.013	NS
Standard deviation	0	0.54	0.78	0.78	0
p-value (variance)	.	0.029	0.011	0.038	.
Riparian Class (Rank 1-7)					
Mean	1	1.43	1.44	1.87	3
p-value (median)	0	0.003	0	0.003	NS
Standard deviation	0	0.54	0.58	0.83	0
p-value (variance)	.	0.01	0	0.012	.
Slope (Degree)					
Mean	0	1.29	5.4	18.33	1.67
p-value (median)	0.001	NS	0.006	NS	NS
Standard deviation	0	1.98	16.26	31.94	2.89
p-value (variance)	.	0	0.011	NS	0.017
Canopy (Rank 0-4)					
Mean	0.2	0.86	1.28	0.6	0
p-value (median)	0	NS	NS	0.028	0.032
Standard deviation	0.41	0.9	1.24	0.74	0
p-value (variance)	0	NS	NS	NS	.
Soil pH	N=3	N=4	N=14	N=8	N=3
Mean	5.69	5.97	5.84	5.7	6.16
p-value (median)	NS	NS	NS	NS	NS
Standard deviation	0.61	0.26	0.55	0.4	0.16
p-value (variance)	NS	NS	NS	NS	0.088
Soil Conductivity (mS cm^{-1})	N=3	N=4	N=14	N=7	N=3
Mean	0.002	0.035	0.07	0.067	0.026
p-value (median)	0.003	NS	NS	NS	NS
Standard deviation	0	0.024	0.09	0.047	0.011
p-value (variance)	0	NS	0	NS	0.052
Aspect (Degree)					
Mean	82	24.29	63.2	71.33	30
p-value (median)	0.031	0.029	NS	NS	NS
Standard deviation	32.34	30.47	46.43	42.57	0
p-value (variance)	NS	NS	NS	NS	.
Frost (Rank 0-40)					
Mean	25.6	21.86	22.3	23.13	23.68
p-value (median)	0.008	NS	NS	NS	NS
Standard deviation	2.32	2.04	31.9	4.34	0.58
p-value (variance)	0.026	0.078	NS	NS	0.028

Table 3.2a (continued).....

Species	**Schpau**	**Carmao**	**Jungre**	**Carsec**	**Cargem**
Sample No.	13	28	25	30	15
Distance (cm)					
Mean	260.85	-17.43	30.44	24.3	61.33
p-value (median)	NS	0	0.025	0.004	NS
Standard deviation	276.35	83.26	53.37	58.96	66.08
p-value (variance)	NS	0	0	0	0
Elevation (cm)					
Mean	8.9	12.21	12.84	13	50.67
p-value (median)	0.033	0.006	0.021	0.025	0.005
Standard deviation	10.39	16.58	14.19	24.17	20.78
p-value (variance)	0	0	0	0	0
Soil Moisture (Rank 1-7)					
Mean	3.15	2.32	2.76	2.53	4.67
p-value (median)	NS	0	0.004	0	0.001
Standard deviation	0.89	0.91	1.2	0.78	1.18
p-value (variance)	NS	0.06	NS	0.003	NS
Riparian Class (Rank 1-7)					
Mean	2.54	1.92	2.08	1.93	3.47
p-value (median)	NS	0	0.005	0	NS
Standard deviation	0.52	0.72	0.64	0.74	1.3
p-value (variance)	0	0	0	0	NS
Slope (Degree)					
Mean	1.92	31.43	26.6	20.33	20.67
p-value (median)	0.077	NS	0.03	0.056	0.014
Standard deviation	3.25	37.68	30.91	26.91	22.1
p-value (variance)	0	0	0.081	NS	NS
Canopy (Rank 0-4)					
Mean	0	0.89	0.36	0.67	0.6
p-value (median)	0	NS	0	0.005	0.028
Standard deviation	0	0.92	0.76	0.76	0.74
p-value (variance)	.	NS	0.056	0.032	NS
Soil pH	N=9	N=9	N=15	N=12	N=3
Mean	6.47	6.22	5.72	6.03	5.91
p-value (median)	0.003	0.09	NS	NS	NS
Standard deviation	0.38	0.29	0.59	0.73	0.81
p-value (variance)	NS	0.031	NS	NS	NS
Soil Conductivity (mS cm^{-1})	N=10	N=9	N=15	N=13	N=3
Mean	0.024	0.054	0.075	0.093	0.09
p-value (median)	0.009	NS	NS	NS	0.066
Standard deviation	0.018	0.031	0.09	0.116	0.04
p-value (variance)	0.001	0.07	0	0	NS
Aspect (Degree)					
Mean	42.31	80	80	46	20.67
p-value (median)	NS	0.029	0.047	0.036	0
Standard deviation	34.19	50.26	51.7	49.38	13.87
p-value (variance)	NS	NS	NS	NS	0
Frost (0-40)					
Mean	24.31	22.36	23.8	22.2	22.6
p-value (median)	NS	NS	NS	0.066	NS
Standard deviation	2.09	3.97	4.12	3.36	4.12
p-value (variance)	0.015	NS	NS	NS	NS

Table 3.2b: Summary of the sample sizes, means and standard deviations of the self-established samples of each fern species. The p-values are the t-test results from a comparison of the medians and variances of one species against all other self-established species in the dataset. (Refer to Table 3.1 for full species names).

Species *Sample No.*	**Phypus** 5	**Blepen** 13	**Blecap** 26	**Blemin** 35	**Bleflu** 8	**Blecha** 12	**Polves** 23
Distance (cm)							
Mean	165	49.08	48.35	69.57	11.13	32.08	186.04
p-value (median)	NS	NS	0.021	NS	0.085	NS	0.001
Standard deviation	89.44	53.87	95.32	121.15	13.99	66.32	120.29
p-value (variance)	0.006	0	0	0	0	0	0
Elevation (cm)							
Mean	7	12.15	21.92	33.2	46.63	58.58	64.04
p-value (median)	NS	0.088	0.095	NS	0.077	0.003	0.001
Standard deviation	2.74	14.83	35.36	26.01	22.97	23.99	47.86
p-value (variance)	0	0	0.027	0	0.023	0.006	NS
Soil Moisture (Rank1-7)							
Mean	3.2	3.31	3.15	3.71	4.13	4.08	4.13
p-value (median)	NS	NS	0.09	NS	NS	0.07	0.009
Standard deviation	0.45	0.75	1.05	0.86	0.35	0.51	0.97
p-value (variance)	0.039	0.04	NS	0.008	0.001	0.002	NS
Riparian Class (Rank 1-7)							
Mean	2.4	2.31	2.42	2.89	3.13	3.18	3.96
p-value (median)	NS	NS	0.093	NS	NS	NS	0
Standard deviation	0.55	0.48	1.14	0.99	0.64	0.84	1.02
p-value (variance)	0.041	NS	0.084	0.003	0.016	0.025	0.031
Slope (Degree)							
Mean	0	16.15	14.04	37.14	58.75	43.33	10.44
p-value (median)	0.047	NS	NS	0	0	0	NS
Standard deviation	0	24.68	18.17	36.63	25.32	29.95	14.76
p-value (variance)	.	NS	0.045	0	NS	NS	0.003
Canopy (Rank 0-4)							
Mean	2.6	2.39	1.62	1.97	1.38	1	1.96
p-value (median)	0.003	0	0.018	0	NS	NS	0.001
Standard deviation	0.55	0.96	0.98	0.86	0.52	0.95	1.22
p-value (variance)	NS	NS	NS	NS	0.038	NS	NS
Soil pH	N=5	N=10	N=17	N=18	N=8	N=10	N=21
Mean	5.79	2.89	5.85	6.25	6.29	6.69	6.08
p-value (median)	NS	NS	NS	0.036	0.032	0	NS
Standard deviation	0.45	0.49	0.57	0.56	0.12	0.23	0.46
p-value (variance)	NS	NS	NS	NS	0	0.003	NS
Soil Conductivity ($mS\ cm^{-1}$)	N=5	N=10	N=17	N=16	N=8	N=10	N=21
Mean	0.018	0.043	0.067	0.031	0.022	0.029	0.037
p-value (median)	0.011	NS	NS	0.052	0.004	0.035	NS
Standard deviation	0.006	0.027	0.047	0.019	0.016	0.024	0.024
p-value (variance)	0	0.024	0.55	0	0.002	0.008	0
Aspect (Degree)							
Mean	0	53.85	25	102.57	113.75	86.67	76.09
p-value (median)	0.001	NS	0	0	0	0.072	0.002
Standard deviation	0	53.16	33.4	38.91	36.23	38.69	24.99
p-value (variance)	.	NS	0.061	NS	NS	NS	0.001
Frost (Rank 0-40)							
Mean	17.8	19.69	20.15	21.74	21.88	23.42	24.44
p-value (median)	0.001	0	0	0.005	NS	NS	NS
Standard deviation	1.09	2.93	3	3.59	1.36	3.06	3.09
p-value (variance)	0.016	NS	NS	NS	0.005	NS	NS

Table 3.2c: Summary of the sample sizes, means and standard deviations of the self-established samples of each tree and shrub species. The p-values are the t-test results from a comparison of the medians and variances of one species against all other self-established species in the dataset. (Refer to Table 3.1 for full species names).

Species *Sample No.*	**Coraus** 32	**Coprob** 40	**Pitten** 19	**Corarb** 14	**Sollac** 16
Distance (cm)					
Mean	147.66	156.56	620.68	127.64	553.31
p-value (median)	NS	0.071	0.001	NS	0.006
Standard deviation	308.86	170.8	1577.51	163.41	839.16
p-value (variance)	0.05	0	0	0	0
Elevation (cm)					
Mean	26.16	36.3	38.95	50.93	115.44
p-value (median)	NS	NS	NS	0.075	0
Standard deviation	40.53	45.21	66.32	41.81	111.11
p-value (variance)	NS	NS	0.059	NS	0
Soil Moisture (Rank 1-7)					
Mean	3.47	3.43	3.61	4.43	50
p-value (median)	NS	NS	NS	0.008	0
Standard deviation	0.95	0.9	0.85	1.02	0.37
p-value (variance)	0.06	0.013	0.058	NS	0
Riparian Class (Rank 1-7)					
Mean	3	3.13	3.05	3.57	4.69
p-value (median)	NS	NS	NS	0.063	0
Standard deviation	40.53	1.51	1.22	1.56	1.7
p-value (variance)	NS	NS	NS	NS	0
Slope (Degree)					
Mean	1.56	5.13	2.37	27.36	11.25
p-value (median)	0	NS	0.005	0.034	NS
Standard deviation	1.69	7.38	7.14	28.39	12.34
p-value (variance)	0	0	0	NS	0.002
Canopy (0-4)					
Mean	0.88	1	1.05	0.71	1.31
p-value (median)	NS	NS	NS	NS	NS
Standard deviation	0.79	0.56	0.78	0.61	1.25
p-value (variance)	0.05	0	NS	0.023	NS
Soil pH	N=17	N=26	N=17	N=14?	N=9
Mean	5.74	5.9	5.54	6.26	6
p-value (median)	0.074	NS	0.002	0.029	NS
Standard deviation	0.32	0.56	0.47	0.62	0.91
p-value (variance)	0.005	NS	NS	NS	0.03
Soil Conductivity (mS cm^{-1})	N=18	N=28	N=17	N=14	N=9
Mean	0.073	0.065	0.049	0.043	0.06
p-value (median)	0.039	0.004	NS	NS	0.077
Standard deviation	0.061	0.043	0.023	0.047	0.03
p-value (variance)	NS	NS	0	NS	NS
Aspect (Degree)					
Mean	71.56	65	60	48.57	48.13
p-value (median)	0.035	NS	NS	NS	NS
Standard deviation	41.44	54.21	6.86	21.07	33.11
p-value (variance)	NS	0.059	0	0.002	NS
Frost (0-40)					
Mean	25.63	24.91	24.94	23.36	25.13
p-value (median)	0.001	0.007	0.029	NS	0.076
Standard deviation	3.23	3.37	2.69	3.05	3.38
p-value (variance)	NS	NS	0.069	NS	NS

Table 3.2d: Summary of the sample sizes, means and standard deviations of the self-established samples of *Phormium tenax*, *Hydrocotyle novae-zeelandiae*, and *H. heteromeria*. *Astelia fragrans* (N=5) had insufficient data for analysis. The p-values are the t-test results from a comparison of the medians and variances of one species against all other self-established species in the dataset. (Refer to Table 3.1 for full species names).

Species	**Photen**	**Hydnov**	**Hydhet**
Sample No.	23	17	9
Distance (cm)			
Mean	44.13	306.68	73.67
p-value (median)	0.065	0.024	NS
Standard deviation	96.79	344.87	84.58
p-value (variance)	0	NS	0
Elevation (cm)			
Mean	18.74	64.8	31
p-value (median)	NS	0.005	NS
Standard deviation	23.16	55.61	24.45
p-value (variance)	0	NS	0.023
Soil Moisture (Rank 1-7)			
Mean	3.09	4.94	4.11
p-value (median)	0.068	0	NS
Standard deviation	1.08	1.19	0.6
p-value (variance)	NS	NS	0.024
Riparian Class (Rank 1-7)			
Mean	2.13	3.94	2.89
p-value (median)	0.009	0.008	NS
Standard deviation	0.97	1.64	1.36
p-value (variance)	0.014	NS	NS
Slope (Degree)			
Mean	7.61	18.82	26.11
p-value (median)	NS	NS	NS
Standard deviation	19	30.39	37.31
p-value (variance)	NS	NS	0.058
Canopy (0-4)			
Mean	1.57	1.35	1.44
p-value (median)	0.02	NS	NS
Standard deviation	0.79	0.99	1.24
p-value (variance)	0.09	NS	NS
Soil pH	N=15	N=9	N=4
Mean	5.88	6.18	5.81
p-value (median)	NS	NS	NS
Standard deviation	0.61	0.55	0.86
p-value (variance)	NS	NS	NS
Soil Conductivity (mS cm^{-1})	N=13	N=8	N=4
Mean	0.089	0.027	0.06
p-value (median)	NS	0.074	NS
Standard deviation	0.08	0.013	0.039
p-value (variance)	0.014	0	NS
Aspect (Degree)			
Mean	45.65	39.41	17.78
p-value (median)	0.069	0.044	0.004
Standard deviation	51.06	39.13	18.56
p-value (variance)	NS	NS	0.008
Frost (Rank 0-40)			
Mean	21.87	22.71	19.56
p-value (median)	0.066	NS	0.016
Standard deviation	3	4.82	4.9
p-value (variance)	NS	NS	NS

Table 3.3: The percentage of species for the plant types of sedges and rushes, ferns, and trees and shrubs, for which the environmental variables were significantly different to those of all other self-established species in the dataset.

Variables	Sedges & Rushes	Ferns	Trees & Shrubs	All Plant Types
Distance (cm)				
Median	80%	29%	40%	52%
Variance	80%	100%	100%	88%
Elevation (cm)				
Median	90%	29%	20%	52%
Variance	100%	86%	20%	76%
Soil Moisture (Rank 1-7)				
Median	80%	14%	40%	48%
Variance	40%	71%	40%	48%
Riparian Class (Rank 1-7)				
Median	70%	14%	20%	44%
Variance	70%	71%	20%	56%
Slope (Degree)				
Median	40%	57%	60%	44%
Variance	50%	43%	80%	48%
Canopy (0-4)				
Median	70%	71%	0%	52%
Variance	20%	14%	60%	24%
Soil pH				
Median	10%	43%	40%	24%
Variance	10%	29%	40%	20%
Soil Conductivity (mS cm^{-1})				
Median	20%	43%	40%	28%
Variance	50%	86%	20%	56%
Aspect (Degree)				
Median	60%	71%	20%	56%
Variance	10%	14%	40%	20%
Frost (Degree)				
Mean	10%	57%	60%	36%
Standard Deviation	30%	29%	0%	20%

The variances were significant in all cases for elevation, 80% for distance, and 70% for riparian class.

For ferns, the medians of aspect and canopy were significantly different from the medians of other species 71% of the time. The variances of ferns were significantly different a high percentage of the time for the environmental variables of distance from water (100%), elevation (86%), soil conductivity (86%), riparian class (71%), and soil moisture (71%).

Of the trees and shrubs, the medians were significant 60% of the time for slope and frost, and the variances were all significant for distance, 80% for slope, and 60% for canopy.

High percentages of significant variances for a plant type, indicated that there was wide within-species variation for that plant type. The range of percentages for each plant type, and all species together, for each environmental variable indicated that it is difficult to group all species in relation to one set of environmental gradients.

As indicated above, within each plant type certain variables were highlighted as being important. For sedges and rushes, the variables of distance, elevation, soil moisture, riparian class, and canopy appeared to be important, while for trees and shrubs, slope was more important. However, significance levels for environmental variables totalling in the low to mid percentages for a plant type (eg., ferns), indicate that a particular variable was significant for some of the species within the plant type but not for others. Thus an important conclusion is that it is not possible to generalise sets of environmental variables across the plant types chosen in the study.

3.3.2 Do species have specific environmental ranges?

Individual species were shown to be sensitive to different combinations of environmental variables (Table 3.2a-d). This indicates that several variables would need to be measured in the field to ascertain the environmental ranges of particular species.

Some species had narrow ranges and others wide ranges in relation to different environmental variables, eg., *Juncus gregiflorus* had a wider soil moisture range than *Eleocharis acuta* (Table 3.2a). When the t-tests of variance for a species did not indicate a significantly different variance for an environmental variable, the species may have had a wide range for that parameter. These ranges are most clearly illustrated in the boxplots discussed in Section 3.6.

3.4 Testing the Differences Between Self-Established and Planted Samples

Within species t-tests were done on the self-established and planted data for *Cordyline australis*, *Coprosma robusta*, *Pittosporum tenuifolium*, *Solanum laciniatum*, *Juncus pallidus*, *J. gregiflorus*, *Carex secta*, and *Phormium tenax* to ascertain any significant differences between where individuals had been planted and where they had naturally self-established (Table 3.4). Table 3.4 indicates that for several species planted and self-established individuals were in significantly different sites. For example, the median values of the planted dataset of *Cordyline australis* were found to be significantly higher (***) and further away (**) from the water, with drier soil (***) and higher pH (***), less shady (***) and more frosty (***) than the self-established dataset (Table 3.4). The pattern was similar for *Coprosma robusta*, *Pittosporum tenuifolium* and *Phormium tenax*. *Juncus pallidus* planted individuals were in drier sites with less canopy and more frost. *Juncus gregiflorus* planted individuals were in sites further up the bank than their self-established counterparts.

Significantly different results between planted and self-established data for each species are most clearly illustrated in the boxplots for each environmental variable by plant type (Section 3.6).

Table 3.4: Summary of the sample sizes, means and standard deviations of self-established (Self) and planted (Plant) samples for tree, shrub, sedge and rush species, and for *Phormium tenax*. The p-values presented are the t-test results from a comparison of the medians and variances of self-established and planted samples of each species for each environmental variable. (Refer to Table 3.1 for full species names).

Species	Coraus		Coprob		Pitten		Sollac	
Category	**Self**	**Plant.**	**Self**	**Plant.**	**Self**	**Plant.**	**Self-**	**Plant.**
Sample Number	32	21	40	4	19	13	16	2
Distance (cm)								
Mean	147.66	885	156.58	494.5	620.68	926.15	553.31	170
p-value (median)	**0.008**		**NS**		**0.01**		**NS**	
Standard deviation	308.86	1021.62	170.80	672.99	1577.50	849.55	839.16	42.43
p-value (variance)	**0**		**0**		**0.031**		**0.05**	
Elevation (cm)								
Mean	26.16	175.91	36.3	152	38.95	167.69	115.44	90
p-value (median)	**0**		**0.008**		**0**		**NS**	
Standard deviation	40.53	153.50	45.20	99.21	66.32	128.01	111.11	14.14
p-value (variance)	**0**		**0.027**		**0.031**		**NS**	
Soil Moisture (Rank 1-7)								
Mean	3.47	4.67	3.43	5.25	3.61	5.31	5	5.5
p-value (median)	**0**		**0.002**		**0**		**NS**	
Standard deviation	0.95	1.28	0.91	0.50	0.85	1.03	0.36	0.71
p-value (variance)	**0.0142**		**0.026**		**NS**		**NS**	
Riparian Class (Rank 1-7)								
Mean	3	4.71	3.125	5.5	3.05	5.23	4.69	5
p-value (median)	**0.002**		**0.009**		**0**		**NS**	
Standard deviation	1.69	1.93	1.51	1.00	1.22	0.60	1.70	0.00
p-value (variance)	**NS**		**NS**		**0.014**		.	
Slope (Degree)								
Mean	1.563	3.81	5.16	22.5	2.37	2.31	11.25	0
p-value (median)	**0.055**		**0.029**		**NS**		**NS**	
Standard deviation	4.10	5.71	7.38	15.00	7.14	3.88	12.32	0.00
p-value (variance)	**NS**		**0.051**		**0.033**		.	
Canopy (Rank 0-4)								
Mean	0.88	0.24	1	0	1.05	0.54	1.31	0
p-value (median)	**0.001**		**0**		**0**		**NS**	
Standard deviation	0.79	0.62	0.56	0.00	0.78	0.77	1.25	0.00
p-value (variance)	**NS**		.		**NS**		.	
Soil pH								
Mean	5.74	6.78	5.88	.	5.54	6.48	6	6.7
p-value (median)	**0**		.		**0.002**		**NS**	
Standard deviation	0.32	0.46	0.61	.	0.47	0.45	0.91	.
p-value (variance)	**NS**		.		**NS**		.	
Soil Conductivity (mS cm^{-1})								
Mean	0.073	0.074	0.065	.	0.049	0.047	0.063	0.043
p-value (median)	**NS**		.		**NS**		**NS**	
Standard deviation	0.06	0.06	0.04	.	0.03	0.00	0.03	.
p-value (variance)	**NS**		.		**NS**		.	
Aspect (Degree)								
Mean	71.56	106.19	65	107.5	60	90	48.13	40
p-value (median)	**0.025**		**NS**		**0.061**		**NS**	
Standard deviation	41.43	51.81	54.21	45.00	6.86	48.65	33.11	28.28
p-value (variance)	**NS**		**NS**		**0**		**NS**	
Frost (Rank 0-40)								
Mean	21.13	25.29	20.93	24	21.39	25.69	22.38	21.5
p-value (median)	**0**		**0.001**		**0**		**0.09**	
Standard deviation	2.87	2.08	3.58	0.82	2.06	2.17	4.49	2.12
p-value (variance)	**NS**		**0.025**		**NS**		**NS**	

Table 3.4 (continued)........

Species	**Junpal**		**Carsec**		**Jungre**		**Photen**	
Category	**Self**	**Plant.**	**Self**	**Plant.**	**Self**	**Plant.**	**Self**	**Plant.**
Sample Number	15	14	30	14	25	2	23	20
Distance (cm)								
Mean	-20.33	15.57	24.033	10	30.44	0	44.13	234
p-value (median)	**0.051**		**NS**		**NS**		**0.051**	
Standard deviation	62.21	21.74	18.64	17.54	16.85	0.00	96.80	299.42
p-value (variance)	**0.001**		**0**		.		**0**	
Elevation (cm)								
Mean	3.6	8.57	13	14.64	12.84	50	18.74	83.7
p-value (median)	**0.092**		**NS**		**NS**		**0**	
Standard deviation	27.40	13.94	24.17	20.24	14.19	42.43	23.16	49.56
p-value (variance)	**0.02**		**NS**		**0.06**		**0.001**	
Soil Moisture (Rank 1-7)								
Mean	2.8	3.86	2.53	2.07	2.76	5	3.09	5.35
p-value (median)	**0**		**NS**		**NS**		**0**	
Standard deviation	0.77	0.54	0.77	0.83	1.20	2.83	1.08	1.42
p-value (variance)	**NS**		**NS**		**NS**		**NS**	
Riparian Class (Rank 1-7)								
Mean	1.87	1.86	1.93	1.86	2.08	4	2.13	4.15
p-value (median)	**NS**		**NS**		**0.01**		**0**	
Standard deviation	0.83	0.77	0.75	0.36	0.64	0.00	0.97	1.50
p-value (variance)	**NS**		**0.008**		.		**0.053**	
Slope (Degree)								
Mean	18.3	11.43	20.33	16.79	26.6	40	7.61	5.25
p-value (median)	**NS**		**NS**		**NS**		**NS**	
Standard deviation	31.94	18.44	26.91	26.86	30.91	56.57	19.00	10.70
p-value (variance)	**0.055**		**NS**		**NS**		**0.014**	
Canopy (Rank 0-4)								
Mean	0.6	0.07	0.667	1.29	0.36	0	1.57	0.25
p-value (median)	**0.018**		**NS**		**NS**		**0**	
Standard deviation	0.73	0.26	0.76	1.33	0.75	0.00	0.79	0.55
p-value (variance)	**0.001**		**0.014**		.		**NS**	
Soil pH								
Mean	5.72	6.45	6.03	5.82	5.72	.	5.88	6.63
p-value (median)	**NS**		**NS**		.		**0.005**	
Standard deviation	0.40	0.87	0.73	0.36	0.59	.	0.61	0.44
p-value (variance)	**0.089**		**NS**		.		**NS**	
Soil Conductivity (mS cm^{-1})								
Mean	0.067	0.072	0.004	0.002	0.075	.	0.089	0.058
p-value (median)	**NS**		**NS**		.		**NS**	
Standard deviation	0.04	0.03	0.00	0.00	0.09	.	0.08	0.04
p-value (variance)	**NS**		**0.029**		.		**NS**	
Aspect (Degree)								
Mean	71.33	109.29	46	86.43	80	60	45.65	82
p-value (median)	**0**		**0.015**		**NS**		**0.019**	
Standard deviation	42.57	32.45	49.38	47.00	51.72	0.00	51.06	47.08
p-value (variance)	**NS**		**NS**		.		**NS**	
Frost (Rank 0-40)								
Mean	17.53	19.71	16.87	20.29	17.24	16.5	20.13	22.75
p-value (median)	**0.001**		**NS**		**NS**		**0**	
Standard deviation	5.18	1.90	3.83	5.38	4.67	7.78	2.75	4.14
p-value (variance)	**0.003**		**NS**		**NS**		**0.034**	

3.5 Testing the Independence of the Environmental Variables

Principal Component Analysis (PCA) was used to separate data relative to the axis of the greatest variation in data. Eigenvalues represent the relative contribution of each axis to the explanation of the total variation in the data, and eigenvectors represent the weighting of each of the original variables on each axis. It is assumed with PCA that each axis (of 10 axes) will explain 10% of the variation each if the data was equally distributed through each axis. Any value the same as or less than 10% is considered to be the same as or less than what any one factor in the analysis could explain. The correlation coefficients indicate the relationships between different environmental variables.

By avoiding duplication of environmental variables it is possible to narrow the parameters measured in the field. This is the primary reason for doing the PCA on the present dataset.

3.5.1 Results of the Principal Component Analysis (PCA)

A PCA was performed firstly on the self-established data of each species, and secondly on both the self-established and planted data for each species in the study to test the validity of the initial results with more data.

PCA for Self-Established Data

All samples of the self established dataset were used in the PCA to take into account both the variances and the means in the analysis.

The eigenvalues and the percentage of variance explained are presented in Table 3.5a. Axis One explained 31.7% of the variation in the data, Axis Two explained 18.4% of the variation and Axis Three explained 14.9% of the variation. Cumulatively the first three axes explained 65% of the variation in the dataset.

The eigenvectors (Table 3.5b) indicate that Axis One was a combination of elevation in relation to water (0.915), riparian class (0.876), soil moisture (0.767), distance from water (0.629), and frost (0.684). Axis Two was a combination of soil pH (-0.772), soil conductivity (0.631) and slope (-0.74). Canopy (O.686), frost (-0.656) and aspect (-0.585) were the key variables explained by Axis Three.

The correlation matrix, Table 3.5c, for self-established species only, indicated that soil moisture, riparian class, elevation, distance, and frost were all very highly positively correlated. Slope, pH and conductivity were also very highly positively correlated, as were frostiness with canopy and aspect. Frost was probably indicated on both Axes One and Three due to the inclusion of elevation and canopy in the creation of the frost index.

PCA for All Samples

The eigenvalues and the percentage of variance explained by the axes in the PCA of all samples (Table 3.6a) indicated that Axis One explained 38.5% of the variation in the data, Axis Two explained 15.6% and Axis Three explained 12.7%. In total 66.8% of the variation in the dataset was explained by the first three axes, in comparison to 65% for the self-established dataset. The key difference between using all data versus the self-established dataset was that Axis One of the "all dataset" explained slightly more of the variation than the other variables. In general, however, the results were very similar.

The eigenvector results indicated that Axis One was a combination of elevation (0.91), riparian class (0.847), frost (0.841), soil moisture (0.794), and distance (0.709) (Table 3.6b). The correlation coefficients, Table 3.6c, indicated that all of these variables were very highly positively correlated with one another. For

Axis One the PCA results for all samples were very similar to the PCA for the self-established group.

The eigenvectors indicate that Axis Two is a combination of slope (-0.702), pH (-0.585), and conductivity (0.5) (Table 3.6b). In the correlation of all data, Table 3.6c, pH and conductivity were strongly negatively correlated, and pH and slope were strongly positively correlated.

For Axis Three, the eigenvectors indicated that aspect (-0.619), soil conductivity (-0.488), canopy (0.439) and frost (-0.487) were the key variables explained (Table 3.6b). The main difference was that soil conductivity was more strongly correlated with Axis Three when both self-established and planted data were used.

Plotting the PCA Results

Results of the PCA for self-established data were plotted in Figures 3.4a-c. These figures represent two axes at a time as the multi-dimensional nature of the results is difficult to visualise. It is not possible to literally interpret plant groupings from these figures due to the multi-dimensionality, however, the spread of the species in relation to the environmental variables was what would be expected based on the boxplots presented later in this chapter. Figure 3.4b indicates that *Typha orientalis* was at one end of Axis One, which appeared to explain soil moisture, elevation, distance and riparian class, and *Solanum laciniatum* was at the other end of this continuum representing well-drained sites. If Axis Three primarily explained canopy, *Juncus sarophorus*, *Schoenus pauciflorus* and *Typha orientalis* were at the low end of the continuum (no shade), whereas the *Blechnum* ferns at the other end of the continuum, were associated with shaded sites (Fig. 3.4b). Axis Two appeared to correlate well with slope, with the *Blechnum* ferns at the low end (steep banks), and *Cordyline australis*, *Phormium tenax*, *Pittosporum tenuifolium*, and *Solanum laciniatum* at the high end (flatter sites) (Fig. 3.4c).

Table 3.5a: Principal Component Analysis eigenvalues and the percentage of total variance explained by each axis for self-established data only.

AXIS	1	2	3	4	5
Eigenvalue	3.165	1.844	1.494	0.975	0.85
% of variance explained	31.65%	18.44%	14.94%	9.75%	8.50%
AXIS	**6**	**7**	**8**	**9**	**10**
Eigenvalue	0.727	0.502	0.26	0.172	0.012
% of variance explained	7.27%	5.02%	2.60%	1.72%	0.13%

Table 3.5b: Principal Component Analysis eigenvectors for the first four axes for self-established data only.

AXIS	1	2	3	4
Distance	0.629	0.29	-0.006	0.144
Elevation	0.915	0.002	0.08	0.094
Riparian Class	0.876	0.067	0.207	-0.011
Slope	-0.103	-0.74	0.011	0.205
Canopy	-0.074	0.259	0.686	-0.633
Soil Moisture	0.767	-0.056	0.297	-0.015
Soil pH	0.192	-0.772	0.179	0.103
Soil Conductivity	-0.202	0.631	-0.287	0.191
Aspect	0.12	-0.367	-0.585	-0.664
Frost	0.684	0.092	-0.656	-0.121

Table 3.5c: Pearson product-moment correlation coefficient values, frequency, and significance levels for self-established data only.

	Distance	Elevation	Ripclass	Slope	Canopy	Soil Moisture	Soil pH	Soil Cond.	Frost	Aspect
Distance	1									
	554									
	0									
Elevation	0.593	1								
	554	554								
	0	0								
Riparian Class	0.477	0.789	1							
	554	554	554							
	0	0	0							
Slope	-0.133	0.028	-0.053	1						
	554	554	554	554						
	0.002	0.516	0.216	0						
Canopy	0.039	0.009	0.096	-0.152	1					
	554	554	554	554	554					
	0.362	0.83	0.024	0	0					
Soil Moisture	0.301	0.649	0.733	0.049	0.072	1				
	554	554	554	554	554	554				
	0	0	0	0.247	0.089	0				
Soil pH	-0.092	0.201	0.094	0.369	-0.1	0.152	1			
	348	348	348	348	348	348	348			
	0.085	0	0.081	0	0.061	0.004	0			
Soil Conductivity	0.001	-0.1	-0.123	-0.185	-0.031	-0.176	-0.471	1		
	347	347	347	347	347	347	347	347		
	0.993	0.063	0.022	0.001	0.566	0.001	0	0		
Frost	0.283	0.455	0.369	-0.377	-0.451	0.248	-0.009	0.003	1	
	553	553	553	553	553	553	553	553	553	
	0	0	0	0	0	0	0.862	0.95	0	
Aspect	-0.077	-0.059	-0.108	0.259	-0.038	-0.101	0.106	-0.103	0.43	1
	553	553	553	553	553	553	553	553	553	553
	0.069	0.166	0.011	0	0.378	0.017	0.048	0.055	0	0

Table 3.6a: Principal Component Analysis eigenvalues and the percentage of total variance explained by each axis for all data in Dataset One.

AXIS	1	2	3	4	5
Eigenvalue	3.851	1.556	1.274	0.973	0.805
% of variance explained	38.51%	15.56%	12.74%	9.73%	8.05%
AXIS	**6**	**7**	**8**	**9**	**10**
Eigenvalue	0.639	0.544	0.206	0.138	0.015
% of variance explained	6.39%	5.44%	2.06%	1.39%	0.15%

Table 3.6b: Principal Component Analysis eigenvectors for the first four axes for all data in Dataset One.

AXIS	1	2	3	4
Distance	0.709	0.296	0.068	0.049
Elevation	0.91	0.118	0.144	0.067
Riparian Class	0.847	0.166	0.177	-0.113
Slope	-0.153	-0.702	0.191	0.242
Canopy	-0.432	0.375	0.439	-0.573
Soil Moisture	0.794	0.063	0.232	-0.038
Soil pH	0.439	-0.585	0.275	0.167
Soil Conductivity	-0.188	0.5	-0.488	0.454
Aspect	0.158	-0.442	-0.619	-0.567
Frost	0.841	-0.04	-0.487	-0.095

Table 3.6c: Pearson product-moment correlation coefficient values, frequency, and significance levels for all data in Dataset One.

	Distance	Elevation	Ripclass	Slope	Canopy	Soil Moisture	Soil pH	Soil Cond.	Frost	Aspect
Distance	1									
	937									
	0									
Elevation	0.784	1								
	937	937								
	0	0								
Riparian Class	0.583	0.788	1							
	937	937	937							
	0	0	0							
Slope	-0.179	-0.106	-0.136	1						
	937	937	937	937						
	0	0.001	0	0						
Canopy	-0.173	-0.28	-0.185	-0.073	1					
	937	937	937	937	937					
	0	0	0	0.026	0					
Soil Moisture	0.445	0.699	0.795	-0.086	-0.236	1				
	936	936	936	936	936	936				
	0	0	0	0.009	0	0				
Soil pH	0.127	0.371	0.214	0.213	-0.283	0.298	1			
	541	541	541	541	541	541	541			
	0.003	0	0	0	0	0	0			
Soil Conductivity	-0.031	-0.099	-0.14	-0.132	-0.018	-0.157	-0.343	1		
	539	539	539	539	539	539	531	539		
	0.472	0.022	0.001	0.002	0.683	0	0	0		
Frost	0.468	0.646	0.589	-0.354	-0.6	0.545	0.278	-0.044	1	
	936	936	936	936	936	936	541	539	936	
	0	0	0	0	0	0	0	0.31	0	
Aspect	-0.095	-0.078	-0.069	0.191	-0.082	-0.085	0.069	-0.091	0.408	1
	936	936	936	936	936	936	541	539	936	936
	0.004	0.017	0.035	0	0.012	0.009	0.111	0.035	0	0

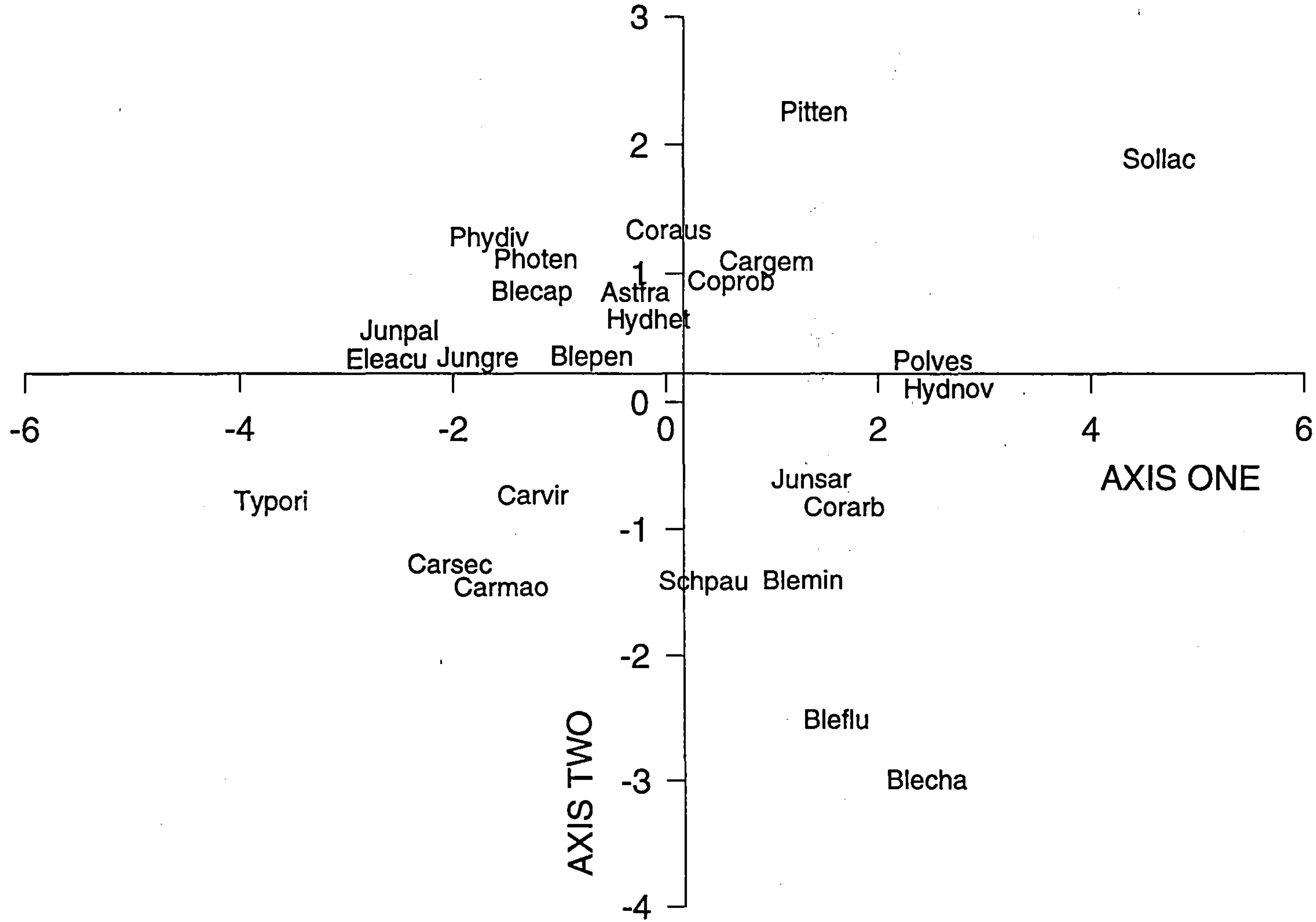


Figure 3.4a: Results of the Principal Components Analysis - Axis One by Axis Two for self-established species. (Refer to Table 3.1 for species abbreviations).

