How can geomorphology inform ecological restoration? A synthesis of geophysical and biological assessment to determine restoration priorities

A thesis submitted in partial fulfilment of the requirements for the

Master of Science Degree in Physical Geography

By

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To family and friends; thanks for your patience and understanding. There is now a chance that I may return to some form of human normality in the not too distant future.

Preface

Each summer my parents took me from my state house in a state house suburb on a charmed, but often bumpy, journey to some distant corner of New Zealand. Those times sitting in the back of the upright Prefect, then the newer little box Prefect, Anglia or Cortina (yes we were upwardly mobile, in today's jargon) found me gazing at every nook and cranny of New Zealand, save for a few extremities such as the Catlins or East Cape. Leaving behind the experience and the wonderment of all the majesty that a child could perceive in the landscape of New Zealand and returning to Wellington was always depressing. Possibly the thought that summer was ending and school was the next port of call had something to do with it. In adulthood most of my life has been spent away from these magical islands but the long white cloud never left the periphery of my vision. A strong connection to the shape of the land and its forest complexity may be explained by my upbringing; but it is hard to say. Possibly it is due to my (childhood) habit of eating soil from my father's garden, making me one with the land. Don't worry, I spat the worms out, I must have known that I would become a vegan.

What is easy to say is that I am deeply saddened by the general loss of a clean healthy environment, the pressure on biodiversity, and the struggle to maintain the integrity of what little is left of an ark that can never be replaced. Along the way, here and elsewhere, small battles have been won (but never permanently, for example, propositions to mine national parks); however, sadly, the war is being lost. Yes, larger and more emphatic change occurred following the dual discoveries, firstly by Polynesians and secondly by Europeans. Yes, I know that the cycles of natural change with glaciation have occurred, but these are not changes imposed by a species alone. With increased affluence, education and understanding it might be expected that we would appreciate the environment upon which we depend for our wellbeing, instead of increasing our impact, vis á vis dairying dry country or damming wild rivers. We continue to enlarge our footprint whilst reducing that of the species that we share this wonderful ball of sediment with; the unprecedented speed of species extinction a marker of the impact.

Though little is spoken of it, the impact of our society really is a serious ethical issue (see Cairns, 2003). It would seem that such an attitude to our environment can only be explained by the increasing distance, in fact divorce, of humans from nature and the role it has in providing for the very society we live in. Possibly we have lost touch with our hearts. But not totally, as there are many people that are in touch with the natural world and attempting to stem the tide in the conservation movement. Additionally, there are those that are prepared not just to stem the tide but wish to turn it back; bringing together the conservation ethic and an ecological restoration ethic. Such people are committed passionate people who approach the restoration endeavour from a myriad of backgrounds; lay and scientific.

My love of the landform and deep sense of compassion for other species is the underlying foundation for this study. Such a foundation has its roots in the heart and in culture, but is still reasoned with the head. Van Diggelen et al. (2001) pondered ecological restoration's scientific relevancy querying the "the state of the art" or "state of the science". Although science may inform ecological restoration, alone it cannot achieve it. To achieve restoration requires ownership by society and a sense of connection to the land.

It seems that in practice ecological restoration is in part art and in part science, placed within a societal construct. Possibly van Diggelen et al. should have rephrased the question, swapping "or" for "and". It is evident from the published work that science has a fundamental role to play in ecological restoration. That this knowledge is not perfect is also apparent. Given the precarious nature of the world's ecosystems there doesn't seem we have the time to wait until the complexity of ecosystems are well enough understood before restoration work begins.

I see people who are very committed to caring for the environment and living harmoniously with the ecosystem, who do not require detailed scientific understanding, simply a connection. These people are achieving to some degree what scientists theorise about. (In a parallel universe) my artistic creation comes from the heart with a strong, in fact, visceral sense of connection to materials and forms, and to the natural world around me which informs my output. I think that ecological restoration is about a visceral, cultural connection to place, and it is very much an art; drawing together the biotic, geographical and the sociological elements. Without full knowledge it will always be so. Since there isn't time to wait for full knowledge restoration needs to proceed with management adapting as our knowledge increases; but also riding on heartfelt passion. What this thesis is about is adding to the knowledge base and hence advancing the success of restoration projects and so helping to maintain society's enthusiasm for the project.

Summary

The central concern that this study addresses is how an understanding of geomorphological processes and forms may inform ecological restoration; particularly practical restoration prioritisation. The setting is that of a hill country gully system covered in grazing pasture which historically would have been cloaked in indigenous forest. The study examines theory in conjunction with an application using a case study centred on Whareroa Farm (the restoration site) and Paraparaumu Scenic Reserve (the reference site) on the southern Kapiti Coast, north of Wellington. The impact that the change of land use has had on the soil and geomorphic condition of Whareroa and the influence the changes may have on the sites restoration is investigated.

The thesis demonstrates a method of choosing reference sites to be used as templates for rehabilitating the restoration site. Geographical Information Systems and national databases are used and supplemented with site inspection. The reference site chosen, Paraparaumu Scenic Reserve, proved to be a good template for the restoration site particularly given that it is located in the midst of a heavily modified area. On-site inspection considering dendritic pattern and floristic composition confirms the database analysis results.

Soil variables (bulk density, porosity, soil texture, pH, Olsen P, Anaerobic Mineralisable N, Total N (AMN), Total C and C:N ratio) are investigated and statistical comparisons made between the sites to quantify changes due to land-use change, i.e. deforestation and subsequent pastoral grazing. Factors investigated that may explain the variation in the soil variables were site (land use), hillslope location, slope aspect, and slope angle. Permutation tests were conducted to investigate the relationships between the independent factors and the SQI (dependent soil variables). Land use and slope angle were most frequent significant explanatory factors of variation, followed by hillslope location whilst slope aspect only influenced soil texture. A number of soil variables at Whareroa were found to be outside the expected range of values for an indigenous forest soil including AMN, Total N, Olsen P, and pH.

Following a sampling within quadrats centred upon the soil sampling sites, the abundance and distribution of vegetation at the reference site are described. Indirect gradient analysis (principally, (Non-metric Multidimensional Scaling) NMDS and Correspondence Analysis (CA)) was used to obtain a picture of the underlying patterns coming from the inventory of the floristic vegetation abundance alone. The site scores indicated a gradient probably due to the hillslope location but the lesser axes were difficult to interpret. Direct gradient analysis (Canonical Correspondence Analysis (CCA)) was also undertaken which ordinates the distribution dependent upon the abiotic factors described above. The general pattern closely matched the pattern produced by CA and NMDS. The relationships of species and factors are of direct interest especially where the abiotic factors are outside their normal range at the restoration site as this will impact on

the success and successional trajectory of the re-established community composition. The CCA ordination suggests that hillslope location, slope, and to a lesser extent aspect, C:N ratio and Total N are the main gradients determining the floristic pattern. As a group the three landform variables have the greatest influence on the floristic community. Cluster analysis (Unweighted Pair-Group Method using Arithmetic Averages algorithm) was performed to investigate spatial patterns of floristic community assemblage. Some evidence supports the influence of landform variables hillslope location on the community assemblage supporting the ordinations.

A geomorphological analysis of the historic sites of discrete mass movement (erosion) at Whareroa was undertaken through mapping a chronosequence of scars identifiable in 6 aerial photos spanning the period 1942 – 2010. The pattern identified susceptibility for slope failure according to slope aspect in the sectors north to west. Susceptibility can also be attributed to slopes above 18°. There was little association between active mass movement and sites of previous mass movement. The common pattern of revegetation of scars and the lack of trends in association with past scars indicate no rapid landscape evolution occurring under the current land-use. A fine scale Digital Elevation Model was created and used to investigate the connectivity and the future risk of erosion of the slopes of the sub-catchment. The analysis indicated in this zero order basin that the slopes and ephemeral swale are well connected, signifying that sediment and nutrient solute will easily enter the fluvial system and possibly affect downstream restoration efforts. Use of a model (Compound Topographic Index) for mapping erosion risk did not provide a clear picture of areas at risk of future erosion. Detailed knowledge of mass movement susceptibility of slopes and the connectivity of landform components is seen as being useful in prioritisation of restoration planning.

Finally, a framework is proposed that may be utilised as a tool to help plan and prioritise ecological restoration projects. The framework is closely based upon the River Styles® framework, which is a catchment scale geomorphic river assessment, and is extended to assess the condition, recovery potential and priorities for restoration in a terrestrial setting. The discrete blocks of information collected in the study are then used within this framework to suggest priorities for ecological restoration of the sub-catchment at Whareroa. According to the process, swales might be an early target of intervention, and once vegetation is established, stream banks followed by side gullies.

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Chapter 1: Introduction

Restoration ecology is a multidisciplinary approach and this study attempts to follow in this tradition by looking closely at how a geomorphic analysis can enhance ecological restoration. Not so much in the sense discussed in the preface relating to cultural or societal dialogue, but in the sense of the feedback between biotic and the abiotic elements of ecosystems. Edward O Wilson writes about consilience being "The jumping together of knowledge, linking facts and fact-based theory across disciplines to create a common groundwork of explanation" (1998, 7). This encapsulates ecological restoration which is the meeting place where biology, geomorphology and culture come together; a place where separate methodologies from various disciplines can be brought together to provide a holistic understanding. Whilst this study is focussed upon the interconnection of geomorphology and biology and the various sub-fields that are party to these disciplines, it is also recognised that society and culture are central to restoration.

1.1 Definitions

Ecological restoration, according to the Society for Ecological Restoration (Society for Ecological Restoration, 2004), is "*….the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed".* This definition is simple yet broad. What is key to this study is the word ecosystem. This implies that restoration is not only about biota but is also about the earth systems which underpin biotic assemblage and abundance. Of course, even the word ecology implies this but the abiotic input is often overlooked in practice. Another word of importance is that of "assisting". Left to its own devices the landscape, in New Zealand and many regions elsewhere would be cloaked in vegetation in time. It might not, however, be the same or even similar to the community that once existed at a particular place (Sullivan et al., 2007).

