Novel Habitats,

Rare Plants and

Roots Traits

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The loss of native plant species through habitat loss has been happening in NZ since the arrival of humans. This is especially true in Canterbury where less than 1% of the lowland plains are believed to be covered in remnant native vegetation. Rural land uses are changing and farm intensification is creating novel habitats, including farm irrigation earth dams. Dam engineers prefer not to have plants growing on dams. Earth dams are consented for 100 years, they could be used to support threatened native plants. Within the farm conversion of the present study dams have created an average of 1.7 hectares of ‘new land’ on their outside slope alone, which is the area of my research. This new land represents important sites for vegetation restoration in another wise highly modified landscape. My research aims to discover if earth dams could be used as restoration sites for rare, threatened or at risk native plants.

The north and south facing outside slopes of four dams were surveyed to find out which plants have established. Four 5 x 5m quadrats per north or south dam wall were used to identify plant species and ground condition on four dams. Twenty three vascular species were identified from 31 vascular taxa found growing in the quadrats. A combination of dam and aspect had an impact on species diversity in the plots. Only six species were recorded as covering more than 5% of the quadrats. There were significant differences between dam wall aspect in both vegetation height, and ground conditions. Temperature changes recorded over 24 hours were different between the north and south walls of dam 1 and were considered to have implications for planting zones.

Five native rare species were chosen due to nursery availability, and studied in detail, from a list of 44 native plants that were recorded in the area of the Te Whenua Hou dams at Eyrewell, Canterbury. The five species are *Aciphylla subflabellata, Coprosma intertexta, Leptinella serrulata, Muehlenbeckia ephedroides, Raoulia monroi.* Quadrats were used to identify species growing with the rare species and the ground conditions. There were 94 plots studied across 22 sites, across Canterbury, from Culverden in the north to Ealing, Ashburton District, in the south. Altitude varied from sea level to

481m across the species. Plot vegetation cover was significantly different between species even though ground conditions were not significantly different. Both species diversity and vegetation height were significantly different. There were six species that were found in at least one plot of each of the rare species.

Roots of seven dam species and four rare species were excavated and scanned using the WinRhizo™ programme at Landcare Research/ Maanaki Whenua for quantitative measurements and to evaluate root traits. The root diameter of the rare species was within the range of the dam species, 0.315 mm for *Agrostis tenuis* to 0.629 mm for *Rumex acetosella.* The root volumes of the rare species were larger than the dam species. There was significant difference between the specific root length of the rare species and the dam species.

The root diameters imply that the four rare species could be grown on the dams as they all fall within the range of diameters of the established plants. The remaining roots traits imply, that for a restoration site, the dams could be used for the rare species.

A protocol has been proposed for planting novel habitats with target species, based on the steps of this research. This includes direct comparison of novel site and target species natural sites as well as root measurements for site specific comparisons.

Keywords: Rare, threatened, at risk, earth dams, roots, novel habitats, species, *Aciphylla subflabellata, Coprosma intertexta, Leptinella serrulata, Muehlenbeckia ephedroides, Raoulia monroi*

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Chapter 1

Introduction to novel habitats, rare plants and roots.

New Zealand species have always been under pressure due to the geological dynamics of the landscape. Since the arrival of humans the landscape changes have increased. These human changes have also created novel habitats that have the potential to provide habitats for threatened species. This thesis is about one of these novel habitats (earth dams) and five threatened flora species that could be grown on these dams.

Figure 1.1 Two examples of the dynamic nature of the NZ landscape. Left; a braided river, the Upper Waimakariri river. Right; a slipping hillside opposite Waipara Conservation Area, Alice Shanks and Jason Butt in right foreground.

1.1 Habitat Disturbance

Native plants in Canterbury have been under threat since the arrival of humans (De Lange et al. 2009). New Zealand has a history of landscape modification with human settlement, this is especially true in the Canterbury region where repeated fires have removed the original forest cover. These fires have been caused by both Maori and Europeans (Brockerhoff et al. 2003; Brockerhoff et al. 2008; Gillespie 2010; Head and Given 2001; Pratt 1999; Rowarth et al. 2007; Walker et al. 2006; Wendelberger et al. 2008). Native plants are currently considered to grow naturally in less than 1% of Canterbury's plain area. Some of these native plants are considered rare, threatened or at risk. Changes in landscape through habitation by humans has created many novel habitats, with some being occupied by native plants, as well as exotics, through self-introduction (Hobbs and Cramer 2007; Rogers et al. 2005; Rotherham et al. 2003; Wendelberger et al. 2008).

1.2 Novel Habitats

Novel habitats are being increasingly used, particularly in urban areas, to support native vegetation and wildlife (Hobbs et al. 2009; Lampinen et al. 2015a; Wendelberger et al. 2008). In farming, the changes towards increased irrigation has also brought about the creation of earth dams (hereafter dams) for water storage and increased the number of water races as part of the landscape. New dams have the ability to provide novel habitats in a rural setting. Potential habitats on a dam include the inside walls above the water, the overflow area and the outside walls. These provide several novel habitats which have the potential to aid the conservation of the rare, threatened and at risk plants of Canterbury (Weeks et al. 2013). In turn these novel habitats will help native fauna to establish in the new ecosystem. This research is focused on the outside walls.

1.3 Earth dams

Earth dams are consented for 100 years offering a habitat that has long term possibilities. Currently some district consents require exotic grasses to be sown but there is no evidence provided to support this requirement (Tasman District Council 2000). From a dam engineer's perspective plants that grow on a dam have the potential to cause extensive damage (Waikato Regional Council 2006). This damage can be in the form of storm or wind damage from trees being toppled and ripping up the walls or from woody or large roots creating pathways for the water to escape causing dam failure. To help mitigate this damage the dams are inspected every five years for seepage or movement in the walls (IPENZ 2015; NZSOLD 1997). The above types of damage are from the roots of the plants, in particular trees. The development of roots in dam walls can affect the ability of dam walls to remain intact, both positively and negatively, similar to hillsides (Marden et al. 2007; Phillips et al. 2011; Phillips and Marden 2006). This thesis research was done by comparing the root traits of the plants that are currently growing on the dams with the root traits of rare or threatened plants that could use the dams as novel habitats.

1.3.1 Traits

Plant traits involve the measurements of the morphological, physiological and phenological attributes that influence establishment, survival and fitness both within and between species (Reich et al. 2003; Violle et al. 2007). Traits are measured at the individual plant level within species. The individual level is used due to environmental factors that can cause differences. The combination of trait measurements provides information on the plants ability to forage for nutrients, access water or their length of life (Kramer-Walter et al. 2016). These traits measurements effectively categorise how each species makes a living in its environment. Traits are used in this research to distinguish the differences between the rare species and the species currently growing on the dams.

1.4 Canterbury Flora

Many Canterbury plants are adapted to the extreme conditions associated with the braided river systems and alluvial soils (Wardle 1972). Canterbury stony alluvial soils have low water holding potential and high evapotranspiration rates in part due to the Nor'west foehn wind (Eger and Hewitt 2008). As the dams themselves are not irrigated the soil is reliant on rainfall for additional moisture, beyond that transpiration through soil from the water stored. The dams are creating a habitat that may be similar to parts of the plains of Canterbury. The plants chosen need to be able to grow and survive in extreme soil conditions, for example; compacted soils, sun and wind exposure. Multiple surveys of Canterbury native plants from past and present provided useful lists of suitable plants (Walker et al. 2004; Weeks et al. 2013; Wiser et al. 2013). Rare and threatened plants from these lists were used as the basis for possible plants to use on the dams for this research.

1.5 Provenance

Current restoration of plant communities is based around the use of eco-sourced or locally sourced genetic material usually in the form of seed (Bischoff et al. 2008; Hancock and Hughes 2012). The reasoning behind this is that the genetic material is local to an area, adapted to the climate, soil conditions, herbivores and pollinators that form parts of that wider ecosystem (Bischoff et al. 2006; Hancock et al. 2013). This belief is contested with research inferring that many species can be moved with no visible affect to change in growth form while a few species have specific niche ranges or adaptations (Richardson et al. 2012; Simpson et al. 2016; Vander Mijnsbrugge et al. 2010).

In New Zealand many areas have very specific geographical characteristics that help confine genetic material. This confinement can lead to speciation or characteristics e.g. leaf colour or size that gives the impression of speciation (Heenan and McGlone 2013; Richardson et al. 2015; Shepherd et al. 2017). Some of the characteristics providing the impression of speciation are related to soil types or water availability and the characteristics can disappear when grown in an area with different variations of those soil or climate conditions (Breed et al. 2012; Hancock et al. 2013). The size of an area considered an eco-source area can vary from less than 10 square kilometres to hundreds of square kilometres. Due to the combination of braided rivers and the Southern Alps creating the main demarcations of the Canterbury Plains the boundaries I used for my research are the Selwyn and Waimakariri Districts. The Selwyn District is bound by the Rakia River to the south, the Waimakariri River to the north and the Southern Alps to the west. The Waimakariri District is partly surrounded by the Selwyn district to the south and west and the Okuku Range to the North. Both districts are bound by the Pacific Ocean, Christchurch city and Banks Peninsular to the east. These two districts created the initial area within which I searched for the rare or threatened species.

1.6 Potential for Seed conservation

The protection of seed source areas is increasing internationally through legislation (Seed 4 Restoration 2017; Smith et al. 2017; Smith 2017). In New Zealand the Department of Conservation (DOC) is expected to provide that protection on public land and the QEII National Trust support protection of private land (Conservation Online; QEII National Trust 2011). However there are areas such as the Canterbury Plains that have limited representation in the Conservation estate (Holdaway et al. 2012). Many of the areas in Canterbury are left unprotected (Harding 2014; Harding 2009). Canterbury has a history of dry stock and crop farming creating this paucity of seed source habitats currently believed to be less than 0.5% of the original native habitat (Meurk et al. 2016). The use of novel habitats as restoration sites has the potential for future seed or propagule gathering and conservation.

In consideration of this issue, seed conservation, my research is based around using novel habitats (earth dams) that have been created for one purpose (water storage) towards having multiple uses i.e. provide a possible seed source habitat, and to assist in the restoration of threatened plants and their communities.

1.7 Aim

The aim was to discover if earth dams could be used as restoration sites for rare, threatened or at risk (from this point on the three classifications will be referred to as rare) native plants using field surveys, and pot experiments, and root measurements for traits.

1.7.1 Objectives

1. To identify which plants were currently growing on earth dams.
2. To survey where native plants that were in the same area as these dams are currently growing.
3. To identify the root traits of the most frequent dam plants.
4. To evaluate that the roots of the native plants were comparable to the dam plants and could grow on the dams.
5. To develop a protocol for comparing rare or target (wanted) species with species currently growing in a novel habitat.

1.8 Chapters

The chapters of this thesis will be arranged as follows:

Chapter 2 – Literature review.

Chapter 3 – Plants on earth dam walls. Field survey of four earth dams at Te Whenua Hou, Eyrewell.

Chapter 4 – Rare species habitats. Identify five rare or threatened plants that were in the Eyrewell area. Where these plants are currently found growing naturally. Identify other species occuring with them. Identify the ground conditions in the quadrants of the species.

Chapter 5 – A comparison of rare plant roots and the roots of plants currently growing on dam walls. All roots were measured for similarities including diameter, volume, and specific root length. The comparison of all roots was briefly discussed.

Chapter 6 – The discussion of earth dams as a habitat for rare species. This draws the previous chapters together and discusses how the different information could be used for both earth dams, other restorations and as a protocol.

Appendices – list of species in frequent use in thesis, list of common native species abbreviations used, full list of species found.

Chapter 2 Literature Review

2.1 General Introduction

New Zealand is a land mass with a long history of geological changes that started with being part of a super continent known as Gondwana, sinking until only islands of mountains were above water level, to raising and having glacial coverage lasting until merely three million years ago (Gibbs 2006). These changes have given rise to a country that has been isolated for millions of years. The flora and fauna that is native have adapted to the isolation, climate and geological changes (Diamond 1990; Gibbs 2006; Russell et al. 2006). The geological and climate changes, earthquakes and volcanic eruptions gave rise to speciation in both fauna and flora (Shepherd et al. 2017; Shepherd et al. 2007). This speciation is valued internationally and New Zealand is a global hot spot of biodiversity (Brooks et al. 2002; Millar et al. 2017). This hotspot unfortunately is also losing species at a rate higher than nearly anywhere else due to; fire for renewal of food sources and ease of transport by early Maori, collection of species in the 19th century by Europeans, and intensive land changes for farming and human development (Figure 2.1) (Wilson 2004).

Figure 2.1 Changes in Canterbury landscape from kanuka through fire, to sheep framing, then pine plantations to dairying. Photos: http://footsteps-mainlyforestry.blogspot.co.nz, Teara, PA Greer.

As New Zealand is considered the last major land mass to be inhabited by humans, with Maori settling here in the 12th century, these changes in species loss and land changes are within oral and written history memory (Wilson 2004). This knowledge is part of the culture of NZ. Since the 1970's there has been a realisation that if we as a country do not make a change by bringing a halt to the loss of biodiversity no-one else will. This movement led to the development of the Department of Conservation (DOC) (1987), Environment Act (1986) and the creation of the Resource Management Act (RMA) (1991). The creation of DOC, the Minister for the Environment, and the RMA provided councils and people with the means to reduce the impact of development on the landscape. Recently with the impact of climate change causing droughts, leading to farming practice changes especially with water use, has brought this area increasingly into the public eye (Brown et al. 2015). Some of these on farm changes have created novel habitats that could be used for species that have lost habitat or are in the process of being displaced (Wratten and Hutcheson 1995). Ongoing taxonomic work for both flora and fauna is identifying species that are threatened, at risk, rare or not threatened (De Lange et al. 1999; De Lange et al. 2009; de Lange et al. 2013). The taxonomic work along with identification of uncommon ecosystems is providing New Zealanders with knowledge that will protect and ensure the survival of many plants and animals (IUCN 2016).

2.2 Uncommon Ecosystems

In the New Zealand landscape it is possible to identify naturally uncommon ecosystems (Holdaway et al. 2012; Williams et al. 2007). The categories used to differentiate these ecosystems include; soil (type, age, particle size, parent material), climate, topography (landform and drainage), and disturbance regime (Williams et al. 2007). Vegetation was considered later through the use of threatened classifications per 100 ha of ecosystem type thus separating the ecosystems further (Holdaway et al. 2012). Naturally uncommon ecosystems account for 3-10% of New Zealand's total land area and are estimated to include 47% of the at risk, threatened or rare plant species (Holdaway et al. 2012).

The plains of Canterbury are predominately river terraces of varying ages created by braided rivers and loess blown from these rivers during dry seasons. There are uncommon ecosystems that have influenced the Canterbury Plains and these include; limestone and volcanic outcrops, sand dunes on river terraces and shingle beaches (Head and Given 2001). Many of these uncommon ecosystems on Canterbury Plains are being reduced in size, or lost along with the plants (Head and Given 2001; Norton and Lord 1992). The recent intensification of farming in Canterbury although causing a loss of habitat and plant species has also created novel habitats. These novel habitats have the potential to replace some of the lost natural habitats to expand the range of threatened plants therefore decreasing their threat risk. In the present study a compilation of suitable plants was created based on existing sources of knowledge (Wiser et al. 2013).

2.3 Novel Habitats

Novel habitats are being increasingly used, mainly in urban areas, to support native vegetation and wildlife (Lampinen et al. 2015b; Wendelberger et al. 2008). Wellington, NZ's capital city, has been very proactive in using urban novel habitats e.g. roundabouts, and curb spaces, to establish and support native species both flora and fauna (Government 2016; Wellington City Council 2017a; b). Since the 2010 earthquakes Christchurch City Council (NZ) has encouraged the inclusion of water storage basins in new subdivisions (Christchurch City Council 2017). Along with these storage basins there has been the development of rain water gardens in the city centre (Couling et al. 2016). Many of these rain water gardens are planted with native species (Figure 2.2).

Figure 2.2 Demonstration rain garden at The Commons, corner of Kilmore and Durham St's, Christchurch, NZ. Adapted from Rain Garden Design, Construction Maintenance Manual (Couling et al. 2016).

Riparian planting in rural areas to protect waterways from fertiliser runoff and stock movement has increased in the recent years as the issue of water contamination and quality has increased (Franklin et al. 2015; Hughes 2016; Marden et al. 2007). The changes from dry stock farming to irrigated farms has also brought about the creation of earth dams and water races as part of the landscape. The creation of these landscape features causes the soil profile to be changed due to the use of machinery in their creation and to effectively fulfil the requirement for water containment. This creation of novel habitats has the potential to help the rare, threatened and at risk plants of Canterbury. These changes in turn can potentially assist the native fauna to establish in the new habitat (Tonietto and Larkin 2017).

2.4 Earth Dams

Intensive agriculture provides regular irrigation of crops and fields, requiring collection and storage of water. Earth dams are constructed with precision to enable effective water storage. A dam wall is built with a 3:1 slope with a core or liner, 700mm to 1 m across to reduce water loss between the inner and outer walls, that is made out of soil and rock material found on site (Figure 2.3) (IPENZ 2015). The outside walls are a mixture of sandy gravel with 10% soil mixed in (R. Goldie pers. comm.). The wall material is compressed through the building process adding a dimension that is not repeated in nature. The ability of plant roots to hold gravel, sand and soil particles in place maintains the slope integrity. Irrigation earth dams are built and consented for 100 years, ideally needing plants that will maintain the wall integrity (Tasman District Council 2000). These dams, although taking up land, are also creating land that will not be used for grazing as stock are not allowed on them. Dams are unsafe as recreation areas due to water being pumped out of them for irrigation. The potential to use this new land for native flora and fauna offers environmental benefit of new ecosystems for floral and faunal communities.

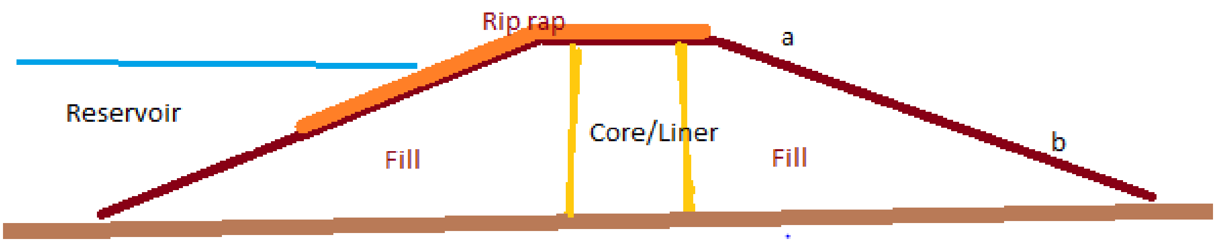

Figure 2.3 A diagram of a dam wall similar to that used for irrigation dams. Rip rap are rocks that are used to reduce the effects of water movement on the dam walls. The slope with points a and b is the outside wall that was used for this research. Rip rap rock is a soft rock to reduce erosion from wave, wind or rain action. Adapted from (IPENZ 2015).

The consent process requires dams to be vegetated. However, it is important that plant roots do not damage the core or liner of the dam. Shrubs (less than 2 m high) and low growing plants were chosen for this research In recognition of the damage caused by trees to the structural integrity of dam walls through exposure to the Nor'west foehn winds (Phillips et al. 2015; Tasman District Council 2000).

The success of the flora community selected will depend on the ability of their roots to develop in the compressed material making up the dam walls (Figure 2.4). Large woody roots are treated as structural materials as part of bioengineering in high shear stress areas for the stabilization of slopes (Marden et al. 2007; Mickovski et al. 2010). We can utilise the shallow slope of dams that have a reduced shear stress from erosion to use other plants with fine roots that are not normally considered, e.g. grasses or herbs (Phillips and Marden 2006; Tasman District Council 2000). Many dams have been sown with exotic grasses as part of this erosion reduction process and for consent processes (Tasman District Council 2000). These exotic grasses and herbs can be used as a comparison with native plants for the differences of their root systems. The roots of some grasses, forbs and herbs create a mat that will hold the top soil layer together, although this may not be anchored to the rest of the dam wall (Li et al. 2009). The anchoring of the top layer of soil to the dam's lower layers reduces erosion by layers (Pohl et al. 2009). This anchoring is created by using plants that have different root structures and rooting depths (Phillips and Marden 2006). This anchoring requirement creates a need for a variety of plants to be used. The variety needs to be based on the knowledge of the plants roots and root systems.