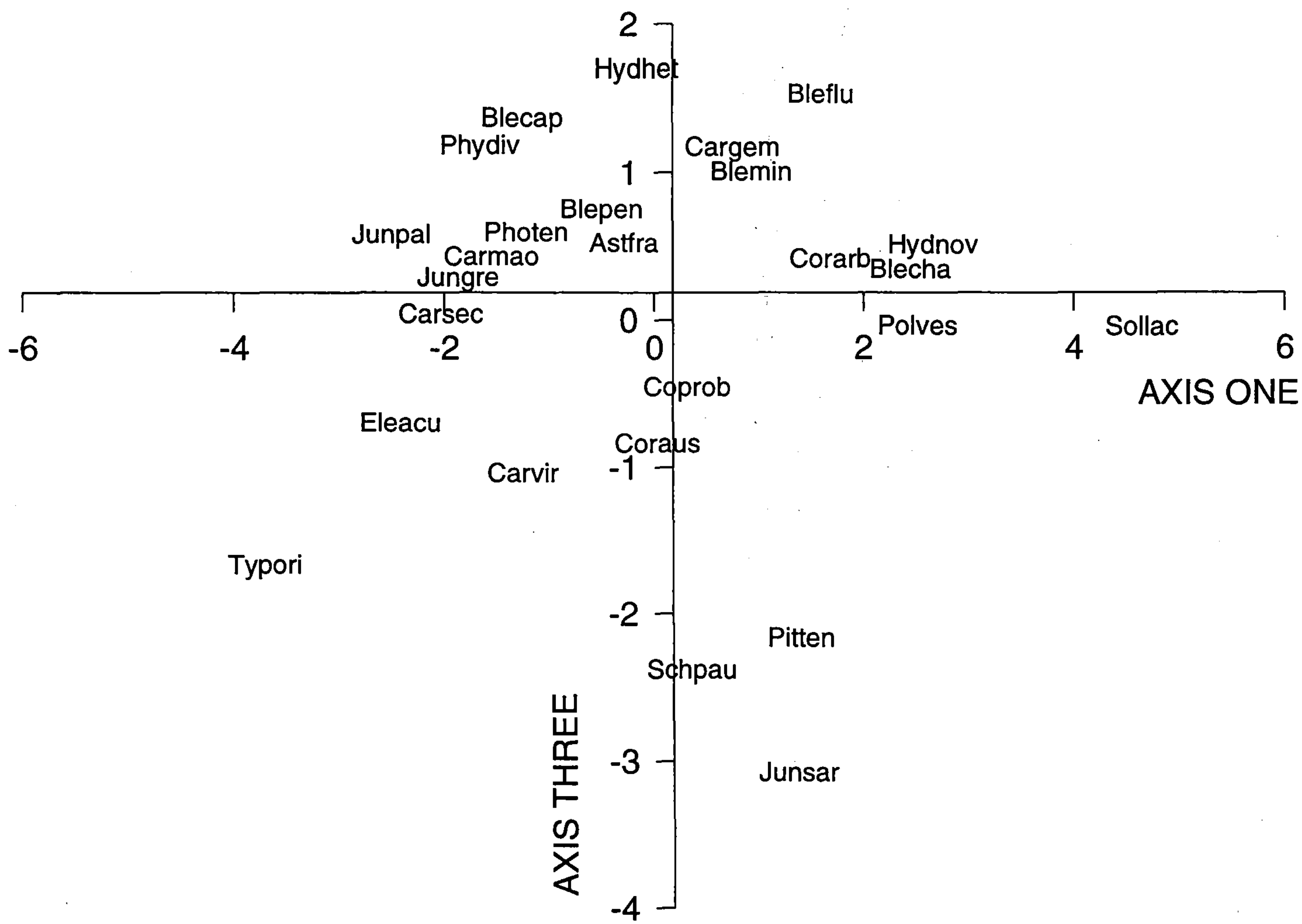


Figure 3.4b: Results of the Principal Components Analysis - Axis One by Axis Three for self-established species. (Refer to Table 3.1 for species abbreviations).

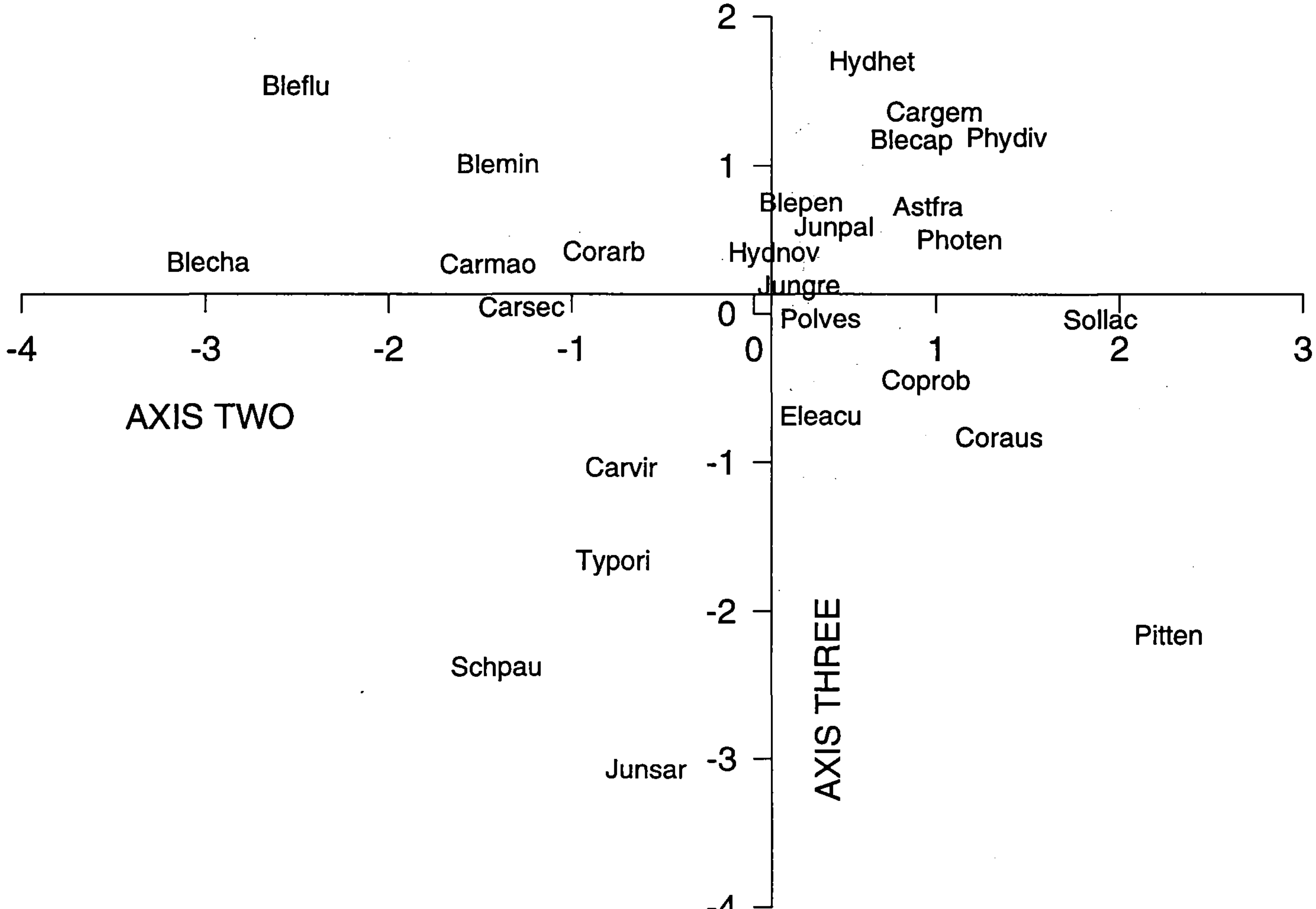


Figure 3.4c: Results of the Principal Components Analysis - Axis Two by Axis Three for self-established species. (Refer to Table 3.1 for species abbreviations).

3.5.2 Selecting Variables for Further Analysis

The Principal Component Analysis results for the self-established dataset only were used to select the key environmental variables for detailed consideration. The assumption was that the self-established data would give a more reliable indication of species ranges than the self-established and planted data combined.

In the case of Axis One, the highest eigenvectors were elevation, riparian class, soil moisture, distance and frost. One or two environmental variables could have been chosen to represent Axis One. It was decided, however, to present the results for the first three variables due to their potential combination in a quantitative index of soil moisture. Distance was not presented in the boxplots. As frost index was a combination of other environmental variables that spread across three axes it was presented.

Axis Two was a combination of slope, soil pH, and soil conductivity. Soil pH and slope were highly positively correlated (Table 3.5c), but as the variables measure distinctly different components of the site, both were plotted. Soil conductivity was strongly negatively correlated with both pH and slope (indicating that values of soil pH, slope and conductivity moved together), and it was excluded from further analysis.

Axis Three was primarily explained by canopy, frost and aspect. Canopy and frost were presented in the boxplots. Aspect was not further analysed due to problems with accuracy of measurements in a flat environment (improvements are suggested in Chapter Four).

In summary, the PCA highlighted that elevation and distance from water, soil moisture and riparian class all appeared to measure the same parameter and could be simplified down to one or two variables in future studies. The combinations of variables on axes two and three were less likely to be measuring the same site attributes, but more likely to indicate that values of some variables move together. Variables excluded from further analyses were distance, soil conductivity and aspect.

3.6 Species Ranges in Relation to the Environmental Variables

What were the patterns of individual species ranges in relation to the environmental variables?

The patterns of environmental ranges for each species and plant type for the environmental variables are presented in boxplots and described in detail. Where significantly different, the self-established and planted data for a species were plotted separately within their plant type groupings. The boxplots provide an indication of possible environmental ranges of each species to be included in a decision support process, and provide a graphic comparison of between-species ranges.

In the boxplot, the environmental variables and species are represented by the x and y axes respectively (Fig. 3.5). Boxes in a figure without whiskers or median lines either indicate very small sample sizes, or a relatively homogeneous species sample for that particular environmental variable. A rank class of poor, fair and good vigour was used in the field to broadly assess plant health at a site. Vigour is mentioned in the text if it might explain outliers or the 10th and 90th percentiles. Species names in the figures were abbreviated to six letter codes as described in Table 3.1. An "X" indicated species with less than 15 samples.

Supplementary to the boxplots, summary histogram percentages for the environmental variables of slope shape and broad riparian class were compiled and are presented in Table 3.7.

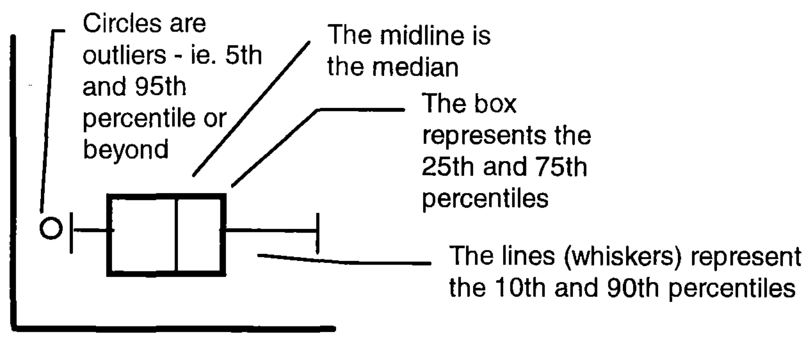


Figure 3.5: Explanation of the boxplots.

3.6.1 Elevation

The elevation of the plant in relation to average winter water levels was measured in centimetres.

Sedge and Rush Species

Figure 3.6a shows that *Typha orientalis* was only found in the water and *Eleocharis acuta* and *Carex virgata* had narrow ranges right on the water's edge. *Schoenus pauciflorus* and *Juncus sarophorus* also had narrow ranges, between 5 and 15 cm above the water. *C. maorica* had a wider range from 0-25cm above the water. *Juncus pallidus* was found from -10cm into the water to 10cm above the water, and *Juncus gregiflorus* from 5 to 35cm above the water. *C. secta* was found between -5 to 40cm, with two plants of only fair vigour at 40cm and one plant at -20cm. *C. geminata* was recorded in a relatively narrow range between 50-65cm above the water.

Fern Species

Figure 3.6b shows a graduation in elevation above water from *Phymatosorus pustulatus* up to *Polystichum vestitum*. For *P. vestitum*, the outlier at 10cm above the water was only of fair vigour. Several of these species have low sample size, which may affect their overall position on this scale. Plants of fair vigour were recorded at the 10th percentile for *Blechnum minus*, and at 50cm above the water and -10cm into the water for *B. aff. capense.*

Tree and Shrub Species

Figure 3.6c shows that the self-established individuals of *Cordyline australis*, *Coprosma robusta*, and *Pittosporum tenuifolium* were primarily found between 0 and 40cm from the water. *Cordyline australis* outliers at 130cm above the water and 5cm into the water were only of fair vigour. *Coriaria arborea* and *Solanum laciniatum* had slightly wider ranges, between 5-70cm and 20-110cm above the water respectively.

Comparison of Self-established and Planted Data

The median values of the planted datasets of *Cordyline australis* (***), *Coprosma robusta* (**), and *Pittosporum tenuifolium* (***) were all significantly higher (Table 3.4) than the self-established datasets (Fig. 3.6c). Planted individuals of *Cordyline australis* were only of fair vigour at 250 and 300cm above the water.

Other Species

Figure 3.6d shows self-established individuals for *Phormium tenax* occurred between 10 and 45cm above the water. *Astelia fragrans* was found on the water's edge, *Hydrocotyle heteromeria* occurred from 0-50cm above the water, and *H. novae-zeelandiae* from 40-100cm above the water.

Comparison of Self-established and Planted Data

Phormium tenax planted samples were in sites significantly higher (median***) (Table 3.4) above the water than self-established samples (Fig. 3.6d).

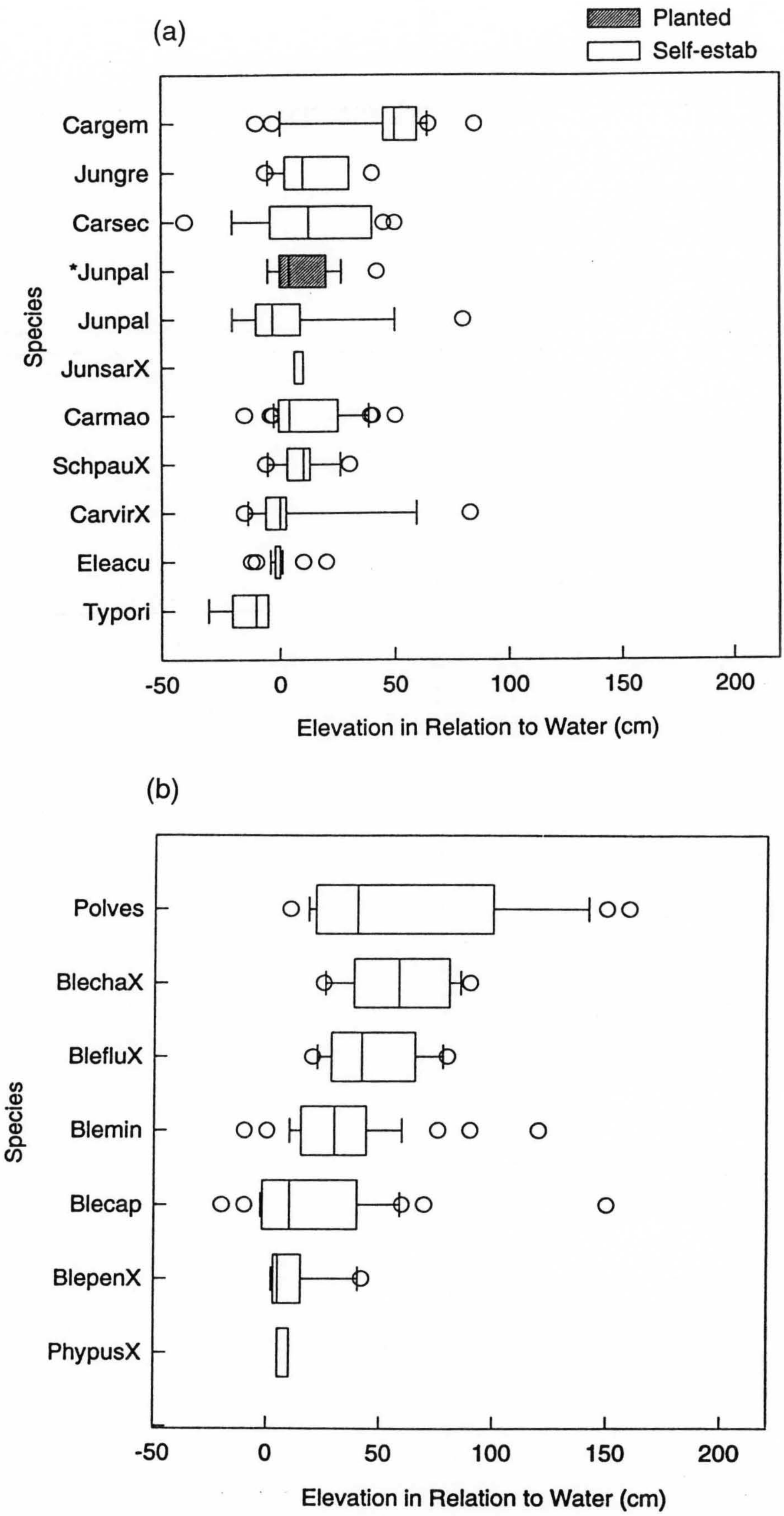
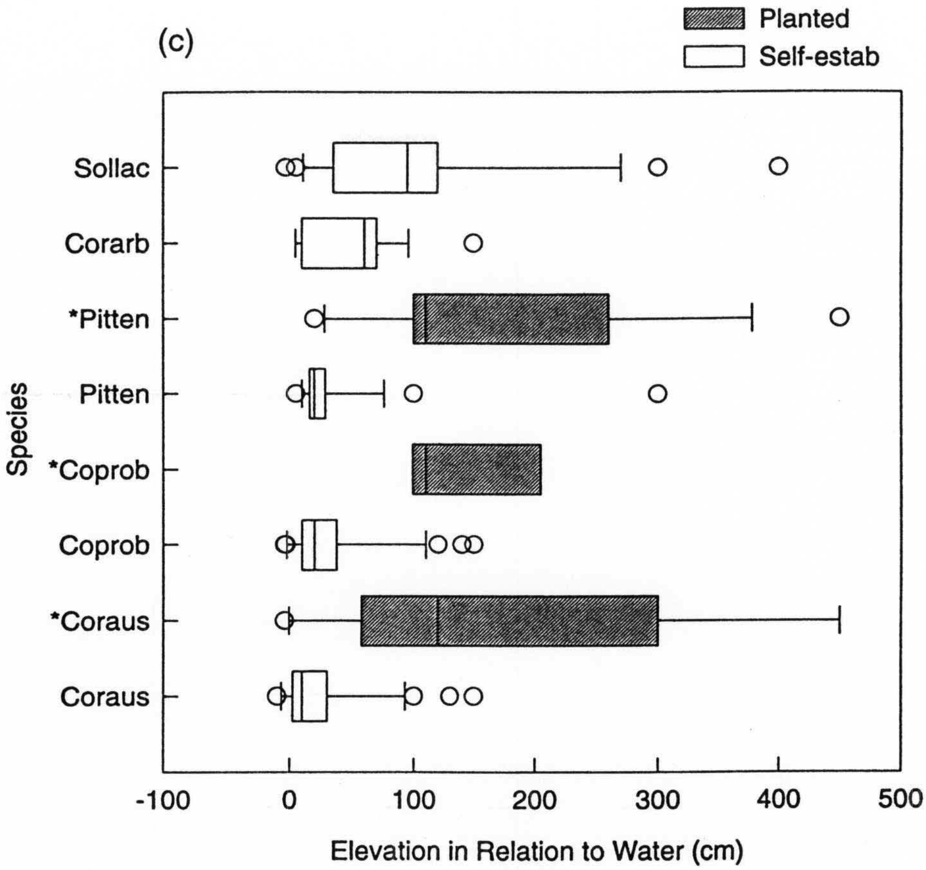


Figure 3.6: Elevation for sedge and rush species (a), and fern species (b). Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).



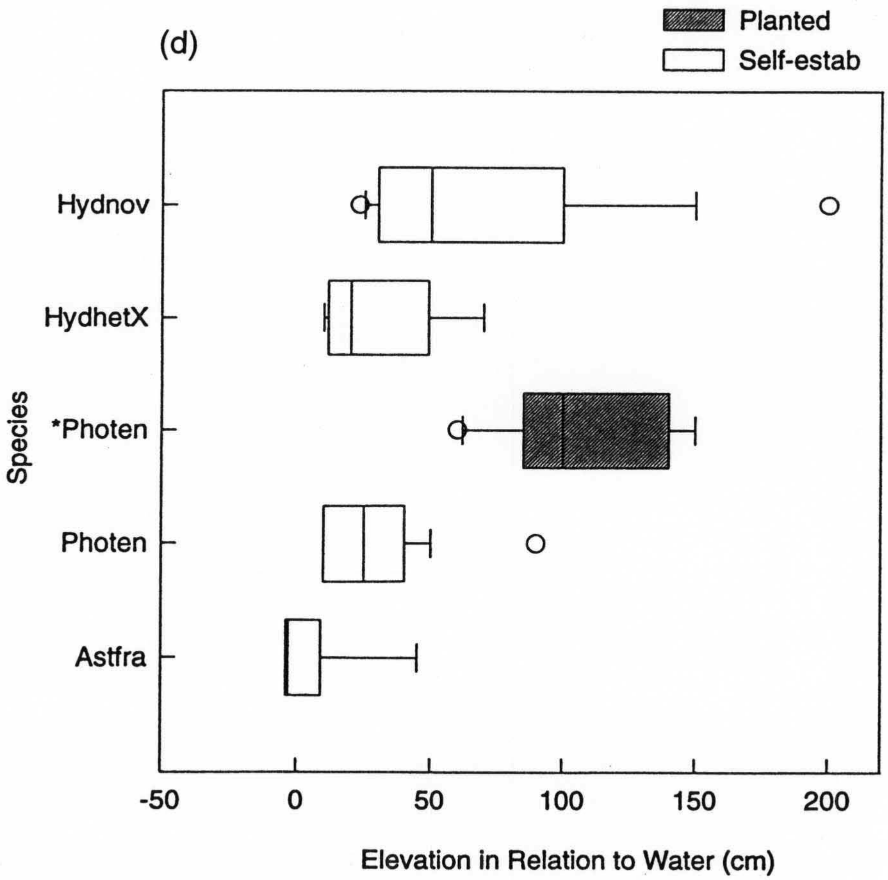


Figure 3.6 continued:. Elevation for shrub and tree species (note -50-500cm range) (c), and miscellaneous species (d). Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

Summary

The results for elevation indicate that several sedge and rush species were found in relatively narrow ranges near the water's edge, as were some ferns. Other ferns, trees, shrubs, and *Hydrocotyle novae-zeelandiae* were found in sites higher above the water.

3.6.2 Specific and Broad Riparian Class

Two plant site classifications in the riparian zone were recorded during field data collection - the specific and the broad riparian class. Broad riparian class referred to whether the plant was growing near a river, stream, lake, backwash (still water out of the main flow), backswamp or water race. Histograms of broad riparian class for each species gave an overview of the broad habitats in which a species was found and are summarised in Table 3.7. Specific riparian class was where the plant was growing in relation to the water, with rank "1" just into the water, and rank "7" on the upper terrace. Results of this classification are presented in boxplots (Figs. 3.7a-d). The classifications are discussed together.

Sedge and Rush Species

Results for sedge and rush species are presented in Figure 3.7a and Table 3.7). *Typha orientalis* was found in streams and rivers (40% of the time) and 20% of the time in the backwash of rivers. *Eleocharis acuta* was found in a tight range around the water's edge, in and near streams (17%), in the backwash (25%) and backswamps (13%) of streams, the backswamps of rivers (21%), and on the edges of water-races (25%). *Carex maorica, C. virgata* and *Juncus pallidus* were found in the water and at the lower bank (specific riparian class). A planted individual of fair vigour was recorded for *J. pallidus* at the 10th percentile at midbank. 87% of *J. pallidus* self-established samples were found on the rivers edge. 65% of *C. maorica* recorded in the study were in or near water-races, 24% in the backswamps of rivers, and 12% near streams. Self-established *C. secta* individuals were found in a range of broad riparian sites: stream (17%), backswamp of a stream (13%), backwash of a stream (4%), near larger rivers (35%), in the backwash of rivers (22%), and near water-races (9%). A self-established individual of fair vigour was noted at the midbank (10th percentile) for *C. secta*. 43% of *C. virgata* were found near streams, 29% near rivers, and 29% in the backswamps of rivers.

Juncus gregiflorus self-established individuals were found around the lower bank, primarily in the backswamps of streams (30%), and rivers and water-race edges (26%). *Juncus sarophorus* had a very low sample size and was found only at the midbank near a stream (Fig. 3.7a). *Schoenus pauciflorus* was found primarily between the lower bank and mid-bank, 62% near streams and 38% near rivers. Both *J. sarophorus* and *S. pauciflorus* were observed in poorly drained paddocks. *Carex geminata* was found between the lower bank and upper bank, with 94% of samples recorded near rivers, and 6% in the backswamps of rivers.

Comparison of Self-established and Planted Data

The variance of the self-established dataset for *Carex secta* was significantly (**) wider than the planted dataset (Table 3.4). The median for planted individuals for *Juncus gregiflorus* indicated that the planted dataset was significantly (**) higher up the bank than the self-established dataset (Table 3.4).

Fern Species

Results for fern species are presented in Figure 3.7b and Table 3.7). *Blechnum aff. capense* and *B. minus* were found in similar riparian classes, primarily lower to midbank. *B. aff. capense* was found near streams (27%), rivers (18%), and in the backswamps of streams (18%) and rivers (36%). *B. minus* was found near streams (52%), rivers (21%), and water-races (21%).

Both species had 10th percentile individuals of only fair vigour at the upper bank and *B. aff. capense* had two individuals of fair vigour in the water.

Blechnum fluviatile and *B. chambersii* were found from ranks 3 to 3.5. *B. chambersii* and *B. fluviatile* both had low sample sizes and were only found at one location, therefore 100% of samples were recorded near streams for both species. *B. penna-marina*, and *Phymatosorus pustulatus* were found in lower bank and mid-bank sites. *B. penna-marina* was found in the backswamps of rivers (67%), and near streams (25%) and rivers (8%). *P. pustulatus* was recorded in the backswamp of rivers (75%) and in the backswamp of streams (25%). *Polystichum vestitum* was found from the mid-bank to the levee, with an outlier at the lower bank of only fair vigour. It was found 61% near streams, and 33% near the backswamps of rivers.

Tree and Shrub Species

Results for specific riparian class for tree species are presented in Figure 3.7c and results for broad riparian class in Table 3.7. *Cordyline australis* self-established individuals were found in a wide range of riparian sites, primarily from lower bank to upperbank, but with outliers into the water and up to the levee. Three self-established individuals were of fair vigour at the 10th percentile at rank 1 and two at the 90th percentile at rank 5. *C. australis* was found in a wide range of sites: streams (13%), backswamps of streams (13%), backwash of streams (8%), near rivers (25%), and in the backswamps of rivers (42%).

Self-established *Coprosma robusta* individuals were found primarily from the lower bank to the levee. Two individuals in the water were of low vigour. Self-established *C. robusta* were recorded primarily on river banks (39%) and in the backswamps of rivers (39%).

Pittosporum tenuifolium self-established individuals were found from the lower bank to the upper bank, 50% of the time on the banks of rivers, and 44% in the backswamps of rivers. *Solanum laciniatum* was found from the mid-bank to the scarp, 88% of the time near streams and 13% near rivers. *Coriaria arborea* was found from the mid-bank to the levee, 90% of the time near streams and 10% near the backswamps of rivers.

Comparison of Self-established and Planted Data

The median of the planted dataset for *Cordyline australis* was found to be significantly higher (**) than for the self-established dataset (Table 3.4), with planted individuals on sites from the upper bank to the scarp with outliers to the lower bank and up to the terrace. Planted individuals on the scarp (rank class of 7) were only of fair vigour. Planted individuals of *C. australis* were recorded 39% near rivers, 28% in the backswamps of rivers, 28% near streams, and 6% in the backwash of rivers.

The median for the planted dataset for *Coprosma robusta* (N=4), was significantly higher (**) (Table 3.4) in the riparian zone than for the self-established dataset. The planted individuals were found on the levee and the scarp (three individuals by rivers and one by a stream).

Planted individuals for *Pittosporum tenuifolium* were significantly higher (median***) in the riparian zone (from the levee to the scarp) (Table 3.4) than the self-established individuals. They were recorded 58% on the banks of rivers, and 33% of the time near streams.

Other Species

Self-established *Phormium tenax* individuals were found in the water to the mid-bank, near streams (50%), rivers (32%), and the backwash of streams (18%) (Fig. 3.7d).

Hydrocotyle novae-zeelandiae was found in a wide range in the riparian zone from the mid-bank to the scarp (Fig. 3.7d), 69% of the time near streams, and 31% near rivers (primarily in areas maintained through mowing).

H. heteromeria was found lower in the riparian zone, from the lower bank to the upper bank (Fig. 3.7d), 56% of the time near streams, 33% in the backswamps of streams, and 11% near rivers. *Astelia fragrans* (N=5) was found predominantly at the lower bank in the backswamps of streams (60%) and 20% of the time near streams and rivers (Fig. 3.7d).

Comparison of Self-established and Planted Data

The median of the planted dataset for *Phormium tenax* indicated that planted individuals were significantly (***) further up the riparian zone (from the mid-bank to the levee) (Table 3.4), and were all found near rivers (Table 3.7). One planted individual of only fair vigour was found on the levee (rank 5).

Summary

Specific riparian class

Most sedge and rush species were found in or around the water's edge as expected. Fern species were slightly higher up the bank. *Polystichum vestitum*, *Phormium tenax*, *Solanum laciniatum* and *Coriaria arborea* were in similar ranges from the mid-bank to the levee. *Cordyline australis*, *Coprosma robusta* and *Pittosporum tenuifolium* ranged from quite low in the riparian zone to the upper bank (*P. tenuifolium*) and the levee (*C. robusta*).

Broad riparian class

A high proportion of species were found by streams and rivers. Species in more than four different broad riparian classes included *Eleocharis acuta*, *Juncus gregiflorus*, *Blechnum minus*, *B. aff. capense*, *Cordyline australis* , *Coprosma robusta*, and *Carex secta*. Species found by water-races included *E. acuta*, *Carex maorica*, *J. gregiflorus*, and *B. minus*. The species recorded at least some of the time in the backswamps of rivers included *C. virgata*, *C. maorica*, *E. acuta*, *Phymatosorus pustulatus*, *B. minus*, *B. aff. capense*, *Polystichum vestitum*, *Cordyline australis*, *Coprosma robusta*, and *Pittosporum tenuifolium*.

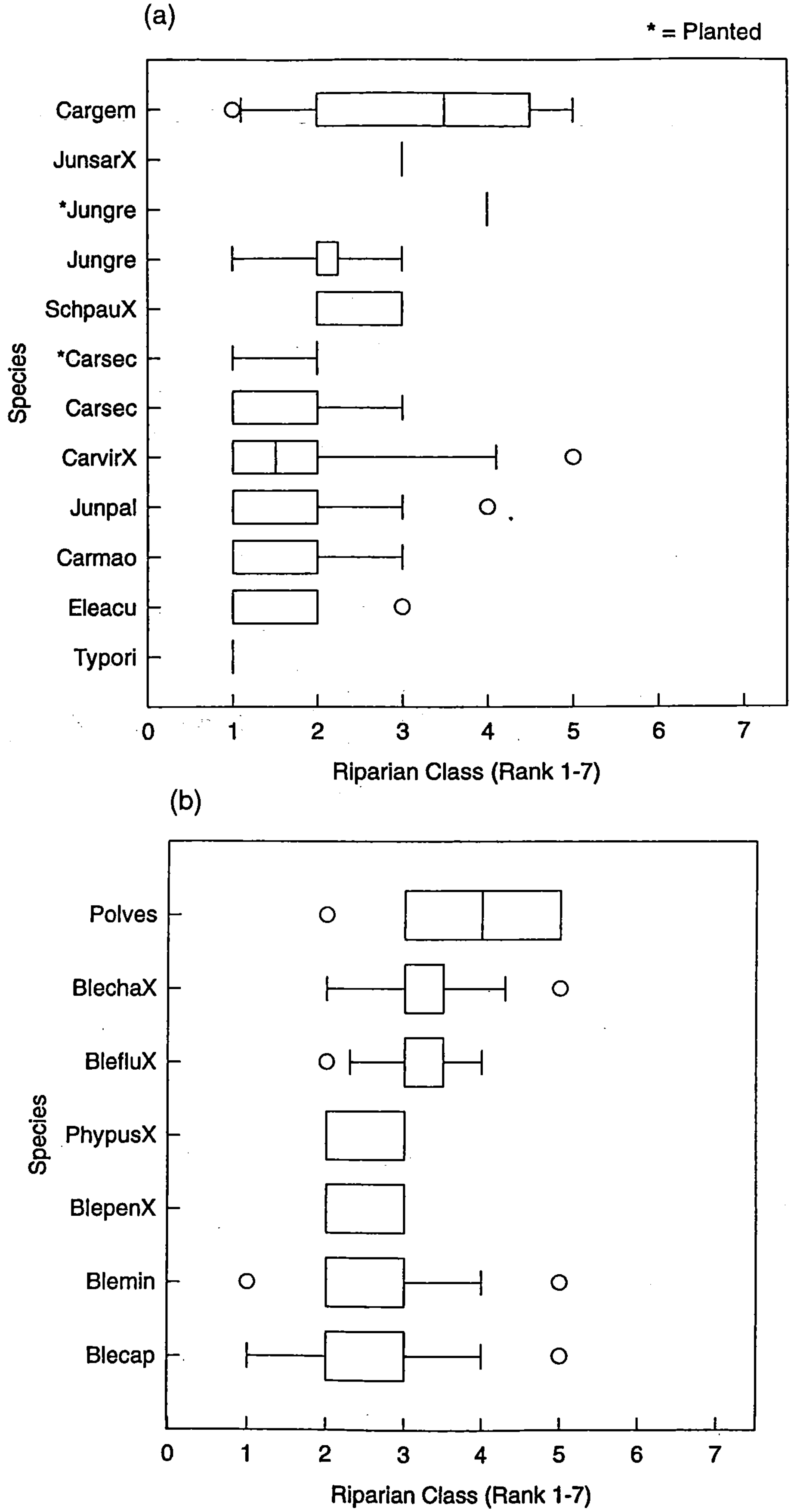
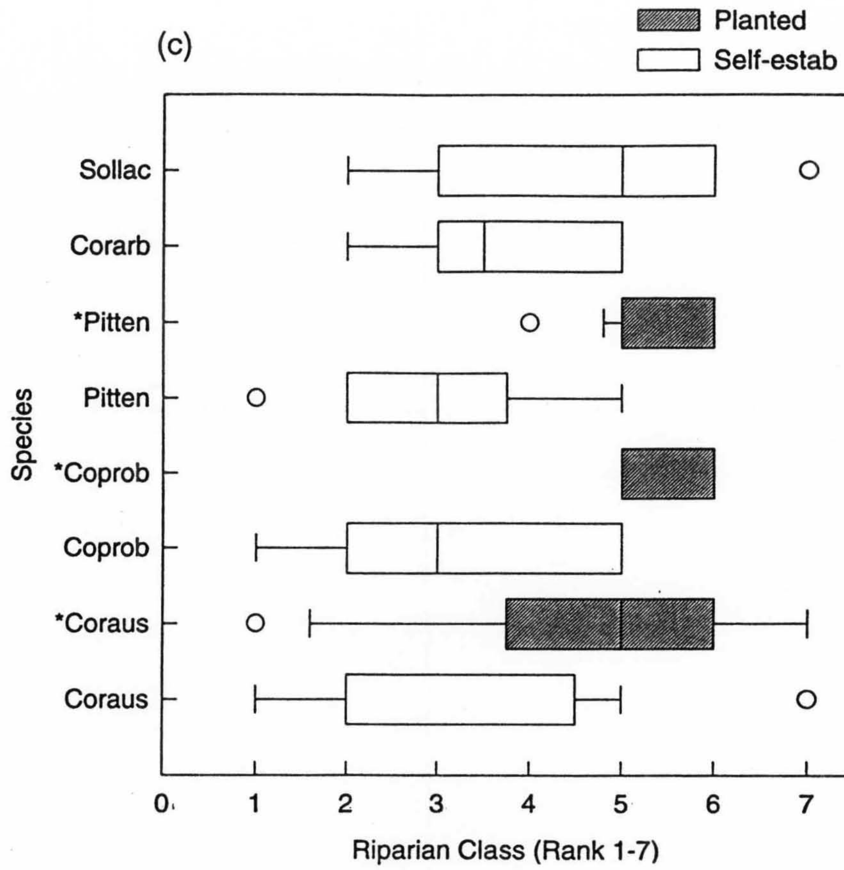


Figure 3.7: Riparian class rank for sedge and rush species (a) and fern species (b). Rank 1=in the water, to 7=upper terrace. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).