A word that also has relevance is "guiding". An interpretation, therefore, is to assist by guiding the community to a chosen suite of species dependent upon the vision and objectives of the restoration plan. To achieve such an outcome the underlying abiotic and biotic processes within the ecosystem need to be returned to a functioning level as expected in an undisturbed site. Additionally, the aim may be to try and accelerate the recovery so that further degradation is avoided and so improving the resilience of rare or threatened species to future impacts. Such resilience also applies to the general biotic community per se (Olsson and Folke, 2004; Walker and Salt, 2006).

The other discipline which is central to the study is that of geomorphology, for which a definition can be very simple or extremely contested. Sticking with the simple, it can be defined as the study of the form of the earth, a translation from the Greek basis of the word. Ahnert (1996) describes it as the science which investigates the landforms of the earth. This in turn can be expanded to include not only the form but the processes which determine the form of the earth and, in turn, which are mediated by the form of the earth (Burt et al., 2008). Further, it is the study of landscape genesis and evolution. While there is feedback in this relationship so too is there in relation to the vegetation that covers the earth. Whilst the substrate has a controlling role in the biotic community, conversely, so vegetation is a major control of the geomorphology (Selby, 1993). Soils, in addition to being a product of climate and biota, are a function of the geology and the geomorphological processes, and are considered here under geomorphology (Schaetzel and Anderson, 2005).

1.2 Old fields New Zealand style

Increasing attention to old field restoration (Cramer and Hobbs, 2007) as understood in North America or Australia promoted my interest in a question besetting New Zealand. Old field restoration is the return of pasture to a natural meadow or woodland following the cessation of agricultural activity. That question might be framed; what is the sustainability of marginal steep hill country farming in the face of its economics and, more pertinently here, the ongoing erosion of these susceptible landscapes? Essentially it relates to retirement of uneconomic hill country pasture. There has been research undertaken looking at the effects of landslides and production (DeRose et al., 1995), landslides and succession (Blaschke, 1988; Smale et al., 1997), and landslide susceptibility (Glade, 1997). Other researchers have investigated the impact of farming on forest remnants (Smale et al., 2008) and also the temporal impact of the nutrient signature left in the land following retirement from pastoral practices (Stevenson, 2004; Dodd and Power, 2007); not to forget the successional trajectory given different management techniques (Sullivan et al., 2007). Others discuss an interventionist or non-interventionist approach (Prach and Hobbs, 2008). These all provide background for this study which is to investigate the impact that the removal of forest has on the landscape in the context of returning the landcover to indigenous forest.

Whilst much of the above research addresses impacts from land use, also pertinent is whether farming steep hill country with slopes susceptible to erosion is sustainable. Emphasis is now being placed upon the externalities of farming, an example being nutrient run off and subsequent pollution of waterways (for example, the Dairying and Clean Streams Accord: Fonterra et al., 2003). An extension of chemical run-off is the question of cost regarding impacts from poorly managed hillslopes and the sediment deposited downstream (Dodd et al., 2008). Poorly managed hillslopes bring increased flooding and concomitant costs that society in general has to pick up, rather than the landowners responsible (Marden et al., 2005; Dymond et al., 2010; Hicks, D.L., 1991). Pointing out the cost to society of unsustainable practices, the office of The Parliamentary Commissioner for the Environment (2001) published a report looking at the sustainability of land use, highlighting the need to better manage these landscapes.

Although this is a complex problem, one that past governments have exacerbated by encouragement of forest removal through provision of subsidies, land use choice will become more contentious in the future as society has to allocate fewer funds to increasing environmental problems. Land use change through reforestation and subsequent carbon sequestration may be promoted as a consequence and if there is to be a concerted effort to mitigate climate change then carbon trading will be an element of the response (The Parliamentary Commissioner for the Environment, 2008; Phillips, 2005). This brings with it opportunities for landowners to be provided with an economic alternative to the continued practice of grazing unsuitable slopes. Not all, but some, will choose to restore indigenous forest rather than exotic production forests, (Trotter et al., 2005), particularly if cultural and ecological facets are considered important. Possibly this may simply mean allowing an unassisted reversion, whilst it is possible that in some instances there will be an assisted intervention. Cultural landscapes are of significance, particularly to Maori, and may be a significant part of the transition to restoring steepland to indigenous forest (Funk and Kerr, 2007).

2. Research foci

The central goal of this study is to look at ecological restoration through a geomorphological lens. The overarching question to be answered is: "In what way can geomorphology inform ecological restoration?" As an outcome of the results of the investigation the question is then: "Does a synthesis of geophysical and biological assessment provide means to determine restoration priorities?"

There are frequent publications (Hobbs, 2002; Kondolf et al., 2006; Molau, 2008; Naylor et al., 2002; Naylor, 2005; Viles, 1995; Renschler et al., 2007) discussing the need to look at whole ecosystems, including abiotic factors (essentially geomorphic process/form elements), when considering restoration. Other authors argue that the success of science driven ecological restoration is questionable due to the process being values driven (Davis and Slobodkin, 2004); because of the impossibility of true restoration (Davis, 2000); given the rigidity of science in a heterogeneous landscape (Cabin, 2007); due to lack of true success in returning ecosystems to pre-disturbance states (Allison, 2007). It may be that by looking holistically, both at the communities that are the goal and the physical processes and conditions required to support them, increased probability of success will be achieved. Essentially, what is proposed is to gain a measure of understanding of some of the factors and variables that are of an abiotic physical nature that influence floristic community assemblage. Additionally, of interest is the nature of the impact of altered systems and processes that may be encountered at a restoration site. This will be achieved by examining theory and by application through a case study.

The case study is situated in a sub-catchment scale site at Whareroa Farm at the southern end of the Kapiti Coast, north of Wellington in New Zealand. It is a hill country farm, managed by the Department of Conservation (DOC), located in a greywacke geological setting. Whareroa Farm is maintained partly as a working farm but more than half has been retired and is reverting to scrub. Public access has recently been allowed following track construction and the site is now being managed as a multi-use recreation reserve. This includes trails for mountain bikes and horses. In order to understand the nature of past conditions that might have been expected at the restoration site a second study site has been chosen as a reference site. This is Paraparaumu Scenic Reserve. It is a site which is covered in indigenous forest and has been maintained for conservation purposes since 1905. It is currently administered by DOC.

2.1 Framework for the research

In order to achieve the central goal of the study, five core questions have been identified that will lead the investigation. These are:

1. *Can national databases be a useful tool in the process of site selection of a reference site in ecological restoration? (chapter 3)*

2. *Is there any significant difference in community floristic vegetation assemblage dependent upon hillslope location and aspect, and do the measured gradients influence the floristic assemblage? (chapter 4)*

3. *Is there any indication of physical/chemical conditions that may require remediation prior to biological restoration? (chapter 5)*

4. *What are the means of interpreting geomorphological change related to land use change and can they be usefully utilised in a restoration context? (chapter 6)*

5. *Is there a practical and useful way to relate geomorphic understanding to ecological restoration prioritisation? (chapter 7)*

3. Overview of Methodology

Methodology used in this study is disparate and specific to each of the separate endeavours above. As such these are presented in detail in each of the chapters with only an outline sketched here.

3.1 Can national databases be a useful tool in the process of site selection of a reference site in ecological restoration?

National databases were used in a Geographical Information System (GIS) environment to select a reference site. Land Environment New Zealand (LENZ) is a database predicated upon climate factors, soil factors and topography with up to 500 separate environment classes identified for the whole country. This was used to identify the environment classes at the restoration site. Concurrently, the Landcover Database 2 (LCDB2) was used to identify where indigenous forest coincided with the LENZ environments that were identified at the restoration site by the LENZ enquiry. Selections were made by utilising the basic geoprocessing tools and selection tools provided in ArcGIS.

3.2 Is there any significant difference in community floristic vegetation assemblage dependent upon hillslope location and aspect, and do the measured gradients influence the floristic assemblage?

Vegetation abundance was measured using quadrats stratified into hillslope locations and aspect. Abundance was measured by estimating coverage of species' canopies projected onto the ground and recorded as a percentage of overall quadrat area. The estimate was assigned to one of six abundance classes. This action was completed for 6 structural tiers and summed, then transformed to provide an abundance value. Analysis was undertaken using Indirect and Direct Gradient Analysis to discover associations. Cluster analysis was used to identify groups of assemblages.

3.3 Is there any indication of physical/chemical conditions that may require remediation prior to biological restoration?

Samples of soil were collected from three points on transects stratified by hillslope location, aspect, and site. These were the independent main effects. One covariable, slope angle, was used. The dependent variables were soil variables which are accepted as important to vegetation abundance and composition. Analysis of results was undertaken using a non-metric method, that is, permutational multivariate analysis of (co)variance.

3.4 What are the means of interpreting geomorphological change related to land use change and can they be usefully utilised in a restoration context?

The method of analysing the geomorphology of the restoration site was undertaken by identifying erosion from a sequence of aerial photos spanning the years 1942 – 2010. GIS was used to analyse the results regarding association of new mass movement with previous mass movement and separately, with slope aspect and angle. Finally, connectivity of slopes was examined by the creation of a fine scale DEM which was used to run flow models. Within ArcGIS the Compound Topographic Index (Thorne et al., 1990) was run to identify sites of erosion susceptibility.

3.5 Is there a practical and useful way to relate geomorphic understanding to ecological restoration prioritisation?

For question 5 the results of the previous questions were used to summarise the information and examine how this information may be utilised. River Styles® is a framework within which to appraise the geomorphic condition of rivers, from whole catchments down to segments of reaches. Its aim is to determine the recovery potential of rivers and to determine priorities for restoration. An extension and modification of the

River Styles framework is proposed and outlined. In this section I utilise modified elements of River Styles framework to assess the condition and recovery potential of the study site and, using the results of the assessment, propose prioritisation of ecological restoration of the study site.

4. A regional context

In the site context section I first examine elements where a general description will be sufficient to describe both sites at once. This is then followed by elements which are specific to each site.