Figure 2.4 Roots that were growing under a rock for moisture. Dam 3 Te Whenua Hou.

2.5 Role of roots

Roots of plants are part of the ecosystem that are often overlooked although roots are known to play an important role in stabilising soil slopes (Phillips et al. 2015; Warren et al. 2015). Most research on slope stabilisation by plants has been related to trees and their roots with very little done on NZ native plants, tree or otherwise (Holdaway et al. 2011; Phillips et al. 2011; Tasman District Council 2000; Watson and O'Loughlin 1985). Trees and large shrubs are not recommended for growing on dams due to the potential damage caused by wind throw or storm damage (Waikato Regional Council 2006). Other damage could be caused by large wooden root systems accessing the main body of water and creating drainage holes after the roots die (Tasman District Council 2000). The use of plants with fine roots (less than 2mm diameter) could increase soil stability (Iversen et al. 2017). By selecting plants based on the basic root characteristics of diameter, length, and volume, can limit the range of species to be considered for these novel habitats e.g. no trees but shrubs (up to 2 m high), grasses and ground covers. These novel habitats also have abiotic factors that need to be taken into consideration and measured, e.g. comparison of the traits and abilities to access nutrients and water, and assess the quality of the soils that are suitable for potential habitats for the different species.

2.6 Root Traits

The differences in soil nutrient availability can impact on the growth form of plants which can be seen in root development as well as above ground vegetation (Holdaway et al. 2011; Iversen et al. 2017). The differences that cause changes in growth form are explored through root traits which have been developed in relation to leaf traits (Pérez-Harguindeguy et al. 2013). Fine roots (<2 mm) are of importance to defining the environmental adaptions of plants (Iversen et al. 2017; Sun et al. 2016). Root traits are used for this research instead of leaf traits as the plants that are to be considered need to be able to support and maintain dam integrity.

Root traits are multidimensional. The ability of roots to exploit fertility in soil and form associations with mycorrhizae creates traits that are considered similar to leaf traits but are acknowledged as more complex (Eissenstat 1991; Eissenstat et al. 2015; Kramer-Walter et al. 2016). Root depth and spread is important for a plants ability to tolerate droughts and floods, and is often utilised for erosion control (Padilla and Pugnaire 2007). The ability of roots to adapt to soil fertility and changing conditions creates a complexity that is not directly comparable to that viewed in the above ground vegetation (Kramer-Walter et al. 2016; Larson and Funk 2016; Ryser 1996). Some of these traits can be measured by root diameter, volume, specific root length (SRL), root to shoot ratio and tissue density.

Root diameter is consistently associated with SRL and the ability to forage for food (Eissenstat et al. 2015; Larson and Funk 2016). The diameter can have impacts on the suitability of plants to reduce erosion and creation of channels for water leakage on dams (NZSOLD 1997). Roots with larger diameters (>2 mm) often have drier soil underneath the plant e.g. *Phormium tenax* (Franklin 2014). Through knowing the diameter and the soil types we will know if the species is suitable for use in any given situation.

A plants root volume can indicate how useful that plant could be for erosion control, nutrient foraging and ability to retain water (Eissenstat 1991; Mickovski and van Beek 2009). The volume is used to determine tissue density in roots. Using the known root volume of a species to work out the occupation within an area creates a better understanding of the interaction between roots and soil (Shields and Gray 1992).

Higher Root to shoot ratio (R:S) is considered an adaptation to drought tolerance (Lloret et al. 1999; Padilla and Pugnaire 2007). The higher the R:S the larger the root mass in proportion to the shoot mass. This higher root mass is believed to provide the plant with an increased ability to gain water. Root depth can play an important part in the ability to access water (Padilla et al. 2007). The initial root mass measurements from the R:S are used to determine RSL and tissue density. R:S is a simple way to compare drought tolerance or sensitivity of species within an area as it is based on the mass of the roots and above ground vegetation of the plant (Wyse et al. 2014).

Specific root length (SRL) is considered to have a range of 3-350 (m/g^{-1}) (Pérez-Harguindeguy et al. 2013). Plants with a high SRL are considered to have higher rates of nutrient and water uptake (Holdaway et al. 2011; Pérez-Harguindeguy et al. 2013). The high SRL may enhance nutrient acquisition (foraging) in low fertility soils. The combination of high SRL and low root diameter appears more frequent in low fertility soils. SRL is gained by root length /root mass.

Root tissue Density (g^{-1}/mm^2) is positively related to longevity and negatively related to nutrient uptake (Holdaway et al. 2011; Sun et al. 2016). Density is also associated with a slow growth strategy in infertile soil (Kramer-Walter et al. 2016). Density is gained by root mass/root volume.

By comparing the above traits knowledge about species is gained that can explain why some plants will survive in areas that were considered inhospitable. The adaptions to different soils, climates and altitudes can be clarified through the root traits. Knowing the root traits of rare plants increases our ability to use them in sites that may have initially appeared as inappropriate.

2.7 Threatened Plants

In New Zealand there is an increasing recognition of our threatened plants (De Lange et al. 1999; de Lange et al. 2013). These plants are at risk for a variety of reasons which include: loss of habitat, change in climate, loss of close individuals for pollination, and loss of pollinators due to distance between communities. For some of these plants there is limited knowledge beyond taxonomic description and the place where the type was initially found and recorded (Wardle 2002). The more knowledge about plants that can be added to the species data base increases their opportunity to be introduced to suitable new habitats or to reintroduced them to old habitats from where they have disappeared (Marden et al. 2005; Phillips 2005; Phillips et al. 2011; Wardle 2002).

Many Canterbury plants are adapted to alluvial soils. These stony alluvial soils have low water holding potential and high evapotranspiration rates in part due to the Nor'west foehn wind (Eger and Hewitt 2008). Dams are erected using soil found *in situ.* It follows that utilising knowledge of the history of plants from that area increases the success from a climate and provenance view point. However as the engineering process has altered the natural compaction and changed the soil structure this may affect a plants ability to put roots deeper into the dam wall and not create roots that are just below the looser soil surface (Figure 2.4). More research is required to determine which plants would be suitable for use on these dam walls. If native plants can be used on the dams they will create new communities and seed sources for future projects as well as a new habitat for native fauna (Bodley et al. 2016; Case and Barrett 2004; Fay 1992; Gaskett 2011; Lehnebach et al. 2005; Thorsen et al. 2009; Thorsen et al. 2011; Tonietto and Larkin 2017; Wotton et al. 2016).

The combination of uncommon ecosystem and plant loss in Canterbury creates an opportunity to investigate the use of novel habitats that are being created through farm intensification. The present study investigates whether rare plants can provide an answer to vegetating dams for consent requirements.

2.7.1 Protocol

I hope to discover if this is a suitable opportunity and create a protocol to assist in restoring native plants through the exploitation of novel habitats. The use of specific or target species to rehabilitate an area is often used in restoration projects (Volis 2015). The research that follows outlines the steps that have been taken to set up a protocol. The target species in this study are at risk native species (referred to as rare). This protocol will be considered by comparing plant species that are currently growing on dams with native species that previously grew in these areas, and the root systems of both native and exotic species.

Chapter 3

Survey of Plants on earth dam walls

3.1 Introduction to plants on dam walls

The earth dams (dams) that are currently being created in Canterbury for irrigation are required to have vegetation on them as part of the consent process. There are no vegetation guidelines supplied by Environment Canterbury, the regional council that carries out the consent process for earthworks in Canterbury, although they do supply a list of exotic grasses for planting. This part of the research was instigated to find out what plants have established themselves on the dam walls.

Earth dams are created from the soil (including rocks) that are part of the immediate landscape of an area that is to be turned into a dam. Cocksfoot (*Dactylis glomerata*) was drill sown into the Eyrewell dams according to the manager in charge of the restoration at Eyrewell as part of their consent process (B Giesin, pers. com. 7.06.2017). Based on observations of these dams over three years there are other plants that were either in the soil seed bank or have arrived through wind or animal dispersal that are now growing on the walls (Figure 3.1).

3.1.1 Aim:

The aim of the research reported in this chapter was to investigate what plants have established on the dam walls.

3.1.2 Objectives:

- Identify species currently growing on dam walls
- Identify other relevant conditions including; ground conditions, altitudes, vegetation height.

Figure 3.1 South side of dam 2, winter 2016. The species that is dominant in the photo is *Rumex acetosella.*

3.2 Methods to survey plants on dam walls

Four dams were selected to represent the dam population in the Eyrewell area. These four dams were selected as they have walls facing as near true North and South as possible (Figure 3.2). The dams were built in 2014 and 2015. The walls used are free of overspill zones or vehicle access tracks. The slope of the dams chosen were over five metres in length to allow 5 x 5m quadrats (plots) down (Figure 3.4). The walls were over 60m in width to allow four plots along the wall. There was 10 m in between plots outside edges. Where possible the plots were positioned in the centre of the wall and at least 10 metres in from the corners. The slope length was measured for each quadrat and the middle of the slope determined (Figure 3.4). This mid-point became the mid-point for that quadrat to allow for differences in slope length along the wall and between dams, n= 4(dams) x 2(aspects) x 4(plots per aspect). The dam tops were walked for measurement of the outside walls using GPS to measure the circumference to ascertain the land created.

Figure 3.2 Map of Eyrewell with dam walls marked. Created using Google Earth.

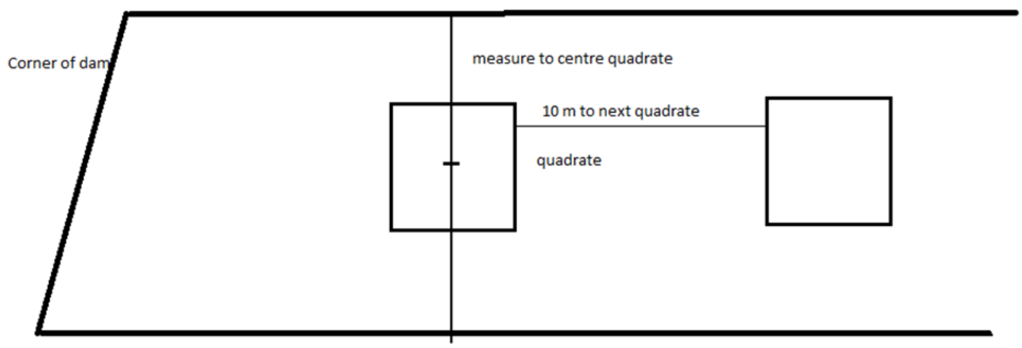

Figure 3.3 Out-side wall of dam with quadrat measurements. Measurements are not to scale.

The vegetation was identified to species level where possible and recorded using the Grasslands Recce sheet and cover system, Appendix D (Allen and Manaaki Whenua-Landcare Research New Zealand Ltd. 1993; Hurst and Allen 2007a; Hurst and Allen 2007b; LandcareResearch n.d.). Ground conditions (percentages of bare soil and differing rock sizes) was added to the sheets for analysis. From this information a selection of species from the most common and/or with the greatest plot coverage, and an acknowledgement of root types will be used for trait research in Chapter 5.

3.2.1 Temperature

Temperature data were collected using HOBO® pro v2 weatherproof data loggers with two external temperature probes connected with 1.8m cables. The probes were placed approximately 2m up or down the slope from each other and 5cm into the soil. The probes were placed into soil that was relatively free of large stones on the surface. The data loggers were left insitu from 13 September until 14 October 2017, due to availability of the loggers. Only one data logger per wall was used due to availability.

3.2.2 Data analysis

Midpoint percentages were created from the cover classes prior to analysis as per Wiser and Buxton (2008) Table 3.1.

Table 3.1 Cover classes from Grassland Recce Sheet converted to midpoints for analysis.

Cover Number	Cover Range	Analysis Percentage
1	< 1%	0.5
2	1-5%	3
3	5-25%	15
4	25-49%	37
5	49-75%	67
6	75-100%	87.5

Microsoft Excel (Microsoft Professional Plus 2016) was used to analyse the species frequency and illustrate the relevant graph. The differences between the dams, aspect and species were analysed using one-way ANOVA with post-hoc Tukey (HSD) test. Statistical analysis was undertaken using Minitab® 18 (Minitab Inc. Sydney, Australia. Means (±SE) for each species, treatment and dam were calculated and illustrated by using SigmaPlot (Version 13, Systat software, San Jose, Ca) or Excel.

3.3 Results

3.3.1 Dam Walls

There was an average of 17460m^2 between the four dams (Table 3.2). The total wall length of the four dams varied from 1240m to 2820m. The slope lengths varied from 9.3m to 12.09m between the dams.

Table 3.2 Wall length, slope length and area (wall*slope) of the four dams used in this research. The dam top was walked with a GPS for measurement.

Dam	Top Circumference (m)	Slope (m)	Area (T*S)(m2)
1	1410	9.3	13113
2	2820	10.25	28905
3	1320	12.08	15945.6
4	1240	9.58	11879.2
Mean	1697.5	10.3025	17460.7

3.3.2 Plants on Dam walls

The plants identified on the dam walls were predominately common exotic plants that are often found in pasture, gardens and along roadside edges. There were only two native species found in the plots.

The six species with the greatest plot cover were *Agrostis tenuis, Dactylis glomerata, Cytisus scorparius, Rumex acetosella* and *Trifolium repens* (Figure 3.4). However the five most frequent species were *Agrostis tenuis, Cytisus scorparius, Dactylis glomerata, Plantago lanceolata* and *Rumex acetosella* (Figure 3.6).

There were 23 identified vascular plant species found on the dam walls. Eight other vascular taxa and mosses were unidentified (full list of species, see appendix C). The four dams shared similar plant assemblages with the exception of five species being absent from the north facing wall plots (*Cirsum vulgar, Echium vulgare, Lathyrus species, Lysimachia arvensis* and *Trifolium pratense*). Similarly *Dichondra repens*, *Geranium brevicaule, Jacobaea vulgaris, Digitalis purpurea* and *Leontodon taraxacoides* were not found within the plots surveyed on the south walls.

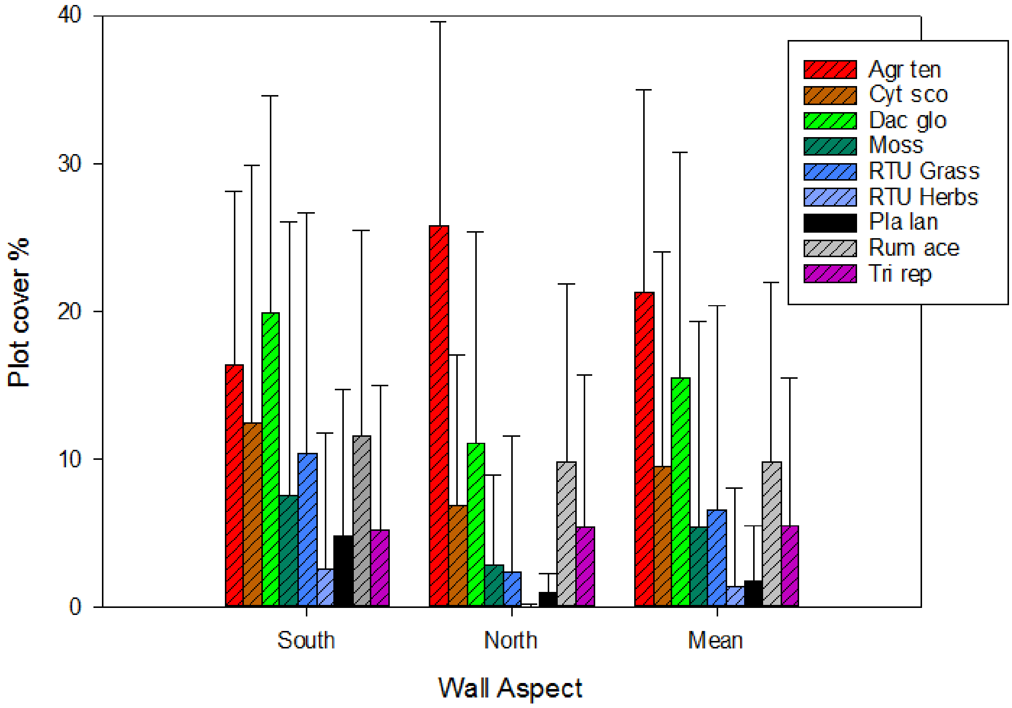

Figure 3.4 Species plot cover on dam walls with > 1% mid-point means and the overall mean of both walls (±SE). Plots (n=16 North, n=16 South) were 5 x 5 m, 10 m apart. Full list of species with codes, see Appendix A.

The results of the species richness and plot frequency were similar with *Plantago lanceolata* being in more plots than *Trifolium repens*. The species that had less than a 1% mean (Figure 3.4) in either north, or south facing walls are also those found in the least number of plots (Figure 3.6).

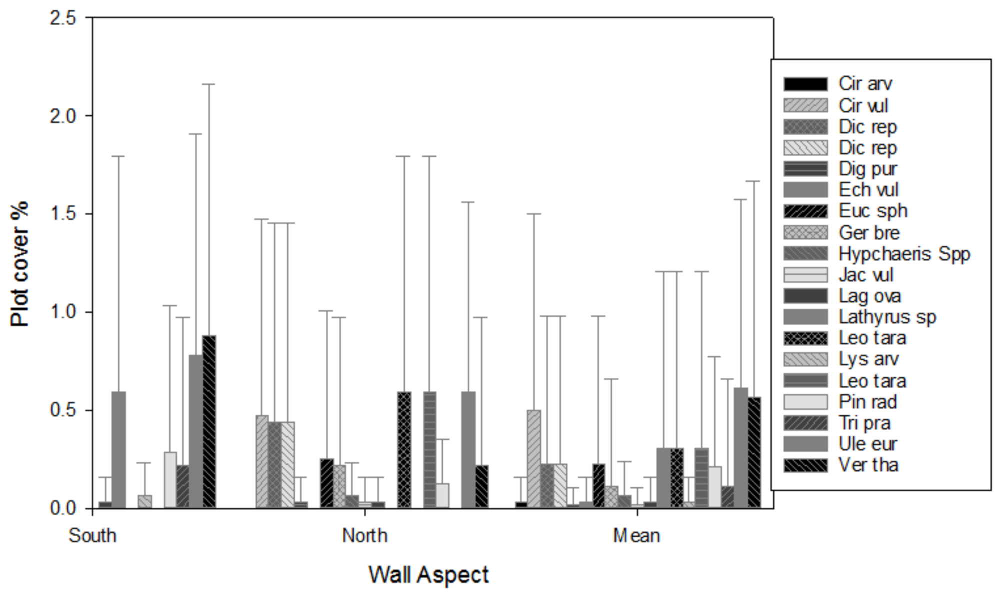

Figure 3.5 Species plot cover with a mid-point mean of <1% found on irrigation dam walls with mean of both walls (±SE). Plots (n=16 North, n=16 South) were 5 x 5 m, 10 m apart. Full list of species, see Appendix C.

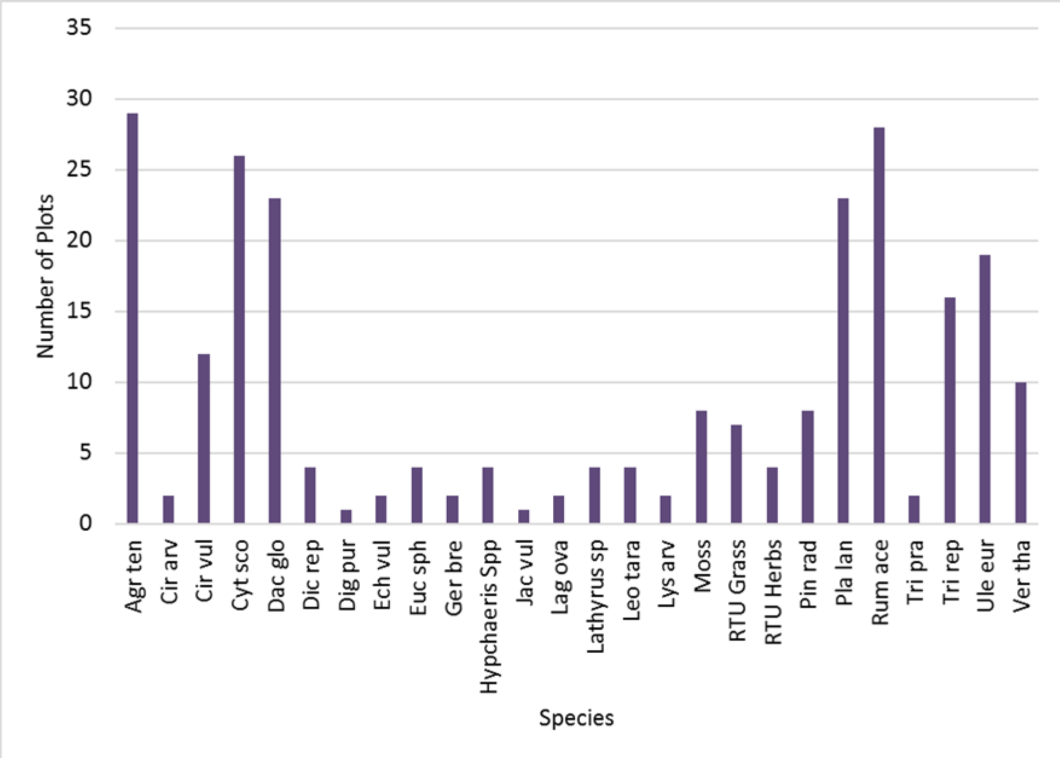

Figure 3.6 Number of plots in which each species was found in (n =32). Full list of species with full names, see Appendix C.