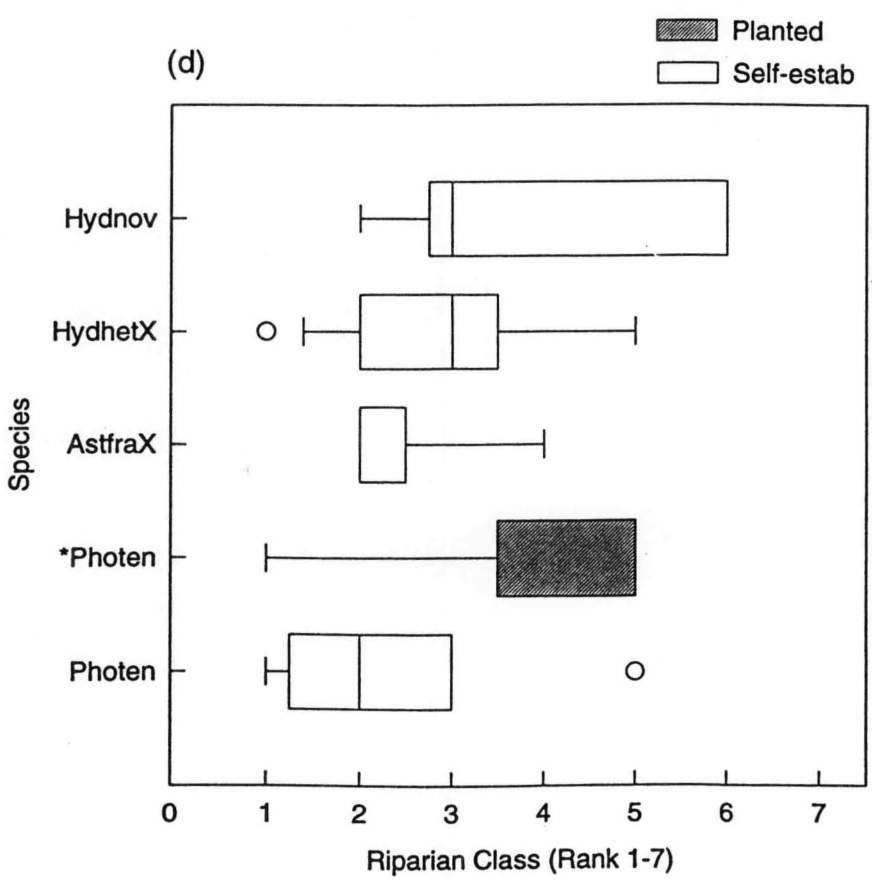


Figure 3.7 continued: Riparian class for shrub and tree species (c), and miscellaneous species (d). Rank 1=in the water, to 7=upper terrace. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

Table 3.7: Summary of histograms for the environmental variables of broad riparian class and slope shape (next page) for all species. (Refer to Table 3.1 for full species names).

Species		Broad Riparian Class						
	Sample Size	Stream	Back-swamp (stream)	Back-wash (stream)	River	Back-swamp (river)	Back-wash (river)	Water-race
Sedges and Rushes								
Typori	15	40%	0%	0%	40%	0%	20%	0%
Carvir	7	43%	0%	0%	29%	29%	0%	0%
Eleacu	24	17%	13%	25%	0%	21%	0%	25%
Junpal - self	15	13%	0%	0%	87%	0%	0%	0%
Junpal - planted	13	0%	0%	0%	69%	31%	0%	0%
Junsar	3	100%	0%	0%	0%	0%	0%	0%
Schpau	13	62%	0%	0%	38%	0%	0%	0%
Carsec - self	23	17%	13%	4%	35%	0%	22%	9%
Carsec - planted	10	10%	0%	10%	60%	0%	20%	0%
Carmao	17	12%	0%	0%	0%	24%	0%	65%
Jungre - self	23	17%	30%	0%	26%	0%	0%	26%
Jungre - planted	2	0%	0%	0%	100%	0%	0%	0%
Cargem	16	0%	0%	0%	94%	6%	0%	0%
Ferns								
Phypus	4	0%	25%	0%	0%	75%	0%	0%
Blepen	12	25%	0%	0%	8%	67%	0%	0%
Blecap	22	27%	18%	0%	18%	36%	0%	0%
Blemin	29	52%	3%	0%	21%	3%	0%	21%
Bleflu	8	100%	0%	0%	0%	0%	0%	0%
Blecha	12	100%	0%	0%	0%	0%	0%	0%
Polves	18	61%	0%	0%	0%	33%	6%	0%
Trees and Shrubs								
Coraus - self	24	13%	13%	8%	25%	42%	0%	0%
Coraus - planted	18	28%	0%	0%	39%	28%	6%	0%
Coprob - self	28	11%	4%	7%	39%	39%	0%	0%
Coprob - planted	4	25%	0%	0%	75%	0%	0%	0%
Pitten - self	16	6%	0%	0%	50%	44%	0%	0%
Pitten - planted	12	33%	0%	8%	58%	0%	0%	0%
Corarb - all	10	90%	0%	0%	0%	10%	0%	0%
Sollac - self	16	88%	0%	0%	13%	0%	0%	0%
Sollac - planted	1	50%	0%	0%	50%	0%	0%	0%
Other Species								
Astfra	5	20%	60%	0%	20%	0%	0%	0%
Photen - self	22	50%	0%	18%	32%	0%	0%	0%
Photen - planted	19	0%	0%	0%	100%	0%	0%	0%
Hydhet	9	56%	33%	0%	11%	0%	0%	0%
Hydnov	16	69%	0%	0%	31%	0%	0%	0%

Table 3.7 (continued).....

Species	Slope Shape			
	Flat	Concave	Convex	Straight
Sedges and Rushes				
Typori	100%	0%	0%	0%
Carvir	43%	14%	0%	43%
Eleacu	79%	8%	4%	8%
Junpal - self	60%	13%	0%	27%
Junpal - planted	15%	0%	31%	54%
Junsar	67%	33%	0%	0%
Schpau	69%	23%	8%	0%
Carsec - self	35%	9%	30%	26%
Carsec - planted	10%	20%	50%	20%
Carmao	59%	0%	0%	41%
Jungre - self	43%	0%	4%	52%
Jungre - planted	50%	0%	0%	50%
Cargem	25%	0%	19%	56%
Ferns				
Phypus	100%	0%	0%	0%
Blepen	50%	0%	17%	33%
Blecap	41%	9%	23%	27%
Blemin	31%	3%	10%	55%
Bleflu	0%	0%	25%	75%
Blecha	8%	0%	17%	75%
Polves	39%	28%	17%	17%
Trees and Shrubs				
Coraus - self	79%	0%	13%	8%
Coraus - planted	39%	11%	22%	28%
Coprob - self	54%	18%	18%	11%
Coprob - planted	25%	0%	0%	75%
Pitten - self	88%	6%	0%	6%
Pitten - planted	75%	0%	0%	25%
Corarb - all	10%	10%	0%	80%
Sollac - self	31%	0%	6%	63%
Sollac - planted	100%	0%	0%	0%
Other Species				
Astfra	80%	0%	0%	20%
Photen - self	59%	23%	0%	18%
Photen - planted	58%	5%	16%	21%
Hydhet	33%	0%	33%	33%
Hydnov	56%	0%	0%	44%

E. acuta, *Carex secta*, *J. gregiflorus*, *B. aff. capense*, *Cordyline australis*, *Astelia fragrans*, and *Hydrocotyle heteromeria* were found at least some of the time near the backswamps of streams. Few species were found in the backwash of streams or rivers, with the exceptions of *Eleocharis acuta*, *Typha orientalis*, and *Carex secta*.

3.6.3 Soil Moisture

Soil moisture was measured as a rank class, with rank "1" indicating the wettest soil and rank "7" the driest.

Sedge and Rush Species

Figure 3.8a indicates a range of soil moisture tolerance for sedge and rush species. *Typha orientalis* and *Eleocharis acuta* had narrow ranges at the very wet soil moisture of rank 2. *Carex secta*, *C. maorica* and *C. virgata* had similar ranges with most of the data falling in ranks 2 and 3; plants of fair vigour were found at the very wet rank 1 for *C. secta* and *C. maorica*. The *C. secta* outliers at rank 4 were self-established individuals of fair vigour only. *Juncus pallidus* and *J. gregiflorus* were also found in the rank 2 to 3 class. *Schoenus pauciflorus* was found between ranks 2 to 4, and *J. sarophorus* at rank 4. *C. geminata* was found to predominantly occupy the rank 4 (wet soil but not dripping) and almost to the rank 6 (dry soil) end of the soil moisture continuum.

Comparison of Self-established and Planted Data

For *J. pallidus*, the median of the self-established dataset was a significantly (***) (Table 3.4) wetter rank (rank 2 to 3) than the planted dataset (around rank 4). A plant of only fair health was found in the planted dataset at rank 4.

Fern Species

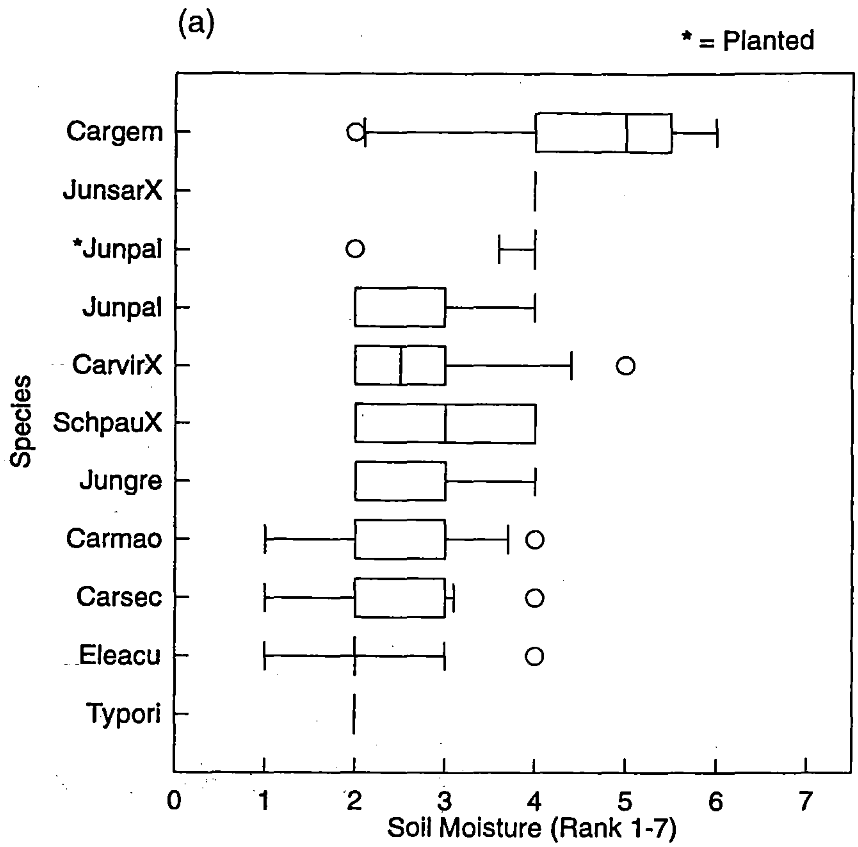
Blechnum aff. capense was found to have a soil moisture range of rank 2 to 4 (Fig. 3.8b), with one plant of poor vigour at the 10th percentile. *B. penna-marina* and *B. minus* had ranks of 3 to 4, with one plant of low vigour at rank 2 for *B. minus*. *Polystichum vestitum* was found in the drier range of rank 4 to 5, with plants of fair vigour at the outlier at rank 2 and the 10th percentile at rank 3. *B. chambersii* and *B. fluviatile* were found around soil moisture rank 4 only, but it must be noted that they were only found at one location near Christchurch.

Tree and Shrub Species

Self-established *Cordyline australis*, *Coprosma robusta*, and *Pittosporum tenuifolium* individuals were recorded in the soil moisture range of rank 3 to 4 (wet soils) (Fig. 3.8c). The individuals at the 10th and 90th percentiles for *Cordyline australis*, two individuals at the very wet soil moisture rank of 2 for *Coprosma robusta*, and the outlier at rank 2 for *P. tenuifolium* were only of fair vigour. *Coriaria arborea* had a rank range of 4 to 5 (damp soil) with a plant of fair vigour at rank 3, and *Solanum laciniatum* occupied a limited range around rank 5.

Comparison of Self-established and Planted Data

Fig. 3.8c shows that the medians for the planted datasets of *Cordyline australis* (***), *Coprosma robusta* (**) and *Pittosporum tenuifolium* (***) were significantly drier than the self-established datasets (Table 3.4). The three *Cordyline australis* individuals in the dry rank class of 6 were only of fair vigour, and for *P. tenuifolium*, the planted outlier at rank 3 was found to be of fair vigour. The results show that the self-established individuals were found in a wetter soil moisture range than those individuals of each species that were planted.



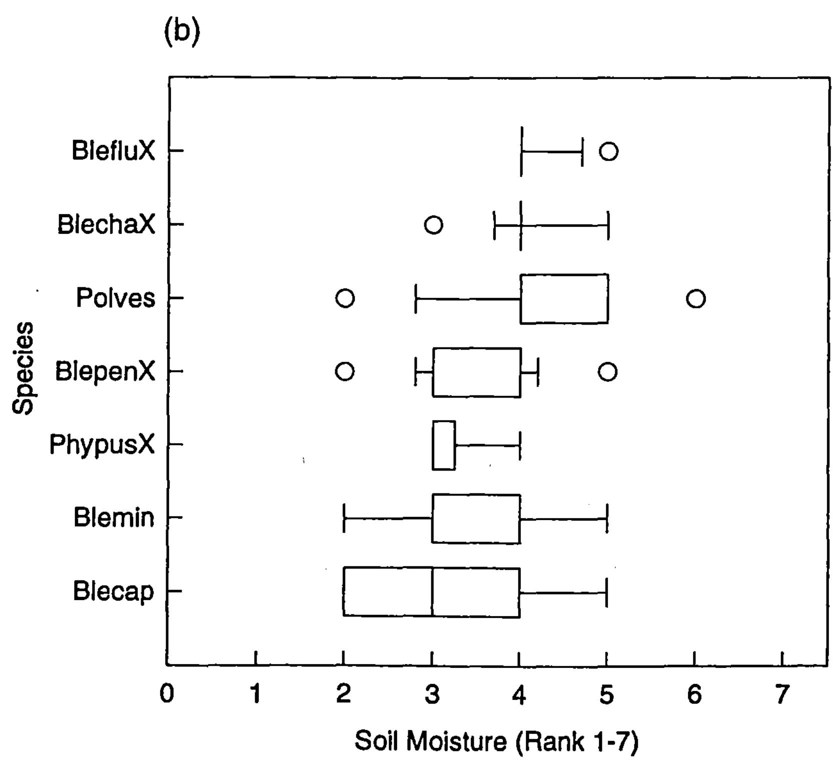
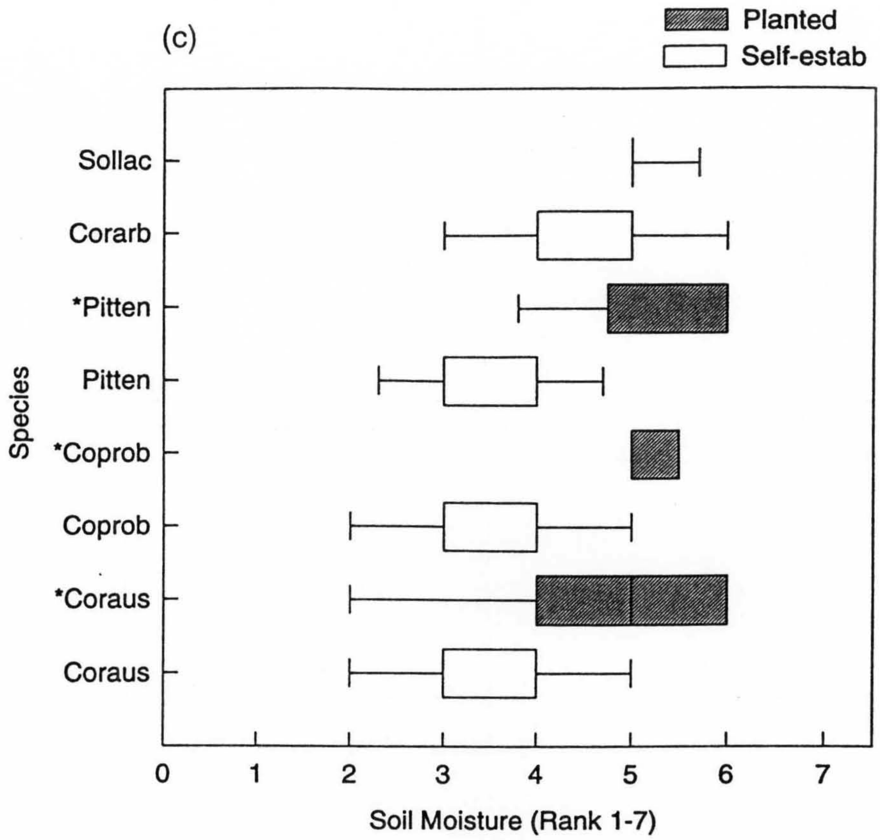


Figure 3.8: Soil moisture rank for sedge and rush species (a), and fern species (b). Rank 1=wettest, 7=driest. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).



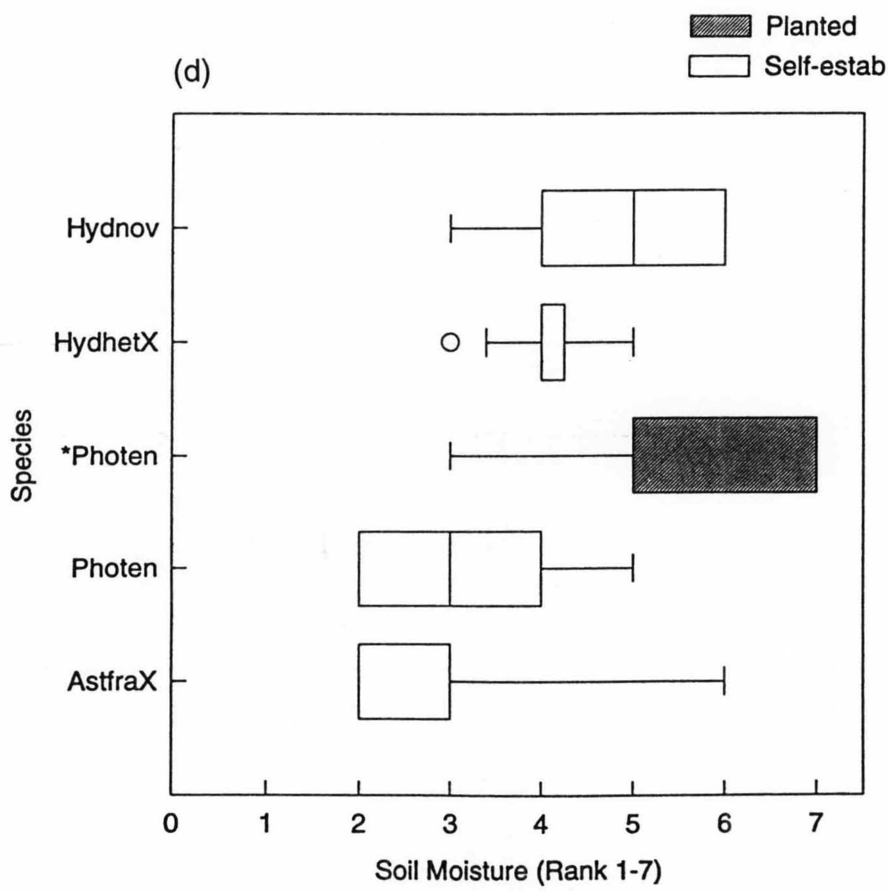


Figure 3.8 continued: Soil moisture rank for shrub and tree species (c), and miscellaneous species (d). Rank 1=wettest, 7=driest. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

Other Species

Phormium tenax was found between ranks 2 to 4 (wet soils) (Fig. 3.8d). *Hydrocotyle novae-zeelandiae* had a soil moisture rank of 4 to 6 and *H. heteromeria* around rank 4. *Astelia fragrans* (N=5), was found in the soil moisture range of rank 2 to 3.

Comparison of Self-established and Planted Data

Self-established data for *Phormium tenax* was found to have a soil moisture range of 2 to 4, while planted samples were found in the significantly drier (***) (Table 3.4) rank range of 5 to 7, with a plant of fair vigour at rank 5.

Summary

As expected from the riparian class and elevation ranges, most sedges and rushes fell in the wet zones (ranks 2 to 3), with most of the ferns and trees (around ranks 3 to 4) in slightly less wet zones. *Polystichum vestitum*, *Solanum laciniatum*, and *Coriaria arborea* were in damp soils (ranks 4 to 5).

3.6.4 Soil pH

Soil was gathered from each plant in the study. Air dried soil was tested in the laboratory for pH.

Sedge and Rush Species

Juncus pallidus (pH 5.5 to 7) had the widest pH range, while *Carex maorica* had the narrowest (pH 6.3 to 6.5) (Fig. 3.9a). Most species fell between pH 5 and 7.

Fern Species

Blechnum aff. capense had the widest soil pH range (pH 5.4 to 6.4), although *B. minus*, *B. penna-marina*, *Polystichum vestitum*, and *Phymatosorus pustulatus* all had similar ranges from pH 5.6 to 6.5 (Fig. 3.9b). *B. fluviatile* and *B. chambersii* have limited ranges, but were both only found at one location in Christchurch.

Tree and Shrub Species

Cordyline australis self-established individuals were in a very narrow soil pH range (pH 5.6 to 5.9) (Fig. 3.9c). The other tree and shrub species had varying ranges between pH 5.2 and 6.7. *Solanum laciniatum* had the widest range - from pH 5.2 to 6.7.

Comparison of Self-established and Planted Data

Planted individuals were in significantly higher pH ranges than self-established individuals for *Cordyline australis* (***) and *Pittosporum tenuifolium* (**) (Table 3.4).

Other Species

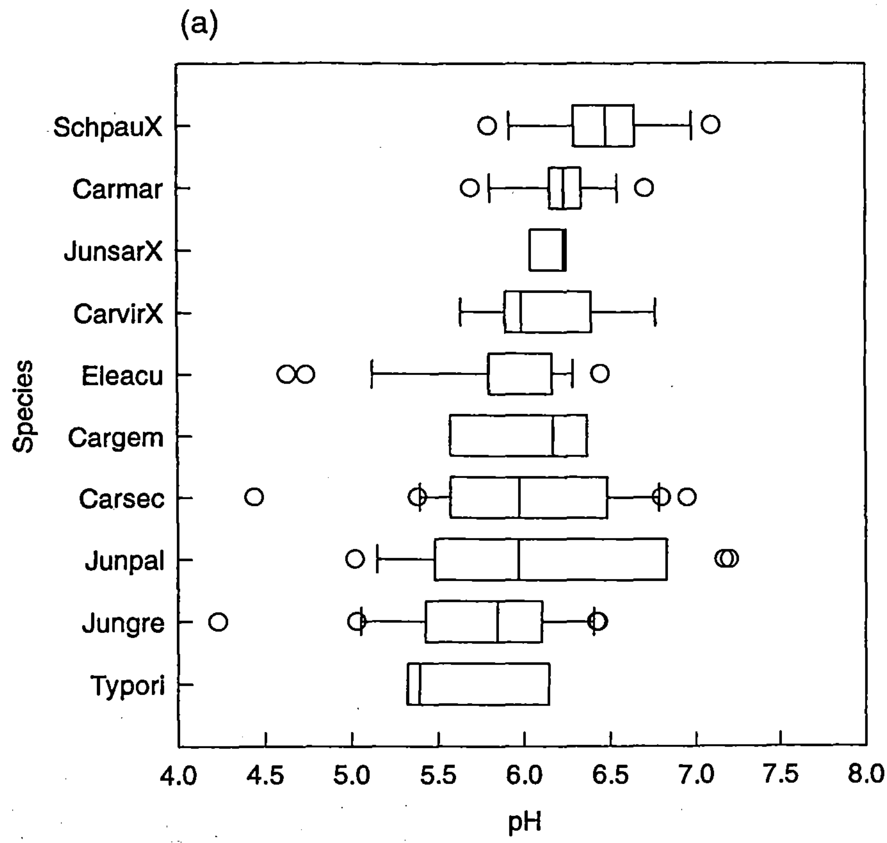
Overall species in this group covered a pH range of pH 5.3 and 6.6 (Fig. 3.9d).

Comparison of Self-established and Planted Data

The median pH of the planted dataset for *Phormium tenax* was significantly (***) higher than the self-established dataset (Table 3.4).

Summary

Most species had ranges between pH 5 and 7. Some species had relatively wide ranges (eg., *Solanum laciniatum*), while others had narrow ranges (eg., *Cordyline australis*), with the pH 5 to 7 range.



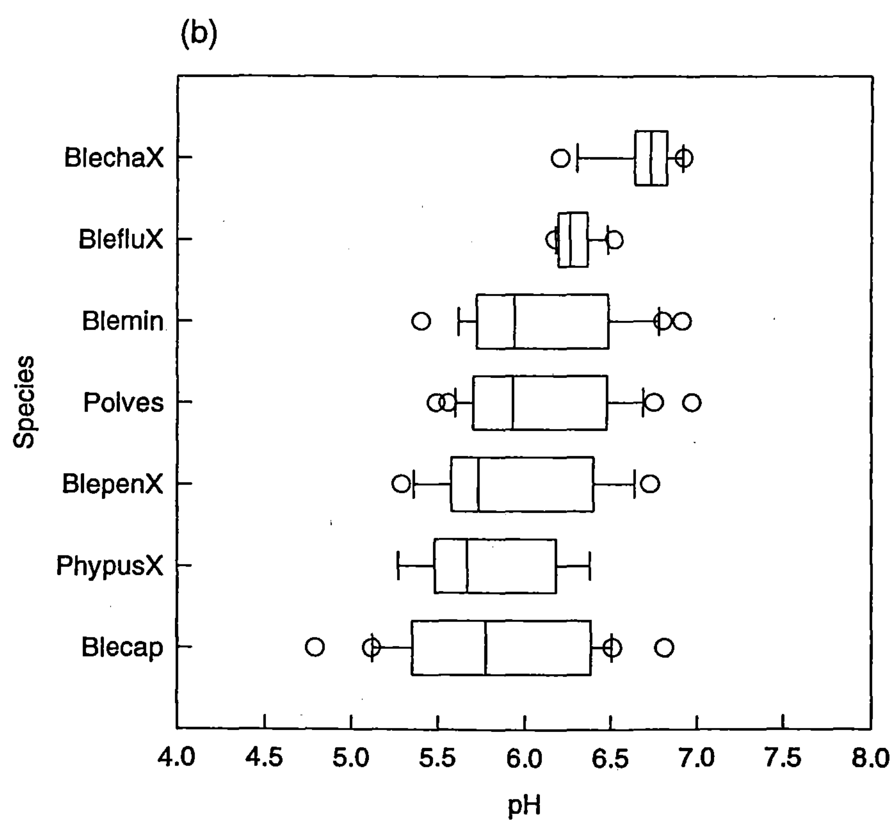
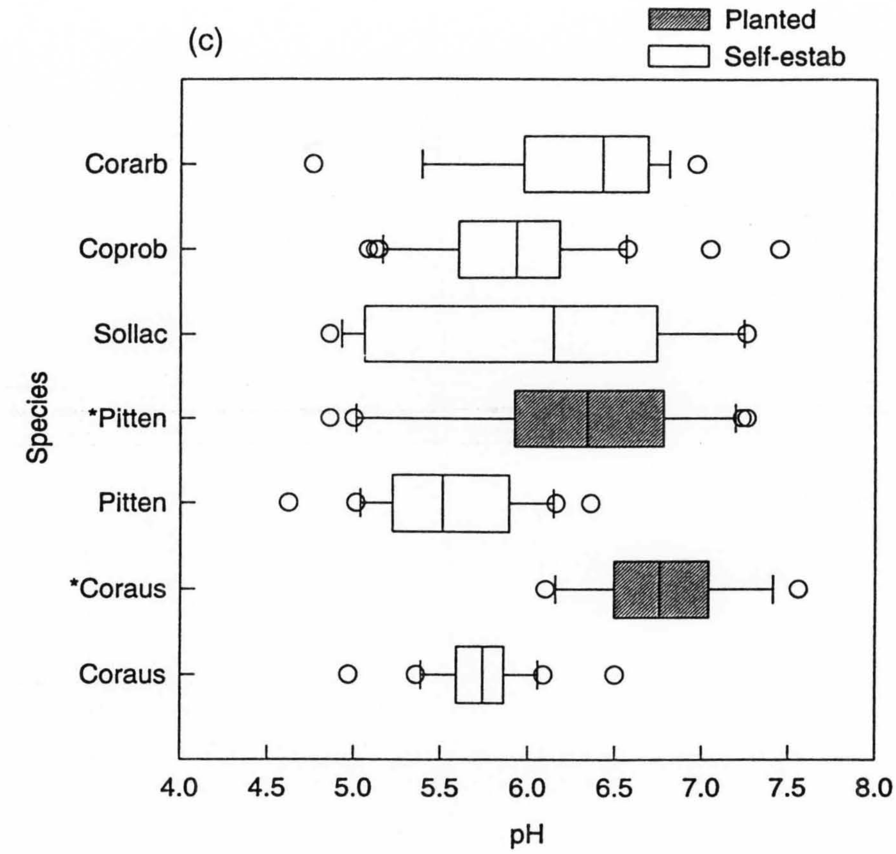


Figure 3.9: Soil pH for sedge and rush species (a), and for fern species (b). (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).



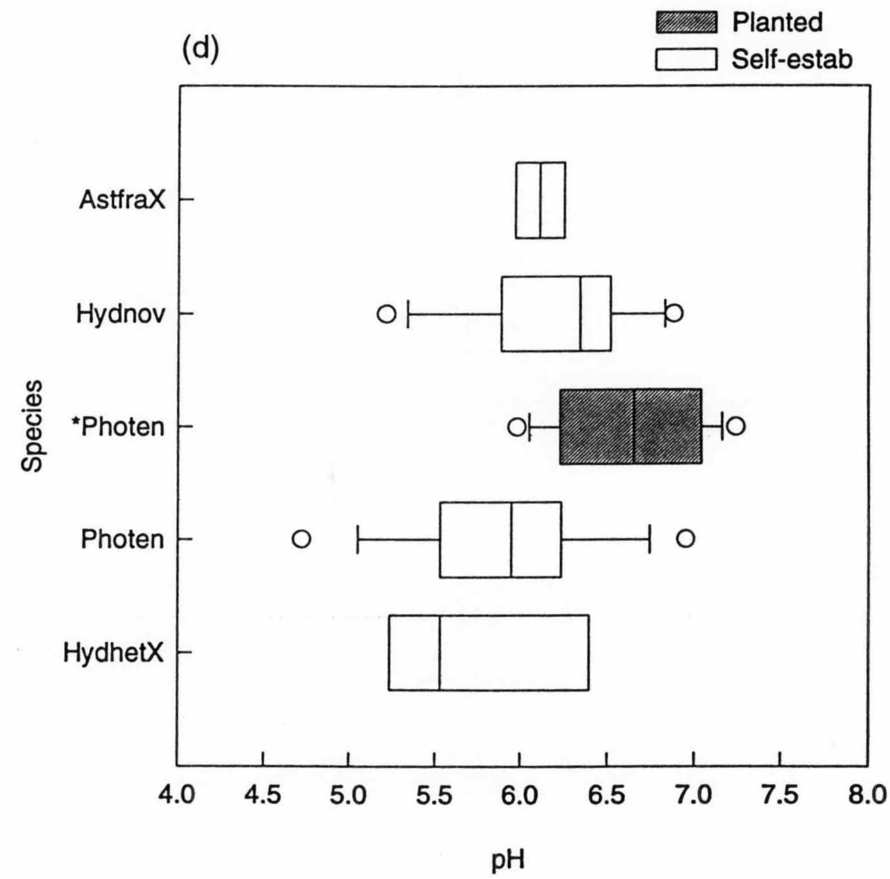


Figure 3.9 continued: Soil pH for shrub and tree species (c) and miscellaneous species (d). Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

3.6.5 Slope

Slope was measured in degrees, and the slope shape of the plant site noted. Slope was measured as an indication of site drainage. The slope shape rank was as follows: 0=flat, 1= concave, 2=convex, and 3=straight. Slope shapes for each species are summarised in Table 3.7.

Sedge and Rush Species

The sedges and rushes (Fig. 3.10a), were found on a wide range of slopes. *Typha orientalis* and *Eleocharis acuta* were only found in flat areas in the water. *Juncus sarophorus*, *Schoenus pauciflorus*, and *Carex virgata* were primarily found on slopes of less than 7 degrees. *J. pallidus* was also found in fairly flat areas, 0-15° degrees of slope. *C. geminata* and *C. secta* were found in the 0-25° degree slope range. The two outliers around 80° degrees for *C. secta* were only of fair vigour. *J. gregiflorus* and *C. maorica* were found in areas with more slope - from 0 to 55° and 75° degrees respectively. The outliers at 90° degrees for *C. maorica* were only of fair vigour.

The sedges and rushes that were found primarily on flat surfaces were *Eleocharis acuta*, *Juncus pallidus*, *J. sarophorus*, and *Schoenus pauciflorus*. Other species were roughly spread among the slope shape categories, some with high percentages in both flat and straight slope rank classes. Figures 3.7a and 3.8a (riparian class and soil moisture) show that species that appear to be on straight slopes (which could be equated with drainage) are actually in the lower bank zone which is often inundated with water, therefore not affecting availability of water for the species. An example is *J. gregiflorus*, which was recorded on the straight slope shape (most drainage) 52% of the time, but had a soil moisture range of 2-3 (very wet, Fig. 3.8a), in the specific riparian class of lower bank (Fig. 3.7a).

Fern Species

The results for fern species are presented in Figure 3.10b. *Phymatosorus pustulatus* was only found in flat areas. *Polystichum vestitum* had a slope range of 0-20^{o} degrees, and was recorded on sites with a range of slope shapes (Table 3.7). *Blechnum aff. capense* and *B. penna-marina* had ranges from 0-25^{o} degrees. 41% of *B. aff. capense* individuals were on flat sites, 23% on convex slopes, and 27% on straight slopes. For *B. penna-marina* 50% of the plants were on flat sites, 17% on convex sites and 33% on straight slopes. *B. minus* had the widest range, from 0-80^{o} degrees, and was found 55% of the time on sites with straight slopes and 31% on flat sites (Table 3.7). Individuals at the 90th percentile were of fair vigour only.

B. chambersii was found from 20^{o} degrees to 60^{o} degrees and *B. fluviatile* on the steeper slopes, of 30^{o} to 80^{o} degrees. *B. chambersii* and *B. fluviatile* were both recorded 75% of the time on straight slopes (Table 3.7). Both of these species had low sample sizes and were found in one location only.

Tree and Shrub Species

Cordyline australis was found in "flat" (Table 3.7) sites of little slope (0-6^{o} degrees) (Fig. 3.10c). *Pittosporum tenuifolium* was recorded 88% on flat sites. *Coprosma robusta* self-established individuals were recorded primarily between 0-10^{o} degrees, on a wide range of slope shapes, with 'flat' sites being the most common (54%) (Table 3.7).

Coriaria arborea had the widest range of slope from 0-65^{o} degrees, and was primarily found on straight slopes (80%) (Table 3.7). *Solanum laciniatum* was found in sites of 0-10^{o} degrees, on both flat sites (31%) and straight slopes (63%) (Table 3.7).

Comparison of Self-established and Planted Data

For *Pittosporum tenuifolium*, the planted sample had a significantly (*) wider variance (Table 3.4) than the self-established sample (Fig. 3.10c). The planted individuals were found 75% of the time on flat sites, and 25% on straight slopes (Table 3.7), while the self-established individuals were primarily on flat sites. For *Coprosma robusta*, the median of the planted species was significantly (*) (Table 3.4) steeper (15-30° degrees) than the self-established median (0-10° degrees) (Fig. 3.10c). Three of the four planted *C. robusta* individuals were on straight slopes (most drainage) (Table 3.7).

Other Species

Astelia fragrans (N=5) was only found in flat areas (Fig. 3.10d). *Phormium tenax* self-established individuals were found on slopes of 0-12° degrees, primarily in flat areas (59%), or with a concave slope shape (23%) (Table 3.7).

Hydrocotyle novae-zeelandiae was found on slopes of 0 to 22° degrees, while *H. heteromeria* was found from 5 to 45° degrees. Slope shapes ranged from flat sites (56%) to straight (44%) for *H. novae-zeelandiae*, and was more evenly distributed for *H. heteromeria* - 33% for each of flat, concave and convex (Table 3.7).

Comparison of Self-established and Planted Data

A comparison of the self-established and planted *Phormium tenax* datasets showed that the planted sample had significantly less (*) variation than the self-established sample. The planted outlier at 35° degrees for *P. tenax* was of fair vigour. Planted *P. tenax* samples were found on flat sites (58%), straight slopes (21%), and convex slopes (16%).