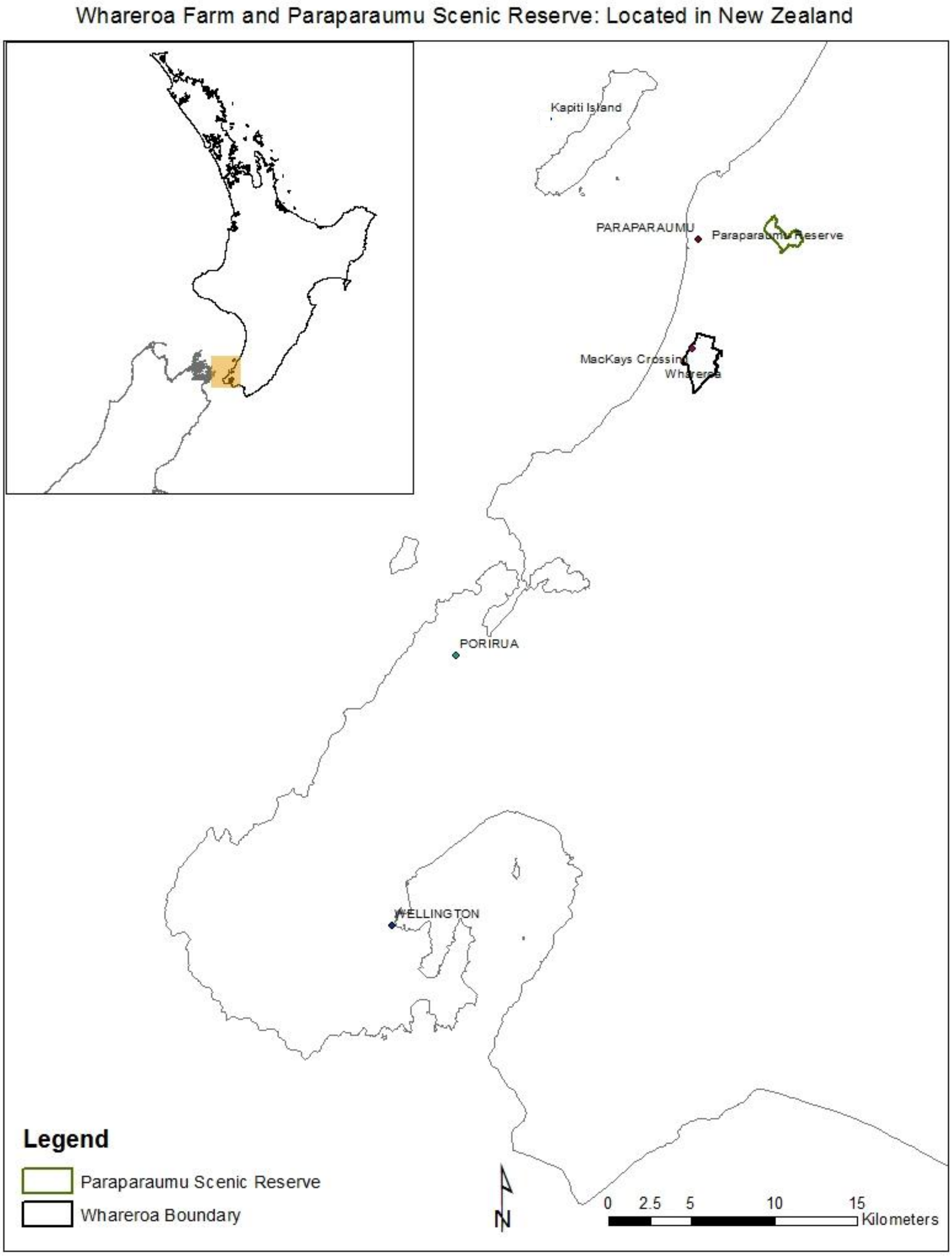

Figure 1: Location of study sites in the regional context.

4.1 Climate

The topography of the Wellington region is particularly rugged and therefore causes myriad of microclimates and spatial contrasts in temperature, rainfall and wind with sharp gradients (Salinger, 2000). The orientation of Cook Strait deflects predominant westerly winds to be north westerly or easterly winds to be south easterly while the

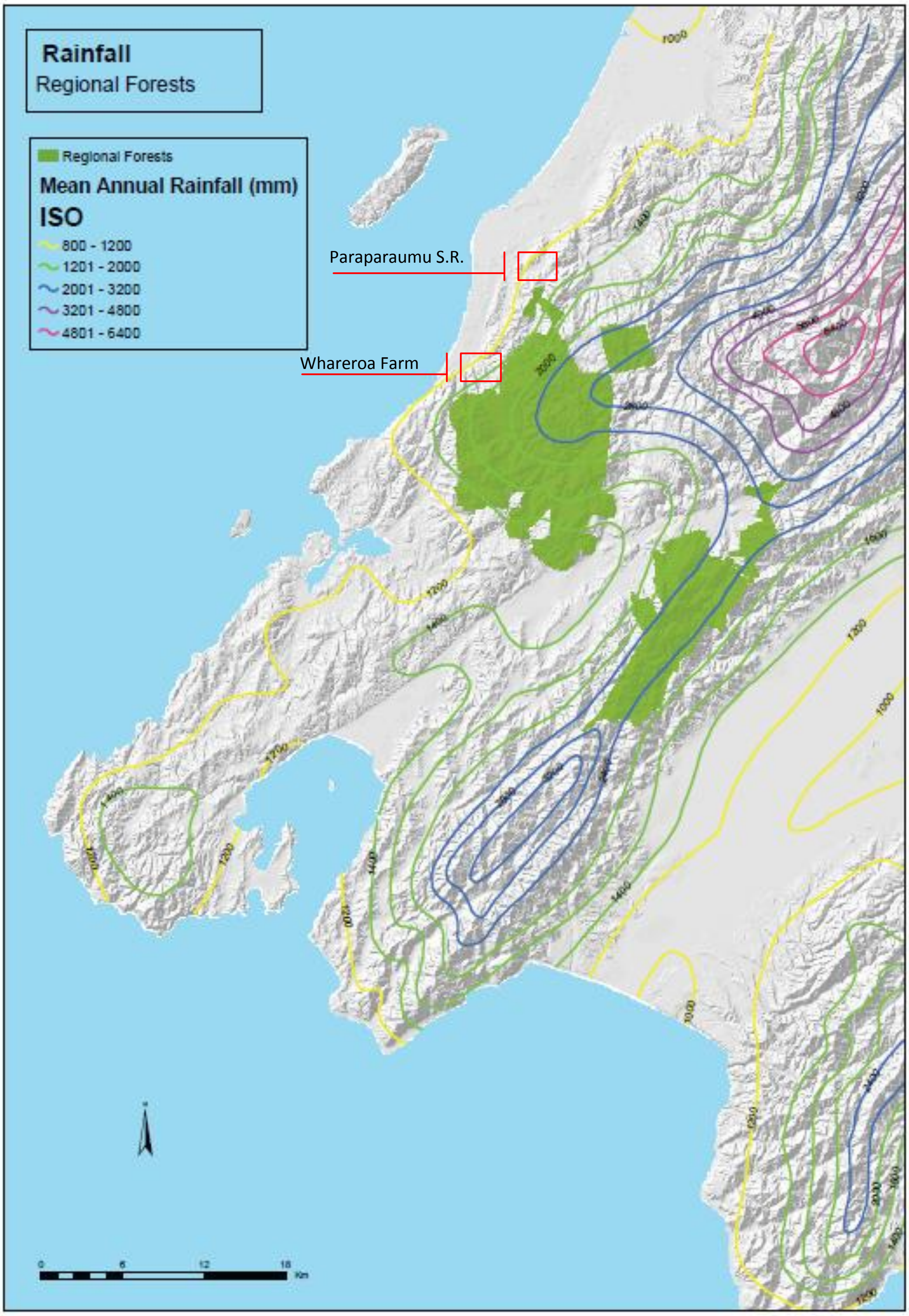

Figure 2: Rainfall isohyets for the lower west of the North Island, New Zealand (modified from Greater Wellington Regional Council, 2008).

funnelling effect of Cook Strait in concert with orientation of the mountain ranges in both islands causes winds to be accelerated. The Kapiti Coast is further removed from Cook Strait than is Wellington, but nonetheless is still influenced by the topography described above. Wind run (a measure describing the distance air travels for a given period at a particular anemometer measuring point) at Paraparaumu airport is 312km/day in March to 532 km/day in October/November (Walzl et al., 2008). With the localised funnelling effect of the topography of Whareroa, wind run may be greater than at Paraparaumu.

The regional oceanic setting determines that the air is moist and air temperatures moderate. Figure 2 shows that both Whareroa and Paraparaumu Scenic Reserve are in the 1200 – 1400 mm per year band. Distribution of rain through the year is uneven; data downloaded from National Institute of Water and Atmospheric Research (2011) for the Paraparaumu Aero climate station show the average for the summer months is 70 mm while the average for the winter months is 99 mm (averaged over the period 1970 – 2000). During summer, periods of no rain can exceed 14 days (Goulter, 1984). Migration of anticyclones and troughs has an approximately 5 – 6 day cycle. Paraparaumu has higher daytime temperatures than Kelburn (Salinger, 2000) with an annual mean of 12.9° C. Due to the predominant wind direction the moist air is forced to rise over the hills to the east of the coast causing cloud formation and so this pattern will have an effect on the measurements for both Whareroa and possibly more so for Paraparaumu.