There were significant differences ($F_{7,31}$= 3.48; P=0.010) between species diversity on three of the dams aspects (Figure 3.8). The south aspects of Dams 1 and 2 had the same diversity mean, the highest out of all the dams, whereas the south aspect of Dam 3 had the least diversity. Dam 1 and Dam 4 were the only two dams with identified native species (*Dichondra repens*, *Geranium brevicaule*) on them, both species were on the North walls of dams.

There were no significant differences when the species diversity was compared to either dam or aspect.

There was no significant difference ($F_{8,31}$=0.55;P=0.807) when Species diversity was compared with altitude. The two highest species diversities of 12 and 13 were at a mean altitudes of 178m and 128m whereas the lowest species diversity of 5 and 6 were at altitude means of 168.3m and 157.7m. Dams 1 and 4 are below 140m, dams 2 and 3 are above 170m.

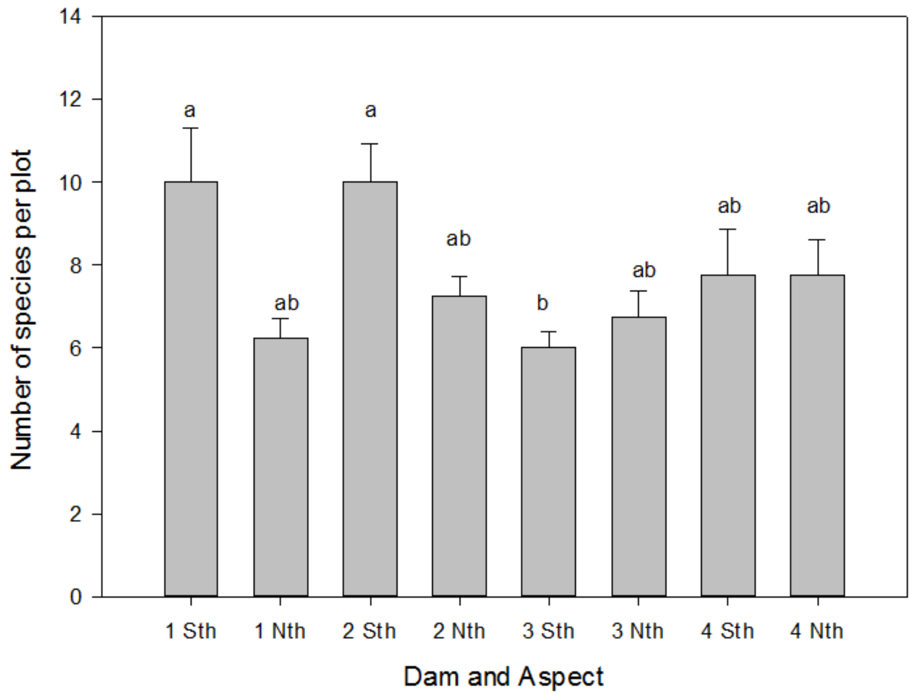

Figure 3.7 Species richness with Dam and Aspect. Number of species per plot mean values (± SE). The differences are significant ($p<0.05$). Letters represent differences using Tukey pairwise comparisons. n=4/dam and aspect.

There was no difference between dams and vegetation height. There was a highly significant difference ($F_{3,31}$=12.742;$P<0.001$) in vegetation height between dam walls and aspect (Figure 3.8). The Tukey pairwise comparisons imply greater differences within the north wall vegetation height means than the south walls. There is no significant difference when species diversity and vegetation height were compared ($F_{8,31}$=0.60;P=0.766).

There are significant differences between the ground conditions ($F_{4,159}$=64.75;$P<0.001$) but not when compared to the Dam and Aspect ($F_{7,159}$=0.33;P=0.939) (Figure 3.9). There are no significant differences between the seven species used for root research (Chapter 5) and individual ground conditions (Vascular- $F_{6,153}$=12.6:P=0.282, Non-vascular - $F_{6,153}$=1.06:P=0.386, Litter - $F_{6,153}$=0.59:P=0.0.736, bare soil- $F_{6,153}$=0.62:P=0.717 and rock - $F_{6,153}$=0.88:P=0.510).

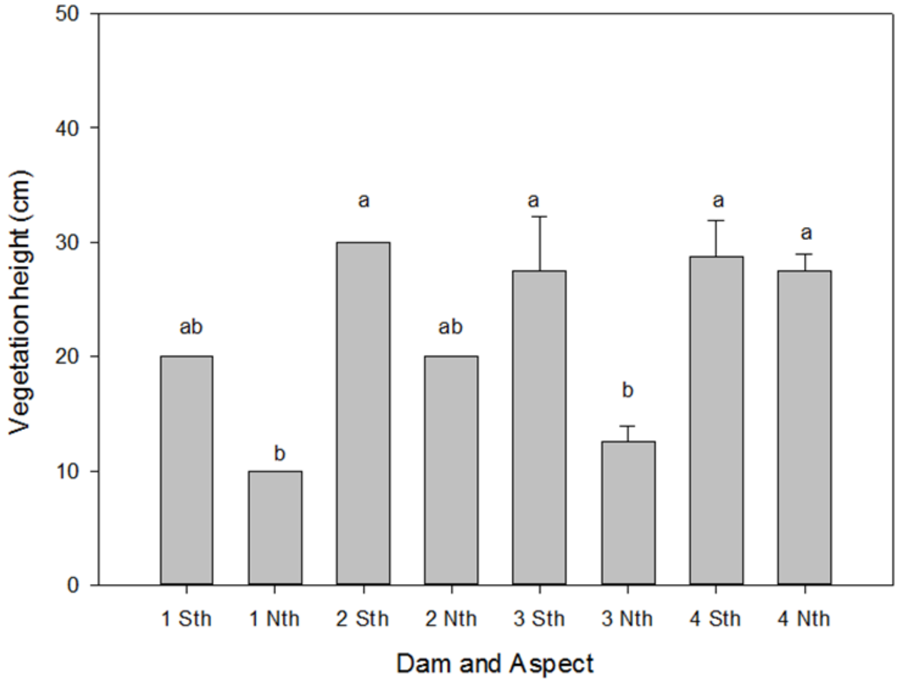

Figure 3.8 **Dam with wall aspect against vegetation height mean values (±SEM). There was a significant difference ($p<0.05$). Letters represent differences using Tukey pairwise comparisons. n=4/dam and aspect.**

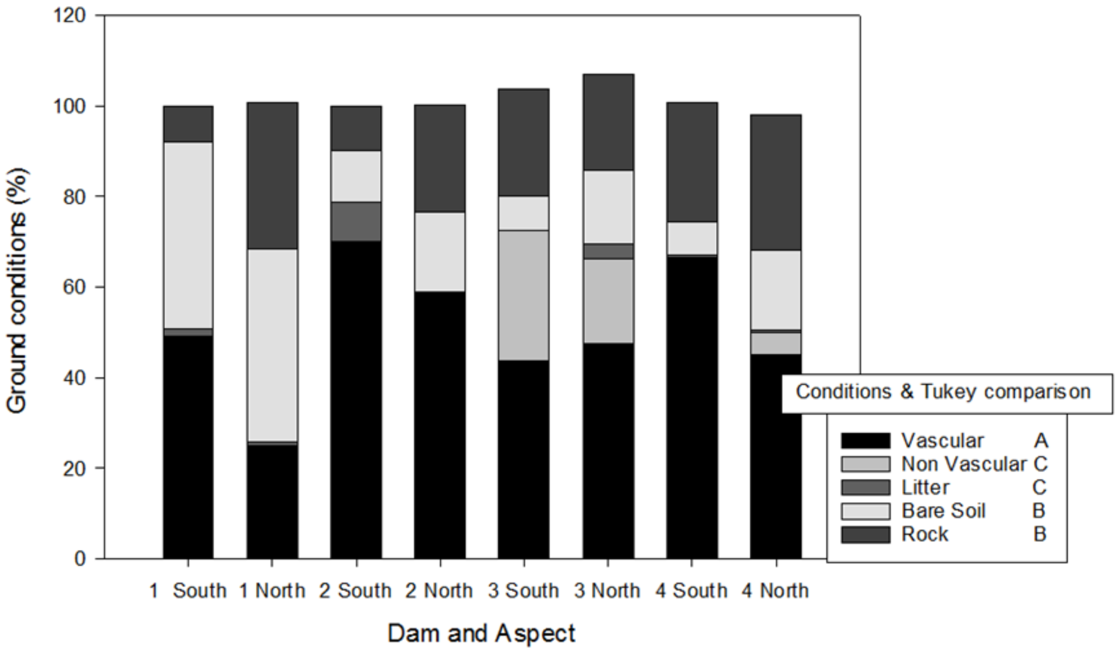

Figure 3.9 **Dam and aspect with Ground conditions in percentages. There were significant differences between the different ground conditions ($p<0.05$) but not for the dam aspects. Letters in the legend represent differences between the ground conditions using Tukey pairwise comparisons. n=4/dam and aspect.**

On the north wall of the dam soil temperature was high between 1300 and 1500 hours in the afternoon and low temperatures were between midnight and 8am (Figure 3.10). On the south wall the high temperatures were between 2300 and 0400 hours at night with the low temperatures between 1600 and 2000 hours. The 24 hour difference between the two wall's mean temperatures was 2.95°C. Statistical analysis were not completed due to the small sample.

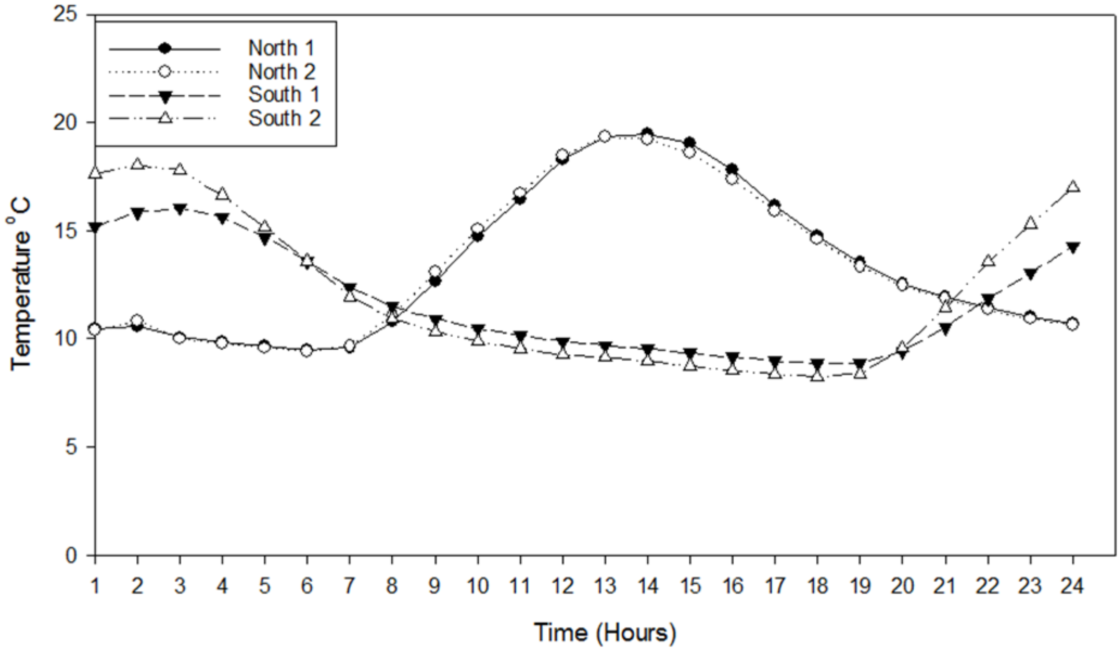

Figure 3.10 Soil temperature (°C) of North and South walls of Dam 1. Differences were not compared due to lack of replication.

3.4 Discussion of dams and species

3.4.1 Dam conditions

The height of the dam walls varied around the dam due to the natural landscape and depth of the dam. The walls are also interrupted by a water race (if race feed) and an overflow outlet for prolonged rain events. The differences along the walls is created by directional facing of prevalent weather, e.g. rainfall direction or wind, as well as wall height potentially creating different habitats.

The combination of dam and wall aspect did have significant effects on the species diversity found. This implies a need to consider both the dam and each walls aspect when considering planting zones. The dam and wall effects were not reflected in the comparison of altitudes of the dams, which ranged from 125m to 192m, to species diversity. The differences in the ground conditions of the plots did not appear to influence the seven species that were used for root trait research (Chapter 5). Other reasons for differences in species diversity that were not considered or limited in this research could include age of the dam, soil nutrient composition, soil temperature and the difference in rainfall as there appeared to be different weather patterns between the dams. The difference in rainfall may have created the difference in vegetation height which had significant difference when compared between the dam walls. Soil temperature is one abiotic aspect that was monitored for a month on one dam.

The soil temperature differences between north and south will have implications for plant species. The temperature differences along with shade and moisture differences could be used for the creation of planting zones.

There were limited differences between the dams in their species makeup. This limited difference could be due to all the dams sharing the same history. The speed at which the dams were created from land, that was pine plantation a year before the dams' creation, and being two to three years in age, would also limit the arrival of a wide variety of new species.

3.4.2 Species on the dams

Dactylis glomerata was the only species drill sown into the dam (B Giesen, pers. com. 7.06.2017). *A. tenuis* had similar percentages to *D. glomerata* in the quadrats. This could mean that either *A. tenuis* (Browntop) was in that seed mix or it had a high representation in the soil seed bank. The other species were either in the soil seed bank when the dams were made or have appeared through wind or animal dispersal from the wider area. All the species identified were in the surrounding landscape in recent PhD research (Dollery 2017a; b).

The range of species found on the dams included grasses, forbs, herbs and woody species. The range of plant types implies that a range of native species would be able to grow on the dams. The plant type limits being created for the health of dams will reduce this range to grasses, forbes, herbs and lianes. This was considered in Chapter 5 where the roots of the dam species were researched.

Through the combination of the plot cover and species frequency results six species were decided on for root analysis (Chapter 5). These species were *A. tenuis, C. scorparius, D. glomerata, P. lanceolata, T. repens*, and *R. acetosella*. *Verbascum thapsus* was added as it was known from previous experience that this species has an extensive tap root whereas none of the other species were known too.

3.4.3 Novel Habitat Protocol

To survey the dams the use of the middle point of the slope provided a means of surveying the middle of the dam walls for direct comparisons between all the dam walls. If the top five metres or bottom five metres were used this would provide direct comparisons between the tops or bottoms, although the height of the dam could influence species at the top. For the use of a protocol, defining the area(s) that is to be researched for the plant comparisons would assist with the zone definitions when planting; for example the differences in aspect or temperature. The 5 x 5 m quadrat would be the smallest quadrat that I would recommend due to spread of the both roots and shoots and the interactions between species. The shoots or above ground vegetation can provide shelter or a micro climate that other species require for growing conditions so need to be taken into account when surveying, see target species protocol Chapter 4. Surveying in different seasons would provide data of seasonal species.

Chapter 4 Rare species habitats

4.1 Introduction to rare species and current habitats

4.1.1 Canterbury

Less than 1% of Canterburys low land plains are believed to contain remnants of natural (non-planted or sown) native plants (Meurk et al. 2016). This is in part due to the introduction of exotic plants, changes in land use and fires –both natural and man-made (Brockerhoff et al. 2003; Brockerhoff et al. 2008; Gillespie 2010; Head and Given 2001; Pratt 1999; Rowarth et al. 2007; Walker et al. 2006; Wendelberger et al. 2008). These changes have reduced the extant of and changed the natural ecosystems that supported the plants of the Canterbury Plains. As part of this process native plants have been marginalised and those that have managed to remain are now possibly living in suboptimal conditions. Some of the original habitats may be surviving but are under threat from spreading exotic plants through bird, animal and wind seed dispersal or deliberate seed spreading.

4.1.2 Scientific reserves

Scientific reserves, such as Eyrewell Scientific Reserve (ESR) and Bankside Scientific Reserve (BSR), were created in New Zealand as it became obvious native vegetation remnant were disappearing due to landscape changes caused by farming and forestry (Molloy 1970; Molloy and Ives 1972). ESR was created in 1970 and BSR was created in 1972. Both sites had similar plant communities and surveys have been carried out on farms and forest plantations in their vicinity (Head and Given 2001; Norton and Lord 1992). Surveys have been undertaken since 2000 in both scientific reserves to discover which species remain, which have arrived or have disappeared (Bowie et al. 2016; Brockerhoff et al. 2003; Brockerhoff et al. 2008).

4.1.3 Plant classifications

The decrease in native plants in NZ has led to their classification as rare, threatened, at risk or not threatened. The classification is updated as new data is established. The Department of Conservation reclassifies New Zealand's vascular plants both in published papers and on websites every three years (De Lange et al. 2009; de Lange et al. 2013; LandcareResearch 2017a; New Zealand Plant Conservation Network 2016).

4.1.4 Aim:

The aim of the research in this chapter was to investigate where some of the selected rare plants are currently growing within the Selwyn, Christchurch, Waimakariri districts.

4.1.5 Objectives

- Identify rare species for a habitat survey and that are available from nurseries for a nursery experiment.
- Identify current habitats for the rare species,
- Identify the plants growing with the rare species,
- Identify other relevant conditions including; ground conditions, altitude, vegetation height and cultural indicators (current or historical land use).

4.2 Methods – Rare plants and current habitats

4.2.1 Rare plants – a desk study

The initial plant lists of both ESR and BSR were compared with surveys, for both sites, that have been undertaken since 2000 to discover which species remain, which have arrived or disappeared. This list was then compared with the most recent Conservation classifications for New Zealand's vascular plants both in published papers and on websites. A list of threatened, rare or at risk plants was created. This list was compared with nursery catalogues for stock availability for planting experiments. The nurseries considered included Motukarara Conservation Nursery, Wai-Ora Landscapes, Trees for Canterbury and Oratia Natives.

Each identified species has the following information recorded; family, describer, NZ classification status, genus distribution, species description, known species distribution and grazing information, if known, with references.

4.2.2 Habitats – a field study

Habitats for the chosen species were identified from Naturewatch, a website for plant identification in NZ, the National Vegetation Database (compiled by Landcare Research from previous surveys), and from members of the Canterbury Botanical society (LandcareResearch 2017b; Naturewatch 2017). Areas that have been identified previously as known habitats of at least one of the selected plant species were walked in a grid search pattern from side to side of the boundary. If the site of a species was known or obvious that was the starting point. Once one of the species was found a quadrat (5m x 5m, the same size as the dam plots) was created with the plant or one species group of plants in the centre. The plants within the quadrat were identified and percentages of cover for the different species were estimated using the Grassland Recce sheet (see Appendix D). The area immediate to that quadrat was then searched for further individuals or groups of that species until a maximum of five quadrates were completed in that area. Where possible the quadrats were to have 10 m between them. A minimum of 1m distance between quadrats was set if the plant was very rare e.g. *Leptinella serrulata.* If two species were found within the same quadrat the rarer species became the centre for the quadrat. I aimed for a total of 25 plots per species across five sites. Each site was no closer than one kilometre to another.