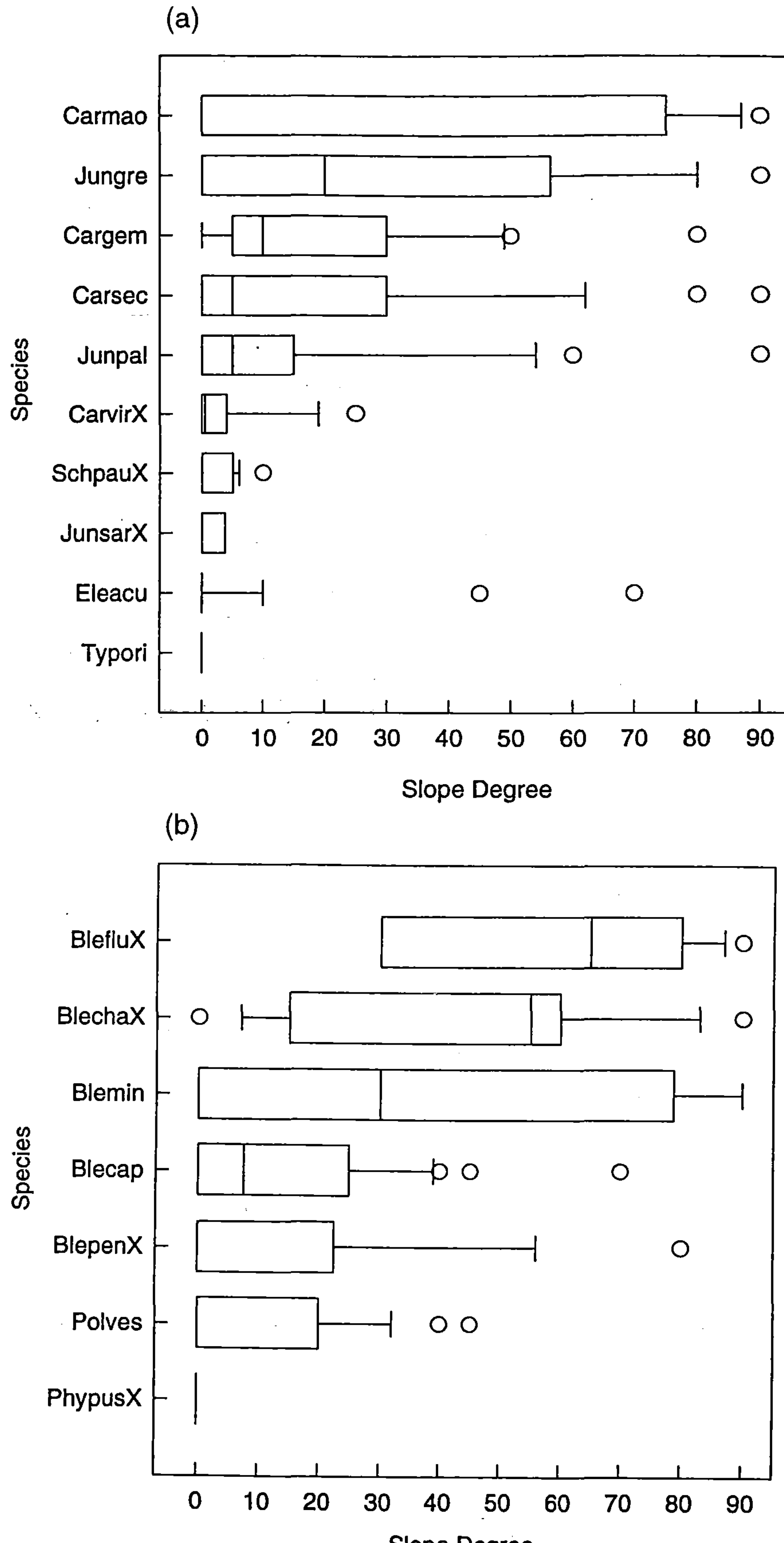
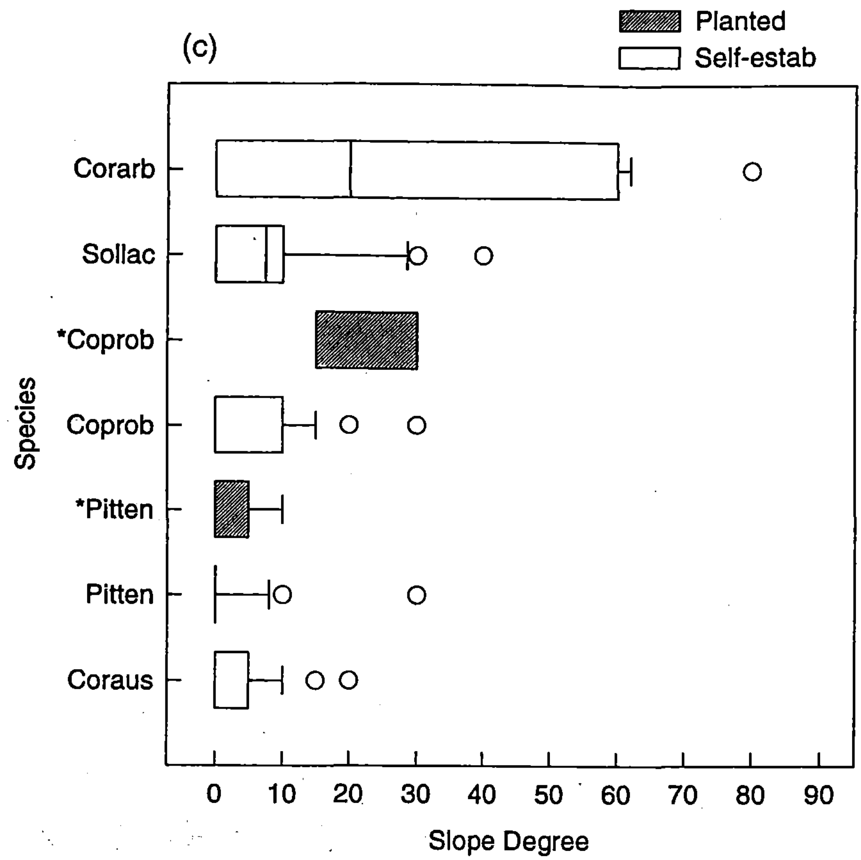


Figure 3.10: Slope degree for sedge and rush species (a) and for fern species (b). (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).



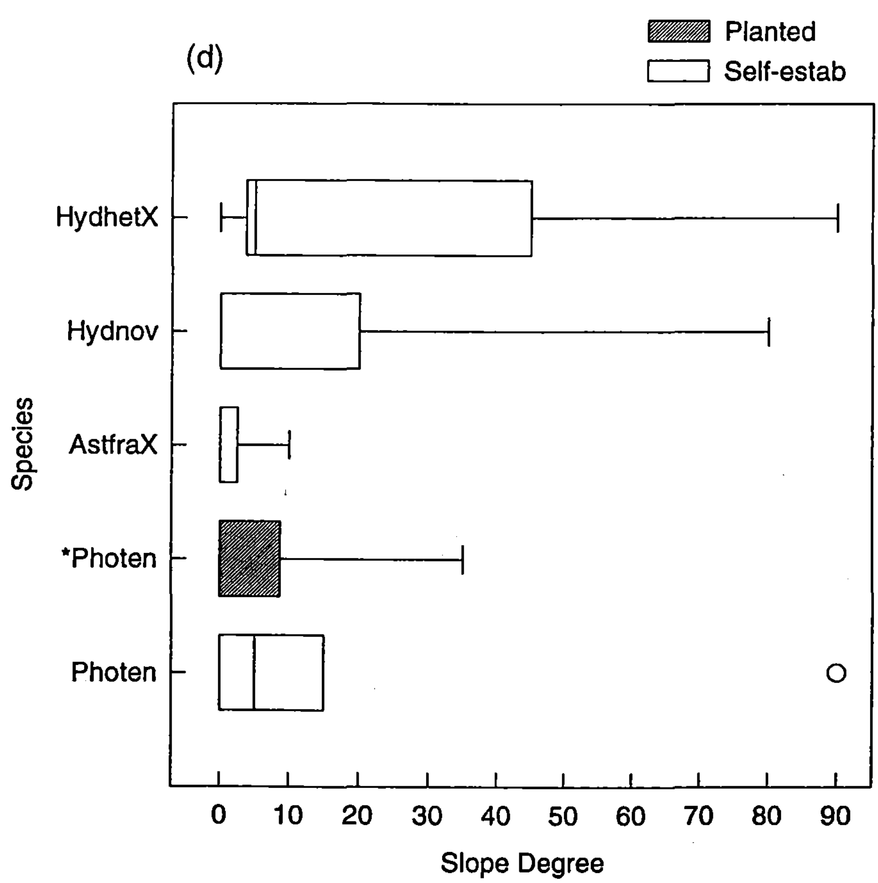


Figure 3.10 continued: Slope degree for shrub and tree species (c) and miscellaneous species (d). Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

Summary

Several sedge and rush species were recorded only on flat areas. Those with steeper slopes were recorded growing in wet sites close to the water. The fern species had the widest slope ranges, with *Blechnum minus* recorded in sites from 0-80° degrees. Most of the self-established individuals for trees and shrubs were recorded in sites between 0-10°, with *Coriaria arborea* the exception (0-60° degrees).

There were relatively few species with high percentages on concave and convex slope shapes compared to flat sites and straight slopes.

3.6.6 Canopy Cover

Canopy cover rank was based on the Braun-Blanquet method of cover-abundance. Five ranks were used, with rank 0 = no shade and rank 4 = full shade all year.

Sedge and Rush Species

Typha orientalis, Juncus gregiflorus, J. sarophorus and *Schoenus pauciflorus* were almost always found in unshaded sites (Fig. 3.11a). *J. pallidus*, *Carex secta* and *C. geminata* were found in sites with no shade to partial shade, and *C. virgata* had a slightly wider range from no canopy to rank 1.5. Three self-established outliers at rank 2 for *C. secta* were of fair vigour only. *C. maorica* and *Eleocharis acuta* were found in sites with no canopy to rank 2.

Comparison of Self-established and Planted Data

The planted dataset for *Juncus pallidus* had a significantly (*) lower median value (Table 3.4) for canopy (less shade) than their self-established counterparts, with the self-established dataset having a significantly wider (***) variance. The planted dataset for *Carex secta* had a significantly (*) wider variance around the median than the self-established dataset (Table 3.4). Two planted individuals for *C. secta* at the 10th percentile (complete canopy), and another two at rank 2 (partial shade to shade all year), were found to be of fair vigour only.

Fern Species

Blechnum chambersii was found in areas of no shade to rank 2 (Fig. 3.11b). *Blechnum aff. capense* and *B. fluviatile* were found in sites with a canopy of rank 1 to 2. *B. minus* and *Polystichum vestitum* were found primarily to have a canopy of rank 1 to 3. Outliers at rank 4 (under a full evergreen canopy) for both *B. aff. capense* and *P. vestitum* were of fair vigour only.

Phymatosorus pustulatus and *B. penna-marina* were found primarily from rank 2 to 3.

Tree and Shrub Species

Self-established individuals of *Cordyline australis*, *Coprosma robusta*, *Pittosporum tenuifolium* and *Coriaria arborea* were all in sites with no shade to low shade (Fig.3.11c). *Solanum laciniatum* was found in sites with no to medium shade. The outliers at ranks 2 and 3 for *Coprosma robusta*, at rank 3 for *Cordyline australis*, and rank 2 for *Coriaria arborea* were of fair vigour only.

Comparison of Self-established and Planted Data

Self-established individuals of *Cordyline australis*, *Coprosma robusta* and *Pittosporum tenuifolium* were all found in sites with significantly (***) more (Table 3.4) shade than planted individuals.

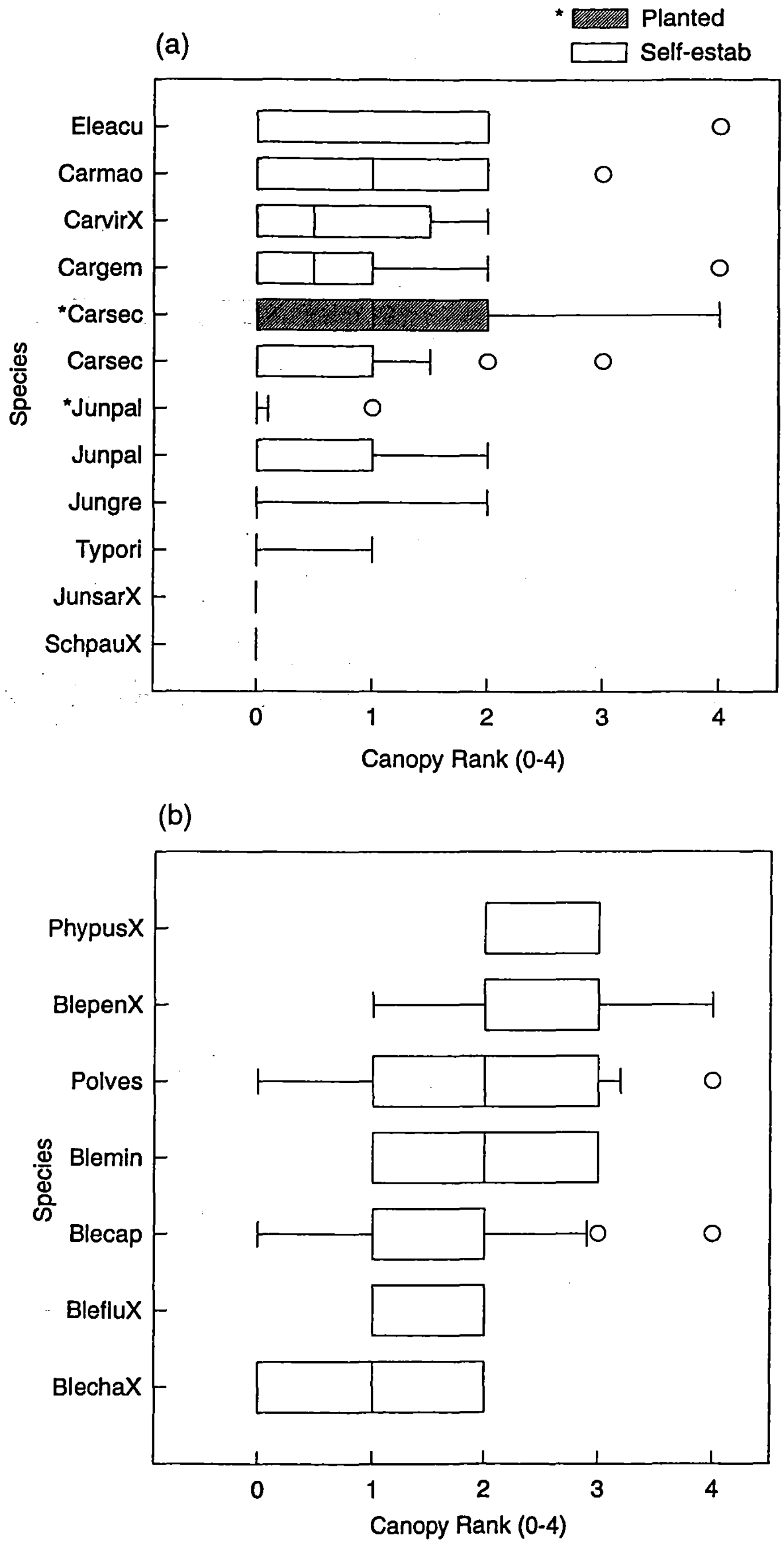


Figure 3.11: Canopy rank for sedge and rush species (a) and for fern species (b). Rank 0=no shade, 4=full shade. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

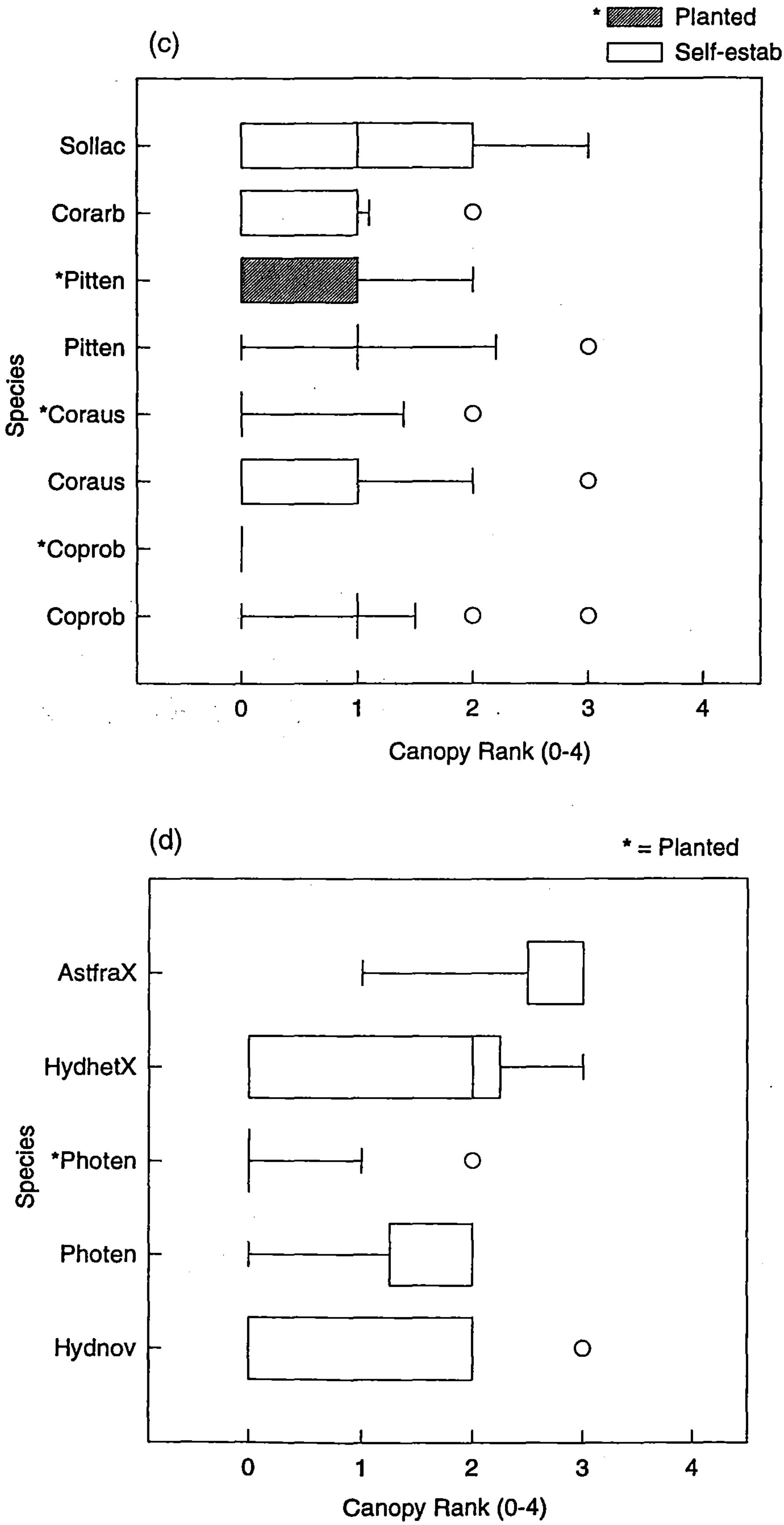


Figure 3.11 continued: Canopy rank for shrub and tree species (c) and miscellaneous species (d). Rank 0=no shade, 4=full shade. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

Other Species

Phormium tenax was recorded between ranks 1 to 2 (partial shade) (Fig. 3.11d). *Hydrocotyle novae-zeelandiae* and *H. heteromeria* were found in areas with no shade to partial shade. *Astelia fragrans* was found in sites with more shade (rank 2.5 to 3).

Comparison of Self-established and Planted Data

Phormium tenax self-established individuals were found in areas of rank 1.5 to 2, significantly shadier (***) (Table 3.4) than where they were planted. Planted individuals were primarily found in sites of no shade.

Summary

Most species and plant types were recorded in sites of no shade to partial shade, with the exception of *Astelia fragrans* and the fern species *Blechnum minus*, *B. penna-marina*, *Polystichum vestitum* and *Phymatosorus pustulatus*, which were recorded in shadier sites.

3.6.7 Frost Index

The frost index was a combination of elevation above water, canopy cover, slope and aspect, and was scaled from 0-40, with high values indicating more likelihood of frostiness at the site.

Sedge and Rush Species

The rushes and sedges had very similar frost index results (Fig. 3.12a). *Carex geminata* and *Juncus gregiflorus* had the widest ranges. *C. secta*, *C. maorica*, *C. virgata*, *Eleocharis acuta* and *J. sarophorus* all had ranges between frost index 20 and 25. The outliers at frost values 16 and 32 for *C. maorica* were only of fair vigour.

Comparison of Self-established and Planted Data

The frost median of the planted dataset for *Juncus pallidus* was significantly (***) higher than the self-established dataset (Table 3.4). The self-established dataset had a significantly (**) wider but lower frost range. The only *J. pallidus* individual of fair vigour was planted, and had a frost value of 28.

Fern Species

The ferns ranged from frost index 17 to 27 (Fig. 3.12b). Outliers at frost value 28 for *Blechnum minus* and *Polystichum vestitum* were of fair vigour.

Tree and Shrub Species

The frost ranges of *Cordyline australis*, *Coprosma robusta*, *Pittosporum tenuifolium*, *Solanum laciniatum* and *Coriaria arborea* all fell between frost indices 22 and 28 (Fig. 3.12c).

Comparison of Self-established and Planted Data

The self-established datasets of *Cordyline australis*, *Coprosma robusta*, and *Pittosporum tenuifolium* all had significantly (***) lower frost ranges than their planted counterparts (Table 3.4). Three planted individuals of only fair vigour were noted at frost value 33 for *Cordyline australis*.

Other Species

Phormium tenax, Hydrocotyle novae-zeelandiae, H. heteromeria and *Astelia fragrans* all had frost ranges between 17 and 25 (Fig. 3.12d).

Comparison of Self-established and Planted Data

Phormium tenax self-established individuals were recorded in significantly (***) less frosty sites (Table 3.4) than planted individuals, and the variance in sites was significantly (*) less for the self-established dataset.

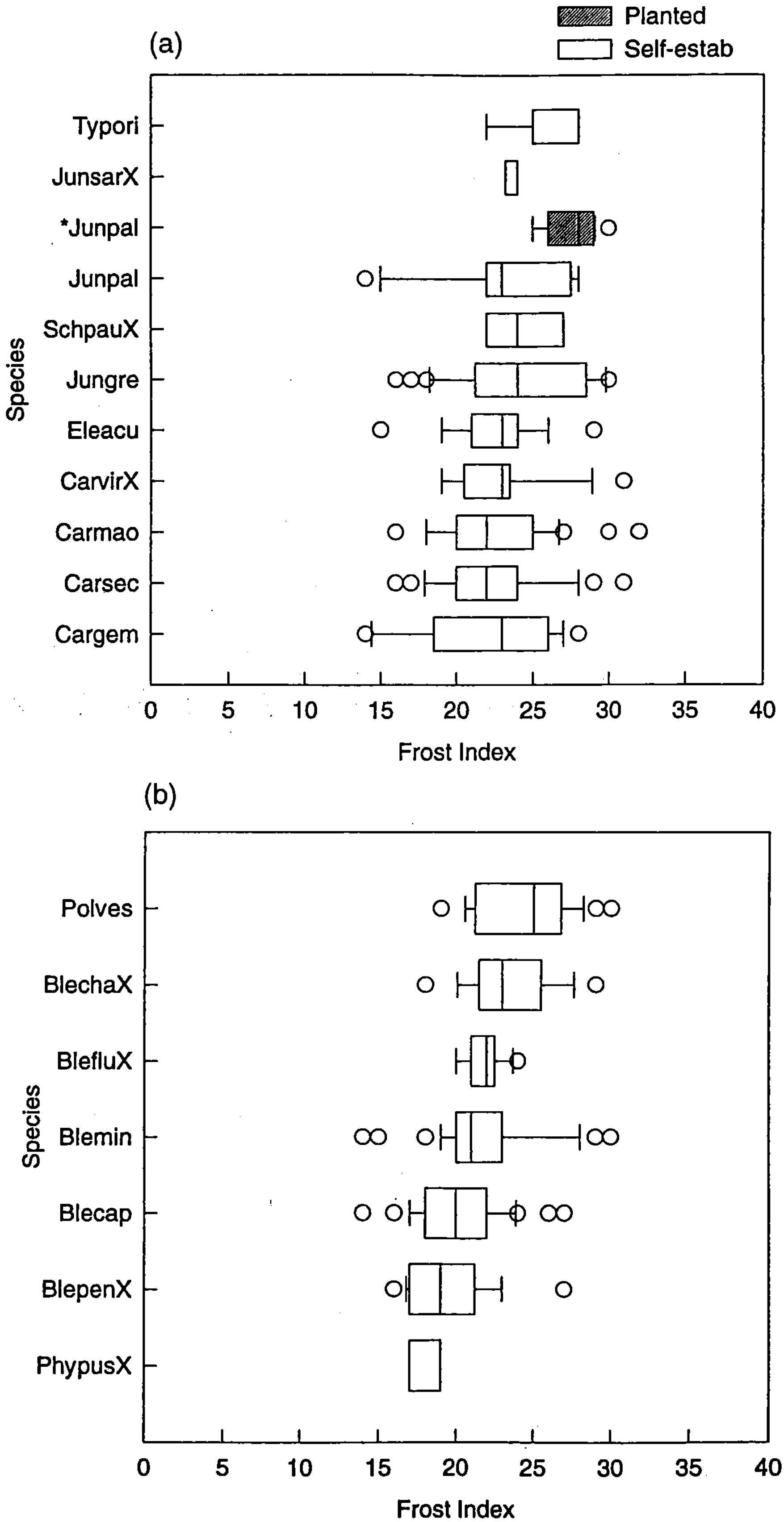
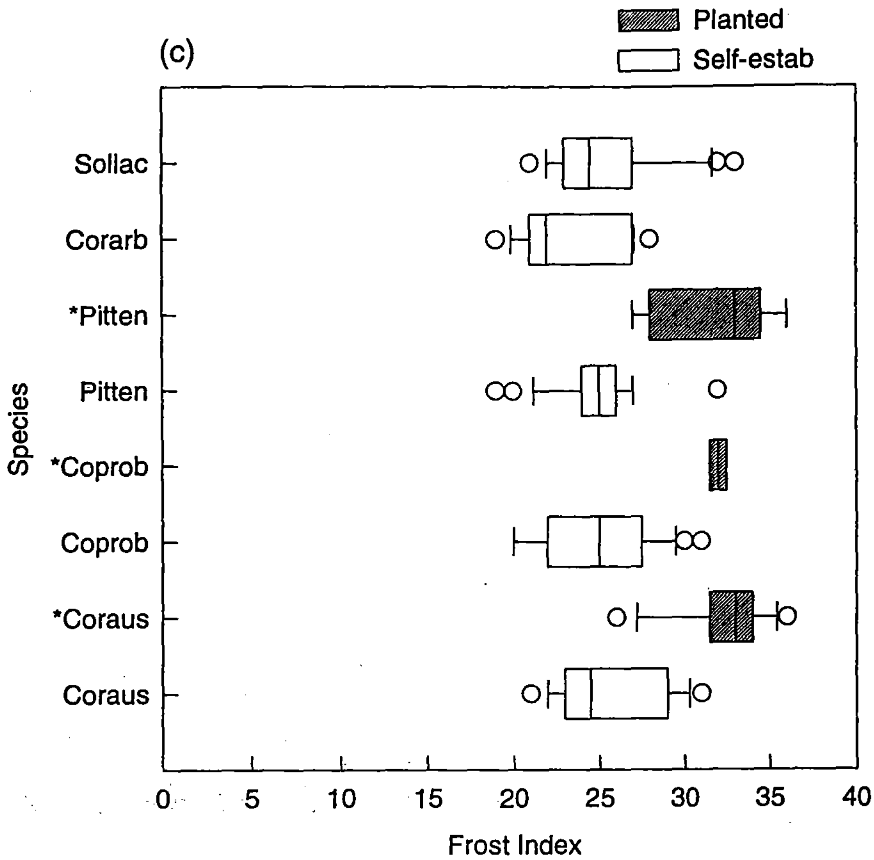


Figure 3.12: Frost index for sedge and rush species (a) and fern species (b). Rank 0=low frost, 40=high frost. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).



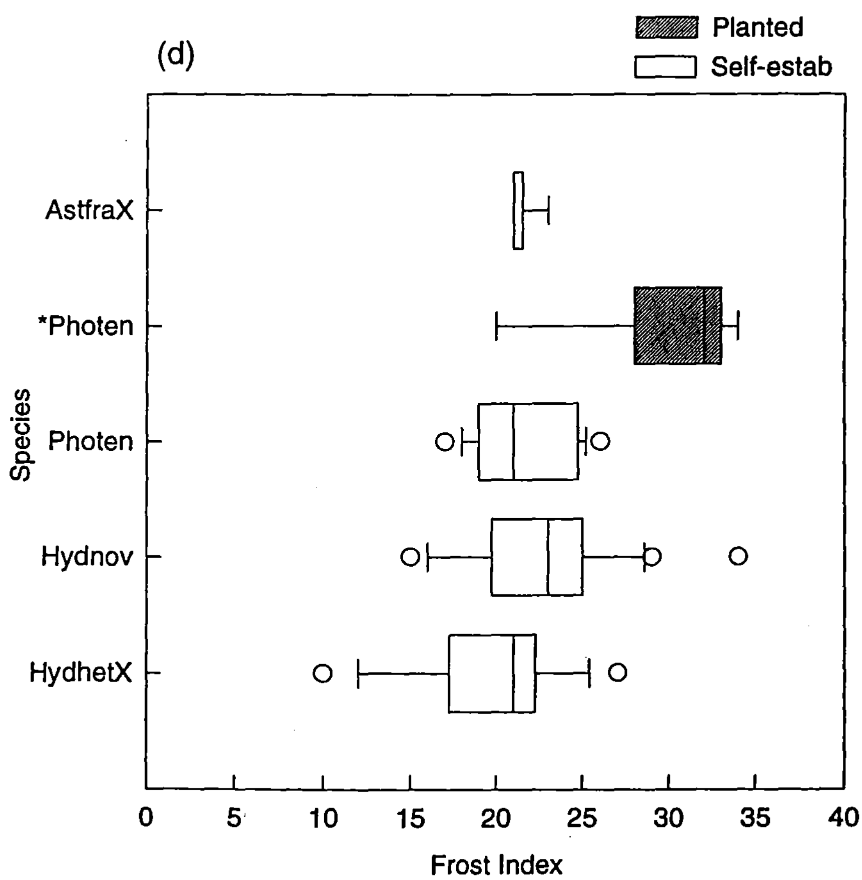


Figure 3.12 continued: Frost index for shrub and tree species (c) and miscellaneous species (d). Rank 0=low frost, 40=high frost. Self-established and planted samples for a species are compared when significantly different. (Refer to Table 3.1 for species codes, X=low sample size, *=planted sample).

Summary

The frost index did not strongly differentiate the self-established species. However, the planted trees were in sites with higher frost values (more frosty) than their self-established counterparts, with several plants of low vigour.

3.7 Selecting and Presenting the Key Environmental Variables for all Species

3.7.1 Methods of Summarising the Data

How might the species ranges in relation to key environmental variables be efficiently summarised for use by restoration practitioners?

A total of three variables were selected as the optimum number of variables to be summarised in one figure and/or table. The figure/table should provide an easy to use visual summary identifying the most important environmental variables.

If only three variables are to be used, then which environmental variables would explain the most variation in the data?

The boxplots in Section 3.6 combined species in plant type groupings for each environmental variable from the PCA results. Elevation, riparian class and soil moisture were found to measure similar variables (Table 3.5b). Soil moisture was selected for the summary figure and table. Canopy and slope were independent variables and therefore both presented in the summary figure and table. Soil pH was not included as it was highly positively correlated with both slope and soil moisture (Table 3.5c) and could possibly be inferred from these variables. Frost was not included as the rank used did not appear to be highly discriminating.

Figure 3.13 and Table 3.8 summarise all self-established species in relation to soil moisture, slope and canopy rank. Only self-established data of good vigour for each species was included. Figure 3.13 and Table 3.8 present the same results but in different form, and were compiled for three reasons:

1) Firstly, to ascertain if species could be grouped in relation to environmental variables;
2) Secondly, as examples of methods for presenting visual summaries of comparative species ranges for a number of key environmental variables, for use by restoration planners and landscape architects; and,
3) Thirdly, to provide a synthesis of the environmental variables for a decision support database for species choice in restoration projects.

3.7.2 Summary of Species Groupings in Relation to Environmental Variables

Species were arranged by plant type in the initial boxplots. Figure 3.13 and Table 3.8 indicate that species could also be grouped in relation to particular environmental variables. While only soil moisture, canopy and slope were selected for this summary, species may also be effectively grouped in relation to the other environmental variables measured in this research.

Soil Moisture

From Figure 3.13 and Table 3.8, the obvious soil moisture groupings were:

- *Typha orientalis* and *Eleocharis acuta* at rank 2, in the water;
- *Carex secta, C. maorica, C. virgata, Juncus pallidus,* and *Astelia fragrans* from rank 2 to 3, saturated soils;
- *Juncus gregiflorus, Schoenus pauciflorus*, and *Phormium tenax* from rank 2 to 4, saturated to very wet soils;
- The ferns, *Blechnum aff. capense*, *B. penna-marina*, *B. minus, Phymatosorus pustulatus*, and the trees and shrubs, *Pittosporum tenuifolium*, *Coprosma robusta* and *Cordyline australis* were from rank 3 to 4, also a wet soil category;

- *Juncus sarophorus, B. fluviatile* and *B. chambersii* at rank 4 (all of low sample size);
- Then a progression from rank 4 to rank 5 (damp soil) of *Hydrocotyle heteromeria, Polystichum vestitum*, and *Solanum laciniatum*; and finally,
- *Carex geminata*, *Coriaria arborea* and *Hydrocotyle novae-zeelandiae* between ranks 4 and 6 (drier or more free-draining soil).

In general, the sedges and rushes and *Phormium tenax* were found in the wettest soils. The ferns and self-established tree species were primarily in wet to damp soils. A mixed group of species were found in the wet/damp to drier soil categories.

Canopy Cover

Canopy groupings were drawn from Figure 3.11. Canopy groups shown in Figure 3.13 and Table 3.8 included:

- *Typha orientalis*, *Carex secta*, *C. geminata*, *Juncus pallidus*, *J. gregiflorus*, *J. sarophorus*, *Schoenus pauciflorus*, *Pittosporum tenuifolium*, *Coprosma robusta*, *Cordyline australis* and *Coriaria arborea* were found in areas of no canopy or partial deciduous canopy (0-1);
- *Eleocharis acuta*, *Carex maorica*, *C. virgata*, *Blechnum chambersii*, *Hydrocotyle heteromeria*, *H. novae-zeelandiae* and *Solanum laciniatum* were all recorded in areas of no shade to areas of partial evergreen canopy;
- *Phormium tenax*, *Blechnum aff. capense*, and *B. fluviatile* were in sites of partial shade in summer to partial shade all year (1-2);
- *Blechnum minus*, and *Polystichum vestitum* were in sites of partial shade summer to full shade summer (1-3);
- *Astelia fragrans*, *Phymatosorus pustulatus* and *Blechnum penna-marina* all fell in the partial shade all year to full shade summer (2-3);
- There were no individuals of good vigour recorded in sites of full shade.

In general, the sedges, rushes, and the tree and shrub species studied were found in areas of no or low shade. A mixed group of two sedges, a fern, and a shrub fell in a wider range of no to partial shade all year. Two ferns and *Phormium tenax* were found in moderately shady sites. The rest of the ferns (4) and *Astelia fragrans* were found in sites with the most shade.

Slope

As presented in Figure 3.13 and Table 3.8, most species were found on slopes of 0-30° degrees. *Juncus gregiflorus, Blechnum chambersii, Hydrocotyle heteromeria*, and *Coriaria arborea* were found at sites of 0-60° degrees of slope. *B. fluviatile* was found between the slope degrees of 30-90°. *B. minus* and *Carex maorica* were found between 0-90° degrees.

Combination of Environmental Variables

In general, most sedges and rushes could be grouped into a low shade, very wet soil, and low slope set of environmental ranges (Table 3.8). The trees and shrubs primarily fell in the wet to damp moisture ranges in areas of low shade and little slope. The fern species were in the wet to damp soil moisture ranges with medium to high shade, with a range of slope classes. The remaining species were quite variable, from low shade to high shade, in a wide range of soil moisture classes, and from low to quite steep slopes. The result for most plant types indicates that while some species within a plant type can be grouped, it is most logical to individually consider the environmental ranges of each species.

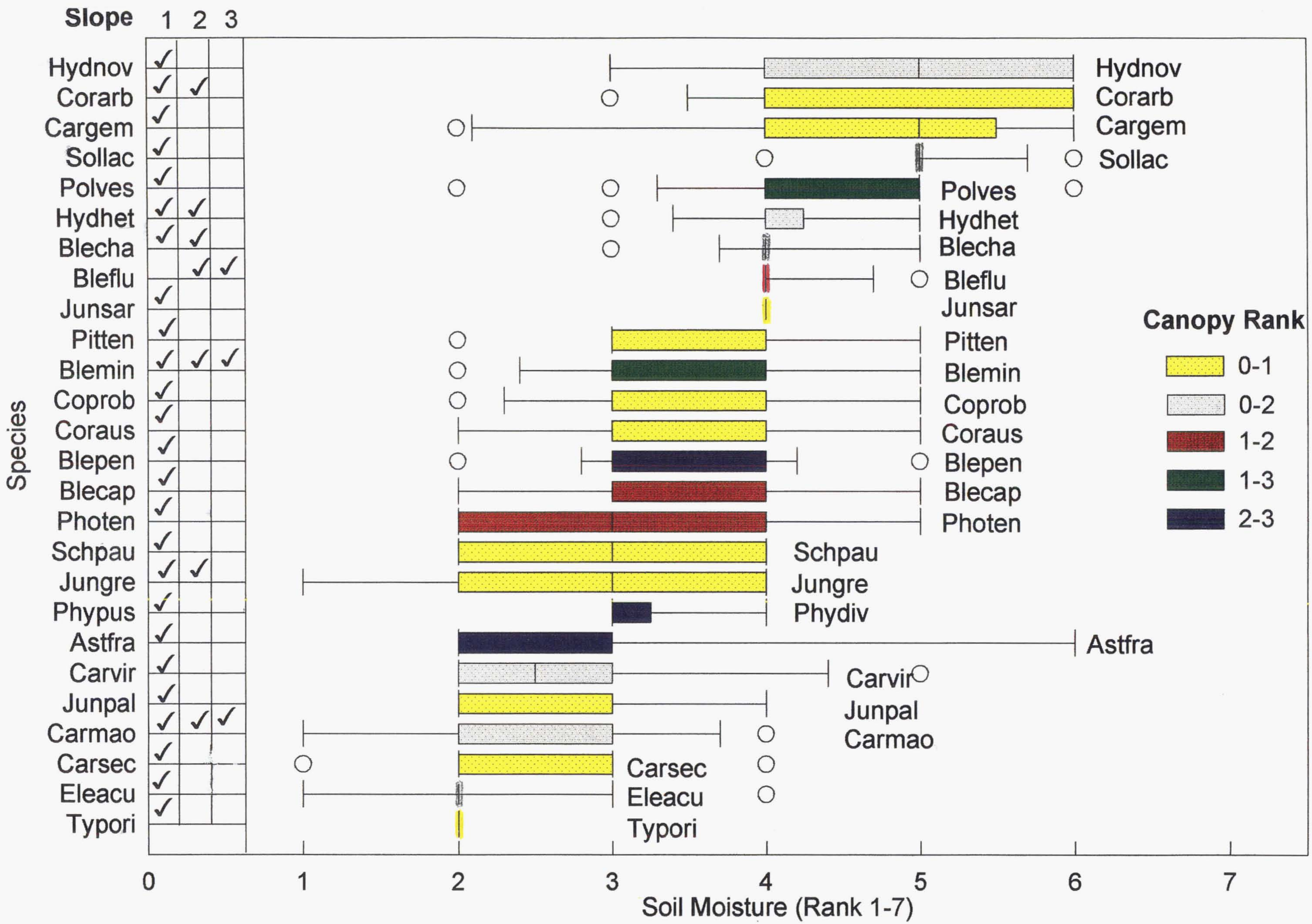


Figure 3.13: Summary of soil moisture, canopy and slope for all self- established species.

Species	Soil Moisture	Canopy	Slope
Typori	2	yellow	1
Eleacu	2	grey	1
Carsec	2-3	yellow	1
Junpal	2-3	yellow	1
Carvir	2-3	grey	1
Carmao	2-3	grey	1,2,3
Astfra	2-3	dark blue	1
Schpau	2-4	yellow	1
Jungre	2-4	yellow	1,2
Photen	2-4	red	1
Coraus	3-4	yellow	1
Coprob	3-4	yellow	1
Pitten	3-4	yellow	1
Blecap	3-4	red	1
Blemin	3-4	green	1,2,3
Phypus	3-4	dark blue	1
Blepen	3-4	dark blue	1
Junsar	4	yellow	1
Blecha	4	grey	1,2
Bleflu	4	red	2,3
Hydhet	4-5	grey	1,2
Polves	4-5	green	1
Sollac	5	grey	1
Cargem	4-6	yellow	1
Corarb	4-6	yellow	1,2
Hydnov	4-6	grey	1

Soil Moisture	
1	In water
2	Saturated
3	Very wet
4	Wet
5	Damp
6	Dry
7	Very dry

Canopy Key	
yellow	0-1
grey	0-2
red	1-2
green	1-3
dark blue	2-3

Slope Rank	
1	0-30
2	30-60
3	60-90

Table 3.8: Summary of soil moisture, canopy and slope for all self-established species.