4.2 Geology

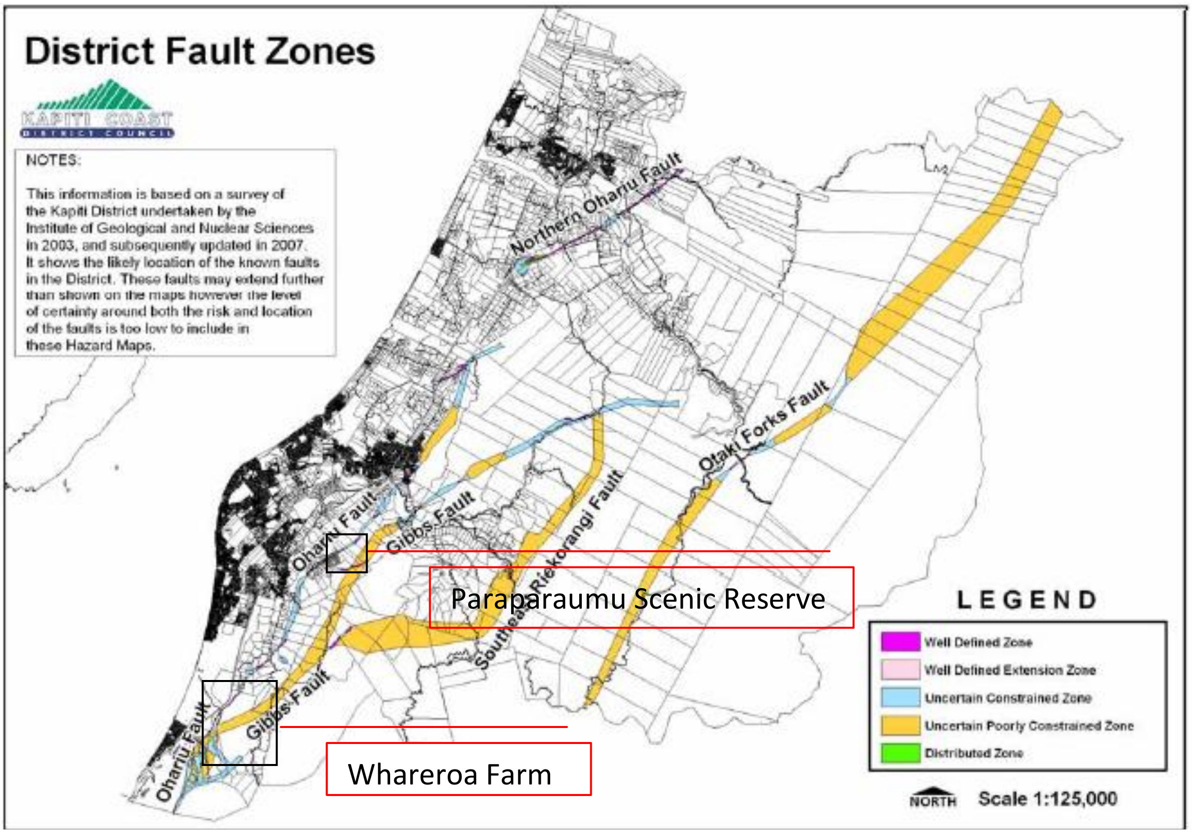

Figure 3: Fault lines in the Kapiti Coast District (Kapiti Coast District Council, 2011)

Whareroa Farm is situated in a valley system breaking the coastal scarp that runs from Pukerua Bay northward. Drainage networks tend to follow fault lines due to the weak crushed nature of the bedrock in the presence of tectonic activity (Te Whiti Love et al., 2008). In this case the valleys are probably a result of the Gibbs splinter fault which runs off the Ohariu fault south of McKays Crossing and passes through the main Whareroa valley and side valley to the north east (van Dissen and Heron, 2003) (refer to Figure 3). This fault continues northward and passes along the eastern boundary of Paraparaumu Scenic Reserve, with Maungakotukutuku Stream tracing its route. The fault is estimated to have movement of less than 1-2 mm per year but the return period is unknown.

Whareroa and Paraparaumu Scenic Reserve are situated in Torlesse super-group of greywacke sandstone and argillite approximately 190 million years old (Begg & Mazengarb, 2000). The Torlesse super-group located in the lower North Island is the substrate forming the axial ranges that are uplifted due to tectonic activity of the current Kaikoura orogeny (McConchie, 2000). The footslopes upon which Whareroa is largely situated are the western extremity of the uplift.

4.3 Restoration site: Whareroa Farm

4.3.1 Background

Whareroa Farm is a block of land that is administered by DOC. Approximately half has been retired from active farm production and is reverting naturally from pasture to early successional native forest. It seems rather incongruous that DOC should have responsibility for land that is not of high conservation value. The fact that it does follows community pressure to prevent the block being sold by Landcorp Farming due to their fear that it may have been subdivided into lifestyle blocks (Department of Conservation, 2011). Close proximity to the Queen Elizabeth Park on the dune lands north of Paekakariki was part of the impetus for Whareroa's conservation. There is a unique opportunity to cloak the landscape with forest from the Akatarawa ranges, which is close to the eastern boundary of Whareroa, to the coastal dunes of Queen Elizabeth Park. I am not aware that other opportunities exist where public land is contiguous in this manner from the inland ranges to the coast in the lower west North Island. Extremely little forest, specifically, lowland coastal forest remains in these particular environments. In a report for the Kapiti Coast District Council the regenerating remnant bush on Whareroa is designated as of regional significance (Wildlands Consultants, 2003). It is noted that the farm lies within the Tararua ecological district. Thus there is the potential for ecological restoration of high regional significance forest and an opportunity to implement ecological restoration with the best knowledge available of the environment.

4.3.2 Landscape

The action of the periods of glaciation has left telling markers in the Kapiti Coast landscape. The sand dune and peat country upon which Queen Elizabeth Park sits is a reflection of this. During the last glacial maximum, some 19000-29000 years before present (Newnham et al., 2007), the sea level dropped by some 120 m due to water being locked in glaciers and icecaps and so the coastline receded west of its present location. While there was no glacial activity in this vicinity, much periglacial solifluction activity took place which saw large amounts of colluvium shifted down slopes denuded of large vegetation by the colder temperatures. This colluvium coalesced into large steep fans which spread to the distant coast. This colluvial gravel underlies coastal sand dunes which have been constructed by the transport of finer material by the aeolian processes as the coastline advanced (prograded) since the inter-glacial highstand.

Also witness to the changing climate is the interglacial high-stand coastal scarp, which lies at the back of the coastal dune and peat lands. The scarp was partly created when the global temperature warmed post the last glacial maximum by about 2 degrees with a maximum about 6500 years ago (Te Punga, 1962; Hawke and McConchie, 2006) and to earlier interglacial periods. This can be seen not only in the steep sided scarps in the greywacke but also in the truncated Te Ramaroa fan (see Figure 4) that fronts the valley that Whareroa Farm is situated in. Besides the coalescing fans providing the footslopes for the steep hills, a series of alluvial flats have been subsequently carved by the action of the streams in conjunction with the altering base level as dictated by the fluctuating sea level. Tectonic uplift may also have contributed to the terrace remains.

Despite extensive deforestation a number of remnant and regenerating patches of indigenous forest remain on Whareroa Farm. These have been degraded due to stock access but most are now fenced off. An assessment by Wildlands Consultants for the Kapiti Coast District Council describes the remnants as small fragments of kohekohe, tawa and titoki having significance at the regional scale (Wildlands Consultants, 2003). In the Queen Elizabeth Park Resource Statement the Whareroa Stream is described as having been affected by lack of riparian vegetation, nutrient run-off, physical damage by stock, and erosion. Palmer (2008) in her thesis related to the health of the stream concluded there were poor riparian characteristics from the headwaters to the coast. This negatively affected the stream ecological integrity, highlighted by the lack of stream biota.

4.3.3 Historical land use

Archaeological studies have found that Maori gardens existed in association with the alluvial/colluvial flats at Whareroa (Figure 4, Aranui, 2008). Substantial gardens and possession of horses, cattle and pigs are recorded during a visit by the Native Secretary in 1847 when Whareroa pa was occupied by Ngati Maru iwi. Land south of Whareroa Stream was sold to the Crown in 1858 and it is recorded at this time that 5000 acres of pastoral land existed whilst the rest of the 34,000 acres was heavily timbered. In the 1870's the MacKay family leased land in the vicinity which was described as containing high stands of manuka in places (Walzl et al., 2008). These descriptions show that disturbance at the site has been an ongoing occurrence for a lengthy period.

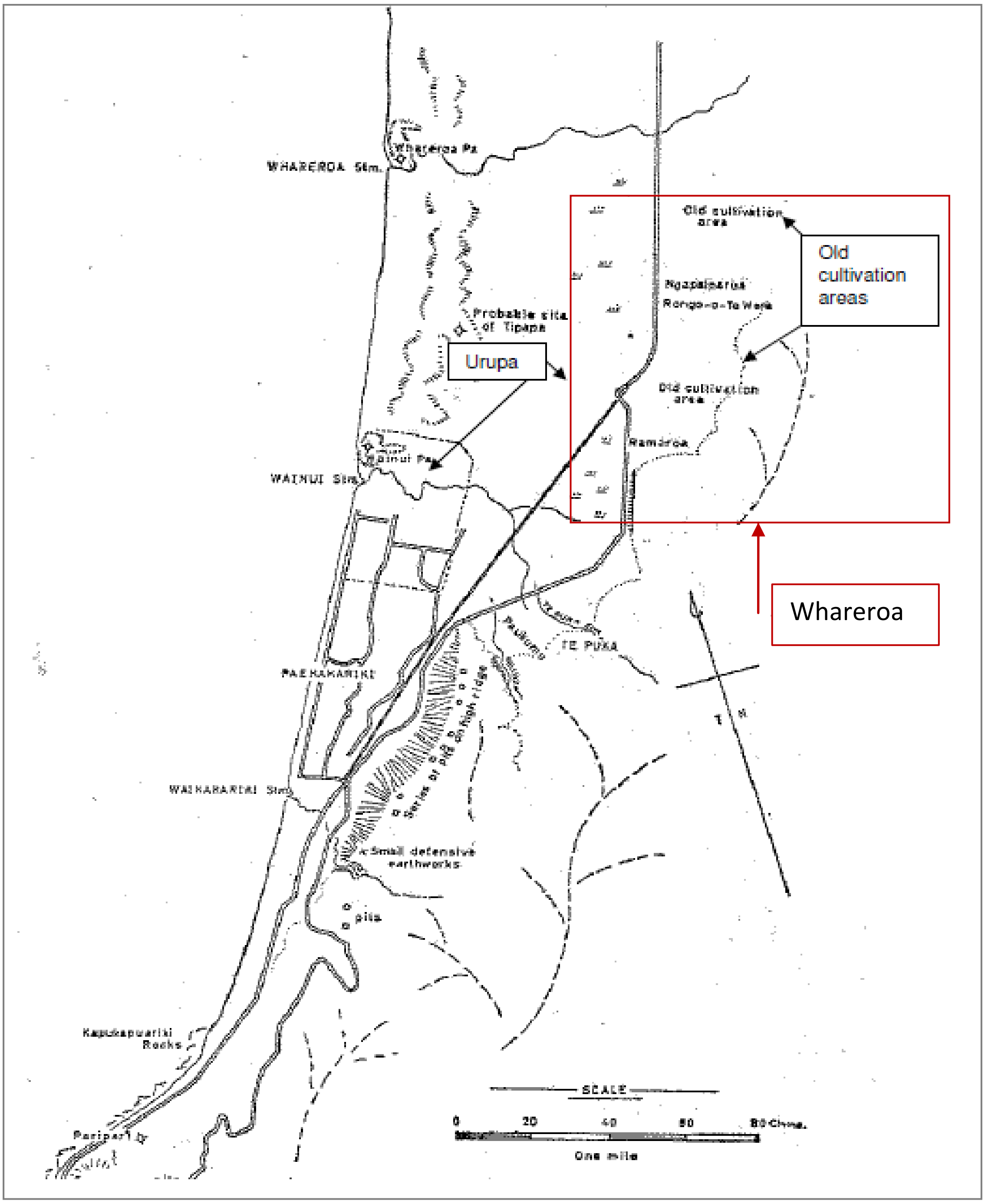

Figure 4: Whareroa with indication of the cultivation site opposite MacKays Crossing. Also of note is the naming of the Ramaroa fan created from the outwash of the Whareroa valley (Aranui, 2008; modified from Carkeek, 2004).