For recording purposes I used the Grasslands Recce sheet and cover system (Allen and Manaaki Whenua-Landcare Research New Zealand Ltd. 1993; Hurst and Allen 2007a; Hurst and Allen 2007b; LandcareResearch n.d.). Ground conditions (percentages of bare soil and differing rock sizes) were added to the sheets for recording.

The surrounding vegetation was identified to species level where possible. Plants I was unable to identify were identified by others, in person or through Naturewatch.org.nz where possible.

4.2.3 Data analysis

Midpoint percentages were created from the cover system prior to analysis as per Table 3.1 (Chapter 3). Differences between species and habitats were analysed using one-way ANOVA with post-hoc Tukey (HSD) test. Statistical analysis was undertaken using Minitab® 18 (Minitab Inc. Sydney, Australia. Means (±SE) for each species and habitat differences were calculated and illustrated by using SigmaPlot (Version 13, Systat software, San Jose, Ca).

4.3 Results

4.3.1 Rare Plants

The desk study revealed a list of 238 species that had been found in either ESR or BSR and their immediate areas since 1969. This list was reduce to 44 species that had been identified as rare, threatened or at risk species. The list of 44 was reduce to 16 that had been found either in articles or on Naturewatch.com since 2010 (Appendix B). This list of 16 was then reduced to five available through nurseries which were; *Aciphylla subflabellata, Coprosma intertexta, Leptinella serrulata, Muehlenbeckia ephedroide*s and *Raoulia monroi*. All are considered 'at risk' species and are either in decline or naturally uncommon. They are all South Island east coast species with *M. ephedroides* the only species that is also found in the North Island of NZ. The altitude range of all species is within the sea level to sub-alpine range. Below are individual descriptions of each species.

Aciphylla subflabellata W.R.B. Oliver (1956) (Umbelliferae/ Apiaceae)

Status - At risk, declining.

Aciphylla subflabellata (Figure 4.1)is one species of the 40 species in the genus *Aciphylla* found in New Zealand with two found in Australia (Radford et al. 2001). *A. subflabellata* used to be found from the coast to the mountains of the South Island, NZ, on the east side of the Southern Alps. (Oliver 1956). Currently it is mainly found in hilly or mountainous areas, as per below National Vegetation survey (NVS) map (Figure 4.2). This species was found at ESR in 1970 when the survey was carried out, but not found in that area on any of the following surveys.

Figure 4.1 *Aciphylla subflabellata* on Gibraltar Rock, Banks Peninsular, Canterbury, 14 June 2017.

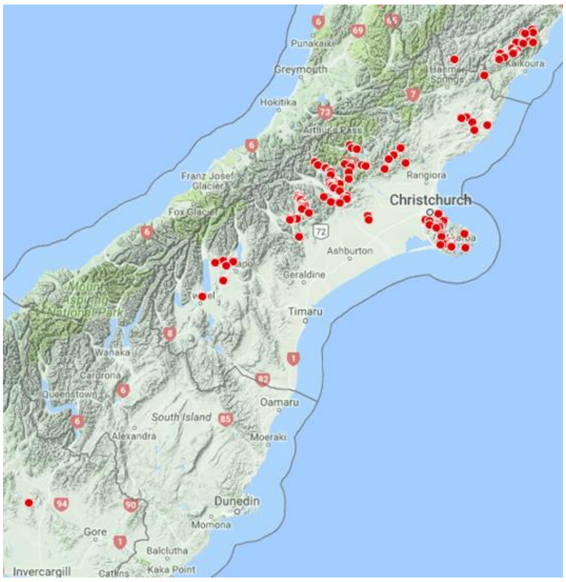

Figure 4.2 Sites of *Aciphylla subflabellata* found during vegetation surveys, 1960-2013. Map from National Vegetation Database (LandcareResearch 2017b).

Aciphylla subflabellata is described as forming dense rosettes that form on a stem up to 50cm long, the overall plant can be up to 1 m in height. The stem is up to 25 mm in diameter. The leaves are sub fan shaped, which is the definition for subflabellata, with a narrow sheath up to 2cm long that divides into 2- 4 ligules with leaflets up to 25cm long and 3mm wide (Allan 1961; Oliver 1956). The end of the leaves are very sharp and gave rise to the English name Spear grass.

Hares, rabbits and farm stock graze *A. subflabellata*.

<u>**Coprosma intertexta**</u> G. Simpson (1945) (Rubiaceae)

Status - At risk, declining.

Coprsoma intertexta is one of over 100 species of *Coprosma* of which approximately 50 are found in New Zealand, the rest are found throughout the Pacific from Australia to Hawaii, and the Java Sea

(Metcalf 2000; Wilson and Gallowy 1993). The leaves and branches in all *Coprosma* species are opposite. The *Coprosma* flowers are small, unisexual, and wind pollinated. Many of the species are difficult to identify as variation within species is considerable and involves both genetic and environmental factors. The presence and morphology of the stipule is often the main identification feature (Wilson and Gallowy 1993).

Coprosma intertexta is native to the South Island, NZ, being found east of the Southern Alps from Marlborough to Central Otago (Figure 4.3). There are limited patches of *C. intertexta* along fence lines in the Ashburton District and Lees Valley.

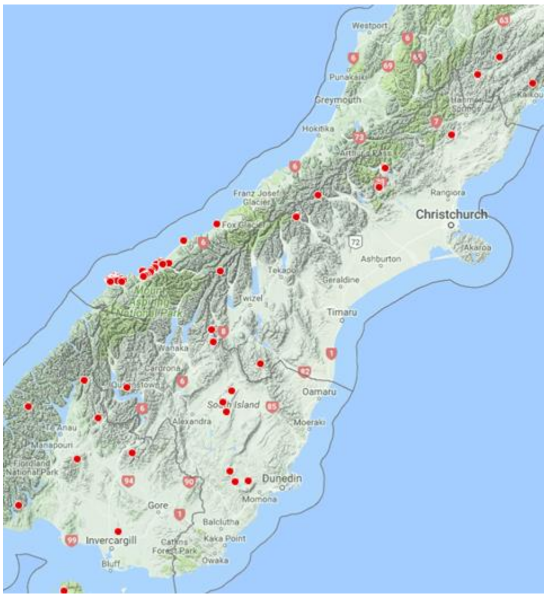

Figure 4.3 ***Coprosma intertexta*** **found during vegetation surveys, 1961-2014. The sites on the West coast may be for a *Coprosma* species that has an affinity to *C. intertexta* leading to misidentification. Map from National Vegetation Database (LandcareResearch 2017b).**

The species is a bushy shrub 2 m in height and width (Figure 4.4). The bark is grey-brown with new branches appearing orange-brown to grey-brown. The leaves are narrow and pointed, curving sideways with prominent red edges, sometimes hairy on the upper surface. The leaves are often in clusters. Stipules are small, short and roundly triangular with a hair fringe but lacking denticles (tooth like projections) at the tip. The fruit is white to pale blue, sometimes with a dark blue speckle, oblong in shape and 4-6 mm long. *Coprsoma intertexta* can be found in a variety of habitats from lowland to montane tussock lands in both wet and dry sites. The species flowers from as early as June although usually September to November, with fruit being produced from November (Allan 1961; Wilson and Gallowy 1993).

The berries of *C. intertexta* have recently been found to be an important late autumn and early winter source of food for kea (*Nestor notabilis*) (Greer et al. 2015; Young et al. 2012).

Figure 4.4 *Coprosma intertexta* in Lees Valley, Waimakariri, Canterbury.

<u>Leptinella serrulata</u> (D.G. Lloyd) D.G Lloyd et C. Webb (1972) (Asteraceae)

Status - At risk, naturally uncommon.

Leptinella is a genus with 33 species distributed from New Guinea to the sub Antarctic Islands and across to South America (Lloyd and Webb 1987). There are 24 species of *Leptinella* in NZ, 21 are endemic. *Leptinella serrulata* was previously known as *Cotula serrulata*. *L. serrulata* (Figure 4.5) is endemic to the east of the Southern Alps of the South Island, NZ. Although *L. serrulata* is found from Marlborough to Foveaux strait from the sea level to 1500 m it is predominately found in inland Canterbury and Otago. The preferred sites for *L. serrulata* are dry intermontane basins and river flats in open sites among the tussock grasslands (New Zealand Plant Conservation Network 2016). *Leptinella serrulata* has been recorded in large patches previously in Canterbury, but current knowledge is limited to Te Pirita, West Melton NZDF land and private land (Figure 4.6).

Figure 4.5 ***Leptinella serrulata*** **(the dark pinnate leaves circled to left of pen) at Te Pirita, Selwyn, Canterbury.**

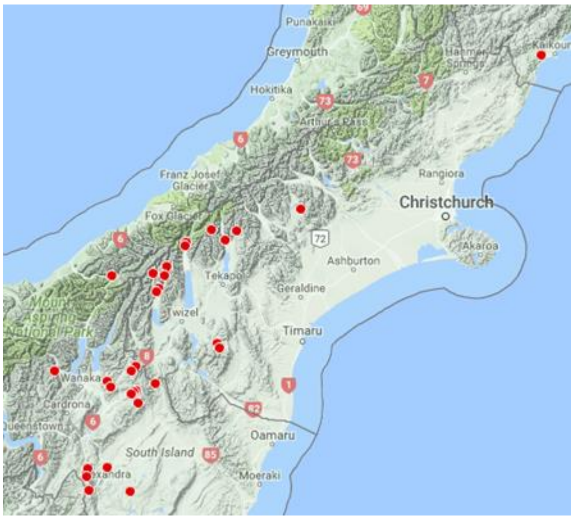

Figure 4.6 ***Leptinella serrulata*** **found during vegetation surveys, 1984-2013. Map from National Vegetation Database (LandcareResearch 2017b).**

Leptinella serrulata is a rhizomous perennial herb that forms small patches with tufts of leaves in open grassland. The pinnatifid leaves are 7-20 mm x 2-6 mm and are spirally arranged 5-15 mm apart. The leaf colour can be green to purple-black. The leaf is elliptic or obovate in shape. Roots are slender and weak, up to 0.4 mm in diameter. Flowers are yellow-green, 2-4 mm in diameter, and appear from September to November with some late flowering to January. Fruit is small (1.4 x 0.8 mm), round with a papery brown surface with one seed that appears from October to February (LandcareResearch 2017a).

<u>Muehlenbeckia ephedroides</u> Hook f. (Polygonaceae)

Status - At risk, declining.

Muehlenbeckia is a genus of 19 species with 16 species found in Australia, New Guinea and South America. In New Zealand five species are found, two of which are endemic. *M. ephedroides* is endemic to NZ (LandcareResearch 2017a; Wilson 1990).

Muehlenbeckia ephedroides is found from coastal to the montane in sandy and gravelly places including rock clefts (figure 4.7). It is an endemic plant found in both the North and South Islands, mainly on the eastern side of both islands from Lake Taupo, and Hawkes Bay to Southland. There were known specimens around Lake Taupo which are now believed extinct. *M. ephedroides* has small populations persisting in the North Island. While rarely common in the South Island, the decline is not considered obvious (New Zealand Plant Conservation Network 2016). The best known site in Canterbury is Birdlings Flat.

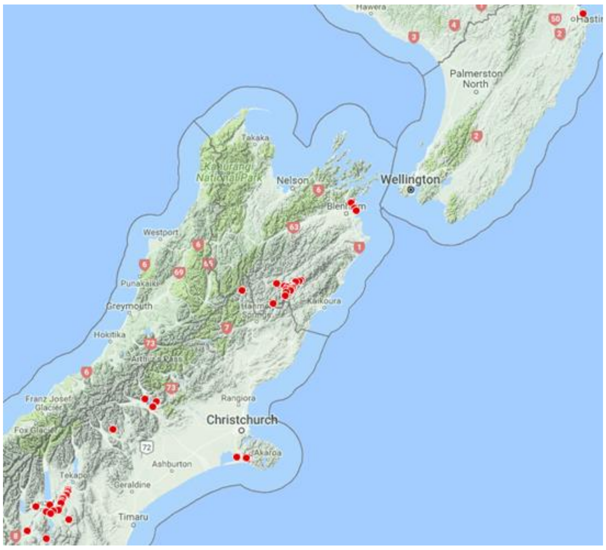

Figure 4.7 *Muehlenbeckia ephedroides* found during vegetation surveys, 1964 - 2013. Map from National Vegetation Database (LandcareResearch 2017b).

Muehlenbeckia ephedroides is a sprawling liane with many branches up to and over 1m long (Figure 4.8). The leaves which are few and far between, are narrow-linear, dark to greyish green mainly 5-10mm long occasionally up 25mm. Flowers are unisexual with sexes often mixed in same fascicle or raceme, occasional with perfect flowers present. The flowers are greenish white, flowering from November to June. The seed is ovid, black, 3x 1.5mm sitting in a half cup of fleshy, white fruit. The fruit and seed is found from November to June (Allan 1961; LandcareResearch 2017a).

Figure 4.8 *Muehlenbeckia ephedroides* on shingle beach at Birdlings Flat, 9 June 2017.

<u>Raoulia monroi</u> Hook.f. (1864) (Compositae)

Status - At risk, declining.

Raoulia is a genus of herbs, which are subshrubs. The forms of these herbs vary from mat forming to densely compact hummock-like shrubs. There are over 20 species in the genus with a few in New Guinea and the rest endemic to New Zealand. The leaves are small and usually very crowded on branchlets. The tips of the branchlets produce the flower heads with no ray florets (Metcalf 2000).

Raoulia monroi is currently found on the east side of the Southern Alps of the South Island, NZ, from the montane to the lowland (Figure 4.9). *Raoulia monroi* is known to be on Kaitorete Spit and in patches along the main rivers of Canterbury.

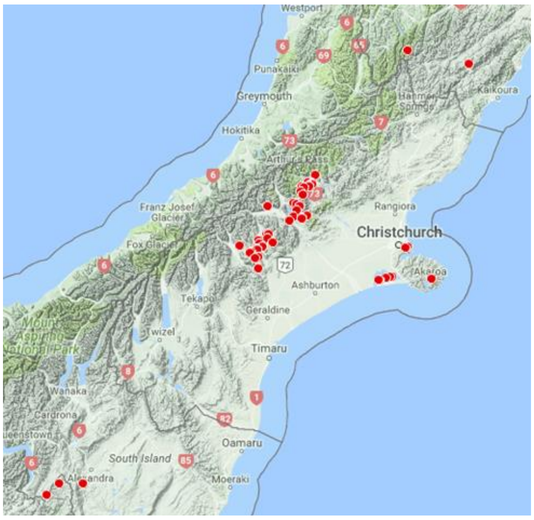

Figure 4.9 *Raoulia monroi* found during vegetation surveys, 1960-2012. Map from National Vegetation Database (LandcareResearch 2017b).

Raoulia monroi is unusual for mat forming *Raoulia* as the leaves (2-3 mm long, linear-oblong) are on a single plane appearing to have been flattened and are fan like in formation (Figure 4.10). The leaves are silvery grey in appearance, although they turn silver green when there is an increase in moisture. The flowers are pale yellow-green, and seeds are approximately 1mm (Allan 1961; LandcareResearch 2017a; New Zealand Plant Conservation Network 2016).

Figure 4.10 Winter closed fan like leaves of *Raoulia monroi* at Te Pirita, Selwyn, Canterbury.

4.3.2 Habitats

Most of the sites were in Selwyn and Waimakariri with the exception of sites in Ashburton and Hurunui districts (Figure 4.11) for *C. intertexta* to gain plots beyond the five I found in Lees Valley, Waimakariri. In total 94 plots across 22 different sites were completed; 20 - *A. subflabellata*; 14 - *C. intertexta*; 9 - *L. serrulata*; 26 – *M. ephedroides*; 25 - *R. monroi*. The sites in Ashburton district and Lees Valley were along road sides. Dagnum is an Environment Canterbury (ECAN) owned reserve on the north side of the Waimakarir River, West Melton is an artillery range owned by the NZ Defence Force and on the south side of the Waimakariri River to Dagnum. Te Pirita is on the north side of Rakia River and currently undergoing change of ownership from LINZ to DOC. Excluding the Ashburton and Lees Valley sites, all other sites are either DOC or ECAN reserves. Gibraltar Rock and Sugar Loaf are both hill tops on the Port Hills, with the exception of Bridlings Flat - a shingle beach, and Kaitorete Spit - a lake edge, all other sites are river terraces of varying ages.

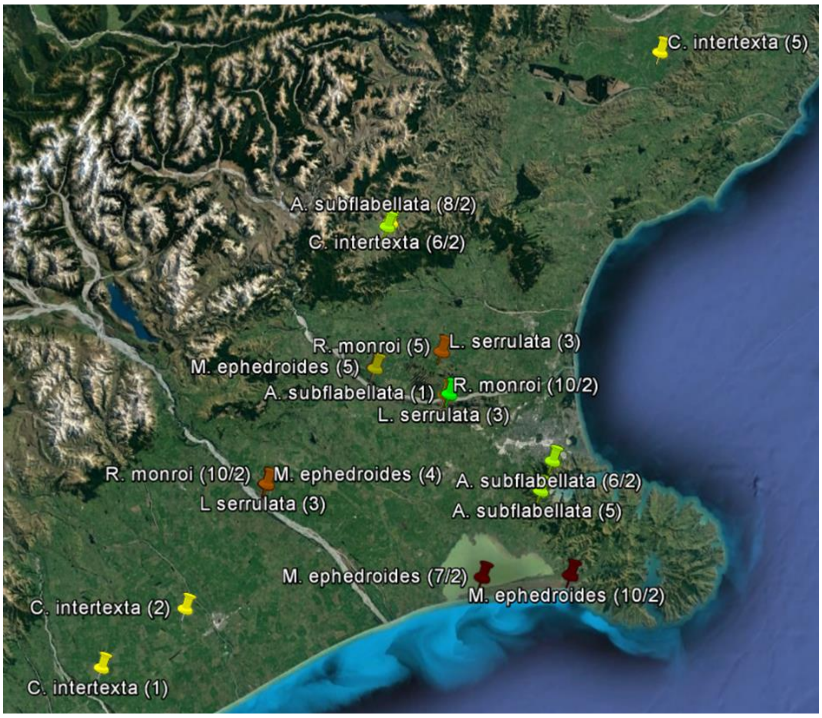

Figure 4.11 Sites across Canterbury were the species were found. Numbers indicate number of plots/number of sites. If there is no number for that site only one site was in that vicinity. Created using Google Earth.

There was a significant difference between plot cover by the five rare species with *M. ephedroides* ($F_{4, 465}$ =12.38;$P<0.001$) covering the largest mean area within plots (Figure 4.12). *Muehlenbeckia ephedroides* and *R. monroi* were the only two rare species found in any of the other rare species plots. *Muehlenbeckia ephedroides* was found in one *R. monroi* plot and *R. monroi* was found with both *M. ephedroides* (4) and *L. serrulata* (6) plots.

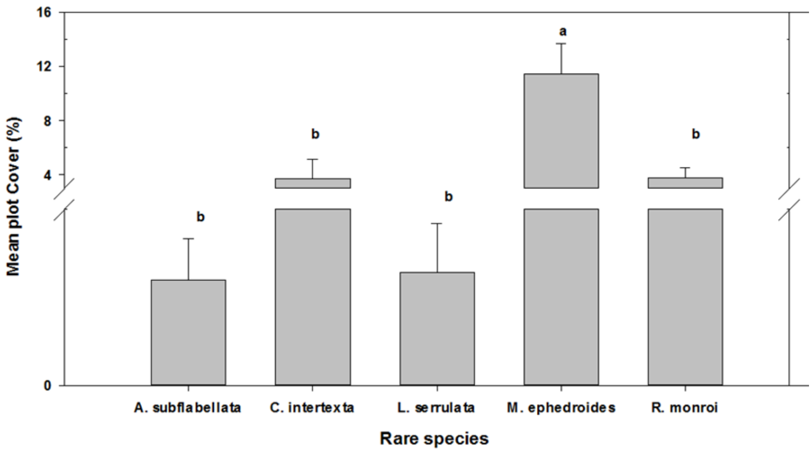

Figure 4.12 Mean plot cover by the rare species across plots they were found in (±SE). This includes plots in which they were not the target species it was centred on. There is a significant difference (p<0.05). Letters represent differences. Scale break is between 1-3 %. Plot size = 5 x 5 m.