3.8 Summary

The results of the plant ecology component of this thesis were first analysed using t-tests and Principal Component Analysis to identify important environmental variables and any duplication in the variables measured. The results for selected variables were presented in boxplots to demonstrate the ranges of species against each important environmental variable. Figure 3.13 and Table 3.8 summarised the ranges of all of the species recorded in the study in relation to soil moisture, canopy and slope. Species were then grouped in relation to these environmental variables.

Can environmental variables be summarised for particular plant types? Do species respond strongly to certain environmental variables?

Species were divided into plant types, which was considered an efficient structure for landscape and restoration purposes. Some species (eg., *Phormium tenax*) did not fall into distinct plant types using this method.

Species within plant types were not necessarily alike in their sensitivity to the various environmental variables. The t-tests and boxplots showed that some variables (eg., soil moisture) were particularly important for a plant type (eg., sedge and rushes), but most species responded to different variables in different combinations. This was also clearly illustrated in Figure 3.13 and Table 3.8.

Were there any differences between the self-established and planted datasets?

Overall, planted individuals were in higher, drier, less shady, more frosty sites, with higher pH, than self-established individuals of the same species. The differences were most clearly illustrated in the boxplots for *Cordyline australis*, *Coprosma robusta*, *Pittosporum tenuifolium*, and *Phormium tenax* for the environmental variables of elevation, soil moisture, riparian class, canopy, soil pH, and frost. Although the ranges for the planted and self-established datasets were different, there were not many plants of low or fair vigour in either group.

Were the environmental variables independent of each other for measuring plant site attributes?

Distance, elevation, soil moisture, and riparian class had high eigenvectors in Axis One of the Principal Component Analysis (PCA) indicating they could be measuring a similar site attribute. High correlations between soil pH and conductivity indicated that the values of these variables may move together; they were both indicated (with slope) on Axis Two of the PCA. Frost was not an independent variable as it was an index combining values from slope, elevation, canopy and aspect.

What were the patterns of individual species ranges in relation to the key environmental variables?

- The species showed similar patterns for the variables of soil moisture, elevation and riparian class, as expected from the PCA.
- Species had narrow ranges for some environmental variables (eg., *Eleocharis acuta* was only recorded at the water's edge), and wider ranges for other variables (eg., *E. acuta* had a wider canopy range than other species).
- Broad riparian class indicated the larger habitat in which species were most likely to be found. A high proportion of species were found by streams, rivers and in their backswamps. Few species were found in the backwashes of rivers and streams.
- Most species were in sites of no shade to low shade, with the exception of several ferns and *Astelia fragrans*.
- Fern species had the widest slope ranges, and most trees and shrubs were on relatively flat sites. If sedge and rush species were on steeper slopes

they were also at the water's edge. Few species were recorded in the concave or convex slope shapes.

- pH appeared to be related to elevation above water. For example, *Solanum laciniatum* had a wide elevation range, and *Cordyline australis* a narrow range. pH for these species followed the same pattern. For some species pH appeared to be higher with corresponding elevation above water; this was supported by Table 3.5c which indicated that pH and elevation were very highly positively correlated (***).
- Frost was not highly discriminating.

How might the species ranges in relation to key environmental variables be efficiently summarised for use by restoration practitioners?

Figure 3.13 and Table 3.8 summarised the variables of soil moisture, canopy, and slope. The species were regrouped in relation to each of these variables. While Figure 3.13 most clearly illustrated species ranges, Table 3.8 most efficiently summarised species into groups.

The results are discussed in Chapter Four, and methods for managing and using the data explored in Chapter Five.

CHAPTER FOUR
DISCUSSION

4.1 Introduction

The aim of this research was to develop an approach for defining the environmental tolerances and optimal conditions for species in relation to environmental gradients in the riparian zone, as a tool to assist in restoring species in the best place.

The species results recorded in this study are compared with species tolerances documented in a recent publication on riparian planting in Christchurch, to assess if they fall within the expected ranges. The reader is referred back to Figure 3.13 and Table 3.8 in Chapter Three to illustrate discussion points. Reasons for differences between self-established and planted data for a species are explored.

The environmental variables used in the approach and analysed in the results section are discussed in this chapter. These environmental variables are evaluated in relation to their relevance and effectiveness in ascertaining species ranges. The efficiency of the methods used to collect the data are also evaluated. The environmental variables that were omitted from the final data analyses, and other potential environmental variables for future studies are summarised. The tables and figures included in this chapter serve to set the present data in context; they are not new data.

Finally, the methods used in the thesis are reviewed, limitations noted and improvements summarised. The following figure (Fig. 4.1) outlines the overall structure of Chapter Four.

4.1 Introduction

4.2 Discussion of Results

4.3 Evaluating the Environmental Variables Used in the Analyses

4.4 Other Environmental Parameters

4.5 Summary of the Methodology

4.6 Conclusions

Figure 4.1: Structure of Chapter Four: Discussion.

4.2 Discussion of Results

The between species t-tests of environmental variables selected for field measurement appeared to be important in different combinations for different species. No one variable, or combination of variables, was found to be important over the range of plant types and species, except for elevation for the sedges and rushes. Soil moisture, elevation, distance and riparian class were found to be measuring a similar variable, most likely a soil moisture relationship. 'Distance from water', aspect and soil conductivity were eliminated from further analysis.

4.2.1 Species Distribution in Relation to the Environmental Variables

While there is information available about the species studied (eg., Wardle, 1991; Johnson and Brooke, 1989), much of the literature is on a national scale, across a range of ecosystem types. As an indication of the reliability of the methodology, it was considered important to identify if the species ranges documented in Chapter Three were what would be expected for local riparian conditions.

The Christchurch City Council Waterway Enhancement Programme recently contracted a local landscape architect, Ms. Lucas, and an ecologist, Dr. Colin Meurk, to develop a riparian planting guide: "Streamside Planting: guidelines for native planting alongside streams in Christchurch" (Christchurch City Council, 1996, copy included in Appendix 4). The guidelines compile the most up to date information on the observed environmental tolerances of provenant riparian species in Christchurch. The environmental ranges of the self-established individuals of species studied in this thesis were compared with the guidelines.

Carex maorica, *C. secta* and *C. virgata* were noted in the guidelines as tolerating sun, half shade, and moist conditions at the water margin or in low areas. In the present study, these species were found in the same soil moisture class, but *C. maorica* was slightly more likely to be found in the shade than *C. secta* or *C. virgata*. Both the specific and broad riparian classifications used in this study supported the guidelines. Wardle (1991) noted that *C. maorica* grows in fertile lowland swamps - it was interesting to note in the present study that it was found some of the time in backswamps (24%) and a large percentage of the time by water-races (65%).

In the guidelines, *Juncus gregiflorus* and *J. pallidus* are noted as being tolerant of sun, moist soil and wind, and are noted together as being in the water edge zone. Both of these species were found at the water's edge in this study, but *J.*

gregiflorus was recorded in a wider soil moisture range, while *J. pallidus* was most likely to be found very close to, or in, the water.

Blechnum minus and *B. chambersii* were noted in the guidelines as being water edge species in shady, moist areas. In the present study these species and *B. fluviatile* were found in moist and partially shady sites, but were most likely to be found slightly further up the bank, in the zone defined as the upper part of zone A in the guidelines. While *B. fluviatile* and *B. chambersii* were found in areas of partial shade, they were only recorded at one location. In less modified situations they may be found growing in more shade (Meurk, pers. com.). *Polystichum vestitum* was noted in the planting guideline as growing in moist soil and shady sites in low areas or at the water's edge. In the present study it was found in a similar range. *Phymatosorus pustulatus* (previously *P. diversifolius*) was noted in the guidelines as growing in damp and shady sites; this was supported by the study. In addition, Brownsey and Smith-Dodsworth (1989) note that *P. pustulatus* can also tolerate slightly drier sites.

Cordyline australis, *Coprosma robusta*, and *Pittosporum tenuifolium* were noted in the guidelines as being tolerant of all conditions - shady, open, moist, dry and windy sites. In the present study, self-established individuals of these tree and shrub species were recorded in moist sites with less shade than planted individuals. They were also recorded near the backswamps of rivers and streams in the study, whereas in the guidelines they are noted as suitable for planting on the slope and crest of the riparian zone. Possible reasons for these differences are discussed below.

Phormium tenax was noted in the planting guidelines as tolerant of sun, moist to half dry soils, and wind. While planted individuals of *P. tenax* were recorded in drier zones, self-established individuals were found primarily in wetter sites with no shade to partial shade.

Astelia fragrans had a low sample size in this study, but as noted in the planting guidelines, was found with good vigour in shady, moist sites.

Species with primarily planted samples were recorded in the field study, but the results were not presented in the main body of the thesis. The results are in Appendix 2, and can be used to assess whether the planted species have been planted in sites within the expected tolerance ranges cited in the guidelines.

Sample Size

As the main aim of the research was to test an approach, species with low sample sizes were included in the analyses. These species were not intended to be representative of the population, nor statistically valid, but they did offer the opportunity of including a range of plant types in the analyses. Species ranges in relation to environmental variables may reflect the low sample sizes. An example is *Carex geminata*. Johnson and Brooke (1989) suggest this species is found mostly in lowland swamps, and other wet habitats. It was recorded in higher and drier sites in the present research. With a larger sample size, the range may include a lower soil moisture rank. The limited sample sizes of some species in this study only allow for limited interpretations of their ranges.

Are the observed ranges optimal?

Phormium tenax was found in sites of low to partial shade in this study; however, in many cases, willow canopies have invaded and shaded *Phormium tenax*, sedge and reed swamps. Meurk et al. (1993) noted that *P. tenax* and sedges may tolerate shady conditions for a considerable time as they receive sufficient light during the autumn, winter and spring through the deciduous canopy, but these conditions are not considered ideal.

Wardle (1991) noted that *Carex secta* tussocks begin life on emersed ground, but once established tolerate permanent flooding of their bases. In the present study *C. secta* was recorded into the water, however Wardle's comments indicate that these sites are not optimal for establishment. It is necessary to consider results as conservative and to consider secondary information on species tolerances to assess optimum species ranges.

In Summary

In most cases, the findings in the present study supported those in the guidelines. In some cases, the findings of the present study differentiated ranges of species in relation to specific environmental variables where the guidelines list the species together in one habitat.

The comparative ranges indicate that the methodology that was applied, even in a highly modified and discontinuous riparian environment, gives a reasonably accurate indication of the environmental ranges of particular species, as observed over time by local and respected ecologists. The methodology offers one way in which information on the ranges of species in a particular region can be compiled. The reliability of the methodology would increase with larger sample sizes and sampling in less modified environments.

4.2.2 Comparison of Self-Established and Planted Data

The results showed that planted individuals for *Cordyline australis, Coprosma robusta, Pittosporum tenuifolium, Phormium tenax* were in sites that were significantly higher, drier, with less shade and more frosty than their self-established counterparts. Possible reasons include:

- The sites where self-established individuals were recorded may have been the only sites available for establishment, and under optimal conditions their ranges would be wider. Also, drier sites in which these species may have originally grown may have been destroyed by riparian modification;
- Sites available for planting are generally in open areas with less canopy and more likelihood of frost;
- Species were planted outside of their natural ranges; or,
- Drier sites are easier and more accessible to plant.

While there were some planted individuals of low vigour, the health of the individuals did not appear to be a real issue (although sample sizes for plants of low vigour were too small to reach a statistical conclusion). This might indicate that the planted individuals recorded in the study may extend the environmental ranges of the species. Future monitoring of plantings will clarify the reasons for the differences and indicate whether the planted ranges are sustainable (ie., are able to regenerate) in the long-term.

4.3 Evaluating the Environmental Variables Used in the Analyses

The methodology developed in this thesis to ascertain species ranges compares favourably to planting recommendations from a recent report on riparian planting (CCC, 1996). The variables most easily compared with the guidelines were soil moisture, riparian class and canopy; however, it does appear from the results of this research that slope is also an important variable for adequate plant site selection. At a restoration site, slope may be a relevant measure of site drainage giving an indication of seasonal changes in soil moisture.

The environmental variables that were presented in the boxplots were elevation, riparian class, soil moisture, soil pH, slope, canopy and frost. They are evaluated in relation to their relevance, effectiveness and efficiency in ascertaining species ranges.

4.3.1 Elevation

Elevation offers a quantitative measure of plant site in relation to water (as distinct from altitude above sea level). Measuring elevation within the relatively flat, low lying region of Christchurch is essentially only at a micro-scale. Elevation was shown to be one of the most significant variables in the Principal Component Analysis and t-tests (Chapter Three). These results indicate there are strong micro-topographic influences affecting plant species distributions in the riparian zone.

In some riparian situations, elevation can function as an indicator of the degree and magnitude of flooding (Menges and Waller, 1983). However, due to a lack of sufficient data on flood events in the present research, it was difficult to assess whether or not species were in particular elevation groups in response to flooding. The impact of flooding may be important, particularly in areas with large and steep catchments where flooding influences may be more extreme.

Elevation was an efficient and quantitative measure for assessing plant site in relation to water. It can also be used as part of an index for other environmental variables, such as riparian class and frost, as discussed below.

4.3.2 Riparian Class

Specific riparian class was devised as an attempt to quickly characterise the site in which a plant was growing (eg., lower bank, mid-bank, etc). Like soil moisture and elevation, specific riparian class was one of the key parameters identified in the t-tests; from the results in Axis One of the Principal Component Analysis, these variables measure similar site attributes.

Broad riparian class (Table 3.7) indicated if a species was found primarily in one broad habitat type, or if it was a generalist over several different habitats (eg., lake, stream, river, backswamp, etc). Table 3.7 highlights the sites in which species were most often found. Each broad riparian class differs in its relationship to water, ie., the likelihood of flooding, and water-table and river level fluctuations affecting plant sites. The species growing at these broad riparian sites must be able to tolerate these conditions. Ideally, both the specific and broad riparian classes would be correlated for each plant of each species (eg., Figure 4.2a shows the results for *Cordyline australis*). However this level of detail was considered beyond the scope of the thesis and a more general approach was preferred.

It would be useful for restoration planners and practitioners, to have a method to identify each riparian class. Specific riparian zones vary in size depending on the sampling location. Some locations had flat, low lying areas adjacent to the waterway, while others had very steep banks - a low or mid-bank zone may have different areal proportions at different locations. Depending on the soil type, texture and degree of compaction, soil moisture and moisture retention in these zones can vary. The figures (Figs. 4.2b-d) for riparian class are presented as a means of assessing whether or not a range of riparian classes can be identified. Figures 4.2b and 4.2c show similar patterns of specific riparian class distribution for slope and elevation, and for slope and soil moisture. The patterns of riparian class shown in Figures 4.2b and 4.2c, are reiterated in Figure 4.2d.

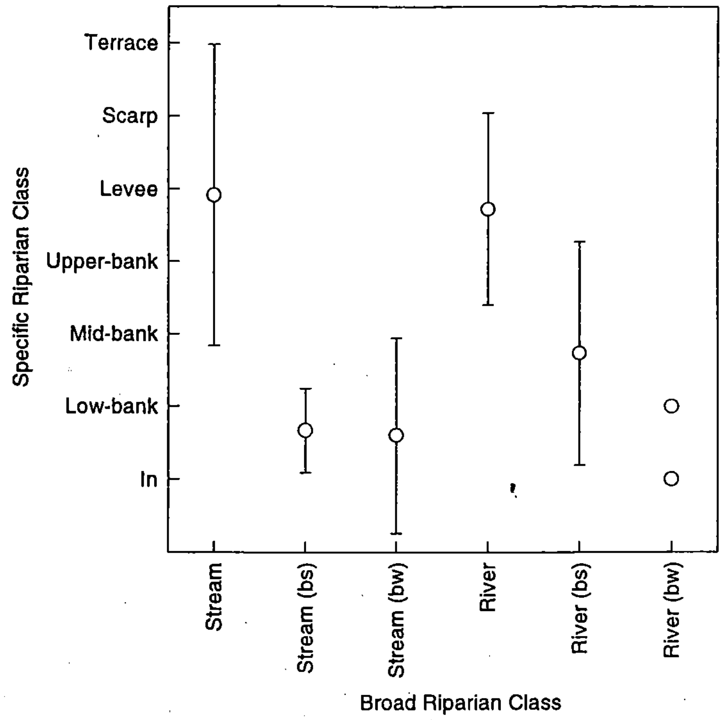


Figure 4.2a: Scatterplot showing the specific riparian classes recorded at each broad riparian class for *Cordyline australis*. (bs=backswamp; bw=backwash). Bars are two standard deviations from the mean.

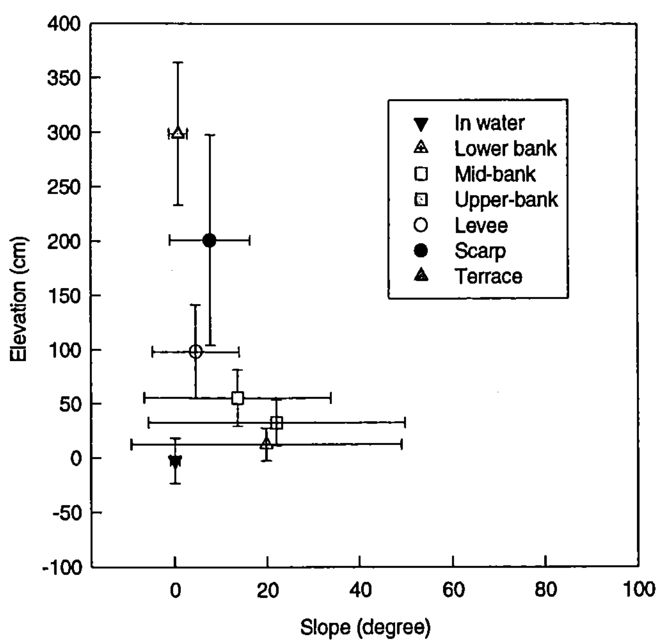


Figure 4.2b: Scatterplot showing the relationship of specific riparian class (all data) to elevation and slope. Bars are two standard deviations from the mean.

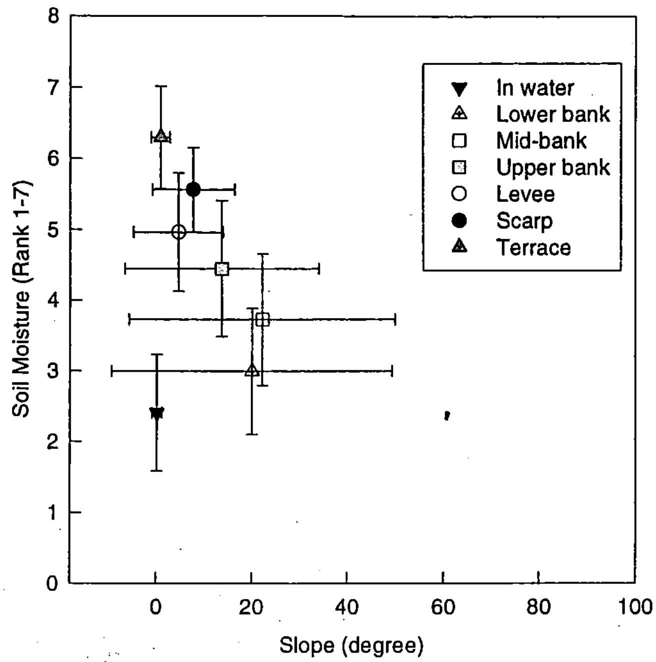


Figure 4.2c: Scatterplot showing the relationship of specific riparian class (all data) to soil moisture and slope. Bars are two standard deviations from the mean.

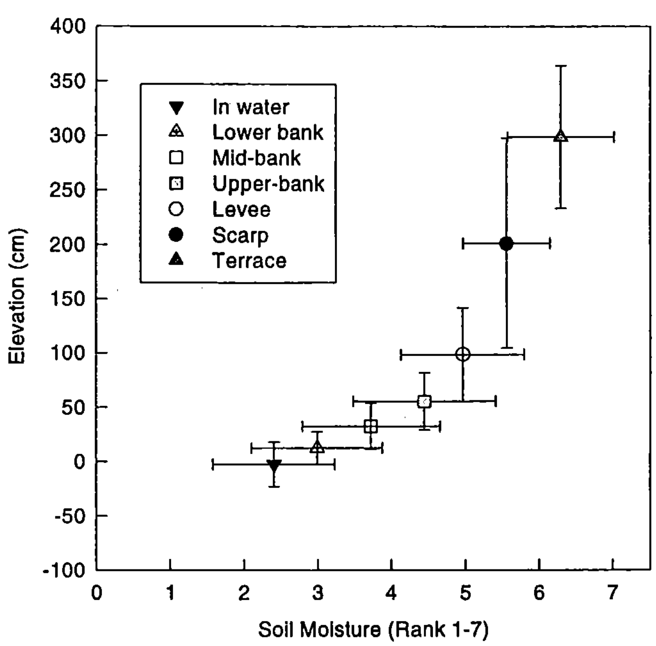


Figure 4.2d: Scatterplot showing the relationship of specific riparian class (all data) against elevation and soil moisture. Bars are two standard deviations from the mean.

The ranges in each specific riparian class for elevation, slope and soil moisture are presented in Table 4.1. The slope range was least at the water's edge as expected, but very wide for the lower, mid and upper bank riparian classes, narrowing again on the levee, scarp and terrace. A clear relationship between elevation and soil moisture is shown. The soil moisture ranges are wide for the lower riparian classes, while the elevation ranges are more narrow. The soil moisture ranges get slightly less in the higher riparian classes, while the elevation ranges get wider. The ranges of each variable overlap for each riparian class.

Table 4.1: Ranges for the environmental variables of slope, elevation, and soil moisture for each riparian class.

Riparian Class	Slope	Elevation	Soil Moisture
In the water	0	-20 to 10cm	1.5 to 3
Lower bank	0 to 50	0 to 15cm	2 to 4
Mid-bank	0 to 50	5 to 50cm	3 to 5
Upper bank	0 to 38	20 to 75cm	3.5 to 5.5
Levee	0 to 16	50 to 130cm	4 to 6
Scarp	0 to 18	100 to 300cm	5 to 6
Terrace	0 to 5	220 to 360cm	5.5 to 7

Elevation, soil moisture and slope could be used to broadly describe riparian class for the highly modified riparian zones of Christchurch. The ranges overlapped for each riparian class and indicated a wide variation in sites available for sampling. With further refinement of a soil moisture rank class, the degree of overlap between riparian classes may diminish. Fewer rank options for each environmental variable would reduce any uncertainty between rank classes (eg., a soil moisture rank from 1-5 would reduce the overlap by reducing the choice of ranks).

It is unlikely that the ranges for each environmental variable mentioned for Christchurch will be exactly the same for riparian zones in other areas of New Zealand. However, the variables of soil moisture, elevation and slope could be used to quantify these riparian classes in the riparian zone to be restored and also in the riparian zones used as templates to assess species ranges.

4.3.3 Soil Moisture

Soil moisture was measured as a rank class of 1 to 7, rank 1 being the wettest and 7 the driest. The soil moisture results are firstly set in a seasonal and annual context. Secondly, the relevance of the soil moisture rank in assessing species ranges in the riparian zone is discussed.

Soil moisture measurements were initially taken at each plant site in winter and early spring. In summer, soil moisture was remeasured within each riparian class at a location, however, not at the scale of the individual plant. Figure 4.3 compares winter and summer soil moisture measurements by riparian class for all sites and locations. This figure indicates that soil moisture at all sites was slightly drier for ranks 1 to 3 (wet zone). It also shows that a substantially larger number of sites had a soil moisture rank of 6 (dry soil) in summer than in the winter sampling period, with slight increases in ranks 4, 5 and 7.

The measurements recorded in Figure 4.3 are from one year of winter and summer sampling. Ideally, plant sites would be sampled over several seasons. This length of time was not available, and it will not normally be available to the restoration planner. To qualify the measurements for 1995 to 1996 (winter to winter period), monthly rainfall during that time was compared against rainfall normals for the period from 1902-1994 for the Christchurch area (Fig. 4.4). Rainfall measurements are from the Botanic gardens near central Christchurch. The Botanic Gardens lie in the middle of the three rainfall zones of

Christchurch, and could be considered an average site for rainfall in Christchurch (Derek Carver, Christchurch City Council, pers com.).

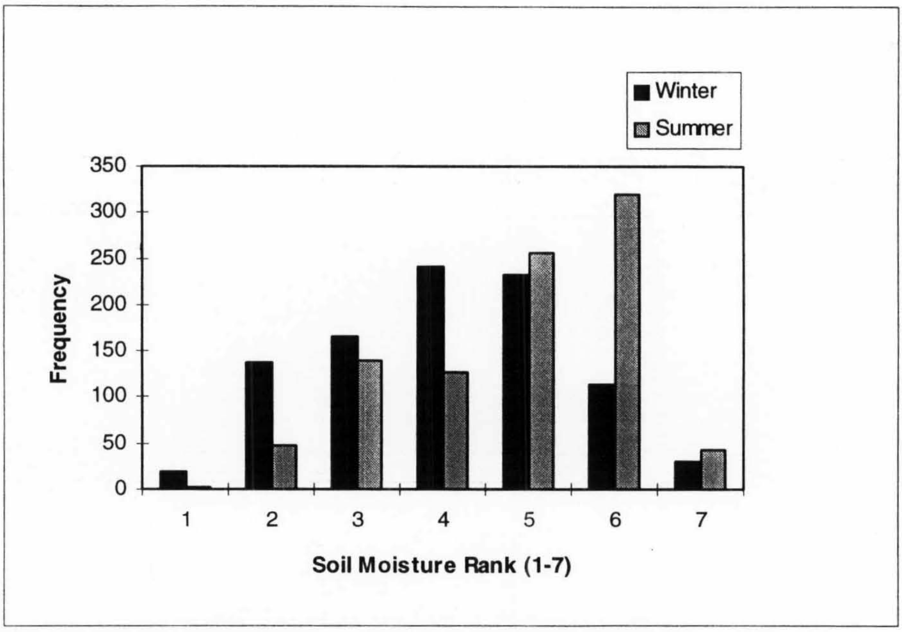


Figure 4.3: Soil moisture changes winter to summer for all sampling locations. Rank 1 = the wettest soil, and rank 7= the driest.

Christchurch experiences little seasonal fluctuation in rainfall, with only a 10-15% decrease winter to summer. Figure 4.4 shows that June, 1995, was a very high rainfall month, with almost 200% more rainfall than the average over the previous 92 years. Overall the 1995/1996 winter was wetter and the summer drier than normal. It could be hypothesised that the species recorded could tolerate slightly drier conditions than those in which they were recorded in winter, 1995. However, the soil moisture classes were aimed at providing relative differences between species, not absolute differences. Therefore, although the year sampled was unusual, and species may in fact "normally" exist in drier soils, it was the discrimination power of the variable that was important. If anything, the results show how hard it would be to develop some "absolute" soil moisture measure.

The t-tests and Principal Component Analysis indicated soil moisture as one of the most significant variables. It was shown to be a useful variable for dividing the species in this study into riparian planting groups (Fig. 3.13). Soil moisture was a subjective measurement and depended on the observer's interpretation of the rank classes. The rank classes were sufficient to separate species into groups, but may need to be narrowed slightly, or based on some quasi-logarithmic scaling, to increase sampling consistency between projects and researchers in the future. In addition, data on rainfall, water table levels, water level fluctuations and flood events would complement the soil moisture data.

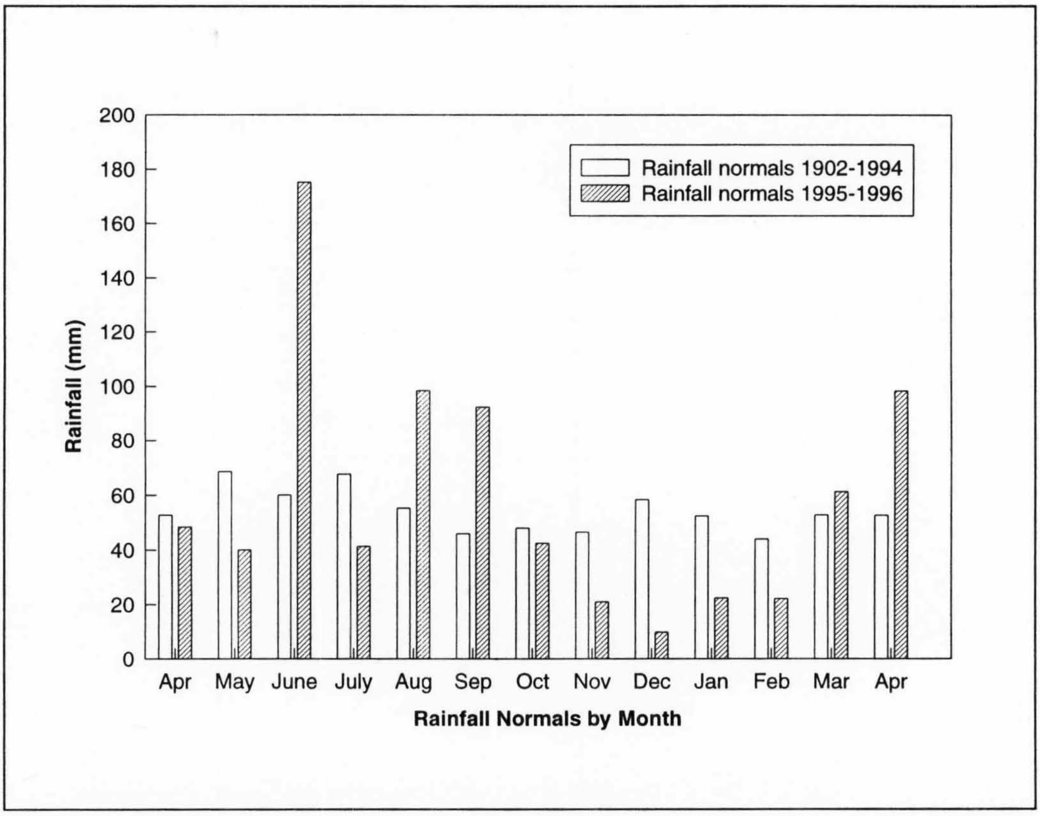


Figure 4.4: Comparison of Christchurch rainfall normals by month from 1902-1994, and the rainfall by month in the sampling year 1995-1996.

Water Level Fluctuations

Water level regimes differ depending on whether the waterway is springfed, from a large or small catchment, part of a larger matrix of waterways, and in response to land and water use practices in the catchment. For the Groynes, and sampling locations near the Waimakariri River, water levels are likely to be influenced by high country rainfall and farming water abstraction.

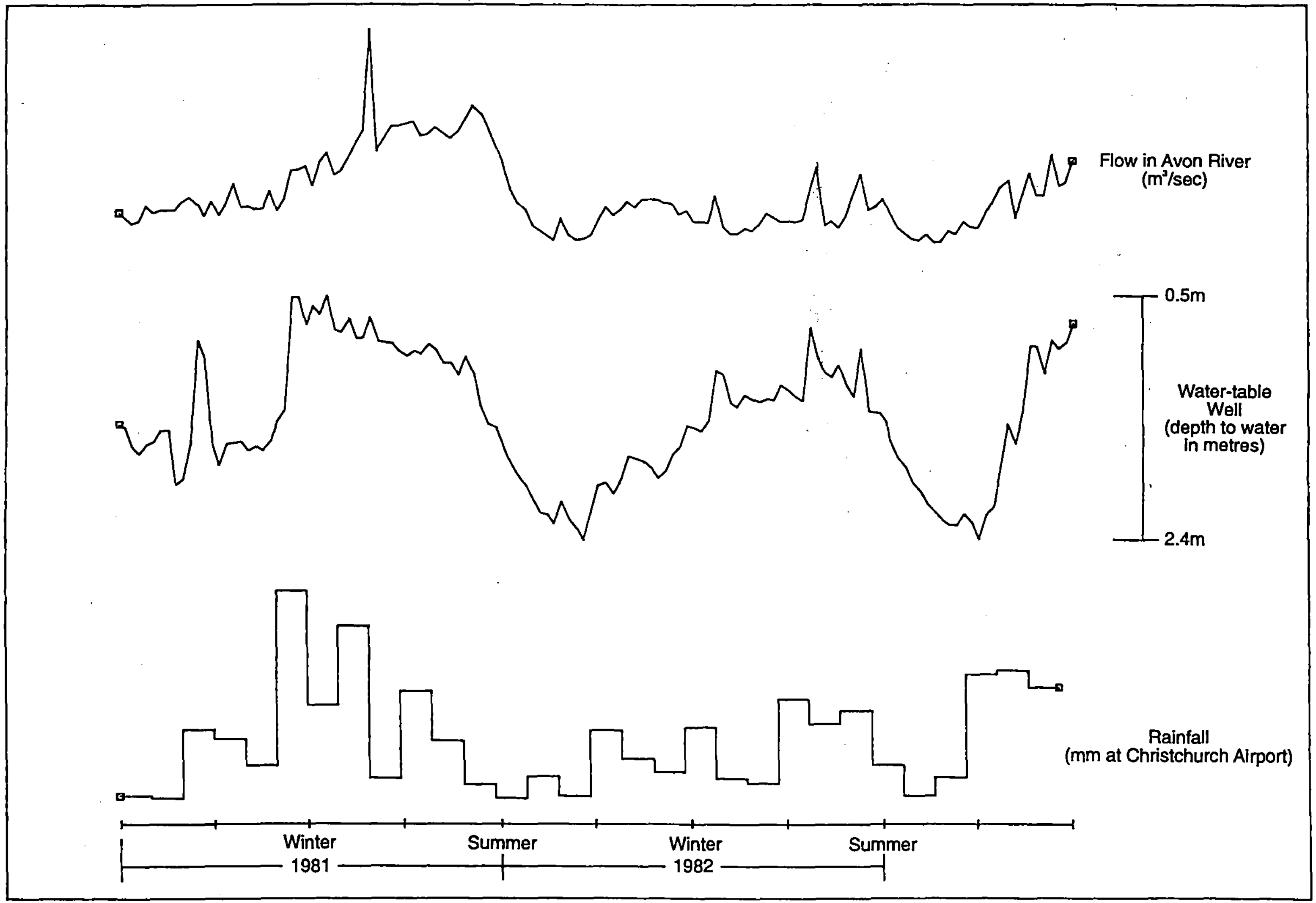


Figure 4.5: A two and a half year's record showing the correlation between rainfall, water-table, and Avon River flow, and the winter-summer cycles of high/low water table (from Brown and Weeber, 1995, p.55, in Molloy 1995).

Figure 4.4 (Brown and Weeber, 1995) shows seasonal and annual fluctuations in rainfall, and corresponding Avon River flow and water table fluctuations. It could be assumed that this pattern exists for all sites on the springfed Heathcote and Avon Rivers. In the sampling period of the present study, neither the low flows nor the frequency and duration of floods were considered unusual (Derek Carver, Christchurch City Council, pers com.). Stream-groundwater interactions can have a significant impact on riparian vegetation (Kondolf and Micheli, 1995). In terms of plant inundation or water availability, the water table acts independently of soil moisture when it is low, and with soil moisture when it is high (Malanson, 1993). Some indication of water table and water level fluctuations at the site to be restored would offer extra information on soil moisture gradients. Malanson (1993) noted that most ecological studies do not include this complexity due to sampling difficulties. While soil moisture was recorded for many sites at each location in the present study, water level fluctuations were not quantitatively measured due to widely scattered sampling locations, difficulty of sampling design, and time constraints.

4.3.4 Soil pH

Soil pH can influence the uptake of macro- and micro-nutrients (McLaren and Cameron, 1990). pH was presented in the boxplots but did not appear to be a highly distinguishing variable for most species. The recorded ranges fell within what would be expected in the Christchurch area (Leo Condron, Soil Science, Lincoln University, pers com.).

The importance of soil pH and conductivity for plant success will vary depending on the area being studied. In volcanic areas in the central North Island, soils may have a lower pH and be influenced by higher levels of certain chemicals, such as sulphur. The percentage of soluble salts (conductivity) will be far higher in the riparian zones of waterways influenced by tidal fluctuation, such as streams feeding into estuaries, than they are in freshwater situations. pH may also only be an issue in saline environments. Different ecosystem types would require different spatial and temporal sampling regimes to assess plant/environment interactions.

Some soil sampling decisions may influence results of pH and conductivity analyses. When soil measurements are taken close to the plant, it is difficult to assess whether the plant is influencing the soil, or the soil the plant. The root microclimate can influence soil, some roots increasing and some decreasing soil chemicals (McLaren and Cameron, 1990). The root depth of the plant being studied can also be important. Field limitations, such as unwillingness to disturb the vegetation, and time, restricted the depth of soil cores taken from plants. The roots of tree species, and therefore the soils that they influence or are influenced by, may have been deeper than the 14 cm of soil taken from the plant base (eg., *Cordyline australis* is likely to have a deeper root structure than *Carex maorica*).

Soil sampling at the plant site was time consuming; transect sampling in riparian classes, where feasible, would be more time-efficient. Measuring soil pH and conductivity in the laboratory was also time-consuming. As species were not differentiated to any great degree by soil pH and conductivity gradients, the measurement of these environmental parameters should be scaled down. Alternatively and preferably, future projects should explore the possibility of employing a soil scientist to fully assess soil horizons, type, texture, drainage, pH, conductivity, chemicals, and fertility at the restoration and remnant sites.

4.3.5 Slope

Slope was measured at a 'micro' scale as one indication of site drainage. Riparian classes closer to the water had a wide range of slope variation. However, lack of slope in riparian classes above the "upper bank" (Figs. 4.2b and c) is a typical feature of Christchurch's low, relatively flat plains. Different results for a similar range of species might be found if the steep hillside streams of Banks Peninsula or the North Island were studied. Measurement of slope in relation to plant success would be on both a micro- and macro-scale in areas of diverse topography.

Traditional riverbank management in Christchurch has steepened, channelised, and straightened rivers, streams, and water races. Recording species that can survive in these areas may add to plant success because many riparian restoration and revegetation sites have modified banks. For example, several of the *Blechnum* species may be useful for planting on steeper banks, and *Coriaria arborea* will also readily colonise them.

For *Eleocharis acuta*, a combination of slope and soil moisture measurements indicated that it should be planted only at the base of the slope, on the flat, just into the water. This indicates that it is necessary to consider a combination of environmental variables when assessing plant site.