4.3.4 Soils and land use capability

The soils at Whareroa are comprised of a number of different soil series. Ngaio soil series are Pallic soils associated with rolling and hilly land developed in silty loess and associated slope deposits (Bruce, 2000; 98). These soils are found on the colluvial fans and some terraces (refer to Appendix 3.5). Paremata Hill soil, is a Pallic soil associated with hilly and steeplands in thin loess overlying colluvial deposits from greywacke (Bruce, 2000; 98) and is found on the moderate-steep slopes of the northern part of the catchment. The steep western and southern hills are classed as Makara Steepland soil, described by Bruce (2000; 98) as brown soils found in moderately steep to very steep landforms and displaying shallow stony profiles on weakly weathered greywacke. It is the Makara soil that is the main soil in the particular gully studied.

The Land Use Capability (LUC) unit (Lynn et al., 2008) for the steep slopes is '7e 1', with erosion assessment of 2Sc1Ss1Sh; for the moderate sloped northern area it is '6e 3' and erosion assessment of 2Ss1Sh1T, the colluvial central area and separate north-western area is '4e 1'; whilst for the western Ramaroa colluvial/alluvial fan the class is '3s 3' (refer Appendix 1.1). Neither of the last two areas is given an erosion category. The land use class 7e 1 indicates that the land is unsuitable for arable cropping and of low suitability for pastoral grazing or production forestry. The main limiting factor signified by the letter "e" is erodibility, while the integer 1 is a number to classify similar areas under the class and sub-class category. The erosion classification 2Sc1Ss1Sh indicates that there is moderate scree erosion, slight soil slip erosion, and slight sheet erosion. For the moderate slope area the LUC class 6e 3 indicates that it is unsuitable for arable cropping, and of low suitability for pastoral grazing and production forestry. The erodibility assessment 2Ss1Sh1T indicates that there is moderate susceptibility to soil slip, slight sheet erosion and slight tunnel gully erosion. The alluvial/colluvial area '4e 1' is classed as low to medium suitability for arable cropping, medium to high suitability for both pastoral grazing and production forestry. The limiting factor is erosion. The Ramaroa fan is seen as having suitability for multiple uses with the limiting factor being the soil.

4.4 Reference Site: Paraparaumu

4.4.1 Background

Paraparaumu Scenic Reserve is a fragmented corridor of forest from State Highway 1 to the Akatarawa/Tararua forests. The reserve perimeter in the west crosses State Highway 1 continuing in a disjunct to the east over the coastal scarp into Nikau Valley. It traverses the next set of hills to cross the Maungakotukutuku Stream, and so join the hinterland forests (sees Figure 5).

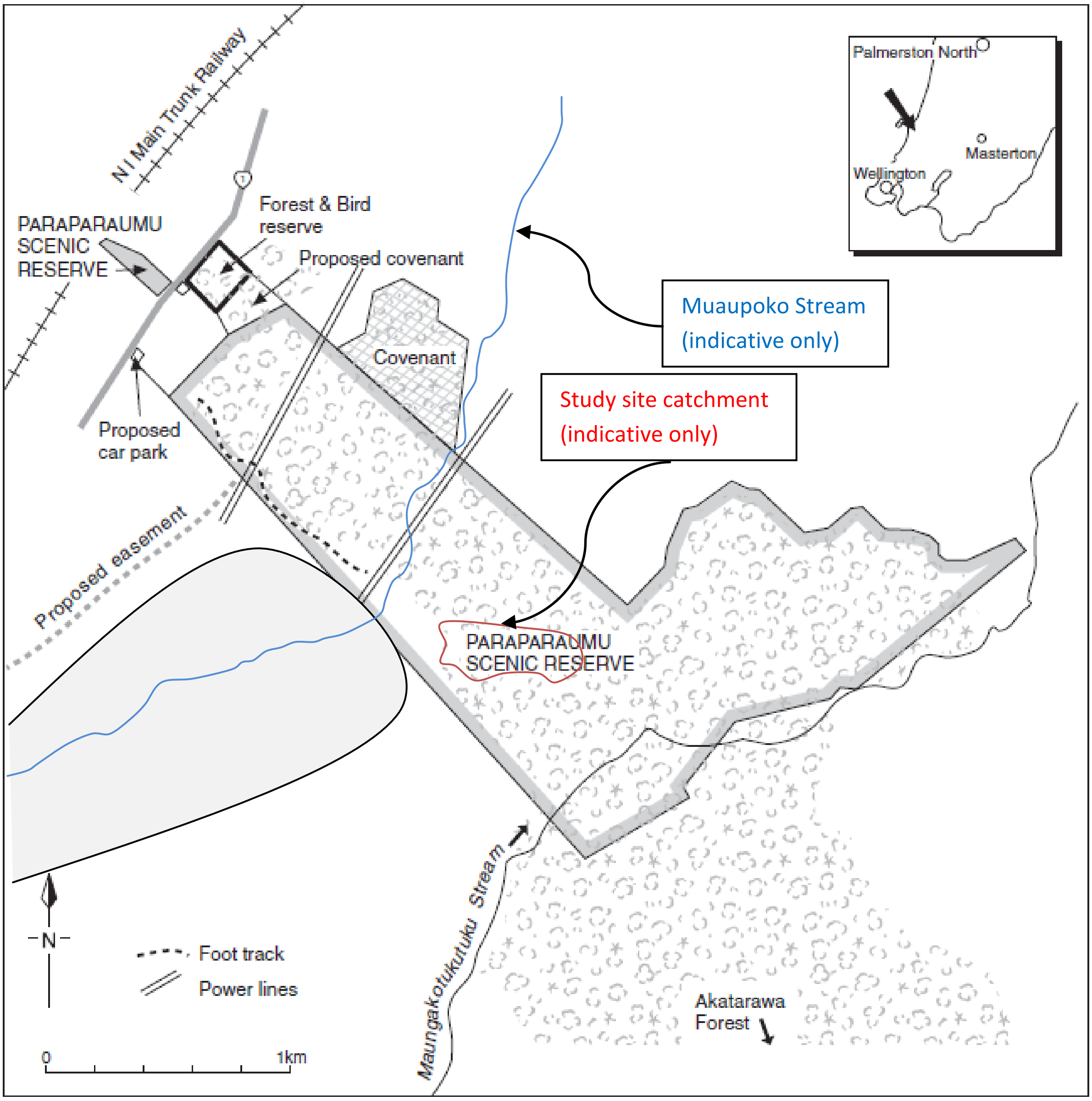

Figure 5: Paraparaumu Scenic Reserve and adjacent forests (modified from DOC: Wellington Conservation Management Strategy, Part two: Places in Wellington Conservancy. Chapter 7, Kapiti and Horowhenua).

The reserve is also in the Tararua Ecological District and is recognised as regionally important as a significant example of rare kohekohe forest. It is described by Wildlands Consultants (2003) as:

> *"One of the largest forest fragments in the area containing good representative examples of the forest types present. Provides habitat for Mazus novaezeelandiae subsp. Novaezeelandiae (Townsend et al. 1998), Adelopetalum tuberculatum (Forest & Bird Society), Northern rata and kereru. Protected in part by Scenic Reserve (Paraparaumu SR), DOC Covenant, and Forest and Bird Reserve".*

DOC recognises the value of the area and has been monitoring and controlling mammalian pests. Of significance is the presence of brown mudfish in Muaupoko Stream which is recommended for monitoring.

4.4.2 Landscape

Paraparaumu Scenic Reserve straddles two small linear ridges. These hills run parallel to the fault line structure in this region, that is, generally south-west to north-east. The Ohariu fault runs along the valley carved out by the Muaupoko Stream and traverses the reserve along the western foot of the inland hill. The Gibb fault runs to the east of the inland hill partly traced by the Maungakotukutuku Stream. It is these faults that have influence over the topography here. In a manner similar to Whareroa, there are large colluvial fans oriented to the west along with alluvial flats that are being incised by Muaupoko Stream with terraces evident. To the north, active farmland bounds the reserve, as it does to the south which has been largely usurped by lifestyle blocks. The boundary to the east is marked by the Maungakotukutuku Stream and beyond this is private forest which is in turn connected to the Akatarawa and Tararua forests.

The sub-catchment in which the sampling site was situated comprises gravelly steep slopes with the mid section of the gully having a very narrow constricted section. The head of the valley, a zero order basin, was more U shaped and was not incised by fluvial action. The swale in this upper section of the gully contained boulder scree. The bottom of the gully widened but maintained a quite deeply channelised fluvial channel and a substantial side gully was evident on the southern spur. There was little evidence of fresh mass movement found during my survey of the reserve, though at least two instances of recovering mass movement scars were observed.