The altitude range of the rare species was over 400m with all the habitats overlapping (Figures 4.13 and 4.14) Altitude ranged from 107m to 481m for *A. subflabellata*, 118m to 437m for *C. intertexta*, 103m to 186m for *L. serrulata*, 2m to 192m for *M. ephedroides*, and 96m to 196m for *R. monroi*. There is a significant difference between the species ($F_{4,93}$ =58.26; P<0.001). All species are different using Tukey pairwise comparisons with only *L. serrulata* overlapping with *R. monroi* and *M. ephedroides* which are also ground covers (Figure 4.14).

Figure 4.13 Examples of study sites. Left *Muehlenbeckia ephedroides* at sea level (Birdlings Flat). Right *Aciphylla subflabellata* at 481m (Gibraltar Rock).

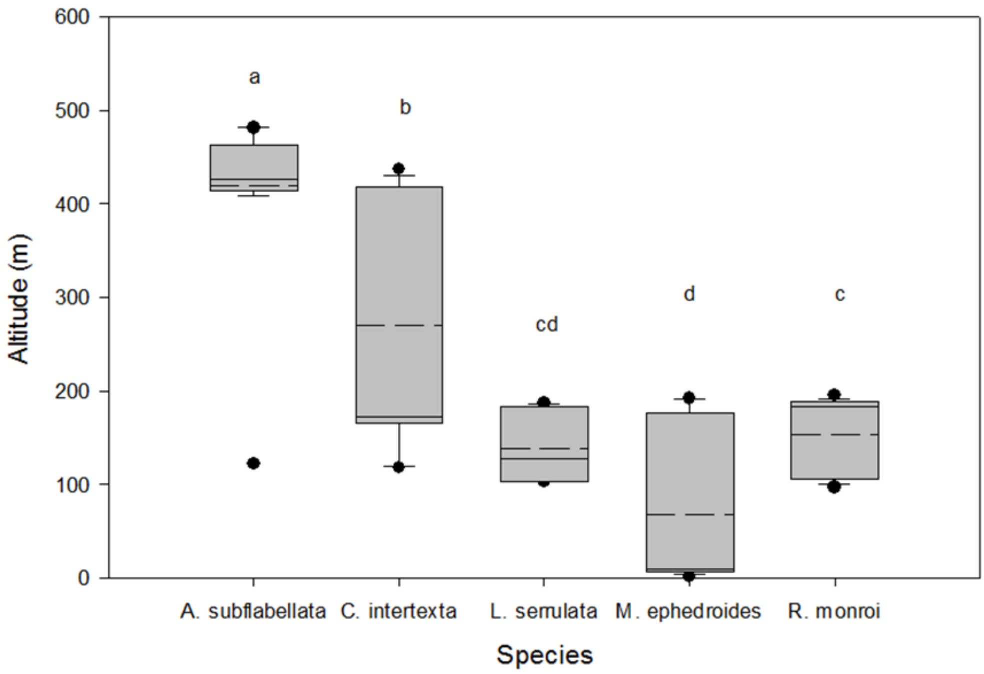

Figure 4.14 Box plot of altitudes where rare species were recorded (±SE). There is a significant difference between species (p<0.05). The letters represent differences. The solid line is the median line, long dashes the mean, solid circles 5th and 95th percentiles.

The recorded ground conditions (Figure 4.15) were significantly different between vascular cover ($F_{4,93}$=630;P<0.001), non-vascular cover ($F_{4,93}$=19.89;P<0.001) and litter cover ($F_{4,93}$=4.59;P=0.002) between the species however there was no significant difference for bare soil and rock cover.

Aciphylla subflabellata plots were dominated by vascular plants and had the least amount of non-vascular plants in its plots with no plot having more than 2%. The rocks in *A. subflabellata* plots were the largest found in any plots with 11 of the 20 plots having rocks over 100mm covering at least 50% of the bare ground. *Coprosma intertexta* was dominated by vascular plants although 3 plots had less than 50% cover. There were 9 *C. intertexta* plots with bare soil or rocks. *Leptinella serrulata* had both vascular (61.67% mean) and non-vascular (25% mean) cover in all plots. One *L. serrulata* plot did not have either bare soil and/or rock cover. *Muehlenbeckia ephedroides* had closer vascular (56.53% mean) and non-vascular (27.5% mean) cover than the other species. Seven *M. ephedroides* plots at Birdlings Flat had no non-vascular cover. 15 of the 26 plots for *M. ephedroides* had bare soil or rocks within the plots. *Raoulia monroi* had non-vascular cover (39.8% mean) in all its plots. There was also bare soil or rocks in all *R. monroi* plots.
Cultural indicators varied from none, through historical grazing to current grazing with some disturbance from logging (2 plots *L. serrulata* at one site) and burning (4 plots *A. subflabellata* at one site). *R. monroi* was the only species to have a form of disturbance in all its plots.

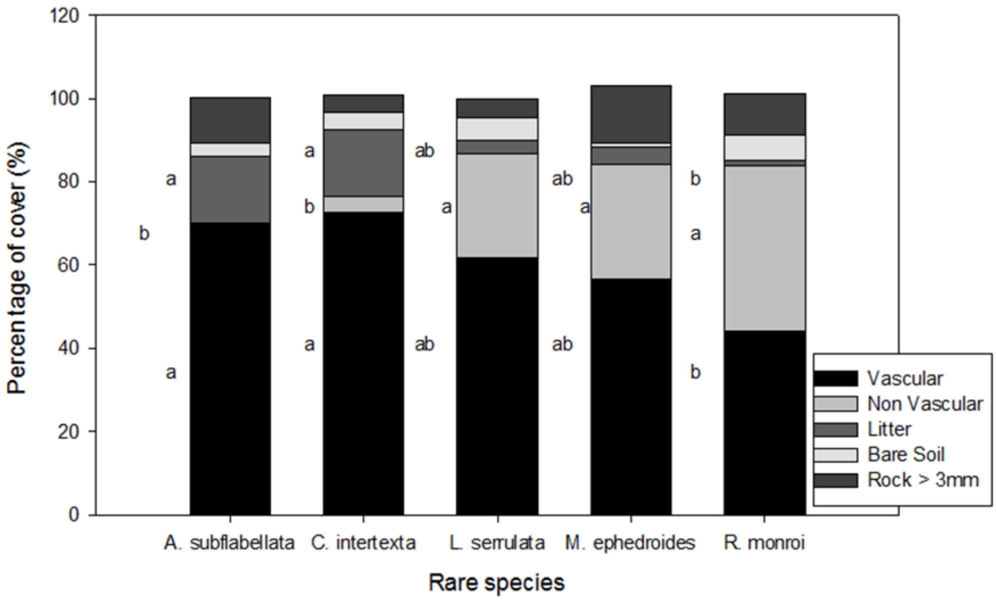

Figure 4.15 Mean ground conditions of the rare species plots based on percentage of cover to 100% of each plot. There was no significant difference between the species. The letters beside the bands of vascular, non-vascular and litter provide differences.

During the identification process over 90 different taxa were found with 74 identified to species level. There were over 36 species were found in the *A. subflabellata* plots with 36 identified (23 exotic, 13 native). Over 35 species in the *C. intertexta* plots with 33 identified (20 exotic, 13 native). Over 38 species in the *L. serrulata* plots with 36 identified (21 exotic, 15 native). Over 51 species in *M. ephedroides* plots with 50 identified (27 exotic, 23 native). Over 41 species in the *R. monroi* plots with 38 identified (19 of each).

There is a significant difference ($F_{4,93}$=13.44;P<0.001) between mean diversity found in the different rare species plots (Figure 4.16). The differences divided the species into two groups with *L.serrulata* and *R. monroi* seperating from the remaining three. *Aciphylla subflabellata* and *M. ephdroides* had plots with the least amount of diversity found, 4 and 5 respectively. *Leptinella serrulata* and *R. monroi* had plots with the greatest diversity, 17 and 15 respectively.

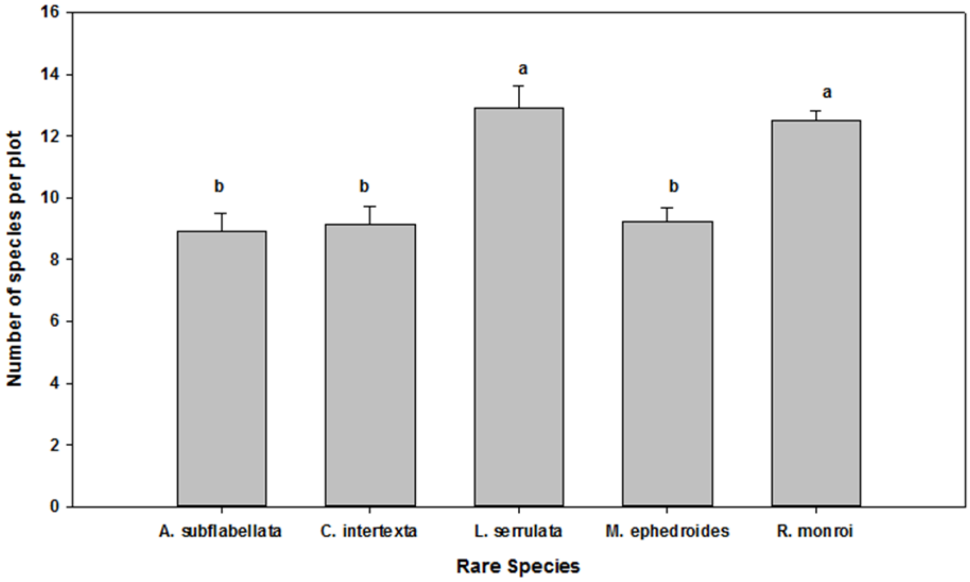

Figure 4.16 Species diversity in rare species plots (±SE). There is a significant difference between the species (p<0.05). The letters represent differences. Plots size = 5 x 5 m.

Six species were found in at least one plot with each of the five rare species (Figure 4.17). They were *Acaena agnipila* (24 plots), *Agrostis tenuis* (62 plots), *Festuca rubra* (21 plots), *Holcus lanatus* (46 plots), *Leucopogon fraseri* (33 plots) and *Rumex acetosella* (50 plots). Not one of these six species was found in every plot. Moss and lichen occurred in at least one plot with each rare species but as they were not identified to species levels were not included. *Leucopogon fraseri* was the only native species to appear in at least one plot of all the rare species. Species of Asteraceae (58 plots) were found with every rare species, but as many were not identified to species level are not included. The reason that many Asteraceae species were not identified to species level was due to size of the plants found i.e. seedlings. There are significant differences between the rare species for each of the common species; *A. agnipila* ($F_{4,93}$=2.83;P=0.029), *A. tenuis* ($F_{4,93}$=3.06;P=0.021), *F. rubra* ($F_{4,93}$=3.23;P=0.016), *H. lanatus* ($F_{4,93}$=2.86;P=0.028), *L. fraseri* ($F_{4,93}$=5.73;P<0.001) except *R. acetosella* ($F_{4,93}$=2.07;P=0.092).

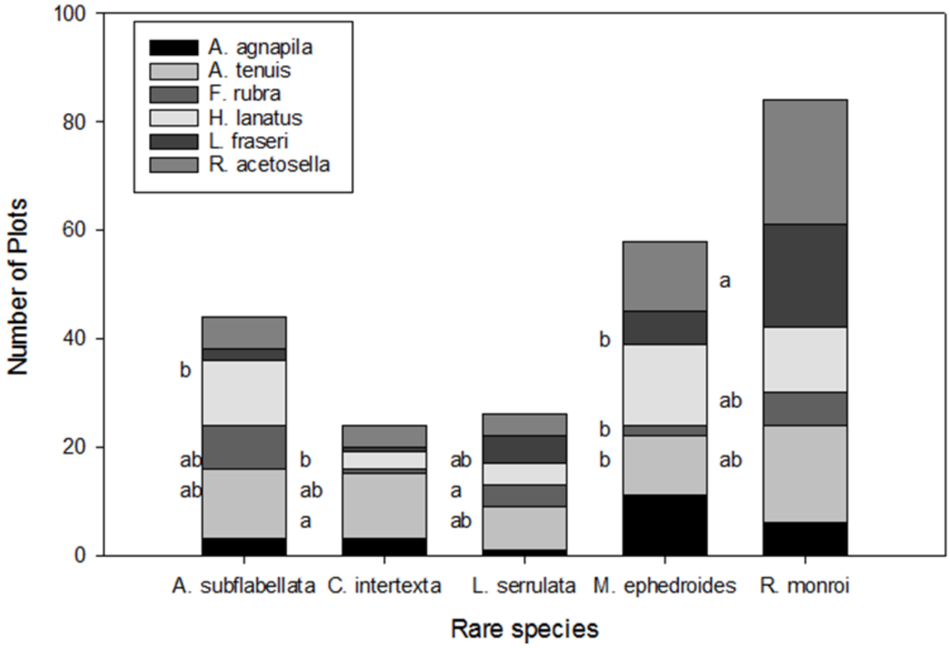

Figure 4.17 **Common species found in at least one of the every rare species plots. The plots can be counted multiple times due to several of these species being found in any one plot. There are significant differences (p<0.05) between the rare species for each of the common species found except *Rumex acetosella*. The letters represent differences for *Agrostis tenuis, Festuca rubra*, and *Leucopogon fraseri* using Tukey pairwise comparisons. Plot size = 5 x5 m.**

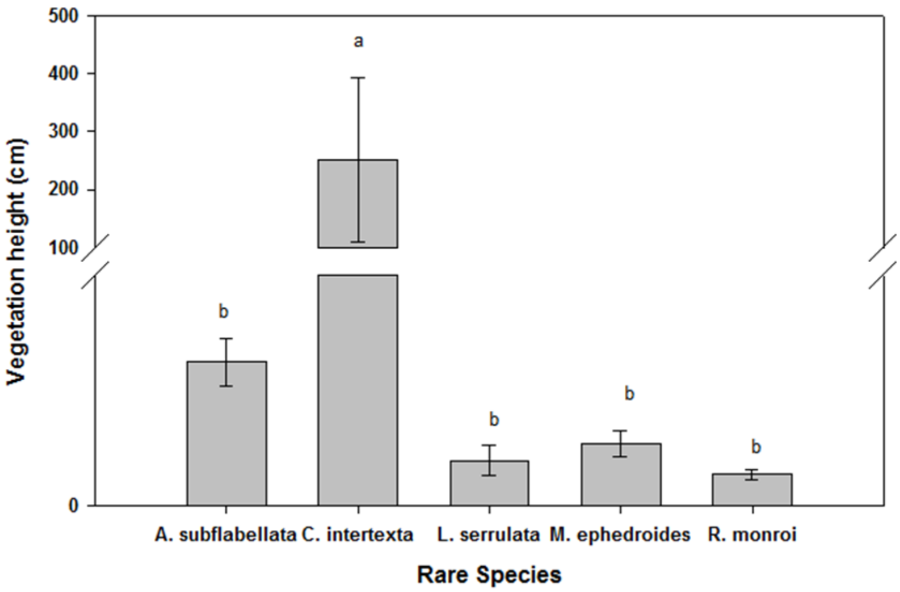

Figure 4.18 **Plot vegetation height means (cm) of the species within the plots surrounding the rare species (±SE). There is a significant difference between species (p<0.05). The letters represent differences using Tukey pairwise comparisons. The scale break is between 30 -100 cm.**

Vegetation height of all the species within the plots varied between rare species with *C. intertexta* having the tallest vegetation across their plots (Figure 4.18). There were significant differences between the rare species ($F_{4,93}$=4.28;P=0.003). *Coprosma intertexta* with a mean vegetation height of 251 cm was the only species to be significantly different (P<0.001). All the other species have mean vegetaion heights below 18 cm.

4.4 Discussion of rare species and current habitats

4.4.1 Rare species

There were numerous name changes of species in the creation of the plant lists due to reclassifications of names since 1969. Fortunately both NZPCN and Landcare Research carried synonyms for species (LandcareResearch 2017a; New Zealand Plant Conservation Network 2016). The reclassifications continued in the changes to threat status as the NZ Threat Classification System (NZTCS) was updated to more accurately reflect the NZ insular rarity of its species as well as updated between the different articles used, again these were available through NZPCN (2016) and Landcare Research (2017a) (De Lange et al. 2004).

Initially it appeared that specimens would be easily bought from nurseries. However the previous three years had been drought years in Canterbury reducing the amount of seed available for collection and germination. The main reason I ended with up with five species was searching for the species at the end of March which meant that most of the species were either bought or pre-ordered for restoration projects.

4.4.2 Habitats and species

Aciphylla subflabellata appeared to be partially protected by tall grasses that could reduce grazing, although as I did not find any young plants on either of the Banks Peninsular sites this suggests that the tall grass reduces the ability of seed to germinate and/or survive due to competition. Lees Valley was the only area where I saw a variety of ages. There were signs of grazing on many of the *A. subflabellata* but it was light in comparison to the size of the plants involved.
I travelled the farthest to find and survey *C. intertexta.* There are no known sites in the Selwyn district. The only sites known in the Waimakariri district were in Lees Valley and Dagnum. Dagnum plants were identified in 1992 (Norton and Lord 1992). I took cuttings from the plants identified as a *Coprosma* species at Dagnum as they looked different to other *C. intertexta* and had them identified by D. Glenny at Landcare Research where they were identified as *C. rugosa*, this specimen was handed on to the Allan Herbarium (tag no. TBC). Of four other sites that I was advised of in the

Ashburton District near Ealing only one plant still remained, the others had either succumbed to fence line poisoning or road works. Ashburton District Council with the help of Forest and Bird had fenced off two sites of *C. intertexta* near Frasers Rd which are closer to the town of Ashburton (Figure 4.19). Apart from two plots all the *C. intertexta* were found growing in groups, this habit is not stated in any of the books or websites used for identification although it is a common occurrence in other *Coprosma* species

Figure 4.19 *Coprosma intertexta* fenced from road and farmland on Winslow Westerfield Rd, Ashburton district.

Muehlenbeckia ephedroides was the easiest species to find and appeared to be sustainable on Kaitorete Spit and around Birdlings Flat, although the grazing in some of the paddocks gave plants a large stem with few branches (Figure 4.20).

Figure 4.20 *Muehlenbeckia ephedroides* at Kaitorete Spit with effects of grazing.

Raoulia monroi was found in patches that held multiple plots in both Te Pirita and West Melton. At Dagnum *R. monroi* was scattered and more difficult to find with higher surrounding vegetative growth. I was unable to find any at Kaitorete Spit sites, a site that had been suggested as *R. monroi* had been found there in 2016 in small patches.

Leptinella serrulata was the hardest species to find. I did not find any at ESR although *Leptinella* was there it was identified as *L. squalida.* Dagnum had been an area that was identified as having *L. serrulata* in 2013 again I was unable to find any even though I was given clear directions as to where to find it. In both of these sites the exotic vegetation height could be the reason of its apparent disappearance. The site at Te Pirita had only been identified in the last two years as having *L. serrulata* and then only as one or two small plants by the Canterbury Botanical Society. I was able to extend the population found at Te Pirita. The *L. serrulata* population at Te Pirita, like the population at West Melton, was confined to an area approximately 20 m long and less than one m wide. It has been suggested that this could be one plant (J. Butt, pers. Comm. 2.17). The three plots in two QEII covenants at NHL on Eyredale Rd provided two different forms (Figure 4.21). One plot was under a Kanuka remnant and had a more open green form while the other two plots were in grassland that was recovering after the Kanuka was bulldozed, with the smaller brown form.

Figure 4.21 Differences of form in *Leptinella serrulata* at NHL. Left under Kanuka, right in grassland.

The varying ground cover of the rare species implies that some would grow better together than others as shown with *M. ephedroides* and *R. monroi* found in each other's plots with *R. monroi* also found in *L. serrulata* plots. Both *C. intertexta* and *A. subflabellata* have the ability to grow above the other species so could be suitable to mix the species together allowing for height changes over time. *Muehlenbeckia ephedroides* is the only species that has the ability to out compete the other species based on its growth form of large mounds, although both *A. subflabellata* and *C. intertexta* would be able to grow through it once established.

4.4.3 Habitats compared

The altitudes of the different plots all overlapped so there would be no issue with altitude limiting the use of any of these plants. The species historic distribution was from sea level to sub-alpine for all species which is reinforced by these results.