Using a clinometer to measure slope degree proved to be awkward. A rank class for slope would be easier to record in the field. In Figure 3.13, slope degree was grouped into 0-30°, 30-60° and 60-90° degree classes as an example of ranking. Depending on the variation in slope at the site, the rank class should be further refined. For Christchurch riparian sites a more appropriate series of rank classes would be 0°, 0-15°, 15-30°, 30-45°, 45-60°, and 60-90° degrees. Modified ranking is in response to the high number of species recorded in the 0-30° degree rank (Fig. 3.13) which suggests that this rank may be too broad to accurately represent the data.

Slope Shape

While designed as a simple measure of site drainage, slope shape was found to be too subjective. It was often difficult to assess the slope shape influencing a particular plant. Table 3.7 (previous chapter) shows species with high percentages on "flat" sites, and in "straight" slope shapes; the results appear contradictory in terms of slope shape as a drainage parameter.

A more reliable drainage index could be developed by combining slope, slope shape, soil type and texture, gleying (redox) and soil moisture, in order to capture the range of parameters affecting site drainage.

4.3.6 Canopy Cover

Plant species tolerate a range of shade levels, some requiring shade for protection from frost and wind exposure, some adapted to low light levels (eg., some ferns), and some relatively intolerant of shade (eg., *Cordyline australis*). Due to Christchurch's highly modified riparian areas, some species may be in less shade or more shade (eg., overtopped by willows) than expected. However, in general, canopy was a useful measure of shadiness of a site for the species studied.

While, "canopy" refers to vegetation in remnant areas, it is a misleading term for assessing the environmental conditions at a restoration site in more highly modified riparian areas of cities. The term "shade" would be more appropriate for determining light levels. In the urban area fences and houses can also influence the amount of shade affecting a restoration site. These urban "canopies" need to be taken into consideration when planning planting programmes. A new rank classification may need to be developed for assessing the amount and duration of shade a plant receives at different times of the day or year. This would include variables such as aspect and height of surrounding structures or trees, and would incorporate the "canopy" rank classes of partial and full deciduous and evergreen canopies.

4.3.7 Frost Index

The frost index was deduced from the scaled values of aspect, slope, canopy cover, and elevation. It was not found to be a highly significant or discriminating variable for many species. The relative scaling of the environmental variables in the frost index may need to be altered to give a more accurate frost index for the riparian zone; some variables may have more influence on frostiness than others. In an environment where structures may shade waterways, shading may have more impact on the vegetation than other variables and should therefore have higher values than the other factors in the frost index. Future experimental research may yield a formula for frostiness that allows for more accurate measurement.

A frost index would only be relevant in areas of New Zealand where frost is likely to affect plant establishment and success.

4.4 Other Environmental Parameters

Only a few environmental variables were measured in this study. Their choice was based on variables used in similar studies, and ease of field data collection. Several variables were tested in the field but were not analysed due to sample size, subjectivity, lack of significance in the t-tests, or where the Principal Component Analysis indicated that several variables were measuring similar site attributes. These variables are listed in Table 4.2.

As mentioned earlier, there are a wide range of other environmental variables that are relevant to plant success in riparian zones that were not fully explored in the present study. Examples of these are included in Table 4.3. Those considered most relevant to measure in future projects are soil texture, water level fluctuations, flood frequency and duration, and plant competition.

While an understanding of the environmental ranges of plant species under "normal conditions" may improve planting success, success also depends in part on the climatic and hydrological (particularly water level and flood frequency) characteristics of the years immediately following the restoration project (Kondolf and Micheli, 1995). Monitoring flood and drought events, amongst other variables, will add to the data supporting restoration decision making and assist in explaining planting successes and failures. In time it may also add to our understanding of ecosystem processes (eg., floods can act as "resetting" agents in long-term succession (Howard-Williams, 1991)).

Table 4.2: Environmental variables tested in the field but not presented in the boxplots.

Environmental Variable	Comments
Soil texture	• offers an indication of soil drainage and substrate type • subjective to measure in the field, expensive to measure in the laboratory
Distance from water	• a quantitative measure • a soil moisture parameter, but not as significant as elevation above water in assessing plant site
Aspect	• canopy and lack of slope confound this measure • may prove to be more important on a macro scale • useful in conjunction with other variables (eg., to develop a frost index)
Water quality	• water pH and conductivity measurements were taken at random intervals. pH and conductivity fluctuate markedly, and require a comprehensive sampling programme to fully assess their ranges seasonally and in relation to flood events • water clarity was noted, but again, this was highly variable depending on rainfall and catchment conditions • water quality is only likely to affect vegetation success where the plants are in direct, regular contact with low quality water

Table 4.3: Examples of environmental variables that could be studied in the future.

Environmental Variables	Comments
Flood events and water regimes	• flood frequency and duration may affect plant success • degree of flooding varies for different waterway types and in different areas • records of water level highs and lows would offer information on species tolerance to seasonal and extreme soil moisture conditions
Other soil parameters • Soil nutrients • Heavy metals • Soil drainage	• Soil nutrients: as an indication of soil fertility, although soil analysis is expensive. Soil nutrients are probably not restrictive for native species • Heavy metals from urban inputs may inhibit plant success in polluted urban areas; however, soil analysis is expensive • Soil drainage: has been discussed
Altitude	• allows for assessment of species suitable for different altitudes in more diverse topography
Competition	• presence of plant site competition, either from weed species or otherwise

4.5 Summary of the Methodology

4.5.1 Choice of Species, Sampling Sites and Field Methods

Species availability and sample size have necessarily limited both the list of species sampled (many other species could grow within the sites sampled), and the species populations on which the results are based. The remnant areas of vegetation available as sampling sites were small and therefore did not represent the indigenous diversity and associations of species once found in the Christchurch area. Historical reports and geological records are invaluable for assessing the past and present vegetation and for identifying missing species. Species that were once found in the riparian zone and are no longer naturally establishing in Christchurch were identified from these reports (Appendix 2). One of the only options available for assessing the ranges of these species in the present Christchurch environment is to monitor their success where they have been planted.

The data collected in this study only indicate where species are presently growing. For this reason, the results for each species must be considered to be conservative ranges to be updated by monitoring programmes in the future. To avoid artificially truncated distributions in restoration projects, species would ideally be planted both within the environmental ranges noted in the study and outside of these ranges, providing the plantings are recorded and monitored through time. Monitoring data can then be included in a species database for informing future planting programmes.

The field methods and analysis techniques used in this research took account of the disturbed riparian environment. Sampling in areas with more intact remnants and soil profiles than were available in this study may involve different sampling techniques. In areas of intact riparian vegetation, the use of presence/absence data from transects could reduce sampling time and allow for the use of predictive statistical methods such as logistic regression.

While it is possible to discuss the limitations in the remnant and extant vegetation, it is also very important to acknowledge that riparian and wetland habitat has been severely curtailed through urban development in the Christchurch area. In potential restoration sites in Christchurch there is a high probability that the soils will be modified by channelisation or infilling with different substrata. While this limits the areas in which we can collect information, it also limits the sites available for revegetation and restoration, and limits the species appropriate to the remaining areas. In this context, the environmental ranges recorded for the planted datasets of certain species in this study may provide an accurate indication of appropriate planting sites in present conditions, avoiding areas where plants were found to have low vigour. Assessment of the environmental conditions at a restoration site is necessary; options for site assessment and mapping are explored in Chapter 5.

At least one question remains - was Christchurch, with its highly modified riparian zones and few riparian remnants, a logical choice for testing the approach outlined in this thesis? Some species were missing from the original plant assemblages and others were difficult to record due to the low number of sample sites and individuals at those sites. In spite of these difficulties, the approach has served to specify environmental ranges of a diverse list of species (sedges, rushes, ferns, shrubs and trees) very similar to those noted in the riparian planting guidelines for Christchurch (CCC, 1996). If some indication of species ranges can be obtained from a highly modified area like Christchurch, then the approach can probably be applied for many other better endowed areas as well.

4.5.2 Data Analysis and Interpretation Techniques

T-tests and ordination allowed for an informed choice to be made between similar variables for use in further analyses. While most of the variables were eventually presented in boxplots, it was important to note which variables may have been measuring similar site attributes in order to select an appropriate set of methods for future projects.

Various methods for the presentation of results were explored. Boxplots were chosen as the best method for the purposes of this thesis as they provided easy comparison of species ranges in relation to the different environmental variables.

Figure 3.13 combines canopy cover, soil moisture and slope in one graph, and Table 3.8 combines the same variables in table form. The graph and table are examples of possible presentation methods that allow a landscape architect or restoration practitioner to quickly assess species suitable for a particular site.

As the variables are further refined, these figures and tables will become easier to compile. For example, more refined canopy cover and riparian classifications may allow for more defined species groupings.

The diverse ranges for each variable for each species indicate that the decisions about planting sites for particular species are quite complex depending on the number of riparian sites available to plant and the diversity of the environmental gradients. A species database designed to assist in selecting species for the different environmental gradients in a riparian zone may be very useful. Figure 3.13 and Table 3.8 are examples of possible outputs.

The data has only been analysed to the extent necessary to test the ecological methodology. In future, if more specific information about a particular species is necessary, individual histograms for the range of environmental variables could be compiled from the data. These histograms could show the percentage of individuals of a species in particular riparian, soil moisture, canopy cover, slope, pH, and frost classes. Self-established and planted data could be compared on these graphs (Fig. 4.6).

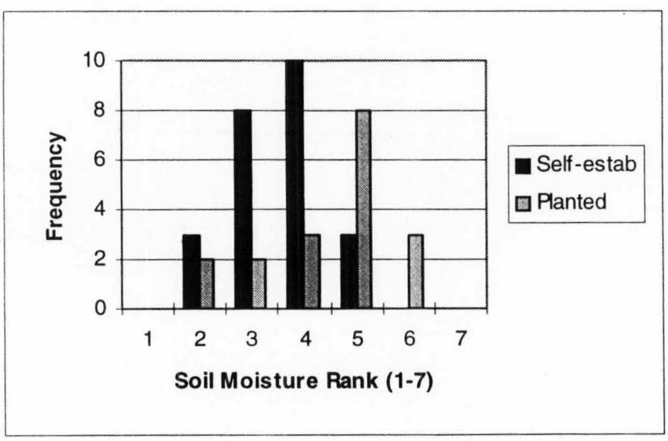


Figure 4.6: Example of a histogram comparison of self-established (N=24) versus planted (N=18) *Cordyline australis* samples of good vigour in relation to soil moisture. This type of information could be easily updated in a species database.

4.5.3 When would this approach be used?

The approach would be most applicable for collecting species data from remnant vegetation in areas where little is known about the species concerned. While local ecologists have observed plant species ranges through practical experience in Christchurch (CCC, 1996), other regions do not have this wealth of information and expertise. Where some information about species ranges is known, the methods outlined in this thesis could be applied in a monitoring programme. This would offer verification of observed ranges and add confidence to future planting schedules. Monitoring may be particularly important in urban areas with modified riparian zones.

4.6 Conclusions

Ten environmental variables were measured for each of the 26 species in the study. As identified in the results section, soil moisture and riparian class (both related to elevation), canopy cover and slope appear to be the most important variables for determining suitable planting sites for riparian restoration. As expected, different species responded to different combinations of these variables. The species researched in this thesis were compared against recently published literature on riparian plants. The study results for soil moisture, riparian class and canopy cover support the expected environmental ranges of species identified in the riparian planting guide for Christchurch (CCC, 1996).

The environmental variables used in the study were assessed in relation to their use as efficient and effective field parameters for assessing the environmental ranges of riparian species. The fully analysed variables (Chapter Three) were elevation, riparian class, soil moisture, frost, slope, soil pH, and canopy cover.

Slight improvements to the methods used to measure some of these variables include:

- Quantifying the riparian class (eg., using elevation, soil moisture and slope) and drainage parameters (eg., slope degree and shape) by combining other environmental variables to increase the accuracy of field data collection;
- Redefining the canopy cover rank to incorporate structures as sources of shade in assessing the environmental conditions at urban restoration sites;
- Modifying the frost index by rescaling its composite variables (ie., aspect, canopy cover, elevation and slope), and adding verification to the index through experimental work; and,
- Employing a soil scientist to assess the range of soil parameters at a restoration and remnant site, to reduce sampling and analysis time.

There are other environmental variables that were not fully captured in this study. Those considered most relevant for future riparian projects include:

- Soil texture in relation to a drainage index;
- Water level fluctuations;
- Flood frequency and duration; and,
- Plant competition.

For every environmental variable there are several methods that could be used to collect data. There is a balance between data collection efficiency and the accuracy of the data collected. Fully quantitative methods for measuring environmental variables (eg., laboratory methods for measuring soil moisture) may be more accurate, but the amount of time, facilities and skills necessary to do the analyses would often result in less data on which to base decisions. Different methods may also work best in different locations. While soil moisture, elevation, and riparian class measure similar site attributes, one or other of these variables may be most applicable for a particular project. The methodology used in this thesis offers a basis to work from.

Summary graphs and tables, like Figure 3.13 and Table 3.8, are ways that the ecological data could be presented to landscape architects and restoration practitioners. Data management tools to enhance the process of data entry, analysis and presentation could be easily developed. Data management options, and the eventual application of the ecological data, are presented in Chapter Five.

CHAPTER FIVE

APPLYING THE SPECIES DATA

5.1 Introduction

This chapter firstly explores options for efficient management of ecological data. The application of the ecological methodology developed in this thesis is then illustrated using a simplified case study. The research on environmental gradients is set into the wider context of restoration ecology. Future directions for developing decision support tools for riparian management are explored. Figure 5.1 outlines the structure of Chapter Five.

5.1 Introduction

5.2 Ecological Data Management

5.3 Applying the Ecological Methodology

5.4 Restoration Ecology and Sustainable Riparian Management

5.5 Future Directions

5.6 Summary

Figure 5.1: Structure of Chapter Five.

5.2 Ecological Data Management

The data collected using the methodology suggested in this thesis must be easily managed. Data entry, storage, analysis and presentation methods could be developed to efficiently inform decision makers on the most appropriate species and species ranges for a particular restoration site. Figure 3.13 and Table 3.8 are examples of the output of a data management tool. Various options exist to improve the species data management process.

The development of a data management tool must explicitly support the riparian restoration decision process. Data are costly to collect and are best gathered to meet certain objectives. A simple database for species ecology is considered sufficient, at this stage, to meet the needs of Boffa Miskell Ltd (for whom this research was done). The database must at least be capable of storing, analysing, and interpreting information on the environmental ranges of species. The method for updating information in the database must also be efficient.

The field data could be entered into a spreadsheet and automatically linked to a set of established data analysis tools. There may be some "decision tree modelling", as part of the species database, that allows for the choice of species based on environmental parameters. Ideally, species ecology data entered into a datasheet would be automatically analysed and presented in a template. Monitoring information would be used to update datasets and interpretive figures in the same way.

At a new site, the data analysis tool may have two levels, as in this thesis. Firstly, a method for assessing the key variables affecting plant species at a particular site (eg., Principal Component Analysis), and secondly, a method for simply interpreting the data (eg., boxplots and histograms). Several levels of data interpretation could be designed. These may range from a plant species list; to plant species groupings by environmental variables; to a combination of revisable primary and secondary data about a particular species, presented as individual histograms for each species.

GIS (Geographic Information System) systems are hardware and software combinations that include collection, storage, analysis, and output of spatially referenced data. GIS has been used as a means of keeping a spatially referenced record of environmental variables (Malanson, 1993). GPS (Geographical Positioning System), a site mapping tool, and GIS are options for mapping a restoration site in relation to environmental variables. Suitable species could then be chosen from the species database for the site conditions.

The GIS map can be used in various ways. An initial map could be used as a template to overlay geomorphological, hydrological, vegetation, wildlife habitat and other site parameters. This series of overlay maps would then serve as a set of baseline data for future evaluation of the restoration project. Depending on the temporal scale decided upon for monitoring, a practitioner could resurvey the site using GPS and add features such as growth of vegetation and quantifiable wildlife parameters to a data dictionary. Areas of a site to be restored could be identified and modified to allow for increased planting sites and potential wildlife habitats. This information would provide overlays to the original map to assess changes through time. GIS offers a comprehensive but time intensive approach to the mapping of an area, and would be used where a detailed plan is required.

The development of data management methods will depend on client demand and the willingness to invest in development of customised software tools.

5.3 Applying the Ecological Methodology: Shirley Stream as an Example

Shirley Stream, Christchurch, is an urban waterway being enhanced by the Christchurch City Council and Boffa Miskell Ltd. A reach of the stream (Fig. 5.2) has been used as an example of how the ecological data collected for this thesis might be applied.

The simplified functioning of a process for selecting species for riparian restoration is illustrated in decision tree flow-charts. The assumption in the example is that indigenous vegetation is preferred, which is not always the case. The approach outlined here could underpin landscape architecture planning and design, or could be part of a full restoration ecology approach with the goals of re-creating ecosystem function and process. Every project is different and the applications suggested may be more or less intensive depending on the scale. The approach has not been tested due to the time needed to plan, plant and monitor vegetation growth; however it is anticipated that this pilot approach will be tested in the future and then modified accordingly. Any statements presented are not recommendations for the stream; a plan should only be developed in consultation with residents.

(a) (b)

Figure 5.2: A reach of Shirley Stream, Christchurch, was used as an example of data application (a). Photos of plants were overlaid on the original image as one way of presenting future scenarios in community consultation (b).

5.3.1 Identifying the Goals and Objectives of the Project

The first phase of any restoration project involves identifying the goals and objectives. These need to be stated quantitatively and qualitatively in order to provide a solid basis on which to monitor restoration successes and failures (Kondolf, 1995). Goal identification includes wide consultation with community and regulatory groups likely to be interested in the project (Fig. 5.3), eg., Maori values will influence decision making and Maori people should be part of the decision process in both problem solving and solutions (Puia, 1990). If at the end of the consultative phase, restoration using native plants is the preferred option, then the process of site assessment and species selection commences. The subsequent phases assume that feedback will allow for continued community consultation in the choice of species. This phase of the process was not explored for Shirley Stream.

5.3.2 Site Mapping

The second phase in selecting suitable species for restoration is to understand the environmental parameters at the site (Fig. 5.4). This includes site mapping, either with detailed GIS overlays, or a simple hand-drawn map to indicate environmental variables, depending on the goals of the project. The mapping process allows for any structural modifications to the site that will impact on the vegetation, such as naturalising the waterway flow by adding meanders and levelling off steep banks, and removing any structures or large trees.

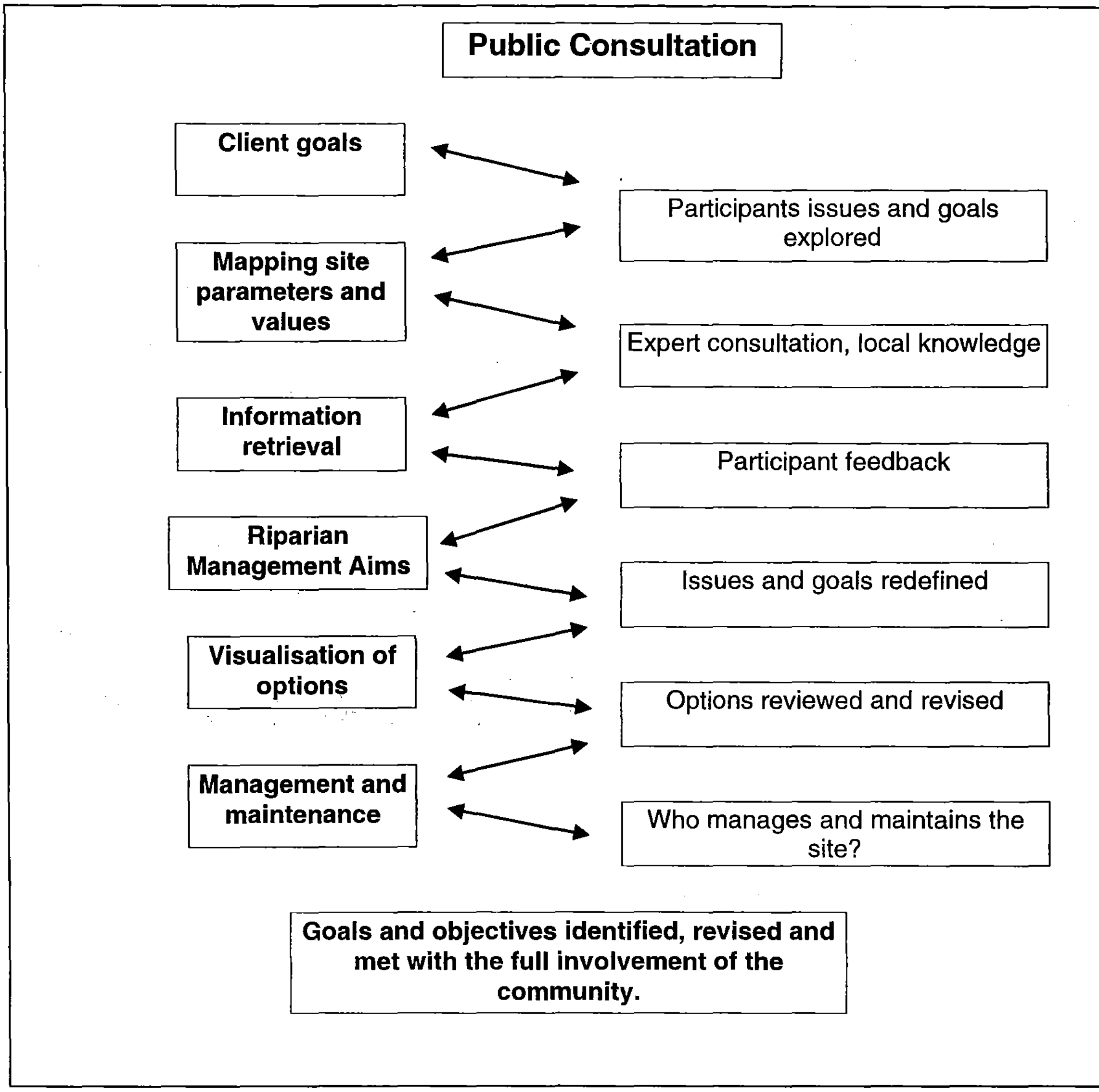


Figure 5.3: An integrated community consultation programme allows for clear identification of participant goals, and for feedback into the decision process at each phase of the restoration project.

As a mapping example GPS (Geographical Positioning System) (using satellite location at submeter accuracy) and GIS were used to map a reach of Shirley Stream. All geographic features of the reach were noted in a data dictionary. The results included detailed description of site parameters such as stream and riparian zone width, soil moisture regimes, slope, shade, and physical restrictions such as fences and houses. This information was downloaded to a file, corrected for satellite inaccuracies and the data applied in ArcInfo, a GIS package. ArcInfo allows various data to be successively overlaid to form a comprehensive map of an area (Fig. 5.5). The final map, with environmental parameters clearly marked, was used for selecting suitable species for the project.

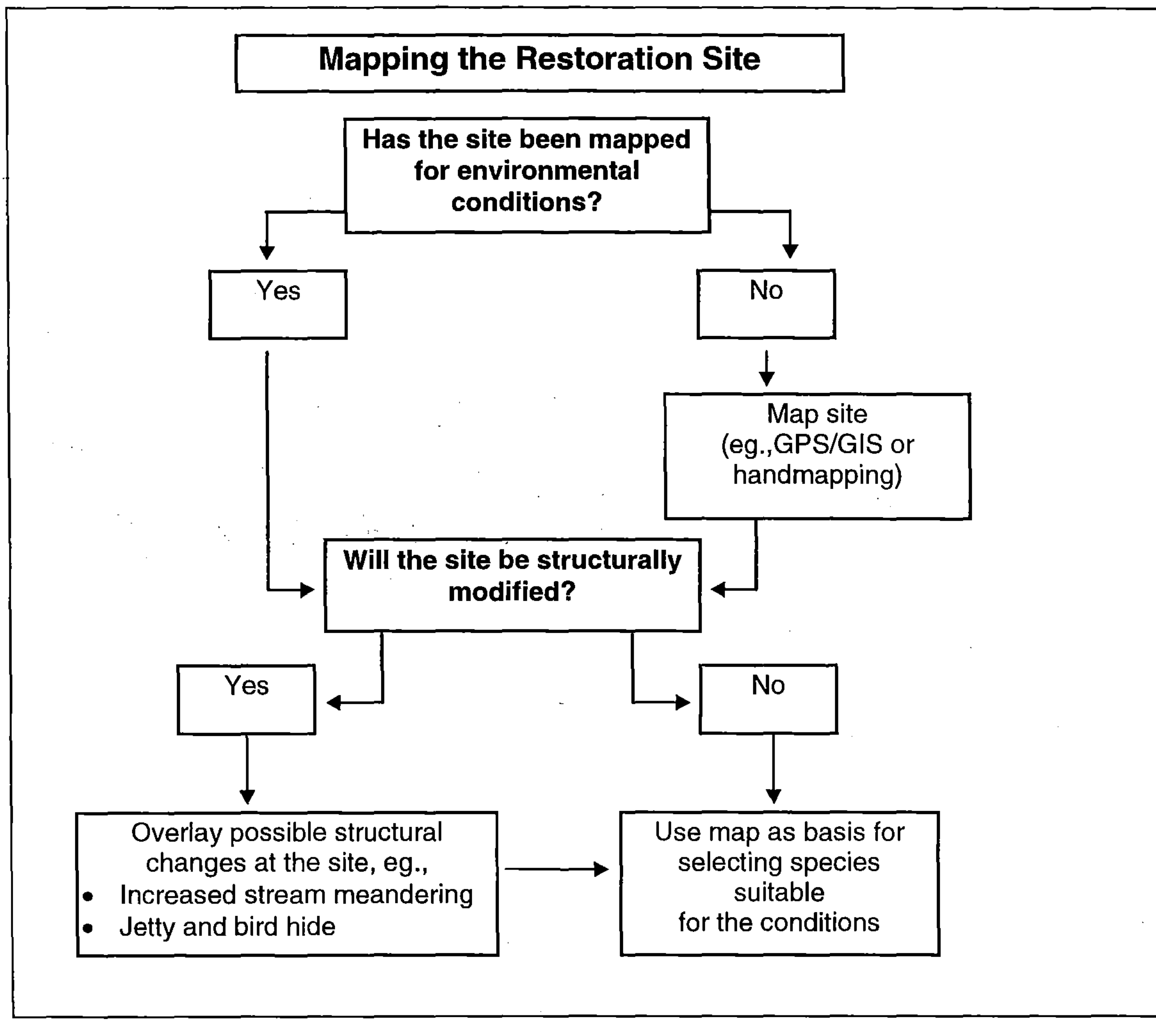
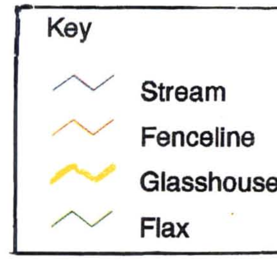


Figure 5.4: An assessment of the environmental parameters at the restoration site can involve revising available plans, or, depending on the scale of the project, mapping the site in detail (eg., using GPS and GIS).

	Area	Environmental variables	Species
	Area One	Ripclass=lowbank Soilmoisture=2-3 Slope=1-2 Canopy=0-1	*Eleocharis acuta* *Carex secta* *Carex maorica* *Juncus pallidus* *Juncus gregiflorus* *Phormium tenax*
	Area Two	Ripclass=midbank Soilmoisture=3-4 Slope=1-2 Canopy=2-3	*Blechnum minus* *Blechnum aff. capense* *Polystichum vestitum* *Phormium tenax*
	Area Three	Ripclass=upperbank Soilmoisture=3-5 Slope=1-2 Canopy=0-1	*Cordyline australis* *Pittosporum tenuifolium* *Coprosma robusta* *Coriaria arborea*



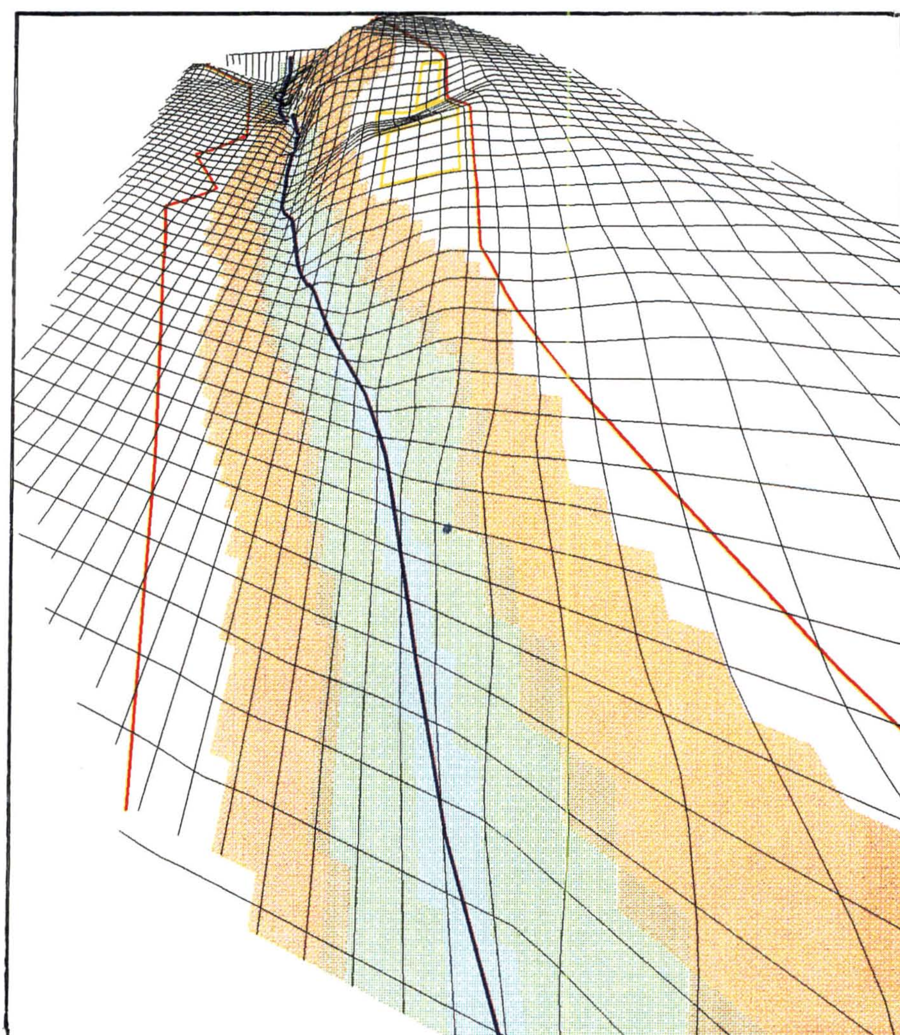


Figure 5.5: A reach of Shirley Stream was mapped in detail using GPS for field data collection and site surveying. ArcInfo was used to create GIS overlays of the environmental parameters of the site. (GIS map by Sandy Hammond, Plant Science, Lincoln University).

5.3.3 Gathering Species Data

Gathering species data involves compiling information on appropriate species for the site from historic records, ecologists knowledge, secondary ecological surveys, and from the collection of primary data (if vegetated remnants exist as templates) (Fig. 5.6). This phase also involves the analysis and interpretation of plant species ranges in relation to environmental variables. The data collected, analysed and presented in this thesis is useful for Shirley Stream and was applied in the example.

5.3.4 Selecting Species for the Site Conditions

Soil moisture, riparian class, slope and canopy were mapped for the reach of Shirley Stream. Using the map overlays, the site to be restored was divided into specific areas in relation to the combinations of environmental variables present. Figures 5.5 and 5.7 show the division of the reach into three main areas; species suitable for each of these areas were selected from Figure 3.13. Other species, such as *Cortaderia richardii*, are also appropriate. As little data exists on the range of this species in Christchurch, it would be planted in the most likely sites and its success monitored. An alternative for efficiently selecting species would be to use a species database, founded on previous and similar projects, particularly where a wide range of environmental parameters may affect plant success.

The species selected for the reach were depicted using computer visualisation tools (Fig. 5.2) for future community consultation purposes. Any changes suggested in the consultation process would be incorporated and a final planting plan designed using the initial map as a base. The planted reach would then be monitored.

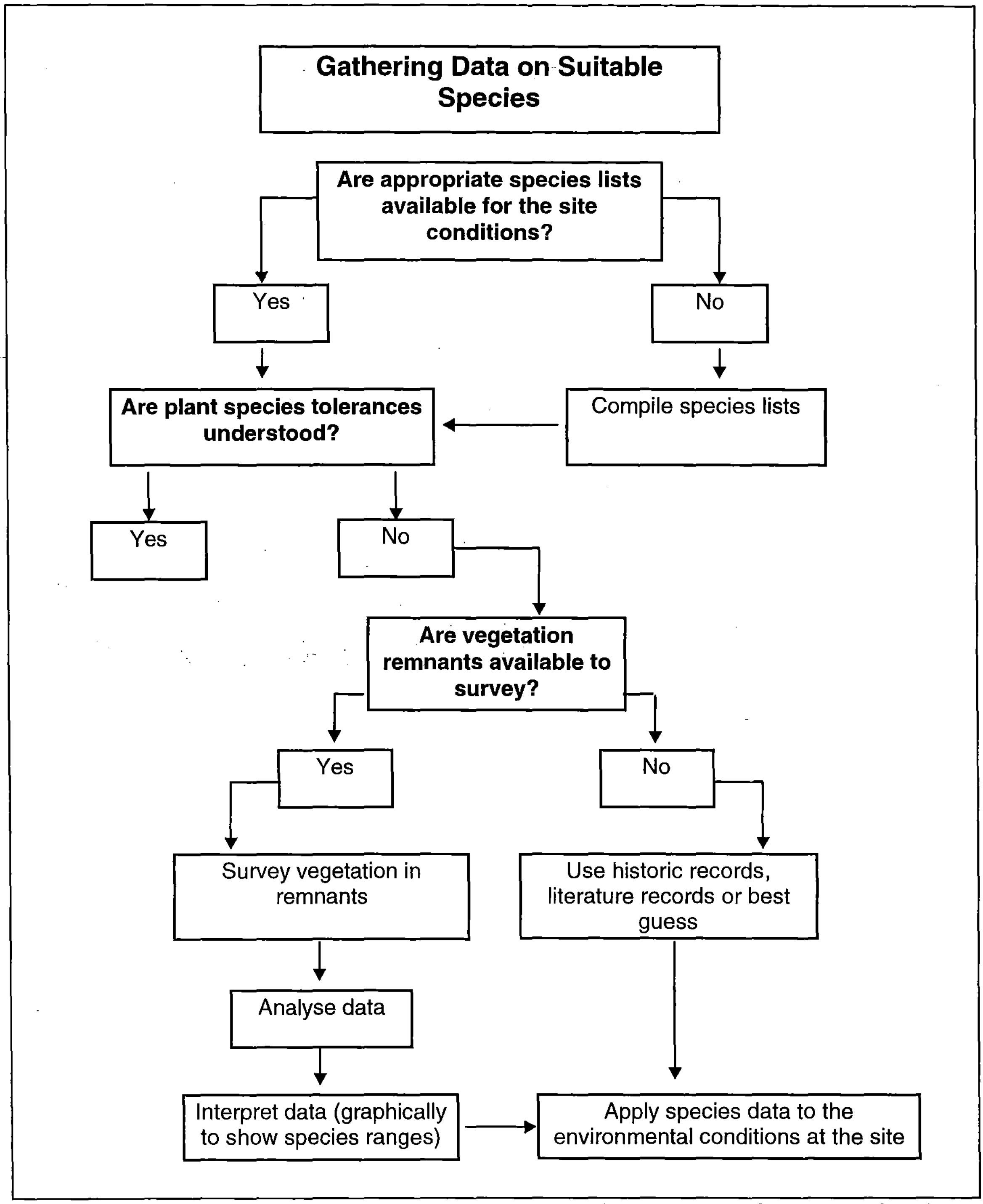


Figure 5.6: Gathering information on suitable species for the restoration project involves secondary research into historic and present records on species and their environmental ranges, and where necessary, primary research to assess the ranges of species.

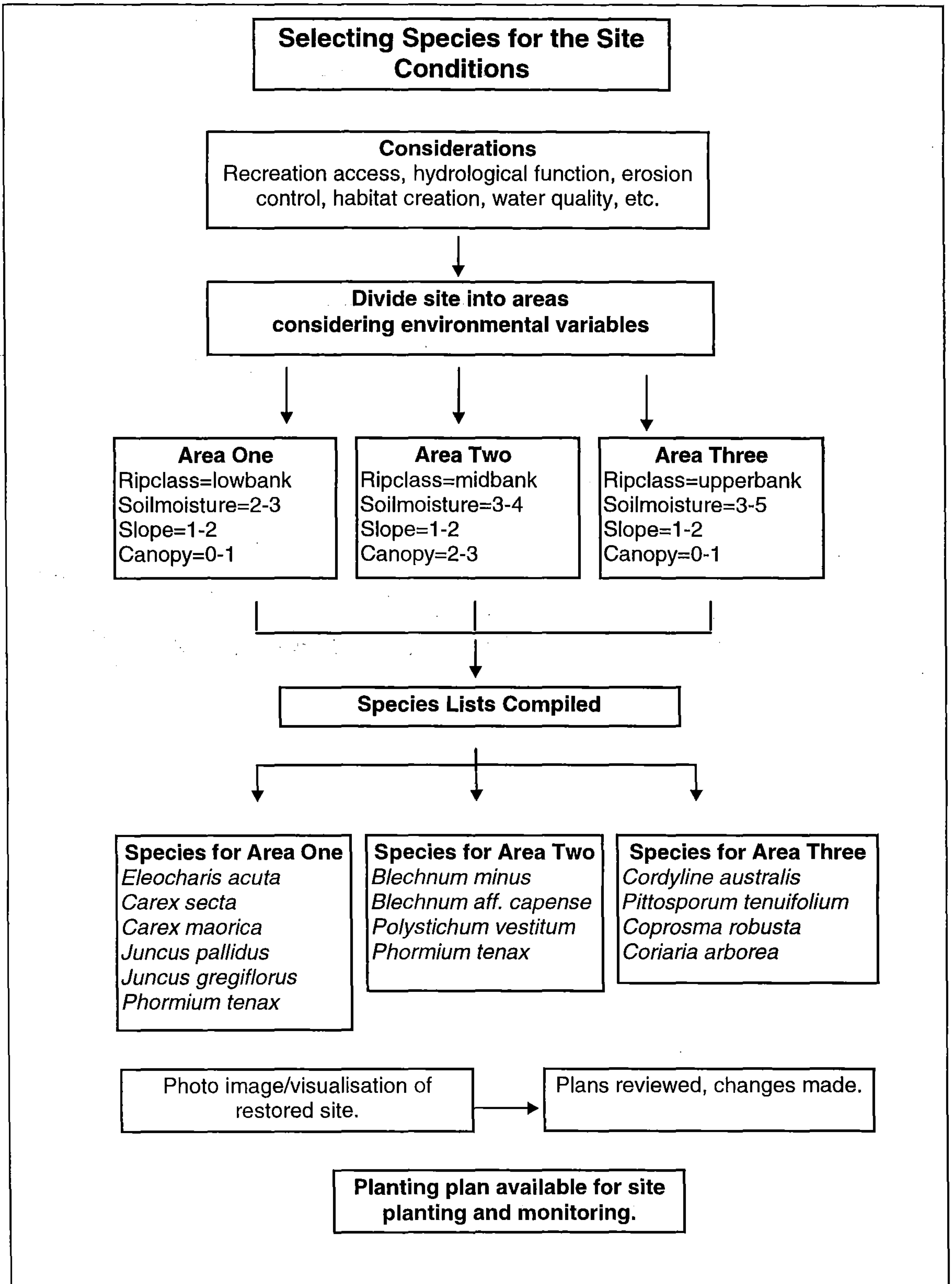


Figure 5.7: Applying species data to the environmental conditions at a stream restoration site, and assessing the public acceptability of the species assemblages.