4.4.3 Historical Land use

This forest has been a reserve since 1905 when it was bought from iwi at a time when concern relating to the loss of native bush was raised. The Waitangi Tribunal publication relating to Horowhenua/Manawatu records this as follows (Anderson and Pickens, 1996; 317):

"The Paraparaumu scenic reserve had been established in 1906, with the taking of 185 acres in Ngarara West C, subdivision 7, the Maori owners being given £300 by way of compensation. The decision to take the land was at the recommendation of the Scenery Preservation Commission, an advisory body set by the Scenery Preservation Act 1903".

DOC records show that permanent plots were established to monitor the condition of the forest (Stone, 2010). In the last general report of the reserve available (1983), the assessors for DOC described the boundary fences at that time as unsound and that margins were highly impacted by stock. It is a little unclear as to the area that they are meaning as the reserve traverses a large area (with changing neighbours). My observations of the area in Nikau Valley were that the fences were robust and that the forest floor had abundant seedlings but that there were areas that showed paucity in the lower to mid tiers which may signify the impact of past browsing. Even though this is only a small amount of knowledge available regarding the reserve the observations at the site indicate that it has been relatively undisturbed. It is likely that it will still be recovering from the impact of stock grazing in the understorey and possibly from possums in the canopy. The 2010 pest control report states that the forest canopy at the permanent sites was greater than 70 percent, the target quantity.

4.4.4 Soils and Land Use Capability

The soils map at Appendix 3.7 shows that the soil for the majority of the study catchment is Makara Steepland with pockets of Ruahine Steepland. Another soil type that intrudes slightly on the south facing slope is that of Paremata Hill phase soil. The colluvial/alluvial area in the lower part of the catchment is Judgeford soil with pockets of Ngaio soil. In the main the soil type is similar to that of the sampled sites at Whareroa.

The land use capability unit for the upper part of the sub-catchment is 7e 1 (Appendix 1.2). The land use class 7e 1 indicates that the land is unsuitable for arable cropping and of low suitability for pastoral grazing or production forestry. The main limiting factor signified by the letter "e" is erodibility, while the integer 1 is used to classify areas similar under the class and sub-class category. The LUC class 6e 3 indicated on the lower slopes signals that it is unsuitable for arable cropping, and of low suitability for pastoral grazing and production forestry. The limiting factor is erosion. These units coincide with the mapping at Whareroa Farm.

Chapter 2. Literature Review: The interface between the distribution of biota and geomorphology.

1. Introduction

The intent of the study is to examine the context in which geomorphological understanding is applied in ecological restoration. In the literature there are numerous calls for the above linkage to be implemented (Hobbs, 2002, Kondolf et al., 2006, Molau, 2008, Naylor et al., 2002, Naylor, 2005, Viles, 1995). Others, e.g. Renschler et al. (2007), outline the interfaces between the fields of ecology and geomorphology but confirm the lack of applications (or at least reporting of such applications at this interface). On the other hand the journal Landscape Ecology has been publishing articles since 1987 relating to issues that connect the disciplines. It is not to say that all articles connect geomorphology and ecological restoration. Articles with a particular focus upon planning actual restoration projects that involve floristic communities are less common. It is apparent that there is a wide call for the inclusion of geomorphic assessment in restoration practice.

Using the Web of Science database search engine and the words ecological restoration plan*, 146 hits were returned, and when searching within these results for "geomorpholog*" only 28 were retained. Of those 28 returned only five specifically and directly related to a restoration project. When "ecological restoration plan*" was used 7 hits were returned and when refined to include geomorph*, no records were retained. A separate search was conducted in the website for the journal Landscape Ecology. Searching for articles within the journal for "ecological restoration" 51 hits was returned. A second search for "ecological restoration" AND "geomorphology" returned 3 articles. The above is not a comprehensive search but may be illustrative of a paucity of research published in relation to the practice of ecological restoration projects and the interface with geomorphology.

The literature review explores the various aspects of biotic and abiotic components in an ecosystem from diverse research perspectives. Often these studies are not in a restoration context, but may have ramifications for restoration practice. It traces the theoreticians' calls for incorporation of geomorphic assessments in ecological restoration, and looks at cases which, at least partly, demonstrate this perspective. There is a brief overview of the disciplines that provide understanding in a landscape and holistic way, and the interconnections and feedbacks of processes and with biota. Frameworks and models for analysing geomorphic condition are then considered. Finally, with a focus on the New Zealand context, research relating mainly to hillslope erosion (but also touching upon other landscape units) and the implications for floristic communities are discussed. The caveat is that much of the literature (international and

New Zealand) that is presented does not come directly from a practical restoration perspective.

2. The global context

Geomorphological understanding of the interconnectivity of, and processes in, the landscape may benefit planning, goal setting and implementation in restoration projects, at both local scale and larger scales (Kondolf, 1998). However, with a few exceptions, for example, Brierley and Fryirs (2000), and Kondolf (1998), evidence suggests (as illustrated in the database search) that geomorphological understanding is peripheral, not central, to ecological restoration research, planning and implementation. Molau (2008) points to the landscape unit, the most commonly used basic geomorphic unit, as being the most useful for ecological understanding. Callicott (2002) discusses the need for the appropriate spatio-temporal scales within which to frame ecological restoration, taking into account ecological disturbance regimes.

Doubts are expressed as to the efficacy of ecological restoration and the success rate of projects enacted (Hobbs, 2009). The lack of success may in part be due to the goals set, inadequate knowledge of reference states, implementation techniques, or negative influence "upstream" of the restoration site (Holl, et al., 2007). This brief survey illustrates the general importance of geomorphology in assessing conditions and its linkages with landscape ecology. It also infers that geomorphic consideration may positively benefit ecological restoration planning leading to improvements in the success of restoration.

A trend in ecology has been to re-evaluate the significance of spatial scale in respect of the relationship between species, populations, communities and ecosystems. For example there is a body of research based upon landscape scale which takes into account metapopulation dynamics and also "bio/geoconnectivity" (Naylor, 2005; Naveh, 1994). It is the expansion of the scope that links ecology and geomorphology and consequently restoration. Renschler et al. (2007) state there has been a tradition of geomorphology informing community ecology [however, of the 38 references in his paper 3 are regarding restoration and only one of those is a direct application; but the authors comment further that restoration is an emerging area for future research]. Renschler et al. (2007; 4) state that "one would expect that these two disciplines would easily merge into well meshed integrative studies, co-informing each other and developing truly integrative and over-arching theories. This has not been the case. Instead, the two disciplines have tended to perform research in relative isolation, selectively picking and choosing snippets of information and theory from the other discipline when needed". Renschler et al. (2007) go on to state ecology could be better performed with a geomorphologists understanding of the dynamic nature of the geomorphic processes and hence the impact on ecosystems and species [at a landscape level/scale]. While the above discussion relies heavily on one paper (due in part to the lack of reviews that consider the two fields comprehensively) it does provide an excellent commentary.

2.1 Interconnections, holistic assessments, scale and thresholds.

When discussing biogeomorphology, Naylor et al. (2002) propose that it should be seen as a holistic earth system approach dealing with biological, chemical and physical characteristics across a range of spatio-temporal scales. Hobbs (2002) writes that pattern in vegetation composition can be related to regional gradients in climate, such as temperature and rainfall, changes in soil, landform type and topography. Fluxes of water, nutrients and material are among other important determinants of landscape pattern as outlined by Hornung and Reynolds (1995). Conversely, these can also be affected by the landscape pattern. Naylor (2005) also highlights the feedback situation between landform and biota.

Geomorphic assessment which accounts for these patterns, interactions and feedback is as important in small scale projects as it is at larger scales and will help ensure realistic and achievable goals improving the likelihood of success. Although not all restoration projects necessarily require an in-depth geomorphological study there may be any number of situations when it is necessary. Even with small scale community projects there may be linkages to other landscape units that impact on the restoration site. For example, the catchment upstream in a small suburban gully will impact upon the restoration site through stormwater drains and housing development; therefore, understanding the connectivity of the landscape units as well as ecological topology (the pattern of the interconnections and relationships in an ecological context, Thompson et al., 2001) is important. With greater geomorphic understanding the decisions as to what sites should have priority in circumstances of scarce resources will improve restoration outcomes (Brierley and Fryirs, 2000).

Other elements of geomorphology and catchment scale understanding which are significant relate to thresholds and equilibria (Hobbs and Harris, 2001). Whisenant (1999) proposes two types of thresholds, firstly, those caused by biotic interactions, and secondly, those caused by abiotic limitations. Hobbs and Harris (2001) discuss the need to look at the degrading factors and if they are biotic then the focus should be on removing these. They state that if the degradation has been due to abiotic factor then removal of that factor and physical repair or chemical adjustment should be addressed, thereby underpinning restoration prior to any biotic manipulation. This model is graphically presented in Figure 1. The focus in the thesis is on the abiotic limitations.