The differences in ground cover, although significant for vascular, non-vascular and litter, overlapped between the rare species. The higher percentage of vascular cover for *A. subflabellata* and *C. intertexta* could be related to the road sides and open fields they were found in with a slightly lower species diversity. Nearly all the plots of the other three rare species were historically grazed with a higher diversity of species found.

The use of the species co-occurring with rare species as indicator plants is possible if they are found growing in novel habitats, in this case dams. Many of the species were found in at least one other rare species plots. When compared to the dam results only three of the species found on the dams were not found in any of the rare species plots (see Appendix C).

As mentioned earlier the height of surrounding vegetation has an impact on germination and survivability of species. Four of the rare species were surveyed in vegetation with mean heights below 18 cm (*A. subflabellata*) with *L. serrulata*, *R. monroi* and *M. ephedroides* below 6 cm. This implies that ground covers would be the best species to plant the rare species with to increase recruitment.

4.4.4 Target species protocol

In comparison to the protocol suggested for the novel habitat, Chapter 3, when the rare or target species are being surveyed if they cover the quadrat the next step would be to repeat the survey with part of the plant in the quadrat (Figure 4.22). If half the target species is in the quadrat this will capture the plants growing around the plant as well as the plants growing through or underneath the target species.

Figure 4.22 Differences to consider when surveying target species. Left; full quadrat survey of *Coprosma intertexta* with target species covering quadrat. Right; edge survey of *Coprsoma intertexta.*

Chapter 5

A comparison of rare plant roots and roots of plants growing on dam walls.

5.1 Roots

Roots are increasingly recognised for their importance in plant development and ability to grow in unfavourable conditions (Ober and Sharp 2007; Robinson 2004). The changes in soil composition created by earth dams may have made this a marginal area for the recruitment of many plants as their roots are unable to establish fully. Through comparing root measurements between species and habitat researchers are able to observe traits that can be affected by environmental stress. Knowledge of root traits could assist in placing plants in areas more suitable for growth or enable the use of marginal areas that may be able to support plants previously considered unsuitable. Certain root traits such as root diameter and root volume, could indicate the plants potential usefulness in slope retention and drainage capacities either to increase or help reduce drainage e.g. *Phormium tenax* roots will increase drainage (Franklin 2014). By comparing the roots of plants that currently grow on these dams with the roots of native plants chosen for the pot trials I hoped to clarify whether the native plants will be able to grow and successfully colonise the dam walls.

5.1.1 Root traits

Root are acknowledged as being more complex than leaf traits (Eissenstat 1991; Eissenstat et al. 2015). This complexity is due, in part, to their abilities to form mycorrhizae associations, adaptations to differences in soil fertility, and soil moisture content that are not viewed in above ground vegetation (Kramer-Walter et al. 2016; Larson and Funk 2016; Padilla and Pugnaire 2007; Ryser 1996). The following traits were considered for this study: root diameter, volume, Specific Root Length (SLR), root to shoot ratio and tissue density.

The smaller a root diameter the less likely that plant will cause erosion or drainage channels on a dam (NZSOLD 1997). The ability of a plant to forage for nutrients is consistently associated with the diameter and SRL (Eissenstat et al. 2015; Kramer-Walter et al. 2016; Larson and Funk 2016). The higher the SRL the high the rates of nutrient uptake. Roots in low fertility soil often have a combination of high SRL and small root diameter (Kramer-Walter et al. 2016). The volume of a plants root system can indicate the usefulness of the plant for erosion control and its ability to retain water (Eissenstat 1991; Mickovski and van Beek 2009). Plant drought tolerance or sensitivity is indicated by the Root to Shoot ratio (R:S) (Lloret et al. 1999; Padilla and Pugnaire 2007). The higher the root mass in comparison to the shoot mass the increased ability of the plant to access or retain water.

A positive relationship to longevity with a negative relationship to foraging is indicated by root tissue density (Holdaway et al. 2011; Sun et al. 2016). A slow growth strategy in infertile soil by plants is also associated with density (Kramer-Walter et al. 2016). Density is measured by dividing root mass by root volume.

Through combining these traits, a comparison of the rare native species to the dam species, ability to survive on the dams will be considered.

5.1.2 Aim

The aim in this chapter was to find out if the roots of four rare native species were comparable with the seven established dam species.

5.1.3 Objectives

1. To compare root diameter and volume between rare species and those currently growing on the dam from the perspective of dam wall protection.

2. To compare Specific Root Length (SRL), Density and root to shoot ratio for root traits between the rare species and those currently growing on dams.

5.2 Methods for measuring root traits

5.2.1 Dam species selection

Dam plant species found to both cover the largest areas in the dam plots and be in the most dam plots were used for this experiment (Figure 5.1). The six species were decided on were *Cytisus scorparius, Plantago lanceolata, Trifolium repens, Agrostis tenuis, Dactylis glomerata* and *Rumex acetosella.* A species from the dam species with a known tap root was used to offer possible difference to the unknown root forms of the other species. *Verbascum thapsus* was added as it was known that this species has a substantial tap root.

Three individuals of each of the seven dam wall species were carefully excavated from the reserves at Eyrewell to preserve as much root mass as possible. The Eyrewell reserves were used as all species had been surveyed in the areas previously (Dollery 2017a). The reserves were used instead of the dams for maximum root growth in similar soils and climatic conditions and to not affect the dam wall integrity. Individuals with small shoots were chosen to increase the likelihood of removing the majority of the root system from the soil. The size of the individual root system will impact on root volume but none of the other measurements will be affected. The other measurements are based on mass in comparison to the amount of roots measured and do not require the whole plants root system as they are relative measures.

Figure 5.1 Excavated plants of three of the dam species studied. Clockwise from top left: *Trifolium repens, Rumex acetosella* and *Verbascum thapsus.*

5.2.2 Rare species

Four of the five rare species decided on were able to be sourced from local nurseries; *Aciphylla subflabellata, Coprosma intertexta, Leptinella serrulata, and Raoulia monroi.* Due to searching for these species late in the restoration season there were limited numbers available and I was able to purchase 10 individuals of each species. The *C. intertexta* was grown in 250 ml pots from Motukaraka nursery and were approximately 1 year old, the others were from Trees for Canterbury in 1 L pots and were 1-2 years old. Nursery plants were used as these species are at risk.

Two different pot heights were used due to the long root length of *A. subflabellata* which had an average of 424 mm. *A. subflabellata* was planted in tubes measuring 1.2 m x 250 mm diameter with a volume of 0.0589m^3 per plant. For the other three species the pots used were 380 mm high x 297 mm internal diameter (average, as these walls have a slope) with a volume of 0.0263 m^3. When transplanting the rare species as much potting mix was removed as possible without extensively damaging the root systems.

The stony alluvial soil from Eyrewell was sieved to remove any stones or rock over 3cm in length or diameter prior to filling the pots. The soil was compressed every 150 mm to replicate the dam walls (Figure 5.2). The top of the soil was covered with 3cm of sandy silt. Each pot contained a single plant. The pots were kept outside for increased root development over the colder months (Poorter et al. 2012c). The tubes containing the *A. subflabellata* were covered with a thin black plastic to reduce direct sunlight effects on root development due to the tube being clear (Figure 5.3). The plants were grown in these containers for six months. The pots were stood in shallow trays to represent the water from the dam and were not watered by hand. This was due to the high rainfall Lincoln had over this time.

The temperature was measured in the pots using the same equipment as for the dam walls over three months.

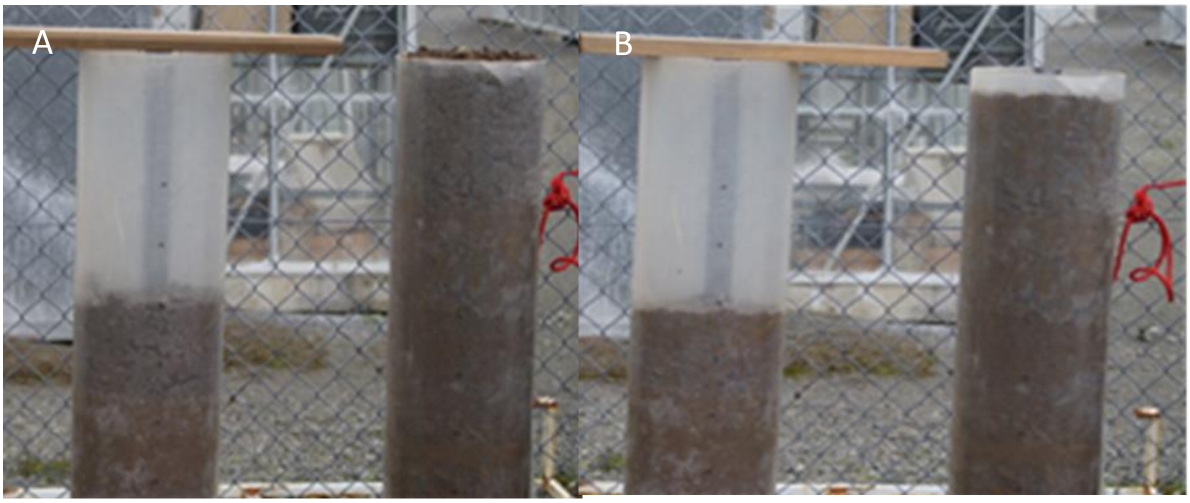

Figure 5.2 The process of compressing the soil for the rare plants. A -Tubes before soil is compressed. B - Soil level after compression. Note the change in level visible in B. One of the compression tools is on top of the tubes.

Figure 5.3 16 of the final 40 pots. *Raoulia monroi* in front, *Leptinella serrulata* second row, *Coprosma intertexta* third row with *Aciphylla subflabellata* at back in tubes.

After six months the roots (Figure 5.4) were harvested, washed to remove as much soil, remaining potting mix and other debris as possible. The roots were then stored in a refrigerated room before being washed to remove remaining soil particles and spread out in a scanning tray (Figure 5.5) as per Win-RHIZO™ (2012b) and the root scanning protocol (Pierret et al. 2013). The larger root masses were divided and cut into shorter or flatter segments to improve scanning measurements. Measurements considered include; diameter (mm), volume (mm^3), Specific Root Length (SRL) (m g), root to shoot ratio and tissue density (g mm^3).

Figure 5.4 Rare species at harvesting. Left to right from top left; *Aciphylla subflabellata, Coprosma intertexta, Leptinella serrulata,* and *Raoulia monroi.* Note the plant tag is 127 mm in length.

The dam plants were harvested from a Te Whnua Hou reserve on the 8-10 May 2017 and scanned on the 12 and 15 May (Figure 5.4 and 5.5). The rare species were harvested between 10 and 13 October 2017 then scanned between the 16 and 19 of October. Thirty eight of the 40 rare plants survived,

both plants lost were *A. subflabellata.* The shoot material of each individual was retained for drying at 65°C for 72 hours, along with the roots, to calculate root to shoot ratios.
The dam plants were not grown on in pots as this was not considered early enough in the experiment for the plants to have the same amount of growth time, likewise the number of individuals of the dam species for root measurements.

5.2.3 Data analysis

Root measurements were analysised by WinRhIZO ™ 2012b (Regent Instruments Inc, Canada). Differences between roots were analysed using one-way ANOVA with post-hoc Tukey (HSD) test. Statistical analysis was undertaken using Minitab® 18 (Minitab Inc. Sydney, Australia. Means (±SE) root differences were calculated and illustrated using SigmaPlot (Version 13, Systat software, San Jose, Ca).

Figure 5.5 Scanning equipment. Left Epson scanner, right HP computer screen. Computer screen has results of scanning including bar graph reflecting the root sizes. All scanning was carried out at Maanaki Whenua/Landcare Research, Lincoln.

5.3 Results

A. subflabellata has the largest mean root diameter of the rare species (0.623 mm), *C. intertexta* (0.485 mm) is next, followed by *L. serrulata* (0.393mm), and *R. monroi* (0.372 mm) which has the smallest diameter. The different mean root diameters of the rare species are within the mean root diameters of the dam species. The mean diameter for the dam species (Figure 5.6) varied from 0.315 mm for *A. tenuis* to 0.629 mm for *R. acetosella.* There was significant difference between the species ($F_{10,42}$ = 4.51; P=0.001).

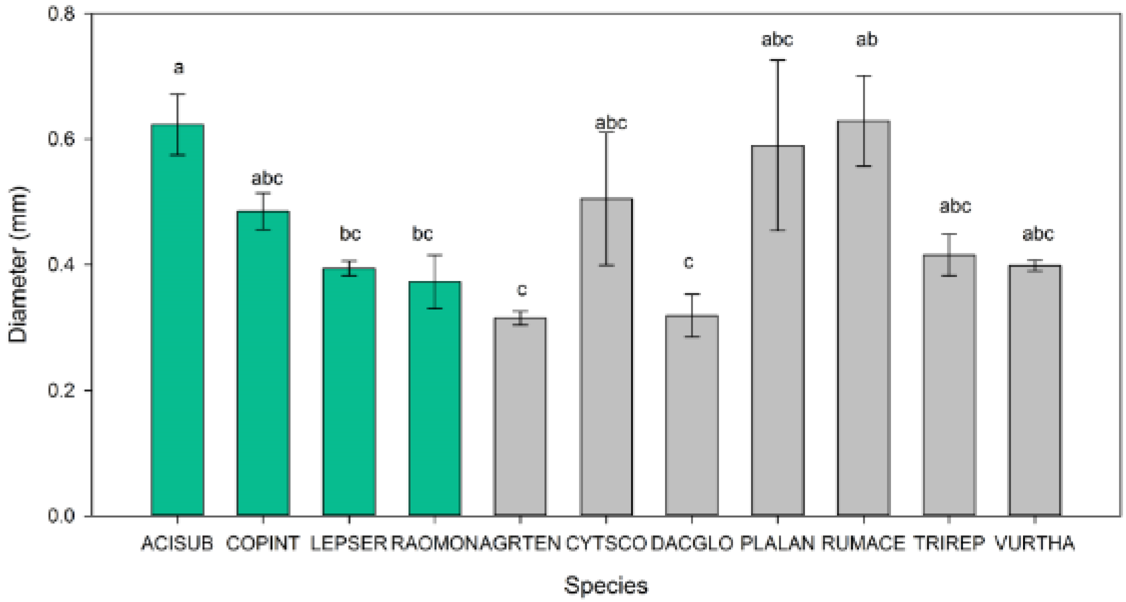

Figure 5.6 Mean root diameter per species (mm) (±SE). There are significant differences ($p<0.05$). *A. subflabellata* was the most significantly different ($p=0.001$), *C. intertexta* the least different ($p=0.540$). The letters represent differences using Tukey pairwise comparisons. Rare species are green, dam species are grey. For code to full name table see Appendix A.

Due to incorrect scanning technique (Figure 5.7) the outliers for the all the following measurements involving WinRHIZO™ scanning were removed from each species. This removal was based around the guide of SRL having a range of 3-350. This meant that the sample size was reduced from 10 for the following; both *A. subflabellata* and *C. intertexta* n=8 and *L. serrulata* and *R. monroi* n=7, all dam species stayed at n=3.

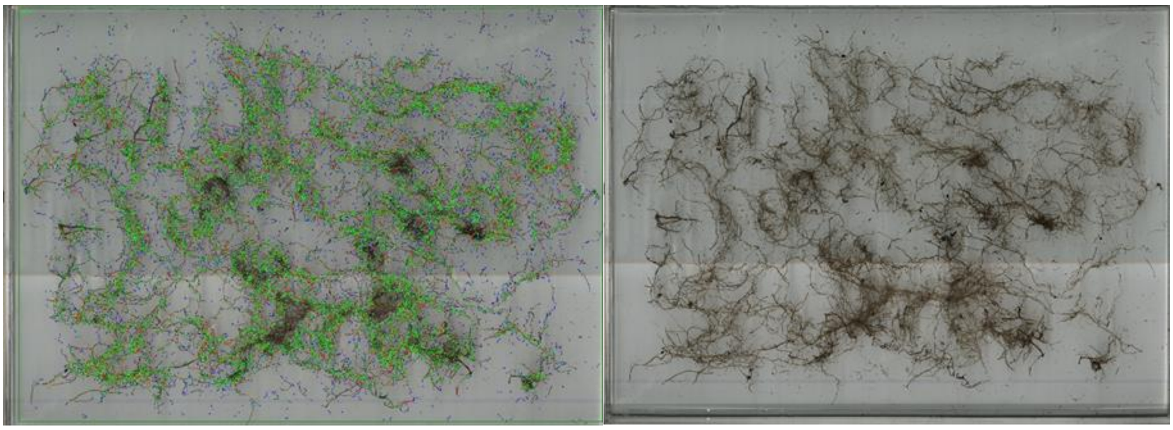

Figure 5.7 Incorrect scanning technique of *Leptinella serrulata*. The scanned screen shot on the left has the coloured measurement zones missing masses of fine roots. The screen shot on the right of the same scan without colour zones.

The mean root volume (figure 5.8) ranged from 269.7 mm^3 for *C. scoparius* to 10398 mm^3 for *P. lanceolata* for the dam species. The rare species have larger root volumes ranging from 349875 mm^3 for *C. intertexta* to 1881512 mm^3 for *A. subflabellata.* There was no significant difference between species ($F_{10,50}$=0.69;P= 0.725). *Aciphylla subflabellata* is the only species to be significantly different (P=0.040). Within the rare species the volumes did have a wide range. *A. subflabellata* had the widest range of volume from 1084 mm^3 to 13122850 mm^3 between the specimens. *Coprosma intertexta* had the narrowest range of volume from 3414 mm^3 to 1076723 mm^3. *Leptinella serrulata* ranged from 547707 mm^3 to 3030119 mm^3 and *R. monroi* ranged from 18345 mm^3 to 1120280 mm^3.

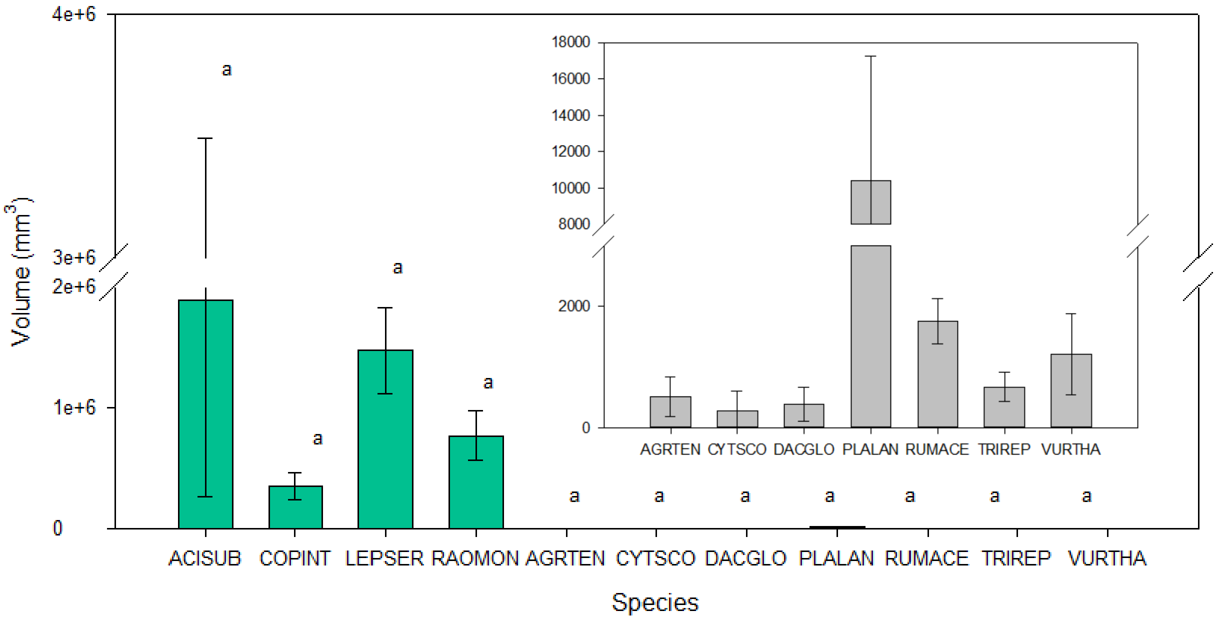

Figure 5.8 Mean Root volume (mm^3). Note the scale difference. There was no significant difference (p>0.05). There were no differences between all species using Tukey pairwise comparisons. Scale break for inserted graph is 3000 to 8000 mm^3. Rare species are green, dam species are grey. For code to full name table see Appendix A.