5.3.5 Monitoring

A monitoring programme can be developed using the initial map (possibly with GIS overlays) as a baseline for evaluating restoration success. In some situations it will be used to evaluate the successes and failures of restoration plantings that are based on primary research. In other circumstances there will be less time and money available; restoration projects could be planned as planting trials and monitored using the ecological methods described in this thesis to inform future projects.

In Figure 5.8, two integrated monitoring components are noted. They are:

1) Monitoring the success of the plant species in relation to environmental variables in order to update a species database; and,
2) Monitoring the impacts of the restoration design on other riparian management objectives (eg., habitat creation and hydrological function) specified for the restoration project, and the socio-cultural perception of the design.

Clearly defined environmental gradients and restoration designs that function as planting trials would allow for accurate monitoring of plant success. The methodology suggested in this thesis offers several simple environmental parameters with which to monitor plant success.

A monitoring programme would also aim to evaluate the various objectives of the riparian restoration project. Guidelines and suggestions for monitoring fluvial geomorphology (eg., flood capacity and channel stability), water quality, habitat, and wildlife populations are discussed in Kondolf and Micheli (1995). Monitoring of public perception of the restoration project can be achieved with standard social science techniques (eg., interviews on post-project attitudes towards the project) (Kondolf and Micheli, 1995).

Although long-term monitoring of the restoration project is an ideal goal it has been rare due to funding constraints. From the results of a 17 year study of a pasture stream in the North Island of New Zealand, Howard-Williams and Pickmere (1994) anticipated that a stable vegetation type of predominantly woody stream bank species will have established after 30 years of protection. Various flora, water quality, habitat, and riparian and waterway management changes occurred during their 17 year study, highlighting the need to monitor for a range of restoration objectives long-term. In long-term monitoring, the people involved may change from one sampling period to the next, necessitating standardised and easily repeatable methods for collecting information. A long-term monitoring programme, adaptable to other projects, would ideally be a component of any restoration project and funded accordingly. The responsibility for monitoring riparian management, social, and economic goals may fall to local, district and regional councils with waterway management functions. Depending on the scale of a species database, the monitoring of species success would be centralised (ie., local government), or updated on a project by project basis by private groups.

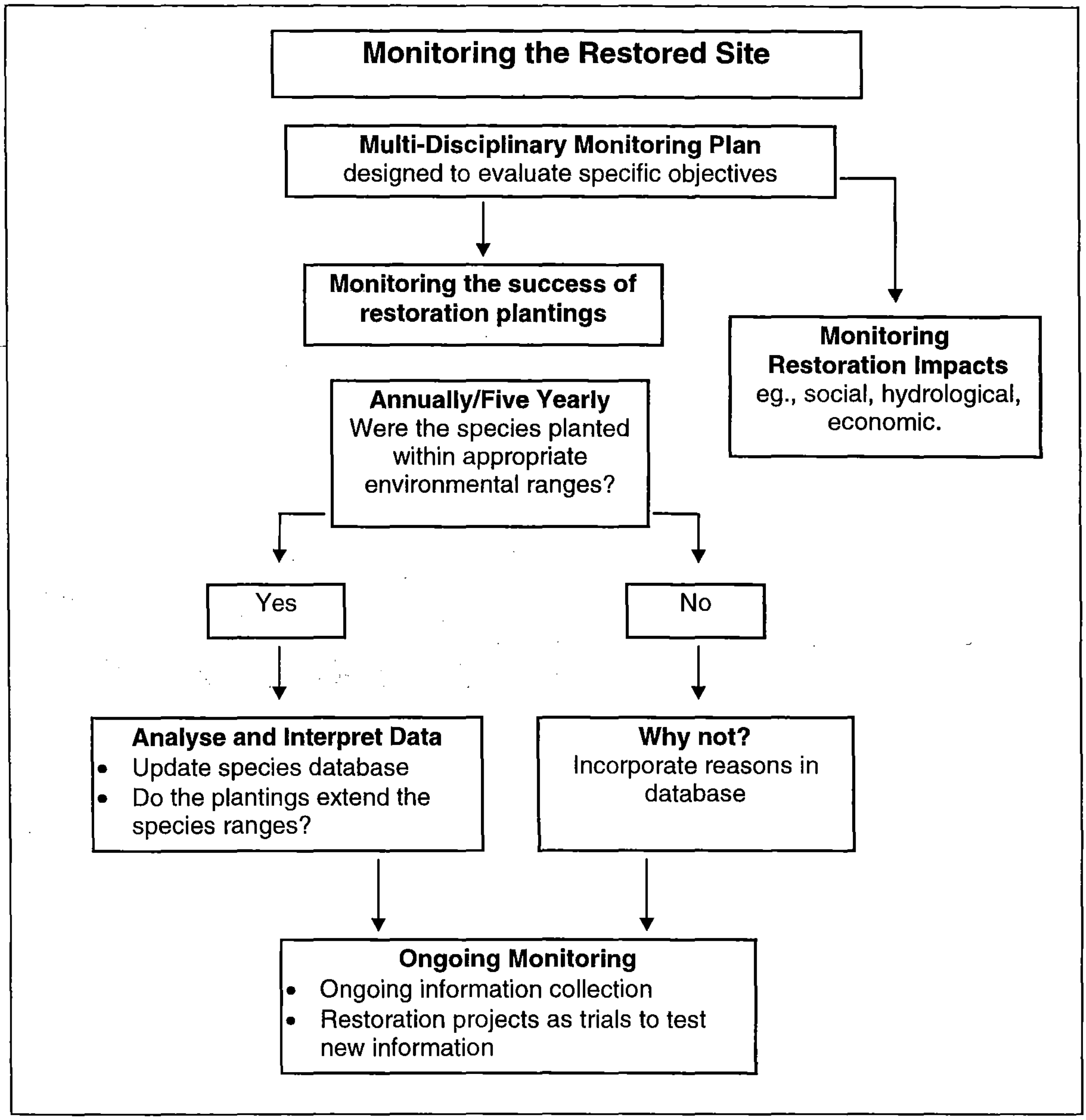


Figure 5.8: Monitoring is used a) to collect information on the success of plant species under certain environmental conditions to inform the species database, and b) to monitor the impacts of the restoration project on identified goals (eg., recreation, water quality, and aesthetics).

The simplified series of flowcharts outlines how the species ecology data might be applied for an urban stream. Depending on the goals of the project, various other components of restoration ecology would need to be incorporated; these are outlined in the next section.

5.4 Restoration Ecology and Sustainable Riparian Management

The focus of this thesis was to develop an approach for selecting suitable species (and assessing their ranges) for riparian restoration to increase planting success. Various other components of restoration ecology are presented in Table 5.1. In general, riparian restoration ecology:

- provides an opportunity to increase planting success through research and interpretation of plant species ranges in relation to environmental variables;
- allows for multi-disciplinary team work for improved processes and "products". Ecologists, landscape architects, hydrologists, soil scientists, surveyors, community members, and council planners and experts may be part of this team;
- serves the purpose of re-creating or creating representative or semi-representative riparian ecosystems that were once part of the New Zealand lowland landscape;
- has educational, aesthetic, recreational and scientific benefits; and,
- allows for multi-disciplinary monitoring (eg., riparian management, ecosystem processes, and social perception) of restoration successes and failures to inform future projects.

Table 5.1: Components of riparian restoration ecology.

Components of Riparian Restoration Ecology
Understanding of species requirements and tolerances:
• explored in this thesis.
Indigenous species richness and plant associations:
• use of pollen and sub-fossil records to recreate plant associations
Ecosystem processes and attributes:
• identification of ecosystem processes as restoration objectives to evaluate the success of the project, eg., pollen and seed dispersal, foodchains and webs, competition, seed germination, nutrient and carbon cycling, species composition and structure
Regeneration and successional processes:
• defining a successional planting approach for the site conditions
• decisions on whether to plant seeds or seedlings
• when and how to plant
Habitat requirements:
• for indigenous bird, fish and invertebrate species in particular
• for some exotic species where valued, eg., ducks and trout
• issues in an urban area, eg., domestic predators
Reintroduction of other taxa:
• possibility of reintroduction of lichens, bryophytes, fungi and algae
Monitoring the success of restoration projects:
• criteria for success
• specific objectives
• monitoring as a research tool
Socio-cultural issues:
• public perception, eg., use of native versus exotic plants
• public consultation
• multi-cultural landscapes
Use of particular species to meet riparian management goals:
• eg., for erosion control and flood mitigation
Landscape architecture interface:
• meeting a range of goals in design
Management and maintenance:
• revision of the goals and objectives of the restoration project
• maintaining and managing for certain functions of the restoration project
• control of pests, particularly weeds.

The restoration ecology components of a riparian management plan would include:

- documentation of historical and present day conditions;
- consideration of provenant plant species suitable to address specific riparian management goals;
- interpretation of species ranges for a particular restoration site;
- surveying and mapping of the restoration site;
- a landscape planting plan based on ecological principles;
- the use of specific plants to meet riparian management requirements;
- plants useful in creation of habitat for particular animal species;
- results of full community consultation;
- socio-cultural values of plants; and,
- and a site-specific management plan to address specific management requirements.

If restoration ecology is used as a riparian management technique, its objectives must remain broad to incorporate management and maintenance changes to attain riparian management, ecological, and social goals.

5.4.1 When would restoration ecology be used for urban riparian management?

Restoration ecology would be most suitable:

- when riparian zones are to be managed for a range of values through the planting of vegetation;
- when indigenous vegetation is aesthetically and functionally acceptable;
- for small to medium, urban or rural waterways which are influenced by their riparian margins, eg., by shading or through addition of woody debris; and,
- when it is a cost-effective alternative to structural engineering.

While applicable, restoration ecology would have less influence on riparian management goals for waterways with large catchments and large volumes of water, especially where flood mitigation by drainage is considered the foremost goal. However, restoration ecology would provide habitat, erosion control and aesthetic values to these rivers.

The form that riparian restoration ecology will take depends on the overall objectives of the riparian management project. There are two extremes with a range of options between them:

1) An overall restoration ecology approach to riparian management where the goals are primarily ecological, eg., local species would be planted within ecological ranges and arranged to meet ecosystem goals such as creation of wildlife habitat; and,
2) An underpinning approach to riparian management where landscape architects and other planners aim to integrate various socio-cultural, ecological and economic values into a final plan. In this context, local species are planted within ecological ranges in a plan designed to meet a range of riparian management goals.

5.5 Future Directions

A methodology for collecting information on the environmental ranges of species was developed to assist in the success of restoration plantings. A species database was suggested as the logical management tool for organising, presenting and interpreting the ecological data collected. Riparian management entails complex decision making (including ecological, social, and economic sustainability goals) - of which the success of restoration planting is only one aspect. Environmental information systems, or alternatively, decision support systems, have been used to assist in complex resource management decision making. The development of a decision support system for riparian management is a potential future project.

Based on Systems Analysis (Checkland, 1981), the systems approach to decision making is a cyclic approach in which decision makers and analysts:

1) Define the problem and select objectives;
2) Design alternative programmes;
3) Collect data and build models to estimate consequences;
4) Calculate the cost and effectiveness of each option;
5) Calculate the sensitivity of the cost effectiveness results to data uncertainties and changed assumptions; and,
6) Question assumptions, re-examine objectives, investigate new alternatives and repeat the process.

(Gough and Ward, 1994)

An environmental decision making system is a systematic (ie., systems) approach to providing an appropriate synthesis of information gathered from many sources and sectors. It is particularly useful where integration of complex information is necessary. Two of the key elements are an efficient information system and an effective structured management framework where efficiency is concerned with the means of achieving the output while effectiveness is concerned with what should be done (Gough and Ward, 1994). Effectiveness means that management objectives must be clearly established before an efficient means of achieving them can be devised.

Stuth and Smith's (1992) list of categories of problems suitable for computer based decision support systems have been listed and adapted below:

1) Tasks involving large numbers of calculations that are not conceptually complex but which are beyond the scope of a scratch pad, eg., updatable data sheets with large amounts of data which is to be summarised into histograms and presented in graphs;
2) Tasks involving large data bases, eg., GIS maps and ecological data summarised into plant type, species, and use values;
3) Tasks involving predictions from good biological, economic or other models; and,

4) Tasks involving many heuristic ideas and a moderate level of uncertainty, especially when factors interact in complex ways (expert systems).

If a restoration ecology approach is developed for riparian management, then a decision support system may be appropriate in the future (based on Stuth and Smith, 1992). So far in this chapter the application and management of species data have been discussed. Various types of data would be required to support decision making, little of which has been gathered as yet date. Collier et al. (1995) offer the most comprehensive set of data on riparian management to date, and would be a preliminary source of information for building decision trees. The development of a decision support system may involve levels (eg., a species database or GIS system) building on each other as sufficient data becomes available. The use of GIS as a component of environmental decision making, or as a stand alone environmental management method, is well documented in the literature. Water managers have employed GIS extensively for complex data management as part of a decision process (Haagsma, 1995; Loucks and da Costa, 1991). A New Zealand example of a decision support system is the development of an interactive software program to assist landowners with land use decisions in the South Island high country (Ockie Bosch and Ros Buick, pers com). This system involves an interactive database, and the application of GIS technology.

Rapid development of information technology may make any software developed over a period of time obsolete before it is fully applied. This may also be true when data management systems for long-term monitoring are to be incorporated. The development of a decision support system would require a multi-disciplinary team for software development and data collection, a centralised repository for the information, and an efficient means of revising the software system.

Social values are not often, if ever, fully captured in a computerised decision support system. Public consultation and community involvement would be required as part of a parallel decision process, both in the development of the system and in identifying objectives in the long-term.

5.6 Summary

The development of a simple database was suggested as the best option for managing the ecological data on species ranges. A case-study of an urban stream was used to demonstrate how the ecological methodology suggested in this thesis may be applied to increase planting success in restoration projects. The application of various components of the process would depend on the location, available knowledge, scale and goals of the restoration project.

This thesis has explored one component of restoration ecology - an approach to understanding the environmental ranges of plant species. Other components of restoration ecology to be considered include habitat requirements, ecosystem processes, use of particular species to meet riparian management goals, socio-cultural issues, maintenance and management (eg., of weeds), and monitoring.

In the future, with more data available, the development and use of an environmental information system may allow for the integration of aspects of ecology, economics, hydrology, landscape design, and recreation into sustainable riparian management decision making.

CHAPTER SIX
CONCLUSIONS

6.1 The Approach

Christchurch was used as a case study for developing and testing an approach for selecting provenant indigenous species, collecting data on the environmental ranges of these species, and analysing and interpreting plant species data for use in urban riparian restoration.

The approach suggested in this thesis for increasing planting success in riparian restoration projects has several steps:

1) Ascertaining a suitable species list for a restoration project through the use of historic records and ecologists' knowledge;
2) Understanding the environmental gradients at a restoration site;
3) Researching and interpreting the ranges of suitable species using a set of environmental variables to select planting sites suitable to the environmental conditions at the restoration site; and,
4) Planting the site and monitoring species success to inform future projects.

A range of environmental variables were selected and sampled in the field for a range of provenant plant species. The species were then grouped into one of three main categories: sedges and rushes; ferns; and trees and shrubs, for ease of presentation. Species that did not clearly fall into these plant types were grouped together. Between species non-parametric t-tests were used to assess the significance of each environmental variable for plant type and each species. Ordination assisted in identifying soil moisture, elevation, distance and riparian class as duplicate variables. Correlation results indicated where the values of certain environmental variables moved together (eg., soil pH and conductivity). The species data for the environmental variables of soil moisture, elevation, riparian class, frost, slope, soil pH, and canopy were presented in boxplots to highlight any patterns in species ranges.

Could the species be sorted in relation to environmental variables?

While some species within a plant type were found to be sensitive to the same set of environmental variables (eg., elevation for sedges and rushes), in general, different species responded to different combinations of environmental variables.

The results of the between species t-tests can be used to identify if species are particularly sensitive (narrow range) or tolerant (wide range) to an environmental variable. This would be particularly useful if a database was developed to select species for particular restoration site conditions. The database could be programmed to select species on the order of importance of each environmental variable, and their ranges in relation to each variable, thereby effectively managing the complexity in the data.

Were the species ranges in relation to the environmental variables those that would be expected?

The data presented for each species was compared with a recently developed riparian planting guide for Christchurch (CCC, 1996). In general, the species ranges were consistent with previous observations in the literature for Christchurch. In some cases species ranges (eg., *Juncus gregiflorus* and *J. pallidus*), which were grouped in the planting guide, were differentiated in this study. Some species in the study may have been in less than optimum conditions, eg., *Phormium tenax* being shaded out by willow canopies. This highlighted the need to consider the research results as conservative, to be validated by reference to secondary data in some instances.

Were there differences between self-established and planted data?

Within species t-tests were performed where a species had both self-established and planted data. Overall, planted tree and shrub species were in significantly higher, drier, and frostier sites than their self-established counterparts. There may be several explanations for this result:

- Self-established individuals may have been establishing into the only sites available, and under optimal conditions their ranges would be wider;
- Environmental gradients have been highly modified (eg., banks oversteepened) in areas that are now being planted, and this may have been reflected in the planted datasets for a species; or,
- Species were planted outside of their natural ranges, implying a systematic bias in plantings. While it appears that some species may have been planted outside of their natural ranges, this will only be confirmed in projects where monitoring is used as a research tool.

6.1.1 Evaluating the Environmental Variables

Were particular environmental variables more important than others for distinguishing species ranges?

Soil moisture, elevation, specific and broad riparian class, canopy and slope were found to be the most useful environmental variables for distinguishing species ranges.

In addition, other variables, while not strongly distinguishing for the range of species, were indicated as relevant for some of the species in the study. They are:

- The frost index, which has potential as a variable but needs refinement; and,
- pH and conductivity, for which some species were in significantly different ranges from other species in the study. However, these are most likely to be species limiting in saline or volcanic environments.

There were several environmental variables measured in the field but excluded from analysis due to sample size and analysis difficulties. Those considered most relevant for future riparian projects include:

- A drainage indicator using soil texture, type, horizon and redox. These variables could be important for restoration of riparian areas but due to field subjectivity should be tested by a soil scientist;
- Water level fluctuation and flood frequency. These environmental parameters are likely to influence planting sites but it was difficult to get accurate information because of sampling difficulties and lack of data at local councils; and,
- Plant competition.

Aspect, slope on a macro scale, and altitude were considered to be potentially useful variables for areas with more defined topography.

How effective and efficient were the methods of collecting environmental data?

The environmental variables measured and analysed in this study were able to differentiate species into the expected ranges recorded in the literature. However, refinements to increase the accuracy and efficiency of some of the methods for measuring the environmental variables in the field include:

- Quantifying the "specific" riparian class using key parameters (eg., elevation, soil moisture and slope) to clearly delineate the riparian zones at both the restoration site and remnant sites in the area under study;
- Composing a drainage indicator (as mentioned above);
- Redefining the canopy cover rank to incorporate structures as sources of shade in assessing the environmental conditions at urban restoration sites;
- Modifying the frost index by rescaling its composite variables (ie., aspect, canopy cover, elevation and slope), and verifying the index through experimental work; and,
- Employing a soil scientist to assess the range of soil parameters at a restoration and remnant site, to reduce sampling and analysis time.

6.1.2 Evaluating Data Collection Methods

Data collection in the Christchurch area, where remnants of riparian vegetation are few and far between, was found to be time-consuming. Where intact remnant areas (suitable as templates for the restoration site) exist, the data collection time would be reduced. In these areas, the use of transects, taking into consideration the various environmental gradients in the riparian zone under study, would be most efficient.

In areas where the flora is diverse, it may be necessary to select only a few species for study. Those species with landscape potential may be selected initially with other species added later. In a modified area certain species, once present (eg., those in Appendix 2), will no longer naturally establish, and will therefore be unavailable for sampling. These species are likely to be included in restoration projects and the approach suggested in this thesis could be used as the baseline for monitoring species success over time.

6.1.3 Methods for Communicating the Ecological Results

Ideally, the data gathered from the approach suggested in this thesis would be easily interpreted by restoration practitioners. Species were sorted by plant type and the data organised by environmental variables. This presentation would allow a restoration practitioner to select species (eg., from the plant type of sedges and rushes) suitable for particular environmental conditions at a site. Figure 3.13 and Table 3.8 are examples of how the ecological data could be generally synthesised and presented for use by restoration planners and practitioners. The boxplot data for all of the species was merged into a figure and table, and plotted against the environmental variables of soil moisture, slope and canopy. While the data is useful in this format, other environmental variables may prove to be important for a particular restoration site. More than three variables are difficult to synthesise in a figure or table. To resolve this problem, a species database designed to assist in managing the complexity of environmental data is suggested. The data could then be updated by monitoring the success of restoration plantings.

6.1.4 Applying the Approach

In Chapter Five, Shirley Stream was used as a hypothetical case-study to illustrate the application of the ecological methodology for ascertaining suitable plant species for the environmental conditions for a restoration project. Various permutations of the approach could be applied depending on the goals, the amount of information available, and the scale of the project.

The methodology could be used by councils (or ecologists and landscape architects working for a council), to develop planting guidelines for a town or city, or non-specialist practitioners for private or site by site projects. Several types of riparian areas may exist in a town or city and the approach would need to be applied for each of these.

This method is most relevant in two situations:

1) When remnant vegetation is easily and cost-effectively sampled and little is known about the suitable species (and their ranges) for the riparian site to be restored. The methodology would be applied to assess species ranges from vegetation templates; and,
2) When sampling remnant vegetation is either too time-consuming or difficult for other reasons, suitable species could be planted in relation to presumed environmental gradients. The plantings would be set out as trials and the success of plants within environmental gradients would be monitored using the methodology developed in this thesis.

In the past, riparian species in Christchurch were often planted out of their "observed" natural ranges. Those planning restoration and revegetation projects have become more aware of suitable environmental gradients, often through planting failures. Where ecologists and other restoration practitioners (eg., landscape architects) are available for consultation the approach suggested in this thesis may require more time than the rewards offer. If information about suitable species is available, then the time and money needed for sampling may not justify the possible increase in planting success. In this context, the methods are best applied for monitoring restoration planting and learning from successes and failures on a project by project basis. Time and money for research may, nevertheless, be justified to ascertain the particular requirements of species that are known to be difficult to grow.

There are, however, few towns and cities in New Zealand in which riparian restoration has been developed as a management tool. The approach suggested would be most likely to increase planting success, and therefore be most cost-efficient, in riparian restoration projects when little is known about the environmental ranges of the species to be used. For areas with no records or little observation, the method developed offers a simple but rigorous approach to observation in the field. A simple research design allows for easily replicable resampling - important for comparing different riparian areas and for monitoring the success of plantings. Planting guidelines generated by an ecological database would be easily developed from the ecological data collected and would assist in the distribution of information to a wide range of non-specialist restoration practitioners. Schools, community groups, and councils would be included in this group.

Ideally, the suggested approach would increase the sustainability (in terms of management) of urban riparian restoration projects by increasing planting success.

6.1.5 Social and Economic Sustainability

Both social and cost-benefit research are necessary to fully evaluate the suggested ecological approach. Social perception of restoration projects, especially the use of native plants in urban areas, will ultimately dictate the support for these projects. One component of social perception is whether restoration is seen as the best use of rate-payer money. To date, restoration has been shown to be approximately one third of the cost of piping a stream (Ken Couling, Christchurch City Council, pers. com.) - future monitoring programmes can assess any unforseen costs and benefits. Questions remaining include:

- Are residents willing to financially support the monitoring of plant success and the impacts of riparian planting? and,
- Will the suggested environmental ranges of species (eg., planting *Carex secta* or *Phormium tenax* on the edges of streams) be compatible with riparian management goals, such as drainage?

Social and economic monitoring will assist in answering these questions in time.

6.2 Future Directions

6.2.1 A Restoration Ecology Approach for Riparian Management

A restoration ecology approach to riparian management was suggested as a means of meeting several objectives simultaneously. As many riparian management goals can be attained with the use of indigenous vegetation, it is logical to suggest that species provenance, natural ranges, more natural plant assemblages, and ecosystem goals could be attained as well. Restoration ecology is far broader in scope than just developing an approach to understanding species environmental ranges, as was done in this thesis. It can provide a framework for riparian management, where the goals are ecosystem focused, or it could underpin landscape design to ensure that the plantings used to meet the goals are appropriate and will be successful at the site.

An urban riparian restoration approach necessarily entails full public consultation and ideally public participation in the planning and implementation of restoration projects. Public participation is important for engendering societal support for restoration in the long-term.

6.2.2 Decision Support Tools for Riparian Management

Ecological data management approaches were outlined in Chapter Five. A simple species database was suggested as the most appropriate data management tool for species information at this stage. GIS mapping may be applicable where the project is complex and requires detailed analysis.

In the future, a decision support system or environmental information system may be appropriate for managing multi-disciplinary and complex data. As yet, there is insufficient information to fuel a computer driven system. However, a well designed multi-disciplinary decision approach, which aims to draw the present research (and organisations) under one umbrella, would be able to direct and manage research with a decision support system as the end goal. There are several lines of research necessary if a restoration ecology decision support system for riparian management is to be developed. Research areas include:

- The habitat requirements of riparian wildlife species, particularly in relation to disturbed and urban waterways;
- Ecosystem processes (eg., succession) in re-created, urban habitats;
- Research on the use of riparian plant species to meet particular riparian management goals (eg., for bank stability or habitat creation);
- Fluvial geomorphological variation and impacts in relation to riparian vegetation change over time. Variations may include changes to the course, shape, and size of the waterway, and impacts may include whether drainage and flooding increase or decrease with waterway changes;
- Socio-cultural perception research; and,
- The use of long-term monitoring as a research tool. Many of the research areas listed above can be studied through a comprehensive monitoring programme.

6.2.3 Integrating the Present Research with Boffa Miskell Skills

The present research can be integrated with the skills of Boffa Miskell Ltd. Using the ecological methodology and data suggested in this thesis, Boffa Miskell can develop a simple species ecology data management system allowing for efficient data storage, analysis and interpretation. The database could be designed as an efficient ecological monitoring programme for riparian restoration projects. Where feasible, the species database could be linked to GIS technology to meet the objectives of a particular project. The species data in graph or table form offers an ecologically based planting guide for use in landscape planning and design. The methodology developed in this thesis allows for similar ecologically based planting guides to be developed for other ecological districts or regions.

The application of ecological data and the restoration ecology approach could be integrated with other Boffa Miskell skills in riparian management. Using the landscape design and planning, public consultation, environmental and recreation planning, asset management, and ecology skills of Boffa Miskell, a full riparian restoration and management package could be developed.

6.3 In Summary

The approach developed in this thesis provides a theoretical basis for urban riparian restoration, and offers a practical methodology for assessing species ranges in the field. Although yet to be tested, the approach is simple enough to be accessible to non-specialist restoration planners and practitioners. It is anticipated that the success of restoration plantings, for some species in particular, will increase with species sampling methods that are efficient and effective to use. The same, or similar methods, could be used as part of a monitoring programme to assess the successes and failures of restoration plantings.

References

These references follow the style of "Restoration Ecology - the Journal of the Society for Ecological Restoration".

Allen, R.B., and Wilson, J.B. 1991. A method for determining indigenous vegetation from simple environmental factors, and its use for vegetation restoration. Biological Conservation, **56**:265-280.

Armstrong, J.F. 1872. On the naturalised plants of the province of Canterbury. Transactions of the New Zealand Institute, **4**:284-91. In B.Molloy, editor. 1995. Riccarton Bush: Putaringamotu. Riccarton Bush Trust. The Caxton Press, Christchurch, New Zealand.

Atkinson, I.A.E. 1994. Guidelines to the development and monitoring of ecological restoration programmes. Department of Conservation Technical Series 7, Science and Research Division, Wellington, New Zealand.

Atkinson, I.A.E. 1988. Opportunities for ecological restoration. New Zealand Journal of Ecology **11**:1-12.

Baird, A. 1992. An overview of botanical information and recommendations for the management of the freshwater reaches of the Avon and Heathcote Rivers. Canterbury Conservancy, Department of Conservation, Christchurch, New Zealand.

Ball, D.F. 1986. Site and soils. Pages 215-284 in P.D.Moore and S.B. Chapman, editors. Methods in Plant Ecology. Second Edition. Blackwell Scientific Publications, Victoria.

Bannister, P. 1986. Water relation and stress. Pages 73-143 in P.D.Moore and S.B. Chapman, editors. Methods in Plant Ecology. Second Edition. Blackwell Scientific Publications, Victoria.

Barker, R., and Simpson, P. 1995. Developing a national strategy for ecological restoration. A discussion paper based on a workshop held in Wellington, 11-13 July 1994. Revised 12 May, 1995. Department of Conservation, Wellington, New Zealand.

Bellingham, M. 1990. Public involvement in island restoration. Pages 166-169 in D.R.Towns, C.H.Daugherty, and I.A.E.Atkinson, editors. 1990. Ecological Restoration of New Zealand Islands. Conservation Sciences Publication No.2. Department of Conservation, Wellington, New Zealand.

Bosch, Ockie. Landcare. Personal communication.

Brown, L., and Weeber, J. 1995. Chapter Three: Geology and Groundwater. Pages 37-58 in B.Molloy, editor. 1995. Riccarton Bush: Putaringamotu. Riccarton Bush Trust. The Caxton Press, Christchurch, New Zealand.

Brownsey, P.J., and Smith-Dodsworth, J.C. 1989. New Zealand Ferns and Allied Plants. David Bateman Ltd, Auckland, New Zealand.

Buick, Ros. Landcare. Personal communication.

Cairns, J. Jr. 1993. Is Restoration Ecology Practical? Restoration Ecology **1(1)**:3-7.

Carver, Derek. Christchurch City Council. Personal communication.

Checkland, P. 1981. Systems Thinking, Systems Practice. John Wiley and Sons Ltd, Great Britain.

Christchurch City Council. 1996. Streamside Planting Guidelines: for native planting alongside streams in Christchurch. Waterway Enhancement Programme, Water Services Unit, Christchurch City Council, Christchurch.

Collier, K.J., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C., Smith, C.M., and Williamson, R.B. 1995a. Managing Riparian Zones: A contribution to protecting New Zealand's rivers and streams. Volume 1: Concepts. Department of Conservation, Wellington, New Zealand. Volume 2: Guidelines. Department of Conservation, Wellington, New Zealand.

Collier, K.J. 1994. Restoration of freshwater habitats: introduction and synthesis. Pages 1-5 in Collier, K.J. Ed. 1994. Restoration of Aquatic Habitats. Selected papers from the second day of the New Zealand Limnological Society, 1993, Annual Conference. Department of Conservation, Christchurch, New Zealand.

Condron, Leo. Soil Science Department, Lincoln University. Personal communication.

Couling, K.C. 1992. Recent Changes in Management Philosophy, Policies and Practices for Christchurch's Waterways. Drainage and Waste Management Unit. Christchurch City Council, Christchurch. New Zealand.

Couling, K. Christchurch City Council. Personal communication.

Craig, J.L. 1990. Potential for Ecological Restoration of Islands for Indigenous Fauna and Flora. Pages 156-165 in D.R.Towns, C.H.Daugherty, and I.A.E.Atkinson, editors. 1990. Ecological Restoration of New Zealand Islands. Conservation Sciences Publication No.2. Department of Conservation, Wellington, New Zealand.

Gough, J., and Ward, J. 1994. Information for environmental decision making: a case study approach. Information Paper No. 50. Centre for Resource Management . Lincoln Environmental. October 1994. New Zealand.

Gregory, S.V., Swanson, F.J., McKee, W.A., and Cummins, K.W. 1991. An ecosystem perspective on riparian zones. Bioscience **41**:540-551.

Grime, J.P., Hodgson, J.G., and Hunt, R. 1988. Comparative Plant Ecology. A Functional Approach to Common British Species. Unwin Hyman, London.

Haagsma, I.G. 1995. The integration of computer models and data bases into a decision support system for water resources management. Modelling and Management of Sustainable Basin-Scale Water Resource Systems. Proceedings of a Boulder Symposium. IAHS Publication, no.231:253-261.

Hobbs, R.J., and Norton, D.A. 1996. Towards a conceptual framework for restoration ecology. Restoration Ecology, Vol. **4 (2):**93-110.

Howard-Williams, C. 1991. Dynamic processes in New Zealand land-water ecotones. New Zealand Journal of Ecology **15(1):**87-98.

Howard-Williams, C, and Pickmere, S. 1994. Long-term vegetation and water quality changes associated with the restoration of a pasture stream. Pages 93-107 in Restoration of Aquatic Habitats. Selected papers from the second day of the New Zealand Limnologial Society, 1993 Annual Conference. Department of Conservation, New Zealand.

Jackson, L.L., Lopoukine, N., and Hillyard, D. 1995. Ecological Restoration: A Definition and Comments. Restoration Ecology **3(2):**71-75.

James, B. 1990. Pakeha perspectives on the relationships between humans and the natural environment. Pages 261-271 in D.R.Towns, C.H.Daugherty, and I.A.E.Atkinson, editors. 1990. Ecological Restoration of New Zealand Islands. Conservation Sciences Publication No.2. Department of Conservation, Wellington, New Zealand.

Johnson, P., and Brooke, P. 1989. Wetland Plants in New Zealand. DSIR Publishing, Wellington, New Zealand.

Kent, M., and Coker, P. 1992. Vegetation Description and Analysis. A Practical Approach. Belhaven Press, Great Britain.

Kondolf, G.M. 1995. Five elements for effective evaluation of stream restoration. Restoration Ecology **3(2):**133-136.

Kondolf, G.M., and Micheli, E.R. 1995. Evaluating stream restoration projects. Environmental Management **19(1):**1-15.

Large, M.F., and Braggins, J.E. 1992. A new combination for *Polypodium pustulatum* Forster f. (Polypodiaceae). New Zealand Journal of Botany **30:**207-208.

Loucks, D.P., and da Costa, J.R. Editors. 1991. Decision Support Systems. Water Resources Planning. Series G: Ecological Sciences, Vol.26. Springer-Verlag, Germany.

Malanson, G.P. 1993. Riparian landscapes. Cambridge University Press, Great Britain.

McEwen, W.M., editor. 1987. Ecological Regions and Districts of New Zealand. Third Revised Edition in Sheet 3. Four 1:500,000 maps. New Zealand Biological Resources Centre Publication. No.5. Department of Conservation, Wellington, New Zealand.

McLaren, R.G., and Cameron, K.C. 1990. Soil Science. An introduction to the properties and management of New Zealand soils. Oxford University Press, Auckland, New Zealand.

Menges, E.S., and Waller, D.M. 1983. Plant strategies in relation to elevation and light in floodplain herbs. American Naturalist **122:**454-73. Cited in Malanson, G.P. 1993. Riparian landscapes. Cambridge University Press, Great Britain.

Meurk, C.D., Ward, J.C., and O'Connor, K.F. 1993. Natural Areas of Christchurch: Evaluation and Recommendations for Management as Heritage. Report for the Christchurch City Council. Centre for Resource Management, Lincoln, New Zealand.

Meurk, C.D. In prep. Habitat Restoration - An Essential Conservation Tool For Mainland New Zealand. Landcare Research New Zealand - Manaaki Whenua, Lincoln, New Zealand.

Meurk, Colin. Landcare, New Zealand. Personal communication.

Molloy, B., and Brown, L. 1995. Chapter Six, Vegetation History. Pages 85-115 in B. Molloy. B, editor. 1995. Riccarton Bush: Putaringamotu. Riccarton Bush Trust, Christchurch, New Zealand.

Norton, D.A. 1995. Ecological basis for restoration in mainland New Zealand. In proceedings of February 1995, Restoration Workshop. Landcare Research, Lincoln, New Zealand. (In press.)

Norton, D.A. 1988. Pyramid Valley - a proposal for the restoration of the original swamp margin vegetation. Journal, Canterbury Botanical Society, **22:**80-85.

Owen, S-J., editor. 1992. The Estuary. Where Our Rivers Meet the Sea. Christchurch's Avon-Heathcote Estuary and Brooklands Lagoon. Christchurch City Council, Christchurch, New Zealand.

Poole, A.L., and Adams, N.M. 1994. Trees and Shrubs of New Zealand. Manaaki Whenua Press. Lincoln, Canterbury, New Zealand.

Puia, S. 1990. Protection and cultural use: Maori concepts of the relationship between Maori people and nature. Pages 272-277 in D.R.Towns, C.H.Daugherty, and I.A.E.Atkinson, editors. 1990. Ecological Restoration of New Zealand Islands. Conservation Sciences Publication No.2. Department of Conservation, Wellington, New Zealand.

Quinn, J.M., Cooper, A.B., Williamson, R.B. 1993. Riparian zones as buffer strips: A New Zealand perspective. Pages 53-88 in S.E. Bunn, S.E. Pusey, B.J., Price, P, editors. Ecology and management of riparian zones in Australia. Proceedings of a National Workshop on research and management needs for riparian zones in Australia, held in association with the 32nd annual congress of the Australian Society for Limnology, Marcoola, Australia.

Ryan, A. 1995. Chapter Five: Climate and Weather. Pages 69-84 in B. Molloy, editor. 1995. Riccarton Bush: Putaringamotu. Riccarton Bush Trust. The Caxton Press, Christchurch, New Zealand.

Salo, J. 1990. External processes influencing origin and maintenance of inland water-land ecotones. Pages 37-64 in R.J.Naiman and H.Decamps, editors. 1990. The Ecology and Management of Aquatic-Terrestrial Ecotones. The Parthenon Publishing Group, Paris.

Saunders, A. Mapara: Island management "mainland" style. Pages 147-149 in D.R.Towns, C.H.Daugherty, and I.A.E.Atkinson, editors. 1990. Ecological Restoration of New Zealand Islands. Conservation Sciences Publication No.2. Department of Conservation, Wellington, New Zealand.

Scott, D., and Groves, R.H. 1989. Empirical Measurement of Environmental Gradients in Ecological Surveys. New Zealand Journal of Ecology **12**:89-94.

Sedell, J.R., Steedman, R.J., Regier, H.A., and Gregory, S.V. 1991. Restoration of human impacted land-water ecotones. Pages 110-129 in M.M. Holland, P.G. Risser, and R.J. Naiman, editors. 1991. Ecotones. The Role of Landscape Boundaries in the Management and Restoration of Changing Environments. Chapman and Hall, New York.