Wilkinson and Humphrey (2006) state that current vegetation patterns may not reflect current soil conditions but may be an historical legacy. The notion that current vegetation patterns actually reflect past conditions may be of significance when looking at reference sites. Alternatively, if, due to the degraded state of a restoration site, certain

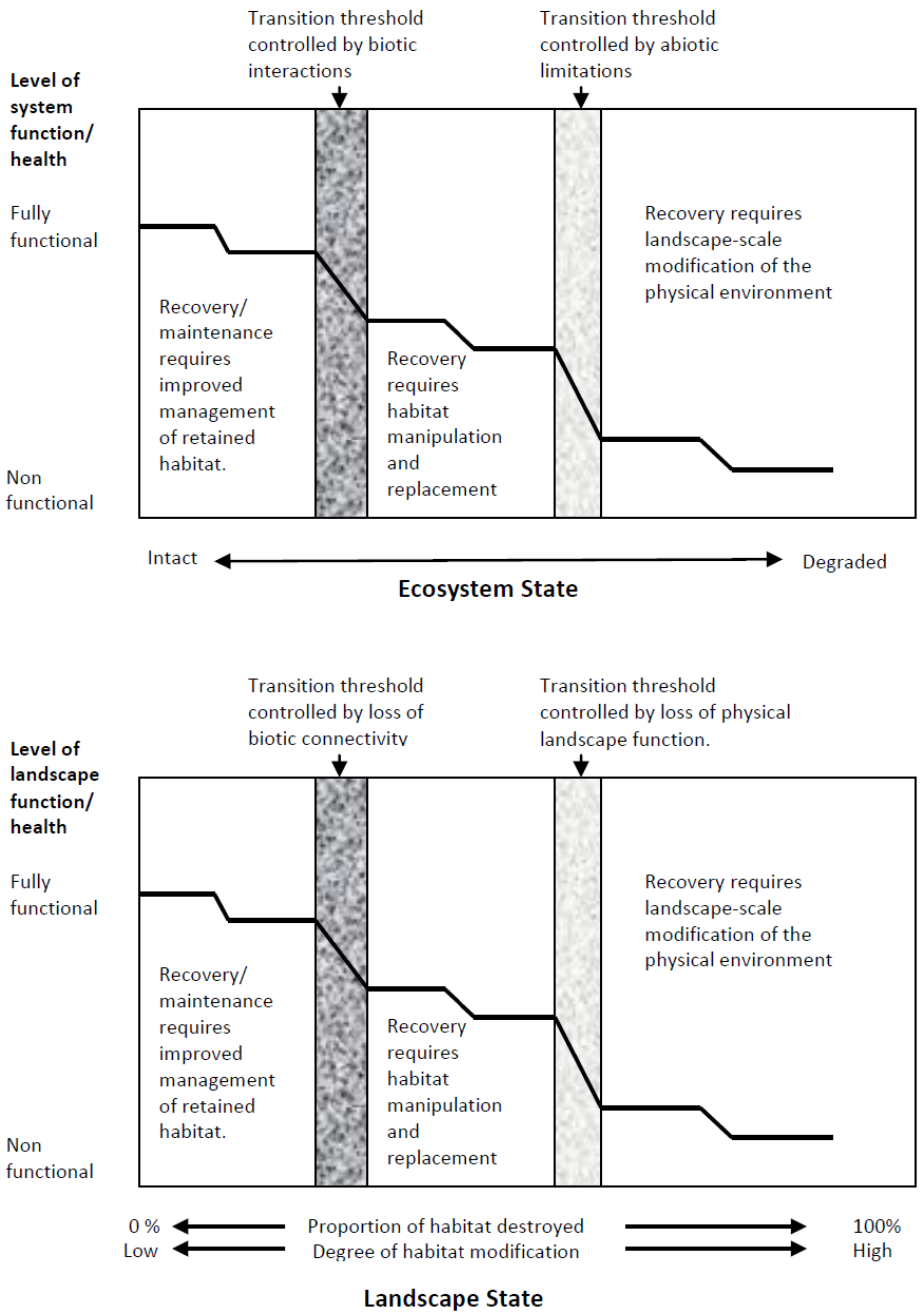

Figure 1: Biotic and abiotic thresholds at the ecosystem scale and the landscape scale with appropriate response action (redrawn from Hobbs and Harris, 2001).

geomorphic factors have changed, for example, sediment delivery, it may not be possible to use a historical reference system. If a return of the system to its previous state is unlikely, the options available will be altered in relation to applicable reference states and hence restoration trajectories. The goals may need to reflect the set of characteristics that is desired for the system in the future rather than the past (Pfadenhauer & Grootjans, 1999). This scenario leaves the underlying abiotic (dis)equilibrium untreated, but at least, due consideration of the equilibria of the system will ensure that restoration is not implemented with inappropriate species given the altered conditions.

2.2 Geomorphic processes associated with ecological restoration.

Processes and functions that influence biota may be involved at the micro or macro scale. For instance, the chemicals exuded by plants may affect the soil chemistry and consequently the soil hydrology, pedogenesis and erosion (Osterkamp and Friedman, 1997). If the impact has been large, it may have tipped the soil over a threshold and a new state may result. If the plants are an unwanted exotic invasive species and the goal for restoration is to reintroduce native species then the soil chemistry may need to be addressed first (Figure 1).

Discussing effects at both scales, Hobbs (2002) addresses the subject of nutrient flux in the landscape. He draws attention to the connection of geomorphic processes to that of the biota stating that the fluxes of nutrient and material is dependent upon geomorphological processes, such as erosion, leaching, and transport. Root biomass will also have explicit influence upon the stability of soil and rates of erosivity (Osterkamp and Friedman, 1997; Marden et al., 2005) and hence the sediment fluxes for a landscape. Also at both the fine and coarse scale, weathering may influence and be influenced by biota (Naylor, 2005). Obviously, even in small scale restoration geomorphic processes will play their part, whether it is through mass movement or through solutes and their influence on biota.

The influence of water through geomorphic processes is seen as fundamental to understanding an ecosystem (Osterkamp and Friedman, 1997). The influence may operate through processes such as rainsplash, dispersed overland flow, and concentrated flow associated with rill formation, gully formation and channel creation. Eventually the process may lead to landform evolution by way of sediment entrainment, mass movement, transport and deposition. Localised sediment transport by these processes is translated to catchment scale as the connectivity of the sediment and the fluvial system is increased. If stream habitat is the concern, then the sediment type and delivery flux will have a major influence on whether the channel will support invertebrates or other desired species. Also of influence in a riparian environment is the flow regime. While these processes do not receive detailed consideration in the study due to the interconnectedness they remain pertinent.

2.3 Biotic interactions in a geomorphic context.

Patterns in the landscape may also be indicative of biodiversity and of the connection between biota and landscape geomorphology. If gamma biodiversity of a broad geographically defined landscape is the goal then geomorphic processes are of significance due to the impact of perturbation on the flow of material and nutrient (Naveh, 1994). Levin (1976) describes three succinct factors that describe the interconnection of biotic and abiotic, and patterns in the landscape; (1) local uniqueness of sites caused by variation of microhabitat, including soils, (2) landscape evolution following localised disturbances, and (3) dispersal capabilities of various organisms.

Geertsema and Pojar (2007) present evidence of how landslides influence biophysical diversity. They describe how landslides will change soil density, structure, porosity, surface texture, chemistry and microclimate. These changes then influence habitat, by facilitating a mosaic of seral stages of succession not previously present, with the creation of patches of non-forested habitat and biota. Alternatively, study of vegetation patterns may reveal historical site conditions, natural disturbance regimes and landscape configuration, things actually obscured by vegetative cover and only read indirectly (de Blois et al., 2001).

Disturbance is ubiquitous in the landscape at both local and global scales, and as outlined above can result in positive consequences, for example, increase in biodiversity. It can also have negative consequences. The effects of changes in landscape use, structure, and soil erosion, was studied by Van Oost et al. (2000; 577) who found that soil erosion in productive landscapes caused “significant ecological damage by depleting soil biodiversity and affecting plant composition”. A review conducted by Blaschke et al. (2000) found that mass movement and the concomitant impact on productivity was significant across a range of landforms and ecosystems. This may be reflected in retired grazing pasture and would be of importance in restoration projects.

Muñoz-Reinoso and Garcia Novo (2005) detailed in their study in the Doñana dune fields that geomorphology mediated the availability of water and hence the vegetation patterns. They also commented on how feedback generated trends which stabilise the dunes. Viles et al. (2008) and Viles (1995) document various landscape forming processes determined by vegetation in a range of process domains e.g. extreme environments and rock breakdown, aeolian regimes, fluvial regimes, hillslopes, coastal wetlands. Consequently, they influence disturbance occurrences and patterns.

Although the focus in the study is on hillslope processes it is necessary to give some attention to the impact on the fluvial system as the sediment and nutrients eventually find their way to the waterways. In the fluvial regime, dispersal of invasive species may occur where conditions have been altered from the normal. Conversely, normal levels of riverbank erosion and sediment transport in conjunction with variable flow regimes which scour channel beds create conditions for species heterogeneity (Florsheim et al., 2008). Additionally, riverbank erosion is necessary for continued diversity through successional processes. These processes also affect fish numbers which are dependent upon hydrology, geomorphology and management (Rinne and Miller, 2006). Large scale geomorphology is important in relation to fish numbers as described by Morris et al. (2006) in relation to log jam construction. These examples illustrate how fluvial restoration needs to consider the geomorphic context.

Considering the wider riparian zone, restoration on polluted flood plains was conducted through the prism of microhabitat differentiation. As a consequence, revegetation and rehabilitation of river dynamics increased heterogeneity over a large 5000ha site in Spain (Carreira et al., 2008). The sediment transport regime was intrinsic to the driving forces increasing the mean value and intra site spatial heterogeneity of soil properties. Bank stabilisation, shading and regulation of nutrient and sediment supply are consequences of revegetation of the riparian margin. They also increased lateral connectivity of biota through physical, chemical and biological processes (Naiman and Décamps, 1997). Poff et al. (1997) and Lake et al. (2007) also discussed lateral connectivity and community dynamics (and metapopulation stimulus) but with emphasis on the need for natural flow regimes. On a more specific note the length of revegetation of streams was seen as a determinant of the extent of chemical and physical processes being restored (Storey & Cowley, 1997; Scarsbrook & Halliday, 1999).

Larkin et al. (2009) state that ecological restoration seeks to create persistent, self-sustaining ecosystems and point out that young restored sites are vulnerable to disturbances that interfere with restoration goals. When considering hillslope restoration the vulnerability may manifest in stress on plantings due to reduced water holding capacity of eroded slopes. At a fine scale, processes such as interception, infiltration, evapotranspiration, and run off interact with vegetation which may control where water flows (Hobbs, 2002). Here, vegetation has direct influence on these processes and biotic absence or presence will have immense impact, in most cases, on the amount of flux of those materials, nutrients and minerals (Hobbs, 2002). In other cases biotic build up or biofilm may act as a protector against erosional processes (Naylor, 2005).While this is true of vegetation having influence on abiotic processes; biota are also dependent upon the location of water. For instance, the presence of water will determine if riparian forest, or swamp forest can exist (Hobbs, 2002).