The Specific Root Length (SRL) measurement split the species into two clear groups. The smaller the number the lower the ability to access nutrients which is where all the dam plants come in as they all have a SRL below 30. There was a significant difference ($F_{10,50}$=11.73;P<0.001). *Aciphylla subflabellata* is the only rare species to have an SRL below 100 (52 mg). This low number would imply that *A. subflabellata* would be able to access nutrients better than the dam plants but less able than the other rare plants that came in between 185 mg (*C. intertexta*) and 286 mg (*L. serrulata*). The SRL range between the species is from 2.36 mg for *A. tenuis* which is below the SRL limit of 3mg to 268 mg for *L. serrulata.* The range within the individual dam species varied from 1 m/g for *A. tenuis* (2-3mg) to 44 mg for *D. glomerata* (5-49 mg). The rare species SRLs were as varied with *L.*

serrulata (280-341 mg) having the narrowest range (61 mg) whereas *R. monroi* (299 mg, 28-327 mg) had the widest range.

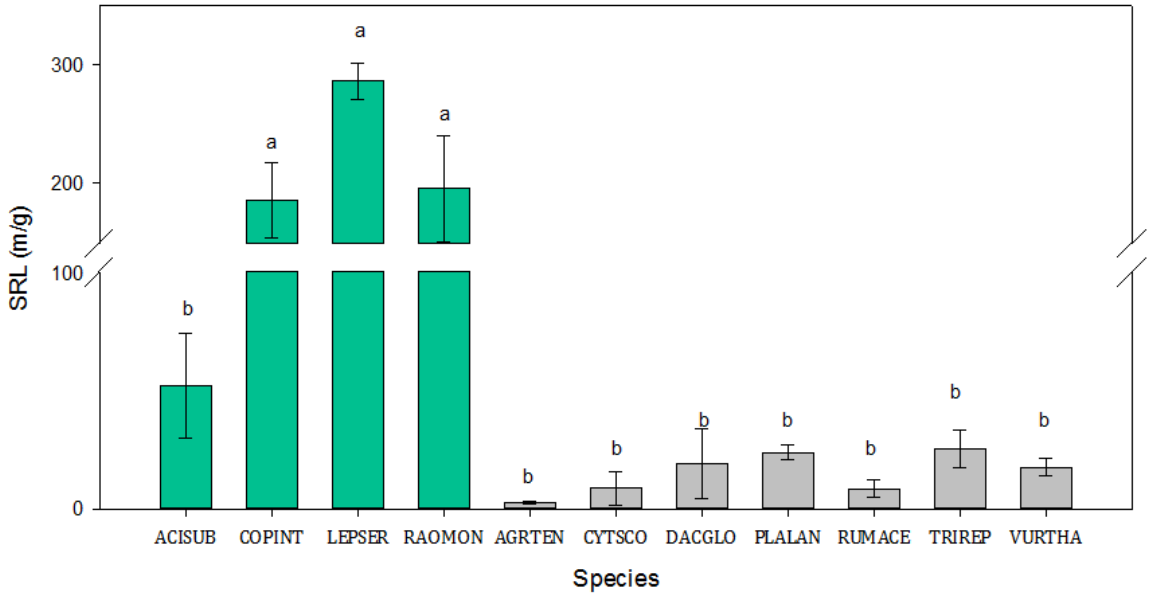

Figure 5.9 Specific root length (SRL) (m/g) Volume/ dry root mass (±SE). There were significant differences (p<0.05). The letters represent differences using Tukey pairwise comparisons. Scale break is from 101 to 149. Rare species are green, dam species are grey. For code to full name see Appendix A.

The root to shoot ratio (Figure 5.10) varied from 0.262:1 for *C. Scorpius* to 6.97:1 for *D. glomerata*. The differences were significant ($F_{10,58}$=7.47;P<0.001).

The root tissue density had significant differences ($F_{10,50}$=7.2;P<0.000). *Cytisus scoparius* has the highest density (0.01917 g mm^3 and *L. serrulata* the lowest (0.000001 g mm^3).

Temperature data loggers were put in the pots from 1 May to 24 August 2017. The mean temperature for the pots was 8.12 ^{O}C. The short pots mean temperature was 7.68 ^{O}C, the tall pots was 8.56^{O}C. The range for the short pots was from -2.97 ^{O}C to 28.89 ^{O}C while the tall pots range was -1.15 ^{O}C to 25.69 ^{O}C. No further statistical analysis was completed.

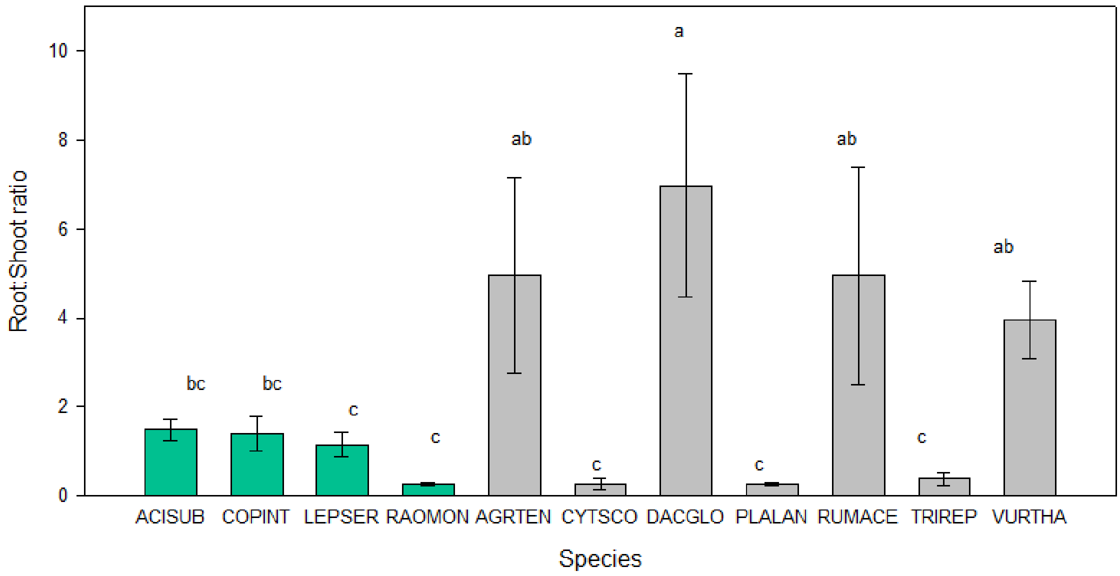

Figure 5.10 Root : Shoot ratio (±SE). There were significant differences between the species (P<0.05). Letters represent differences using Tukey pairwise comparisons. The rare species are green, dam species are grey. For code to full name see Appendix A.

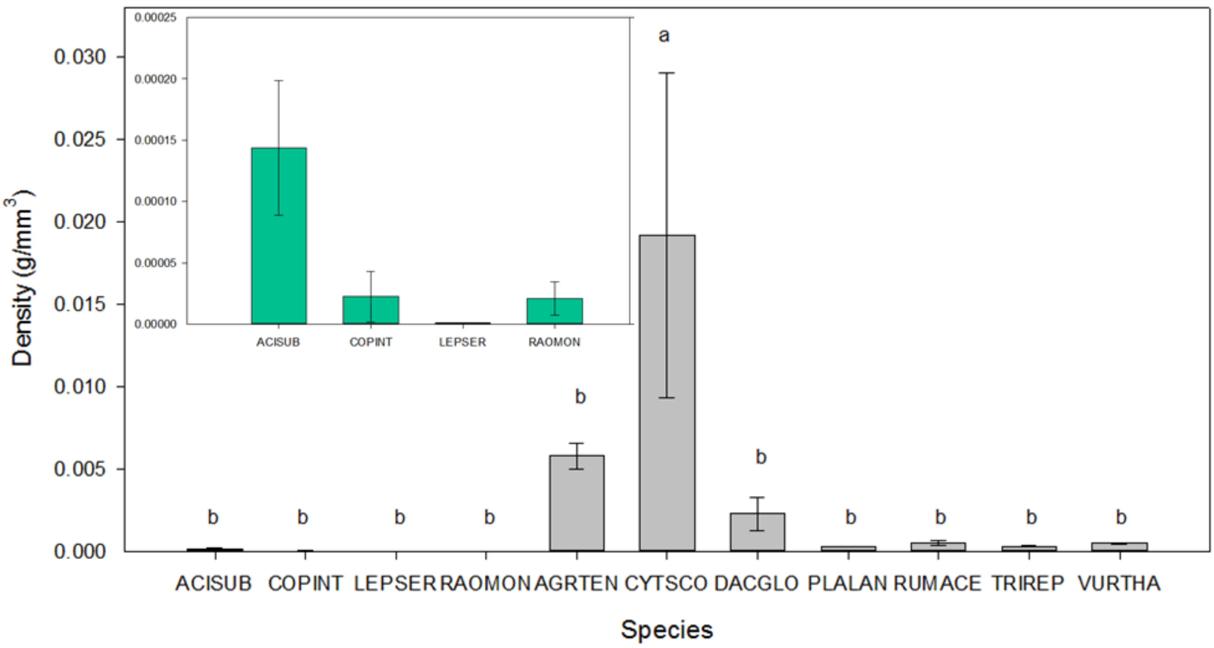

Figure 5.11 Root tissue density (g/mm^3) dry root mass/ root volume (±SE). The rare species are repeated in the smaller graph due to the scale difference. There were significant differences between the species (p<0.05). Letters represent differences using Tukey pairwise comparisons. The rare species are in green, dam species are grey. For code to full name see Appendix A.

In both *A. subflabellata* and *R. monroi* several finer root 'nests' were found to contain fertiliser balls (Figure 5.12).

Figure 5.12 ***Raoulia monroi*** **roots with a fertiliser ball, from potting mix, among the finer roots.**

5.4 Discussion – Roots for dams

5.4.1 Roots traits

Diameter

The diameter of the rare species are within the range of the dam plants implying that any of the species are capable of growing on the dams. The differences within the types of roots may have an impact that is visible with age as the plants mature and the larger roots are established. The number of fine roots on *A. subflabellata* could be the reason the mean diameter is 0.62mm reduced from the large taproots (Figure 5.13, top left). *Coprosma intertexta* does not have the very fine roots that *A. subflabellata* has but does have a single tap root which will increase in size as the plant grows which would increase the mean diameter (Figure 5.13, top right). Both *L. serrulata* and *R. monroi* have adventitious roots (Lloyd 1981). These adventitious roots are more consistent in diameter than either *A. subflabellata* or *C. intertexta* (figure 5.13, bottom). This adventitious diameter consistency would make the species more suitable for long term growth on the dam walls. The suitability is based around the size of holes the adventitious roots would make, which are more consistent than the tap roots which will enlarge over time displacing soil and causing larger holes to be left after root death.

Volume

The root volume of the rare species was larger than the dam species (Figure 5.8) which may be due to the plant age, or that the rare plants had initially been in potting mix helping to establish a root base. The increase in volume may also be due to the foraging behaviour of the roots to search out nutrients. The masses of fine roots from *A. subflabellata* and *R. monroi* found surrounding fertiliser balls from the initial potting mix would increase the volume (Figure 5.12). Roots grown in the field or in this case soil filled containers have been shown to increase root growth (Mokany and Ash 2008).

The temperate for the pots was 8.12 ^{O}C which is below the 15 ^{O}C suggested for increased root growth (Poorter et al. 2012a). The six month difference in timing of harvesting could have an effect on volume of roots as roots growth increases at below 15^{0}C (Poorter et al. 2012a; Poorter et al. 2012b). The way volume is spread through the soil will also change for the both *L. serrulata* and *R. monroi* as the plant spreads out (Figure 5.14).

Specific root length

The SRL number, from 3 to 350, is an indication and can be dependent on the soil affecting root growth, both positively and negatively. The soil at Eyrewell is considered poor in part due to high aluminium content and low moisture retention (Dollery 2017a). The fact that the rare species have high SRL's implies that the species are able to access the nutrients available in the soil through increased root length and production of fine roots to access the nutrients better than the dam plants (Kramer-Walter et al. 2016; Pérez-Harguindeguy et al. 2013). The ability of the plants to adapt to poorer soils and survive better (Figure 5.13 and 5.14) provides habitats with a greater range of species that could be used for new population establishment.

Figures 5.13 Roots after harvesting from pot trial. Clockwise from top left, *Aciphylla subflabellata, Coprosma intertexta, Leptinella serrulata* and *Raoulia monroi.*

Root to shoot ratio

Root to shoot ratio (R:S) is often considered an indication of drought tolerance or sensitivity. The results implied that four of the dam species were drought tolerant (over 3.9) and three sensitive (under 0.5). Three of the rare species fall in between with a R:S between 1.1 and 1.5 which would imply that they are able to go either way depending on their growth form at the time. *R. monroi* is the only rare species to have a ratio below 0.3 which could imply sensitivity. This 'sensitivity' could also be a result of the amount of above ground vegetation growth from the potting mix stage of its life with more grown due to high nutrient availability. There was a difference in the spread of both ground cover species (Figure 5.15). *Leptinella serrulata* spread into the surrounding soil faster than *R. monroi*. This spread could affect the R:S ratio as remaining within the potting mix provided the nutrients with less expenditure on root growth.

Figure 5.14 *Leptinella serrulata* growing in soil, with the original potting mix part (upper left corner) of the plant having died after 2 weeks without rain while the new parts survived.

Root tissue density

The Density of the root tissue is the opposite in graph appearance to the SRL. The rare species are all smaller than the dam species with *A. subflabellata* (0.000143 g mm^3) the closest in density to the dam species. This may be due to the fine roots that give *A. subflabellata* a lower SRL. *Leptinella serrulata* has the lowest density at 9E-07 g mm^3. The lower the density the better the plants ability to access nutrients which reinforces the role of the soil in influencing the root composition of a plant. Based on density, the growth strategies of *L. serrulata* and *A. subflabellata* would appear to be different but the numbers may be too small for the differences to be clear. The differences could relate to differences in growth stages or survival strategies, e.g. *L. serrulata* leaves appear to shrink over summer (J.Butts pers Com). The small density numbers may also be related to the soil as there does appear to be a relationship between root tissue densities with slow growth in infertile soils. This relationship is reflected in a longer root system than those with a high tissue density (Ryser 1996).

Figure 5.15 Difference in spread during the pot trial. Left *Leptinella serrulata* has spread to pot edges, right *Raoulia monroi* has no visible movement.

5.4.2 Roots on dams

The above traits have implied there are differences between the species. These trait differences are within the range of the species already growing on the dams apart from volume and SRL. Volume will change over time as the plant ages and roots are replaced dependant on growing conditions. SRL is an indication of the plants ability to forage and will not have a direct effect on how the plant affects the dam.

The diameter range of the roots infers that all the rare species will be able to grow on the dam with no more impact than the plants that are already on it. The larger volume range could create a substantial network that would reduce the erosion of soil and assist in soil retention. The SRL, R:S and density infer that some species would adapt better to the soil and climate than others. This adaption would be best tested *in situ* or through monitoring of current dam plants during seasonal changes.

5.4.3 Root protocol

The use of whole plants or only roots of single stem plants will limit the trait measurements due to lack of shoot mass for measurements. The grasses, herbs and lianes which are able to have part of the plant (including roots and shoots) used will provide complete measurements and traits. Through following the established protocols for root measurements, traits and scanning, the database that is established will be comparable internationally (Iversen et al. 2017; Pérez-Harguindeguy et al. 2013). The main root sampling technique to remember is n = 5-10.

Chapter 6

Discussion – Earth dams as a habitat for rare species

6.1 Dams as a habitat

The creation of earth dams creates opportunities through disturbance for both native and exotic species. The findings of this research have confirmed that the native species researched are capable of growing in this novel habitat (earth dams). It is argued that this opportunity should be used to assist in the conservation of rare native species.

6.1.1 Rare species

The rare plants had a wide range of co-occurring species growing in their plots. This range of species indicates that the dams could be used to support species that currently grow and historically grew together (Laguna et al. 2004). These new communities of rare plants could be used as native seed and propagule sources or seed farms. These farmed species founded with rare plants would create a new ecosystem. This new ecosystem could be more attractive to native fauna as a suitable habitat and a range of food sources is provided (Greer et al. 2015; Tonietto and Larkin 2017).

6.1.2 Ground conditions

The ground conditions of the dams have more bare soil and rocks than the threatened species habitats which is possibly due to (i) age, all the dams are less than four years old, and (ii) the impact of disturbance. The ground conditions would change over time, as the dams' age, new species would establish themselves and existing species would spread (Stromberg and Kephart 1996). The development of top soil through the recycling of the organic matter would naturally increase the range of species that are able to survive on the dam walls. The increase and change in species would lead to ongoing maintenance issues due to these changes to the dam walls irrelevant of which species grew on the dam.

6.1.3 Maintenance

From an engineering viewpoint the maintenance issue is based on water leaking either as a seepage or an obvious water leak. The continual removal of woody root plants e.g. *Ulex European, Cytisus scoparius,* and *Pinus radiata,* both manually and through stump poisoning reduces the risk of leaking. As the dams are checked every five years for signs of leaking, as part of their ongoing consent process, the plants need to be easily viewed around or through. All of the plants in this research will assist in this checking. For an ecologist the removal of invasive exotic plants irrelevant of root type or size would assist in the maintenance of the native plant community.

As the maintenance is an ongoing issue the use of rare species would not alter that issue. The observation of some of the unwanted species sprouting could be used as a comparison for species to use; e.g. replacing European brooms with native brooms i.e. *Carmichealia corrugata.* The use of rare species would however provide an opportunity to support species that are at risk of disappearing and provide seed or propagule sources for restoration projects in the wider area and a potential economic income (Native Habitats 2017; Seed 4 Restoration 2017; Stromberg and Kephart 1996). The provenance of the species would also be able to be proven if all steps, from original seed source, propagation to planting of the dam walls were recorded. The recording would support the provenance of the propagules from the original source to the planting site via the dam (Breed et al. 2012).

6.1.4 Knowledge

A greater range of native species than those chosen for this research could be used on the dams (Laguna et al. 2004). The ability to use the knowledge of exotic species helps gain insight into current and potential habitats. The use of other knowledge, e.g. slope, aspect and ground temperature would provide a guidance as to how the dams could be zone planted. Through comparing the historical knowledge of other rare species, what they grew with, and the exotic species, what they currently grow with, helps determine potential habitats. The combination of habitat and companion species comparison increases our ability to utilise the novel habitats that are being created both in rural and urban areas.

6.2 The ustilisation of roots

6.2.1 For engineers

The ability of roots to cause structural damage is the main reason that earth dam engineers do not like plants with root on the dams. If evidence can be provided defining which plants can be safely used, this concern would be allayed.

In the present study the root mean diameters were all within the same range (<1mm). *Aciphylla subflabellata* had a greater range of diameter than any other species, due to the multiple tap roots. The tap roots may affect the dam wall as the plant ages. However as I was not able to use mature plants there may be a size limit to which tap roots grow for individual species (Sun et al. 2016). There is a need to find out if there is a diameter limit that would satisfy dam engineers. The combination of soil compression and the effect of gravity on dam mass affects the ability of the root to grow and the soil to replace the root once it dies. *Aciphylla subflabellata* and *C. intertexta* have the largest roots of the threatened species. The likelihood that the age of the plants would affect the integrity of the dam walls is yet to be proven.

The volume that roots create in the dam walls is dependent on age and will change over time as roots are replaced and the species composition changes. The rare species were possibly older than the dam species used for scanning which could have implications for the volume. The largest volume of roots for one plant (an *A. subflabellata*) was 13122850 mm^3 (0.013 m^3) which is just over the 1% of volume (for a cubic metre) that is suggested as possible root displacement in a levee for woody roots (Shields and Gray 1992). This 1 % however may not take into account the full volume of the dam walls which would need to be averaged out as a reference starting point. The use of a variety of root depth lengths would support the dam against erosion (Li et al. 2009; Pohl et al. 2009). This variety of roots could lead to the integration of a plant community similar to that which has existed in the area previously or an existing community.

6.2.2 The importance of traits

The specific root length (SRL) foraging ability of a species is important knowledge when planting an area such as a novel habitat, because the soil is likely to have a change in nutrient status due to the nature of disturbance. The SRL of all the rare species implied that these plants are able to forage extensively for nutrients to establish their root systems. When combined with R:S and Density traits the results are reinforced that these species will be useful due to their foraging abilities and in the case of *L. serrulata* and *R. monroi* the ability of the plants to adapt their form to the soil conditions provides an extra dimension of usefulness (Valverde-Barrantes et al. 2017).