Spellerberg, I.F., and Gaywood, M.J. 1993. Linear features: linear habitats and wildlife corridors. English Nature Research Report. No.60.

Stuth, J.W., and Smith, M.S. 1992. Decision support for grazing lands: an overview. Pages 1-33 in J.W. Stuth, and B.G. Lyons, editors. Decision support systems for the management of grazing lands. Man and the Biosphere Series. The Parthenon Publishing Group, UNESCO, Paris.

Tau, T.M., Goodall, A., Palmer, D., and Tau, R. 1990. Te Whakatau Kaupapa. Ngai Tahu Resource Management Strategy for the Canterbury Region. Aoraki Press, Wellington, New Zealand.

Wardle, P. 1991. Vegetation of New Zealand. Cambridge University Press, Great Britain.

APPENDIX ONE

Table A1.1a: Descriptions of sampling locations. Indications of the species sampled at each site are mentioned in the table. Full species lists for many of these sites can be obtained from Meurk et al. (1993). Map and grid references (NZMS 260, 1:50 000.) for the sites have been noted.

Location	Description	MapGrid
Avon River - Corfe Street	Headwaters of Avon, various sites and riparian classes. Range of self-established and planted shrubs, trees, and ferns.	M35/748426
Avon River near Carlton Bridge	Major river, some riparian classes. Combination of self-established and planted sedges, shrubs and trees. Site for *Carex geminata.*	M35/795427
Avon River Loop	Major river, some riparian classes. Scattered self-established individuals of *Typha orientalis*, *Phormium tenax*, other sedges, rushes, and some planted trees and shrubs.	M35/818428
Avon River between Madras and Manchester Streets	Major river, lower riparian classes present, upper riparian classes mowed. *Carex* spp., some low herbs.	M35/810422
Blackwater Creek, south of Lake Ellesmere	Fenced, deep, spring-fed stream. Wide range of self-established riparian vegetation including *Blechnum* spp., *Carex* spp., *Eleocharis acuta*, *Phormium tenax*, *Cordyline australis*, and *Typha orientalis.*	M37/045533
Coutts Stream, inside stop-banks of the Waimakariri River	Small channelised stream, with several *Blechnum* spp. and other ferns and shrubs present.	M35/750520
Dawsons Road water-race	Water-race lined with *Blechnum* spp., sedges, and rushes.	M35/6434420
Groynes - several sites	Range of low-lying riparian sites. Wide range of self-established tree, shrub, fern, sedge and rush species. Some planted species.	M35/785513
Heathcote River near Hogben School, Halswell	Near headwaters of Heathcote. Degraded site with *Juncus gregiflorus* and *Hydrocotyle* spp.	M36/753382
Heathcote River near Ernlea Terrace	Large area of backswamp, and other riparian sites. Range of planted and self-established individuals.	M35/805382

Table A1.1a (continued).....

Heathcote River near Ansley Terrace	Several riparian classes present. Restored site with a wide range of planted trees, shrubs, ferns, sedges and rushes.	M36/826383
Horseshoe Lake - various sites	Several riparian classes present, large backswamp. Artificially controlled water levels. Willow canopy. Range of sedges, rushes, ferns, shrubs and trees.	M35/837457
Island Farm	Meandering stream in flat grazed paddocks, with *Juncus* spp., *Carex* spp., and *Schoenus pauciflorus.*	M35/740498
Kaiapoi River, downstream of township	Slow flowing section with *Typha orientalis* and some fern and *Juncus* species.	M35/830575
Liffy (LII) stream, near Lincoln	Range of riparian sites available, including backwash. Species include ferns, *Juncus*, *Carex*, trees and shrubs. Some planted individuals.	M36/685305
Stewarts Gully	Ephemeral stream with a range of *Blechnum* spp., sedges, shrubs and other herbs.	M35/830559
St Annes School stream	Planted stream banks, with a range of trees, shrubs, and grasses in several riparian sites.	M35/840415
West Coast Road water-race	Lined with *Blechnum* spp., *Carex* spp., and *Juncus* spp.	M35/670435

Table A1.1b: Field data collection sheet.

DATA COLLECTION	Date:	Water quality sheet for site: Y/N			Site map: Y/N	
Species:						
Site No.						
Map/grid ref.						
Vegetation						
Seedling/sap/adult						
Indiv/clump/patch						
Reproducing						
Vigor						
Disease						
Health - 1,2,3						
Abundance at site						
Water relation						
Distance from water						
Height above water						
In water						
Inundation depth						
Riparian class						
Broad						
Specific						
Slope						
Slope shape						
Aspect						
Canopy Y/N/Partial						
Type						
Plant Association						
Braun-Blanquet 2x1						
Planted (1-4)						
Frost/wind						
Soil						
Moisture (1-7)						
pH						
Cond						
Texture 1						
Texture 2						
Texture 3						
Mottles 1						
Mottles 2						
Mottles 3						
Drainage Class						
Comments:						

APPENDIX TWO

Table A2.1: List of planted tree and shrub species and the abbreviations used in the boxplots. The abbreviations use the first three letters of the genus followed by the first three letters of the species (after New Zealand Forest Service Surveys).

Planted Tree and Shrub Species	Abbreviation
Plagianthus regius	Plareg
Sophora microphylla	Sopmic
Pittosporum eugenioides	Piteug
Hoheria angustifolia	Hohang
Dacrycarpus dacrydioides	Dacdac
Pseudopanax arboreus	Psearb
Aristotelia serrata	Ariser
Griselinia littoralis	Grilit
Melicytus ramiflorus	Melram
Hebe salicifolia	Hebsal
Podocarpus totara	Podtot
Kunzea ericoides	Kuneri
Coprosma propinqua	Coppro
Leptospernum scoparium	Lepsco
Pseudopanax crassifolius	Psecra
Muehlenbeckia australis	Mueaus
Myrsine divericata	Myrdiv
Prumnopitys taxifolia	Prutax
Lophomyrtus obcordata	Lopobc

Table A2.2: Means and standard deviations for the planted species presented in the boxplots. (Species abbreviations are presented in Table A2.1).

Species	Plareg	Sopmic	Piteug	Hohang	Dacdac	Psearb	Ariser	Grilit	Melram	Hebsal
Sample No.	43	32	30	29	26	22	17	17	17	15
Distance										
Mean	649.42	379.28	624.23	959.97	220.04	474.14	398.53	495.29	259	190.67
Standard deviation	562.09	354.23	418.55	783.10	265.47	332.39	414.11	506.95	282.82	209.95
Elevation										
Mean	121.93	136.34	110.83	213.1	23.92	97.41	101.94	141.59	30.53	102.52
Standard deviation	92.42	66.74	63.36	99.00	39.30	69.14	39.02	64.37	47.26	53.14
Soil Moisture										
Mean	5	5.47	5.17	5.82	3.42	5.05	4.82	5.12	3.41	5.27
Standard deviation	1.09	0.8	0.75	0.76	0.81	1.13	0.81	0.93	0.71	0.88
Riparian Class										
Mean	5.02	5.38	5.2	5.89	3.23	5.09	4.77	5.29	3.06	4.47
Standard deviation	1.01	0.94	0.89	0.90	1.77	1.06	0.97	0.92	1.35	1.13
Slope										
Mean	5.93	5.16	4.17	4.48	1.73	4.09	4.12	2.94	4.29	3.67
Standard deviation	13.60	7.24	6.03	7.60	4.46	8.40	7.34	7.51	6.35	7.90
Canopy										
Mean	0.88	0.53	0.43	0.1	1.69	1.46	0.65	0.77	2.06	0.4
Standard deviation	1.22	0.80	0.82	0.30	1.09	1.01	1.06	0.75	0.96	0.73
Soil pH										
Mean	6.13	6.28	6.19	6.49	5.69	5.78	5.66	6.13	5.75	6.29
Standard deviation	0.50	0.33	0.46	0.30	0.37	0.67	0.95	0.60	0.30	0.66
Soil Conductivity										
Mean	0.042	0.032	0.04	0.04	0.032	0.05	0.068	0.035	0.03	0.048
Standard deviation	0.03	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.03
Aspect										
Mean	64	80.42	58.46	56.79	103.64	70	78.33	66.15	70	56.15
Standard deviation	5.41	6.36	6.80	6.21	4.90	6.73	7.73	6.25	4.16	4.63
Frost										
Mean	27.91	29.94	28.9	31.62	25.08	26.5	28.12	29.47	22.77	28.73
Standard deviation	5.04	3.69	3.42	2.11	3.85	4.01	4.43	3.10	3.11	3.53

Table A2.2: (continued).....

Species	Podtot	Kuneri	Coppro	Lepsco	Psecra	Mueaus	Prutax	Myrdiv	Lopobc	Myraus
Sample No.	14	13	11	12	10	8	6	5	4	2
Distance										
Mean	675.71	1646.92	264.55	122.83	800.5	573.75	457	101.6	1053	485
Standard deviation	785.21	1052.87	287.55	201.60	984.37	420.51	662.38	61.69	1130.50	91.92
Elevation										
Mean	124.5	210.77	84.36	57.67	1.02	101.25	94.67	89	158.75	150
Standard deviation	90.01	97.59	32.95	45.83	94.11	88.55	70.33	43.93	121.95	70.71
Riparian Class										
Mean	0.05	5.54	3.18	3.67	4.8	4.63	4.3	4.4	4.75	5.5
Standard deviation	1.47	0.00	2.09	1.72	1.23	0.92	1.63	1.34	1.89	0.71
Soil Moisture										
Mean	5.29	0.05	4.73	4.75	4.8	4.75	4.33	4.8	5.25	5
Standard deviation	0.99	0.00	0.91	0.75	0.92	0.89	1.63	0.45	0.96	0.00
Slope										
Mean	5.71	1.54	6.36	1.25	9	5	0	14	1.25	10
Standard deviation	10.72	3.75	10.02	3.11	16.63	7.56	0.00	13.87	2.50	0.00
Canopy										
Mean	0.71	0	0.55	0.01	0.8	1	1.33	0.8	1	2
Standard deviation	1.14	0.00	0.69	1.04	0.92	0.93	0.52	0.84	1.14	0.00
Soil pH										
Mean	5.93	6.75	6.28	6.04	5.92	6.02	5.91	5.98	6.36	2.67
Standard deviation	0.67	0.44	0.56	0.75	0.54	0.82	0.30		0.53	0.44
Soil Conductivity										
Mean	0.049	0.046	0.055	0.034	0.041	0.07	0.102	0.02	0.064	0.05
Standard deviation	0.03	0.00	0.03	0.00	0.00	0.04	0.00		0.00	0.00
Aspect										
Mean	135	64.62	83	30	88.57	60	56	116	55	
Standard deviation	11.95	5.54	6.57	4.25	7.15	0.00	2.99	5.60	3.16	
Frost										
Mean	27.29	32.54	29.55	24.92	28.3	26	26.67	29.8	28.75	24
Standard deviation	5.22	1.85	3.67	2.84	5.87	3.66	3.01	4.71	6.18	1.41

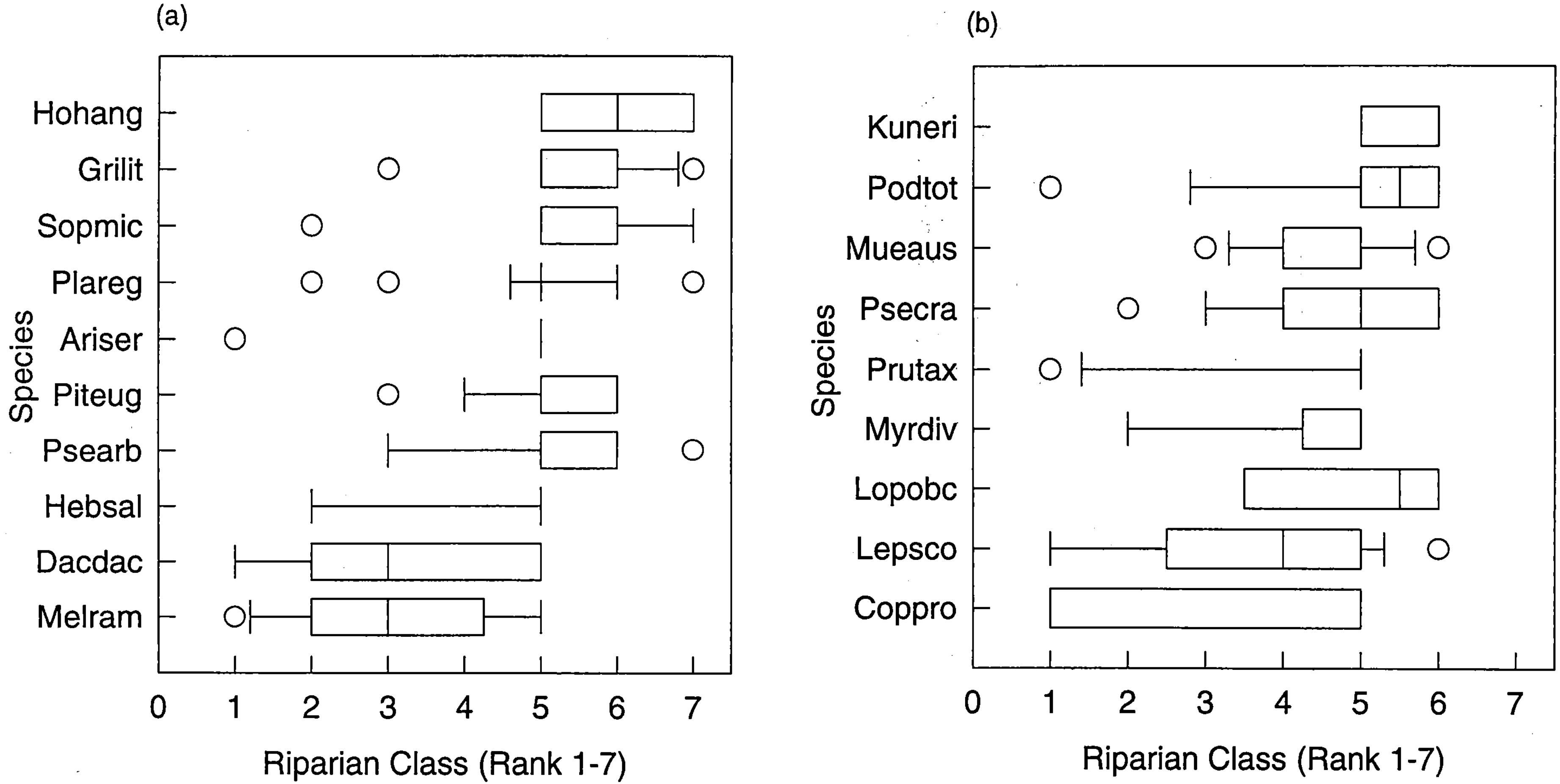


Figure A2.1: Riparian class for planted tree and shrub species of above 14 samples (a) and 14 samples and below (b). (Refer to Table A2.1 for species abbreviations).

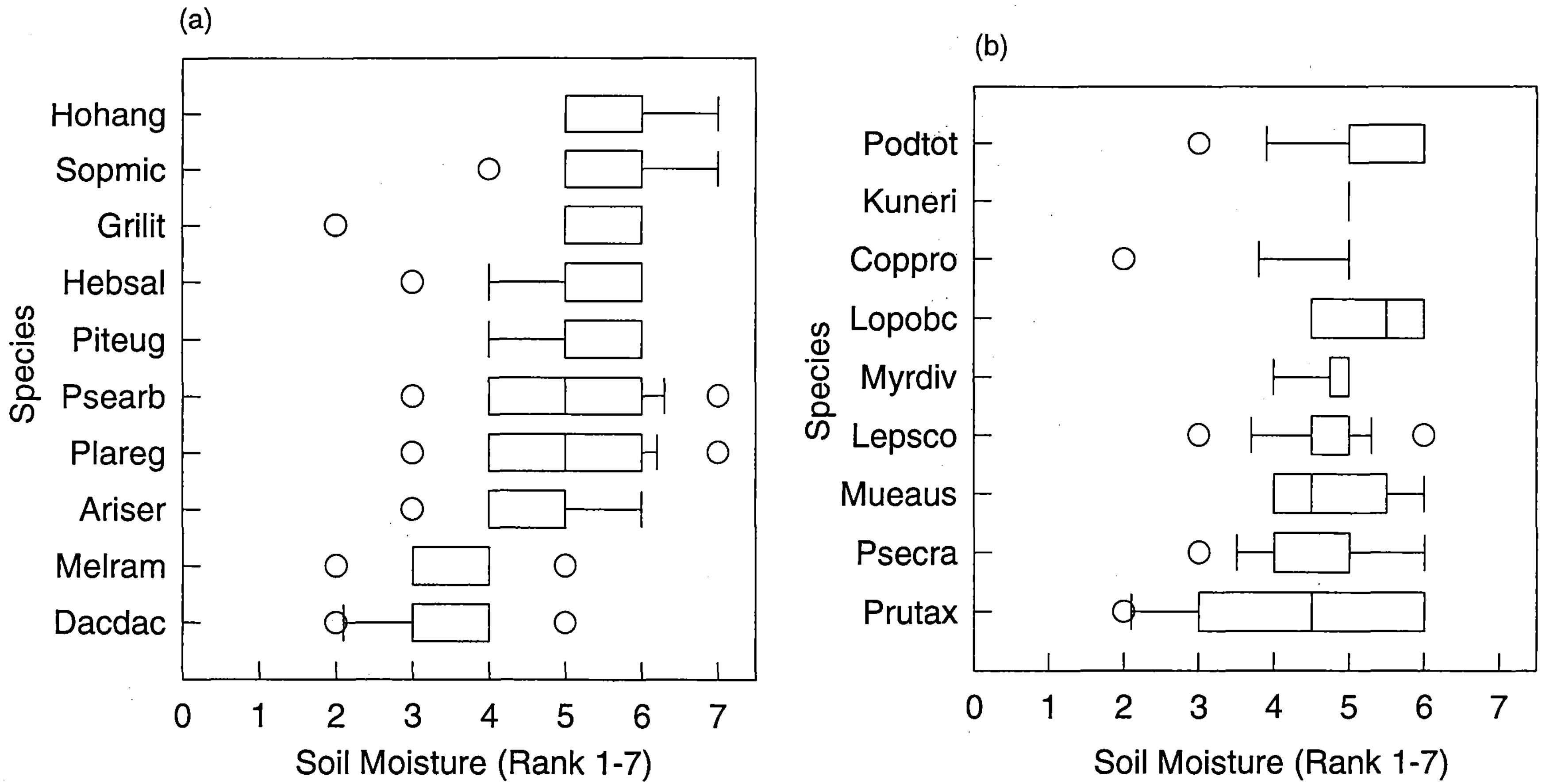


Figure A2.2: Soil moisture rank for planted tree and shrub species of above 14 samples (a) and 14 samples and below (b). (Refer to Table A2.1 for species abbreviations).

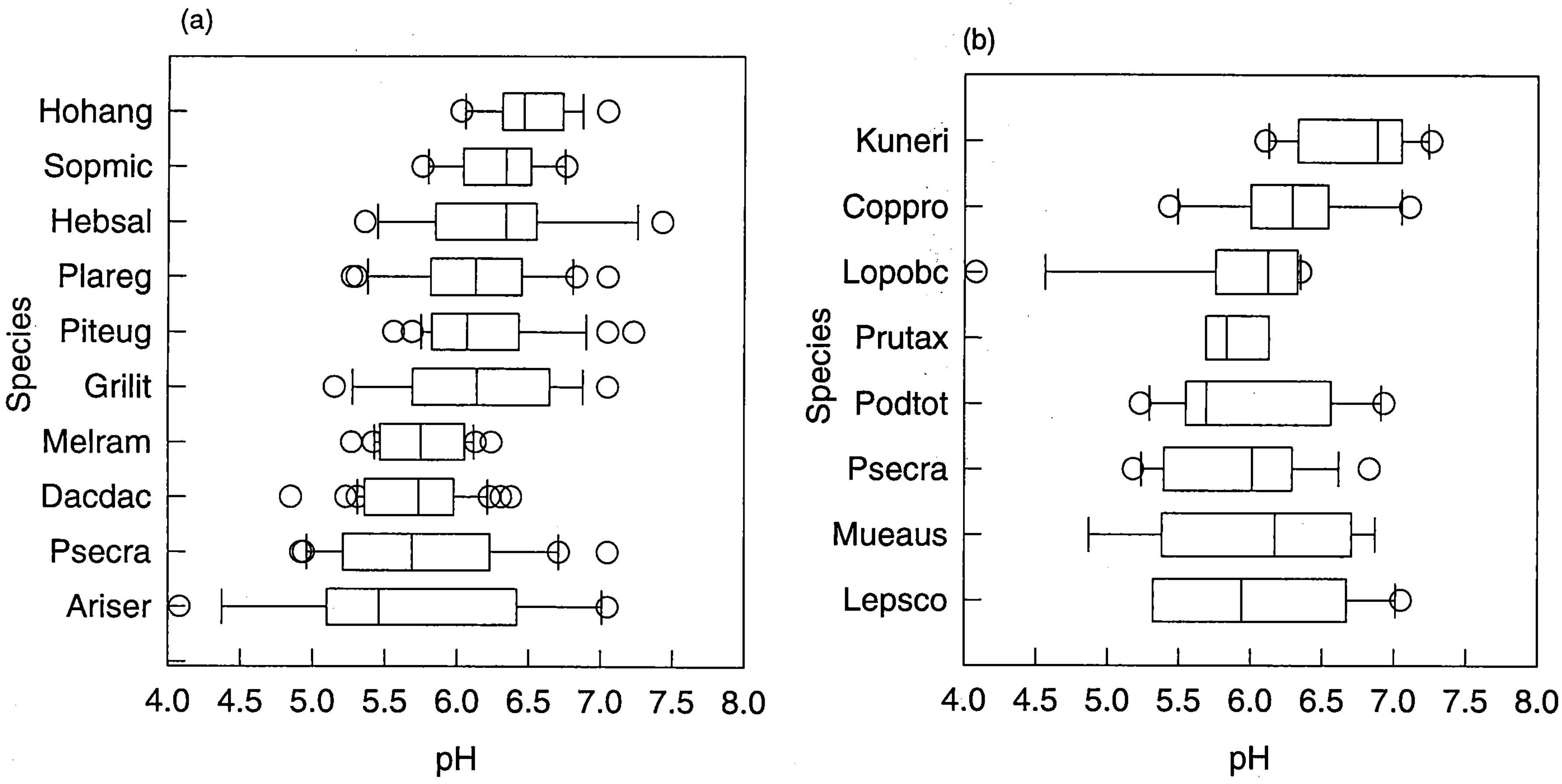


Figure A2.3: Soil pH for planted tree and shrub species of above 14 samples (a) and 14 samples and below (b). (Refer to Table A2.1 for species abbreviations).

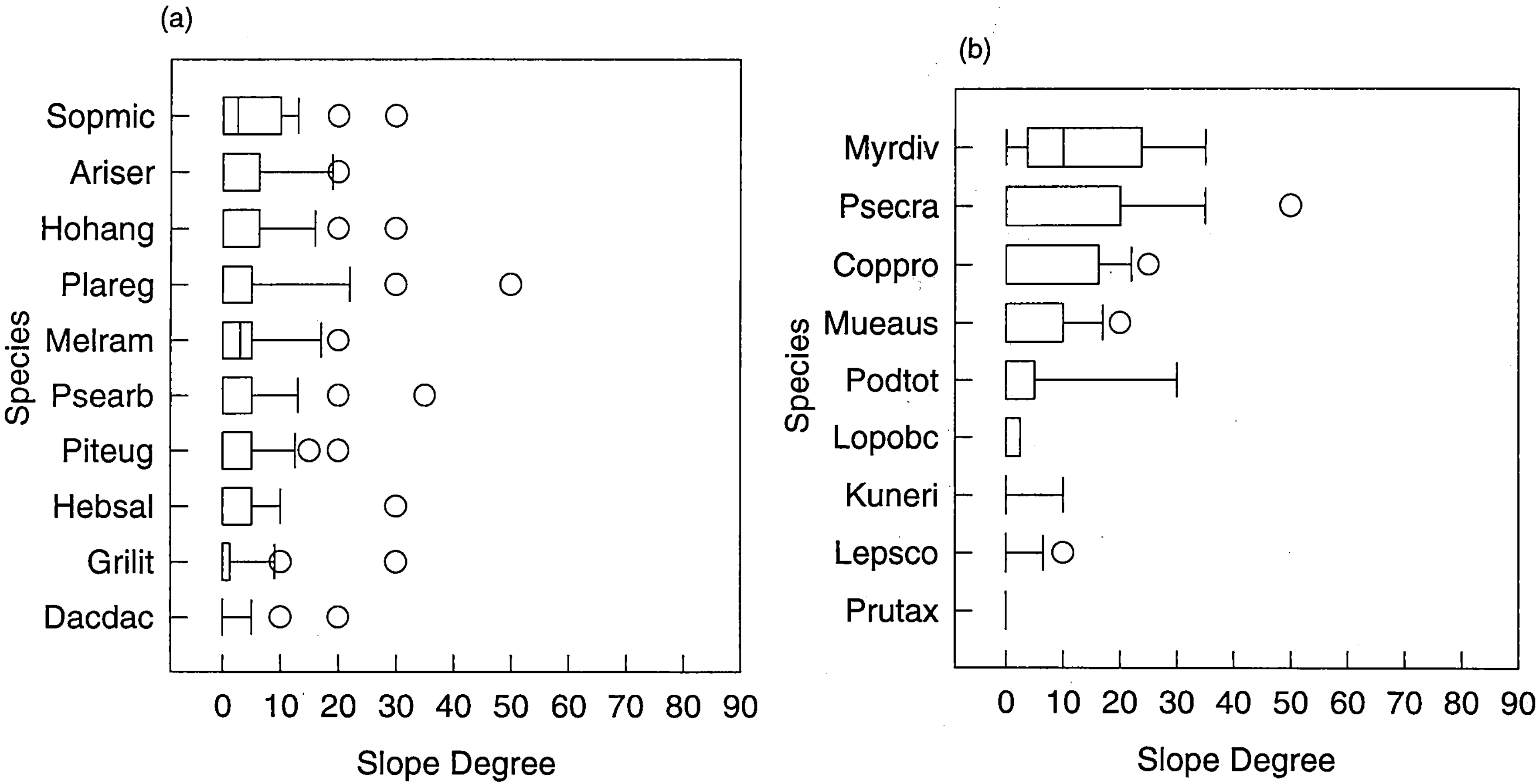


Figure A2.4: Slope degree for planted tree and shrub species of above 14 samples (a) and 14 samples and below (b). (Refer to Table A2.1 for species abbreviations).

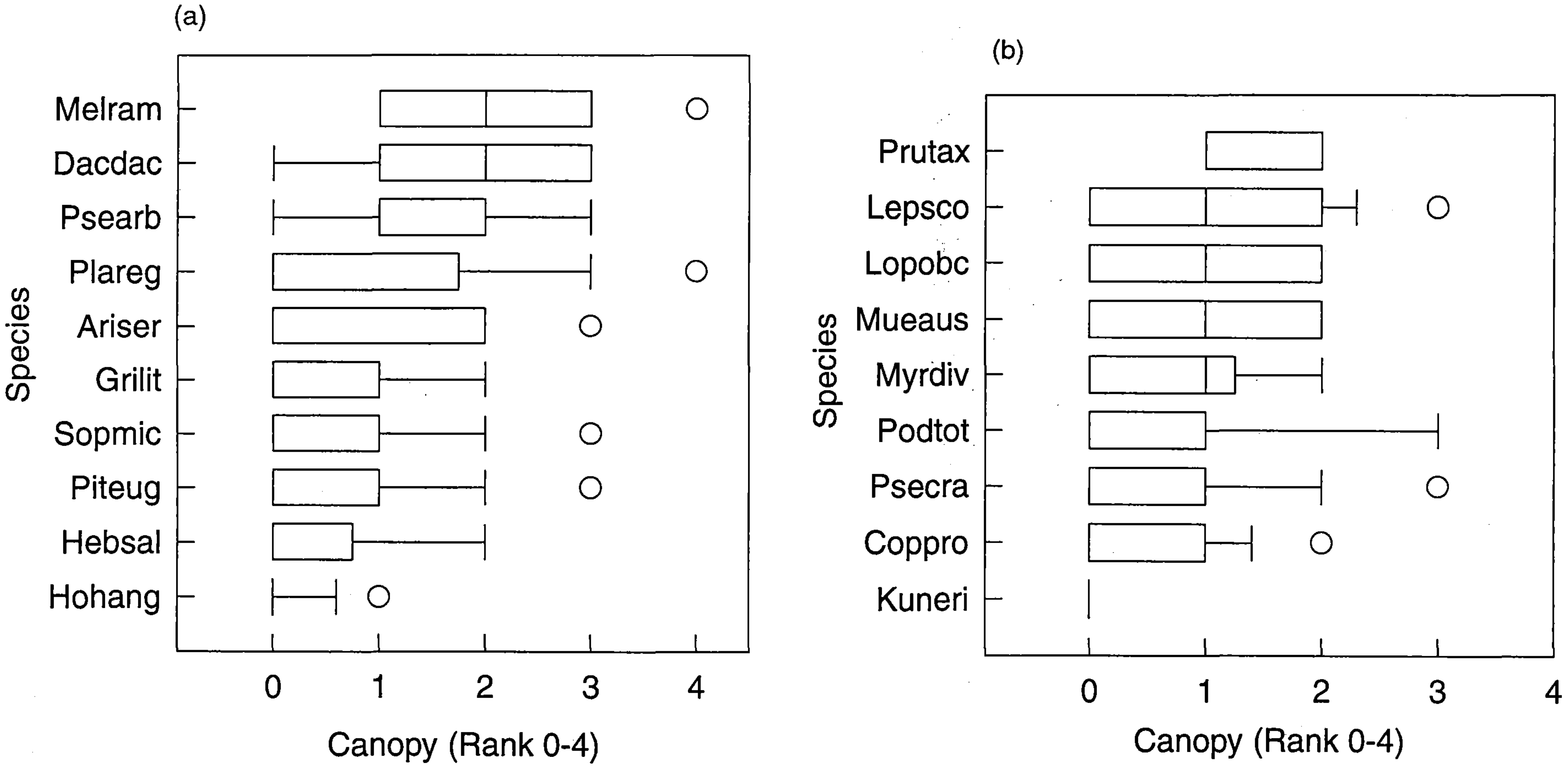


Figure A2.5: Canopy rank for planted tree and shrub species of above 14 samples (a) and 14 samples and below (b). (Refer to Table A2.1 for species abbreviations).

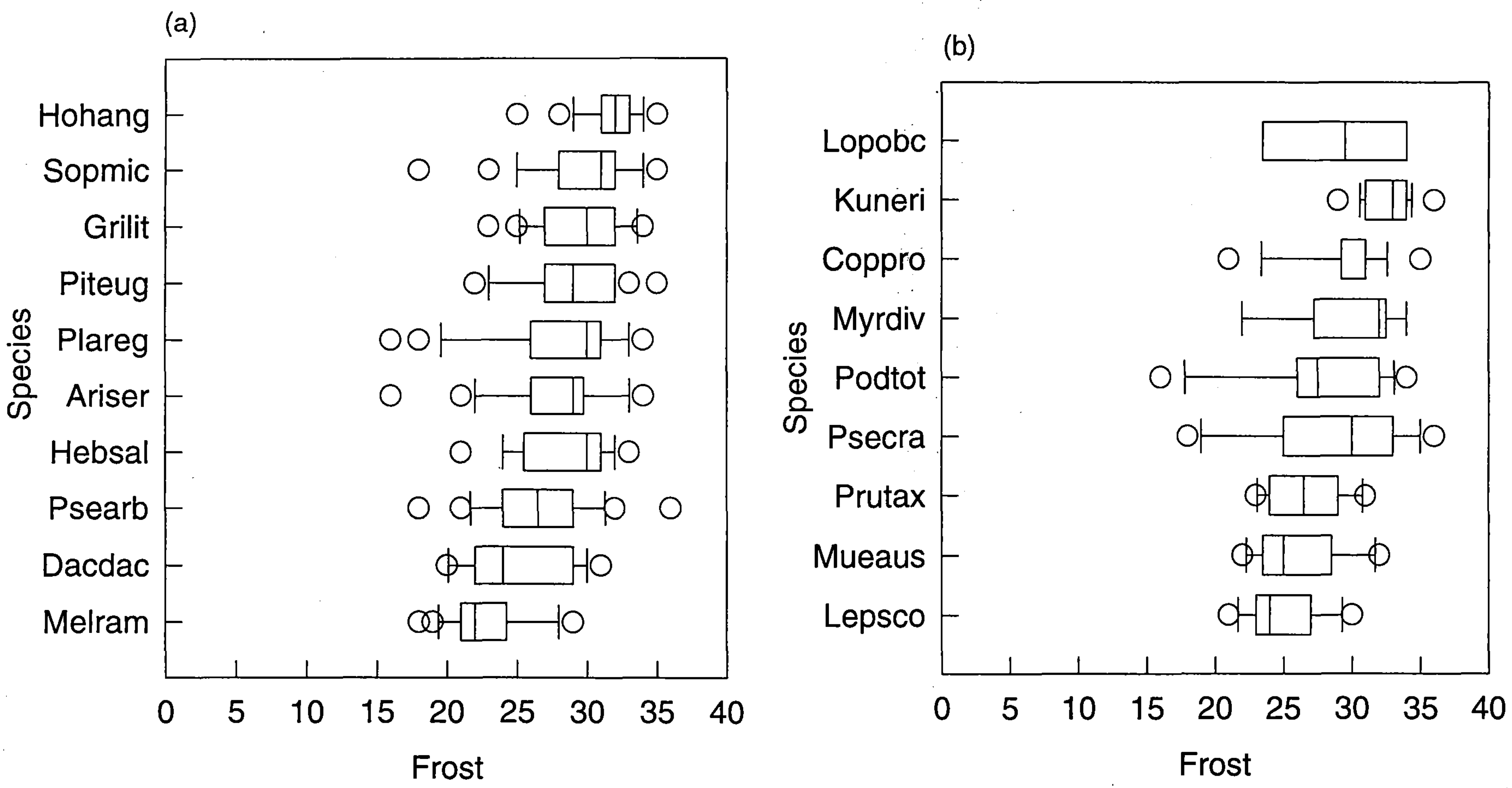


Figure A2.6: Frost for planted tree and shrub species of above 14 samples (a) and 14 samples and below (b). (Refer to Table A2.1 for species abbreviations).

APPENDIX THREE

Table A3.1: Summary histogram percentages for age class, growth style, reproduction, and abundance at site for self-established species.

Species	Sample	Age Class			Growth Style		
	Size	Seedling	Sapling	Adult	Individual	Clump	Patch
Sedges and Rushes							
Typori	15	0%	0%	100%	0%	0%	100%
Carvir	7	0%	0%	100%	57%	43%	0%
Eleacu	24	0%	0%	100%	17%	21%	63%
Junpal - self	15	0%	0%	100%	0%	7%	93%
Junpal - planted	13	0%	0%	100%	62%	0%	38%
Junsar	3	0%	0%	100%	0%	100%	0%
Schpau	13	0%	0%	100%	0%	0%	100%
Carsec - self	23	4%	0%	96%	70%	4%	26%
Carsec - planted	10	0%	0%	100%	0%	0%	100%
Carmao	17	0%	6%	94%	53%	12%	35%
Jungre - self	23	4%	0%	96%	17%	26%	57%
Jungre - planted	2	0%	0%	100%	0%	0%	100%
Cargem	16	0%	0%	100%	0%	0%	100%
Ferns							
Phypus	4	0%	0%	100%	50%	25%	25%
Blepen	12	0%	0%	100%	17%	8%	75%
Blecap	22	0%	5%	95%	41%	14%	45%
Blemin	29	0%	3%	97%	24%	14%	62%
Bleflu	8	0%	0%	100%	100%	0%	0%
Blecha	12	0%	0%	100%	58%	0%	42%
Polves	18	0%	6%	94%	100%	0%	0%
Trees and Shrubs							
Coraus - self	24	38%	33%	29%	79%	13%	8%
Coraus - planted	18	0%	67%	33%	94%	0%	6%
Coprob - self	28	0%	61%	39%	64%	7%	29%
Coprob - planted	4	0%	25%	75%	25%	0%	75%
Pitten - self	16	13%	56%	31%	100%	0%	0%
Pitten - planted	12	0%	58%	42%	100%	0%	0%
Corarb - all	10	40%	0%	60%	100%	0%	0%
Sollac - self	16	13%	63%	25%	100%	0%	0%
Sollac - planted	1	0%	0%	100%	100%	0%	0%
Other Species							
Astfra	5	0%	0%	100%	100%	0%	0%
Photen - self	22	0%	36%	64%	18%	14%	68%
Photen - planted	19	5%	32%	63%	42%	0%	58%
Hydhet	9	0%	0%	100%	0%	0%	100%
Hydnov	16	0%	0%	100%	0%	0%	100%

Table A3.1 (continued).....

Species	Reproducing		Abundance at Site		
	No	Yes	Few	Some	Many
Sedges and Rushes					
Typori	20%	80%	0%	20%	80%
Carvir	0%	100%	43%	29%	29%
Eleacu	4%	96%	25%	33%	42%
Junpal - self	0%	100%	20%	80%	0%
Junpal - planted	0%	100%	23%	15%	62%
Junsar	0%	100%	0%	100%	0%
Schpau	0%	100%	0%	0%	100%
Carsec - self	4%	96%	9%	9%	83%
Carsec - planted	0%	100%	0%	0%	100%
Carmao	0%	100%	12%	59%	29%
Jungre - self	0%	100%	13%	26%	61%
Jungre - planted	0%	100%	0%	100%	0%
Cargem	6%	94%	6%	94%	0%
Ferns					
Phypus	100%	0%	75%	25%	0%
Blepen	0%	100%	58%	25%	17%
Blecap	5%	95%	9%	36%	55%
Blemin	3%	97%	3%	21%	76%
Bleflu	0%	100%	0%	75%	25%
Blecha	8%	92%	0%	0%	100%
Polves	6%	94%	33%	17%	50%
Trees and Shrubs					
Coraus - self	83%	17%	13%	13%	75%
Coraus - planted	83%	17%	0%	67%	33%
Coprob - self	50%	50%	4%	32%	64%
Coprob - planted	0%	100%	25%	75%	0%
Pitten - self	75%	25%	38%	25%	38%
Pitten - planted	67%	33%	42%	50%	8%
Corarb - all	40%	60%	10%	50%	40%
Sollac - self	44%	56%	25%	38%	38%
Sollac - planted	0%	100%	100%	0%	0%
Other Species					
Astfra	80%	20%	20%	80%	0%
Photen - self	45%	55%	18%	5%	77%
Photen - planted	37%	63%	0%	16%	84%
Hydhet	33%	67%	11%	78%	11%
Hydnov	0%	100%	0%	13%	88%