6.3 Species selection

The findings of my research could inform the creation of zoning novel habitats for plantings. The smaller the root diameter, higher SRL and lower density (drought tolerant) the species may be more useful higher on the slope or north facing, whereas the larger the diameter, lower SRL and higher density (drought sensitive) the species may be better on the lower parts of the slope or south facing. Only *Agrostis tenuis* from the dam species, was recorded in at least one plot of each rare species, although only three dam species were not found in any rare species plot. This implies that by determining which exotic species are in the novel habitat and also in the rare species habitat would be a viable option when researching which plants to use. For example, as well as being on the dam *Lagurus ovatus* was found with *L. serrulata, M. ephedroides* and *R. monroi*, whereas *Leontodon taraxacoides* was found with *A. subflabellata* and *M. ephedroides*. The observational method of comparing exotic species with broad niches, with rare species with decreasing niches, could have limitations with the assumptions not implying long term survival. Using a simple observation method that most people could use would be best if multiple species are considered and not just one or two, however in specific situations, i.e. dams, the root dimensions will need to be considered.

The only rare species to be significantly different to any of the others was *A. subflabellata*. This difference was in the root diameter and would imply that species with tap roots may be unsuitable for the dam wall long term. As I have stated in Chapter 5 both *A. subflabellata* and *C. intertexta* have the ability to grow larger tap roots which could affect the integrity of the dam walls. The use of either of these species would require further research into tap root directional growth near a wetland area before use.

6.4 Limitations to the present study:

- The differences between the use of pots for rare species and not growing the dam species in pots. The growing of dam species in pots was suggested late in the research and should be taken into consideration for future comparisons. The differences in growth conditions could have implications for the root measurements that were not detected due to the different species
- The two different pot sizes could have implications especially since they were made of different material and the *A. subflabellata* pots were covered in black plastic to reduce the effect of direct sunlight on root growth (Figure 5.13). Soil temperature recordings of the pots were carried out for three months to consider this and there were no significant differences.
- The number of individual plants of rare species found in the natural environment. Due to the limits of current knowledge about all the species the forms of the species were not always clear. There were suggestions that *L. serrulata* may be one plant over several metres and *C. intertexta* may create multiple trunks once established (similar to other *Coprosma* species).
- Identification of the exotic species – due to the identification being carried out between April and September, a lack of flower or seed heads made identification to species level hard and many were only identified to genus level.
- Time period of surveys – species were found in September that were not found in earlier surveys as they only appear in spring for a short time e.g. *Microtis* species, T*helymitra* species. While other species are harder to find e.g. *R. monroi* becomes cryptic when the soil is dry as the leaves fold up.
- The root scanning for the exotic species was limited as I only used three individuals of each species. Based on the range of results this has affected the means for clarification of traits. The Perez- Hargiundguy et al. (2013) handbook recommends at least 5 and preferably 10 individuals for each species for SRL measurements.

6.5 Future research

It is suggested that future research of the following would be beneficial for both novel habitats and sustainability of rare species:

- Research into the effects of different above ground vegetation form on roots. This would be done in different soils to take into account the different vegetative morphology when scanning as this may impact on the SRL and Density results; e.g. both *L. serrulata* and *R. monroi* change form depending on the nutrient availability in soil.
- Comparison of different soil conditions with species for root traits. This would consider how the different soil fertilities or structure change the form of the plant (roots and above ground vegetation), answering such questions as: What are the possible future implications as soil fertility or structure changes? Will this limit habitats, novel and original, for future growth?
- Detailed studies of soil chemistry would provide information on the different habitats as well as how the species are coping with land changes due to farming and development. This would provide direct comparisons between the current habitats and potential habitats.
- Defining the structure of the habitats of specific plants where targeted plants are surveyed. Is it a shrub-land, tussock, or frost meadow? The above ground vegetation and bare ground aspects are a good starting point, this provides a bare outline of what may influence the ability of plants to germinate and survive in the areas described.
- Researching and comparing the DNA of the species. This will help to determine inbreeding and isolation of communities or hybridization, especially *L. serrulata, C. intertexta* and *A. subflabellata* (Aavik and Helm 2017). Some of the species already have their DNA listed in Genebank which could be used as a reference starting point.
- Research the need to share seed propagation and genetic material between isolated populations; e.g. *C. intertexta* and *A. subflabellata* in Lees Valley with the wider populations or the *L. serrulata* populations. Researching whether these communities need to share genetic material for survival of the species or have enough variation in that community for long term survival would reduce or increase human action through pollination and or increasing plant stock for restoration.
- Research the degree of current pollination and identify pollinators. What insects are pollinating these plants? There was no literature found for *R. monroi* or *L. serrulata* or even their genera that provided any suggestions. Are the main pollinators still able to access these plants or have the populations become too separated and sparse or have the pollinators become extinct? This research would increase pollination knowledge for these species and about the pollinators themselves.

- Research the creation of a root diameter database for engineers, ecologists, nurseries and landscape architects to use for future plantings. Where is the most suitable place for this information to be held? Consider the ease of access for everyone. This would involve multiple species for comparisons and in large genera as wide a selection as initially possible to provide a basis for reference and design. This would provide scientific support for the use of plants in engineered habitats.
- Consider the compilation of historical data, whether scientific or observational. This would be a useful source of information for original plant communities. In the past the use of historical data has been limited by the 'scientific value'. Through the recognition of the value of dairies, photos and oral accounts the addition of these resources would increase the data available.
- Research root growth direction both on a slope and in relation to being beside a water body. There are many common assumptions on how roots grow in relation to water bodies. By proving or disproving these assumptions in specific relation to different species more people would use a wider range of species for dam and riparian planting.

6.6 Protocol for comparing current novel habitats species with target species

The following protocol is proposed for comparing current novel habitats species with target species based on the findings of the present study:

i. Survey current plant species in the novel habitat.

ii. Survey rare or target plants (wanted in the novel habitat) in natural (non-planted) habitats or study records and historic observations.

iii. When identified species are in both sites these would be used as your comparison species.

The following steps are required if root development and soil requirements have created boundaries or limitations on the species to be used;

iv. Use part of the root system for the two dimensions (diameter and volume) needed. This will depend on ease of removal, status of species involved and site of species, n= 5-10 per species (Pérez-Harguindeguy et al. 2013).

v. Take an initial diameter of the largest root prior to scanning as this would be easier than scanning. As a data base is built this step could be related to scanning finding for easier use.

vi. Use scanning methods WinRhizo™ or similar to gain diameter, volume and other required measurements.

vii. Compare the existing species in the novel habitat with the target species.

viii. When the target species are within the same range as the existing plants they should survive in the novel habitat. OR If root limits have been developed for the type of novel habitat they can be used as a guide.

ix. When soil recommendations are being taken into account both roots and above ground vegetation of the plants involved will need to be taken.

When using ground covers, grasses, or tussocks part of the plant can be used for measurements as long as the above ground vegetation is attached to the roots as they are removed. For trees and shrubs this may involve nursery specimens or growing specimens specifically for this role. Growing specimens specifically would also be required for rare species.

If soil recommendations are also being considered the differences in soil would need to be taken into account when comparing the root forms and measurements. The soil differences would be useful information on a data base with the root measurements

In recommending this protocol once a database is established, an existing one e.g. FRED (Iversen et al. 2017) could be used or the dimensions added to the taxonomic records for species. The ability to use plants in a range of novel habitats will be made easier for a variety of professionals and the public.

6.7 Thesis conclusion

This study confirmed that earth dam walls are able to support a variety of native and exotic plants. Most of the dam species scanned were suitable to continue to grow on the dams. Based on habitat and root comparisons, the four rare species that were researched are able to grow in these conditions. Although I would not recommend using *A. subflabellata* or *C. intertexta* due to their tap roots.

A protocol was developed to establish target rare species on earth dams, using the methods explained in this thesis, combining both the species habitats and root knowledge. Exotic species can be used as indicator species for potential novel habitats and help identify the rare and target species suitable for that habitat. The combination of this information will create a valuable and useful data base that has statistical results. These results will supplement the observational and historical records that are currently available. This database would be useful for novel habitat plantings and restoration of degraded sites.

Through utilising the novel habitats that are created as the rural sector changes with the protocol created, New Zealand's rare, threatened and at risk species could be provided with new communities of native plants to flourish in.

Appendix A

Commonly used species names with abbreviations

Table A List of frequently used plant names, abbreviations and codes within this thesis.

Latin	Abbreviation	Family	Code	Common name
Aciphylla subflabellata	*A. subflabellata*	Apiaceae	ACISUB	Spaniard, spear grass
Agrostis tenuis	*A. tenuis*	Poaceae	AGRTEN	Brown top
Coprosma intertexta	*C. intertexta*	Rubiaceae	COPINT	None Known
Cytisus scoparius	*C. scoparius*	Fabaceae	CYTSCO	European Broom
Dactylis glomerata	*D. glomerata*	Poaceae	DACGLO	Cocksfoot
Leptinella serrulata	*L. serrulata*	Asteraceae	LEPSER	Dryland button daisy
Muehlenbecka ephedroides	*M. ephedroides*	Polygonaceae	MUEEPH	Leafless pohuehue
Plantago lanceolata	*P. lanceolata*	Plantaginaceae	PLALAN	Narrow Plantain
Raoulia monroi	*R. monroi*	Asteraceae	RAOMON	Fan-leaved mat daisy
Rumex acetosella	*R. acetosella*	Polygonaceae	RUMACE	Sheep sorrel
Trifolium repens	*T. repens*	Fabaceae	TRIREP	White clover
Verbascum thapsus	*V. thapsus*	Scrophulariaceae	VERTHA	Woolly Mullein

Appendix B

16 rare, threatened or at risk species.

Table B 16 species found since 200 in either Waimakariri or Selwyn (SDC) districts with nurseries. TC = Trees for Canterbury, DOC = Motukarara Nursery.

Latin Name	Status	Structure	District	Available
Aciphylla subflabellata	At risk - declining	herb	Waimakariri, SDC	DOC, TC
Colobanthus brevisepalus	At risk - declining	Herb	SDC	
Connorochloa tenuis	At risk - declining	Grass	SDC	
Coprosma intertexta	At risk - declining	shrub	Waimakariri	DOC, TC
Craspedia uniflora var. uniflora	data deficient	herb	SDC	
Geranium microphyllum	At risk - naturally uncommon	herb	Waimakariri	
Geranium sessiliflorum	At risk - declining	herb	Waimakariri, SDC	
Leptinella serrulata	At risk - naturally uncommon	herb	Waimakariri	TC
Lobelia ionantha	At risk - declining	herb	SDC	
Mentha cunninghamii	At risk - declining	herb	Waimakariri, SDC	
Muehlenbeckia ephedroides	At risk - declining	Lianes	SDC	DOC
Pimelea sp.	Variety of threats	shrub	Waimakariri	
Pterostylis tristis	At risk - declining	Orchid	Waimakariri	
Rytidosperma exiguum	data deficient	Grass	Waimakariri, SDC	
Raoulia monroi	At risk - declining	herb	Waimakariri, SDC	TC
Wurmbea novae-zelandiae	Vulnerable	herb	SDC	

Appendix C

Species and habitats

Table C Full list of species with code, family and dam or which rare species site it was found.

Latin	Code	Family	Dams	ACISUB	COPINT	LEPSER	MUEEPH	RAOMON
Acaena agnipila	ACA AGN	Rosaceae		X	X	X	X	X
Achillea millefolium	ACH MIL	Asteraceae		X	X			
Aciphylla subflabellata	ACI SUB	Apiaceae		X				
Agrostis tenuis	AGR TEN	Poaceae	X	X	X	X	X	X
Anagallis arvensis sudsp. arvensis var arvensis	ANA ARV	Primulaceae	X					
Anthoxanthum odoratum	ANT ODO	Poaceae						
Arabidopsis thaliana	ARA THA	Brassicacea		X		X		
Asteracae species	AST SPP	Asteraceae	X	X		X	X	X
Austrostipa stuposa	AUS STU	Poaceae					X	X
Calystegia soldanella	CAL SOL	Convolvulaceae					X	
Carex species	CAR SPP	Cyperaceae		X				
Carmichealia appressa	CAR APP	Fabaceae					X	
Carmichealia australis	CAR AUS	Fabaceae			X			
Carmichealia corrugata	CAR COR	Fabaceae					X	X
Carpobrotus edulis	CAR EDU	Aizoaceae					X	
Cerastium species	CER SPP	Caryophyllaceae			X	X	X	X
Chamaecytisus spp	CHA SPP	Fabaceae				X	X	X
Cheopodium nutans	CHE NUT	Amaranthaceae					X	
Cirsium arvense	CIR ARV	Asteraceae	X					
Cirsum vulgare	CIR VUL	Asteraceae	X		X	X		
Colobanthus brevisepalus	COL BRE	Caryophyllaceae				X		X
Coprosma intertexta	COP INT	Rubiaceae			X			
Coprosma propinqua	COP PRO	Rubiaceae					X	
Coprosma repens	COP REP	Rubiaceae					X	
Coprosma rigida	COP RIG	Rubiaceae		X			X	
Cytisus scorparius	CYT SCO	Fabaceae		X		X		X
Dactylis glomerata	DAC GLO	Poaceae	X	X	X	X		
Dichondra repens	DIC REP	Convolvulaceae	X			X	X	
Digitalis purpurea	DIG PUR	Plantaginaceae	X	X				
Discaria toumatou	DIS TOU	Rhamnaceae		X	X		X	X
Echium vulgare	ECH VUL	Borginaceae	X		X			
Erodium cicutarium	ERO CIC	Geraniaceae				X		X
Erysimum cheiri	ERY CHE	Brassicacea					X	
Euchiton involucratus	EUC INV	Asteraceae				X		

Latin	Code	Family	Dams	ACISUB	COPINT	LEPSER	MUEEPH	RAOMON
Euchiton sphaericus	EUC SPH	Asteraceae	X					
Festuca rubra	FES RSR	Poaceae		X	X	X	X	X
Galium aparine	GAL APA	Rubiaceae			X			
Gazania species	GAZ SPP	Asteraceae					X	
Geranium brevicaule	GER BRE	Geraniaceae	X				X	X
Glaucium flavum	GLA FLA	Papaveraceae					X	
Helichrysum filicaule	HEL FIL	Asteraceae		X				
Holcus lanatus	HOL LAN	Poaceae		X	X	X	X	X
Jacobaea vulgaris	JAC VUL	Asteraceae	X					
Juncus species	JUN SPP	Juncaceae		X				
Kunzea robusta	KUN ROB	Myrtaceae		X				
Kunzea serotnia	KUN SER	Myrtaceae			X	X		
Lagurus ovatus	LAG OVA	Poaceae	X			X	X	X
Lathyrus species	LAT SPP	Fabaceae	X	X			X	X
Leontodon taraxacoides	LEO TAR	Asteraceae	X	X			X	
Leptinella serrulata	LEP SER	Asteraceae				X		
Leucopogon fraseri	LEU FRA	Ericaceae			X	X		X
Lobularia maritima	LOB MAR	Brassicacea					X	
Lolium perenne	LOL PER	Poaceae			X		X	
Melicytus alpinus	MEL ALP	Violaceae		X	X			
Microtis spp	MIC SPP	Orchidaceae			X			X
Muehlenbecka axillaris	MUE AXI	Polygonaceae				X	X	X
Muehlenbecka ephedroides	MUE EPH	Polygonaceae					X	X
Muehlenbeckia australis	MUE AUS	Polygonaceae		X				
Oxalis exilis	OXA EXI	Oxalidaceae				X	X	X
Petroselinum crispum	PET CRI	Apiaceae					X	
Phormium tenax	PHO TEN	Xanthorrhoeaceae			X			
Pilosella officinarum	PIL OFF	Asteraceae		X		X		X
Pinus radiata	PIN RAD	Pinaceae	X		X		X	
Plantago coronopus	PLA COR	Plantaginaceae					X	
Plantago lanceolata	PLA LAN	Plantaginaceae	X		X	X	X	
Plantago spp	PLA SPP	Plantaginaceae						X
Poa cita	POA CIT	Poaceae		X	X	X	X	X
Poa pratensis	POA PRA	Poaceae					X	
Podocarpus laetus	POD CUN	Podocarpaceae		X				
Pteridium esculentum	PTE ESC	Dennstaetiaceae			X			
Raoulia australis	RAO AUS	Asteraceae					X	X
Raoulia monroi	RAO MON	Asteraceae				X	X	X
Rumex acetosella	RUM ACE	Polygonaceae	X	X	X	X	X	X
Rytidosperma species	RYT SPP	Poaceae			X	X	X	X
Schedonorus arundinaceus	SCH ARU	Poaceae						X
Scleranthus uniflorus	SCL UNI	Caryophyllaceae				X	X	

Latin	Code	Family	Dams	ACISUB	COPINT	LEPSER	MUEEPH	RAOMON
Sedum acre	SED ACR	Crassulaceae				X	X	X
Spergularia rubra	SPE RUB	Caryophyllaceae					X	
Thelymitra species	THE SPP	Orchidaceae			X	X	X	X
Trifolium arvense	TRI ARV	Fabaceae				X	X	X
Trifolium pratense	TRI PRA	Fabaceae	X		X			
Trifolium repens	TRI REP	Fabaceae		X	X		X	
Ulex europaeus	ULE EUR	Fabaceae	X	X		X		X
Verbascum thapsus	VER THA	Scrophulariaceae	X					X
Viola arvensis	VIO ARV	Violaceae			X			
Vulpia species	VUL SPP	Poaceae						X

Appendix D

Grassland Recce sheet

Figure D Copy of Recce sheet from National Vegetation Survey Databank (LandcareResearch n.d.).

RECONNAISSANCE (RECCE) SHEET

National Vegetation Survey Databank (http://nvs.landcareresearch.co.nz/) Page _____ of ____

RECCE IDENTIFIER: ______________________ DAY/MONTH/YEAR: ______________________

SURVEY: ______________________ AERIAL PHOTO: ______________________

REGION: ______________________ TOPO. MAP NO. & NAME: ______________________

CATCHMENT: ______________________ GPS REFERENCE: GPS Make & Model: ______________

SUB-CATCHMENT: ______________________ Easting: ______________________

MEASURED BY: ______________________ Northing: ______________________

RECORDED BY: Single / Averaged; 2D / 3D; ± ____ m; Datum: NZGD49 / NZGD2000

SIZE OF RECCE		**MESOSCALE TOPOGRAPHIC INDEX** (°, record +/–)	**SURFACE CHARACTERISTICS:**	
ALTITUDE (m)			Bedrock %	
PHYSIOGRAPHY	Ridge, Face, Gully, Terrace		Broken rock %	
ASPECT (0–359°)			Size of broken rock	<30cm / >30cm
SLOPE (°)	Convex, Concave, Linear	N	Alluvial, Colluvial, Moraine, Volcanic	
PARENT MATERIAL		NE	**GROUND COVER %:**	
	Mapped / Observed	E	Vegetation	
DRAINAGE	Good, Moderate, Poor	SE	Non-vascular	
CULTURAL	None, Burnt, Logged,	S	Litter	
	Mined, Grazed, Tracked	SW	Bare Ground	
APPROACH		W	Rock	
		NW	AVERAGE TOP HEIGHT (m)	
			CANOPY COVER (%)	
		LOCATION DIAGRAM		
NOTES (including cultural)				

BROWSE

Species	Severity	Herbivore	Species	Severity	Herbivore
	L M H			L M H	
	L M H			L M H	
	L M H			L M H	
	L M H			L M H	
	L M H			L M H	

FAUNA (e.g. mammal, bird, reptile, invertebrate)

RECCE IDENTIFIER: ______________________________ MEASURED BY: ______________________________

DATE: ______________________________ RECORDED BY: ______________________________

Cover-classes: 1 = <1%, 2 = 1–5%, 3 = 6–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–100%.

	Tier 3	**Tier 4**	**Tier 5A**	**Tier 5B**	**Tier 6A**	**Tier 6B**
	5–12 m	**2–5 m**	**1–2m**	**0.3–1m**	**0.1–0.3 m**	**<0.1 m**
Overall cover						
Tier 7						
Epiphytes						

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