2.4 Landscape restoration frameworks and models

Brierley and Fryirs (2000) in their study of the Bega catchment in southern New South Wales outlined a framework they have coined 'River Styles®'. This methodology is designed for river analysis and restoration and the catchment scale is proposed as the basis of study. The River Styles framework can be briefly outlined by the following. A full analysis of reaches of the fluvial system, entailing examination of their current state, their conservation value, the degree to which they have been compromised in terms of extent of change from their natural state towards an alternative state, likelihood of successful restoration with the resources available provides the means for prioritisation of restoration activity. Further examination of the implementation detail is included in chapter 7. Another example of a framework is that of Coulthard et al. (2007) who advocated that cellular modelling of river catchments may be of assistance in understanding the response of the fluvial system. The inference is that by researching catchment characteristics and the fluvial system, knowledge will be available to inform restoration priority.

Other frameworks for assessing the environment exist, but a literature review did not reveal those which describe a structured analysis in a restoration context where systematic consideration of the geomorphic factors is included. What then should the focus be? Palmer (2008) states that, amongst other imperatives, the focus of restoration should relate to process and the identification of limiting factors, not structures. Palmer (2008) also challenges the usefulness of reference sites given the global background of change and hence the likelihood of locating truly undisturbed natural environments. Palmer provides theoretical arguments to support her argument but no framework to implement her theories in a practical restoration context. Reference sites can be seen as important where disturbance has reduced biodiversity at the restoration site and help guide the process of restoration (Society for Ecological Restoration International Science & Policy Working Group, 2004).

Another approach for assessing the landscape for environmental purposes is through the use of models. An example of a model that has been developed for the wetlands in southern Florida is the Total System Conceptual Ecological Model, (Ogden et al., 2005). The model is designed to link stressors to changes in ecosystem characteristics by inclusion of multiple cause and effect through factors such as loss of extent of ecosystems, loss of connectivity and changes in geomorphology, amongst others. The detail that is introduced into this model is beyond the scope of this study, but the study highlights many pertinent linkages that are generalisable. Research undertaken has looked at landscape scale interactions in an agricultural landscape dealing with fragmentation with a view to identifying irreplaceable sites for conservation (Thompson, 2011). It involves use of an algorithm in a GIS environment. Dymond et al. (2010) use a mathematical model and GIS for assessing and mapping erosion rates under varying land-use scenarios. Whilst the model has not been utilised in a restoration context it may have some application. Use of modelling in a GIS environment is also utilised by Lane et al. (2008) to identify restoration opportunities and includes analysis of likely success and a prioritisation element. Another GIS application, integer modelling, (Crossman and Bryan, 2006) has been applied to a small catchment in South Australia to demonstrate a process to identify landscapes that require, given certain input parameters, conservation and restoration.

The interconnectedness of the hierarchical and nested nature of geomorphic processes is affected by temporal and spatial scale is considered as an important consideration in the creation of models by de Boer (1991). Processed operating at different scales of either a spatial or temporal nature will have different evolutionary morphological outcomes. In an ecosystem assessment model for planning restoration at regional to local scale by Nakamura et al. (2005) utilises a geomorphological paradigm. Approaches looking at catchment scale issues and concerned with conservation and restoration give some insight into species and habitat conservation and management (Lindenmayer et al., 2008) and water quality assessment, as shown in models by Randhir et al. (2001) and Rosgen (1996), which outline a geomorphic approach for river restoration. These approaches briefly outlined use a systematic consideration of catchments and their value for conservation. However, they do not extend the structure to include a detailed analysis of implementation of restoration in a planning context and how altered conditions at the site may impact the restoration process. Nor do they focus upon the priorities at a scale that is of interest in this study.

Thompson (2011) uses the yardstick of "irreplaceability" of habitat in order to prioritise and plan restoration in an agricultural setting. Given the setting and scale this study considers "irreplaceability" is not totally relevant but is still useful in a theoretical sense and requires consideration. Another perspective is expressed by Peterson (1999) who sees the various components of a catchment having a particular function to play, whether that is stream channels, floodplains, alluvial fans, or ridge tops to mention some. Each of these landscape components has a specific hydrological function and ecological potential. He states that if any of these do not function appropriately the whole catchment is affected, as all the landforms are interconnected and act as a system. His method of assessing the landscape is one of observation to evaluate if the various elements are functioning optimally or if they are impaired and if so to determine what the cause is. An example may be a fan system "designed" to dissipate energy within water flow, which when degraded will become dissected with gullies due to concentrated flow paths. Following observation, the next phase he suggests is to plan and manage and to work with nature. His strategy is to firstly, decide what components can functionally be restored given technology available, secondly, develop alternative management systems to restore the components of the system, and thirdly, implementation ensuring hydrological function of the components.

Much restoration is community based (Brierley and Fryirs, 2000). If so, it may be argued that the method of characterisation of catchments and subsequent prioritising methodology may not be compatible for community-based work due to the technical knowledge necessary. Ultimately though, given the amount of funding that is invested in restoration, the aim must be to get the greatest environmental return for the investment or resources available. As such, some protocol to guide restoration and the inherent priorities, such as the 'River Styles' approach, will be a useful tool to ensure logical and rational decisions are made in restoration plans and activity. It may be that in some circumstances it could be practical for community restoration projects.

3. The New Zealand context

The preceding paragraphs have looked at the international literature seeking to outline the interconnections between geomorphology and ecology. Only in a small number of cases does the illustration of interconnections come from text which is specifically in a restoration context. It comes mostly from a pure or applied ecology standpoint. The next section hones in on the New Zealand perspective. Again, a lot of the literature sourced is of an applied nature and does in some cases consider geomorphology and restoration in the same breath. Frequently, the research described looked at discrete examples of environmental degradation and its consequences, but not holistically with broad geomorphic consideration in a restoration context.

3.1 Geomorphology in the context of active restoration

In New Zealand, in a reflection of a world trend, there has been a shift in emphasis relating to biological conservation. The trend has been towards a focus on the ecosystem, signalling a movement away from species-centric restoration (With, 2005). Although the species focus has (and will continue to have) a place, particularly relating to endangered species, it can be argued that with a holistic ecosystem approach more species will benefit. The Society for Ecological Restoration (2004) definition for an ecosystem is “An ecosystem consists of the biota (plants, animals, microorganisms) within a given area, the environment that sustains it and their interactions”.

If it is accepted that the ecosystem is the stage for conservation and, by extension restoration, then it follows that the geological and geomorphological aspects are of intrinsic importance. One of the few instances of a review of restoration in the New Zealand context was the investigation of the rehabilitation of a dam project site at Aratiatia on the Waikato River conducted by Smale et al. (2001). Their study revealed a community composition dependent upon the substrate, the ground cover, and the revegetation species planted. Slope angle was also analysed but was not found to influence community composition. The results indicate that if there is a specific mature community as a target of the restoration, it will not be adequate to simply let ‘nature’ take its course from within a disturbed state. Another longitudinal study looked at successional trajectories and assessed whether ecosystem function had been returned to a pre-disturbance condition at a study site in the Port Hills of Banks Peninsula (Reay and Norton, 1999). This study did not strictly incorporate a geomorphic approach though assessment of the physical functions was determined by proxy through vegetation and invertebrate indicators. Longitudinal studies in the New Zealand setting which examine the outcome of active restoration appear to be rare, particularly with a geomorphic context.

3.2 Vegetation pattern, succession, and substrate

Ecological restoration can be completed with various levels of complexity and intervention. In some cases the action required to make substantial differences may be very small. Simply fencing off remnant native vegetation may be all that is required, particularly if the expected species already exist in the location and are readily dispersed. Dodd and Power (2007) examined a number of remnants of tawa (*Beilschmiedia tawa*) dominated forest in the Rotorua Basin, fenced off for periods ranging from 1-53 years. They measured seedling and sapling numbers, groundcover, epiphytic abundance, litter cover and diameter at breast height, along with tree basal area. They concluded that once grazing ceases significant changes in diversity, structure, and soil characteristics can be expected and that recovery will continue to approximate that of ungrazed forest. While the Aratiatia case included slope angle and aspect in its analysis the Rotorua study examined how floristic composition was influenced by soil chemistry but did not consider geomorphic process/form factors.

A study that looked at the substrate in conjunction with community composition is that of Walls and Laffan (1986) who related the effect that soils have on vegetation patterns in the Marlborough Sounds. The study was not presented in a restoration context but it does convey information of significance for ecological restoration. The authors demonstrated clear links between soils and vegetation which facilitated reconstruction of past vegetation patterns. These soils were found to be a product of topography, altitude, local climate, and geological conditions which correlates with Jenny's (1994) factors of soil formation. The analysis accords with van Diggelen (2006) who stated that gradients in a natural landscape are closely linked to geomorphologic structures and soil types. Smale (1984) attributed the composition of species to soil texture and drainage in his study of White Pine Bush, a kahikatea remnant in eastern Bay of Plenty. Soil properties are clearly of importance when considering restoring disturbed sites as land use change may have altered conditions that will impact on success of species establishment and community composition.

Wassilieff (1982) found that floristic community composition at different seral stages had some correlation with soil and topographical patterns in the Marlborough Sounds. The main focus in Wassilieff's thesis was the relationship between soil and regenerative succession and community composition, but the author found little evidence to suggest a correlation between soil type and rates of regeneration. However, she mentioned that previous studies had shown faster rates of regrowth on southern slopes compared with northern slopes. It was hypothesised that the reasons may be that soil moisture status, prevailing wind, and greater intensity of fires affected north-facing hills. Such observation relating to slope aspect may be relevant when determining the priorities amongst many restoration choices. It may be that those with a southerly aspect will respond successfully with little intervention.

In a different geological setting and soil type Smale et al. (1997) also showed that there was little difference in growth of *Kunzea ericoides* (kanuka) on primary succession landslide scars compared with surrounding grazed pasture. Soil (re)accumulation was also rapid and it was hypothesised that this was due to the geological nature of the mudstones providing fertility with a tendency to weather quickly and in a manner that readily creates regolith, the weathered loose material above the bedrock. The rate was much greater than the eastern Taranaki hill country studied by Blaschke et al. (1992) with a similar but not identical lithology. The main differences were the higher rainfall of Taranaki along with steeper slope angle. Also of interest are the differences in species that predominate in the conditions found in the East Coast compared with Taranaki and its contrasting climatic regime. These examples flag the influence of topography and soil upon regeneration of perturbed sites and hence may influence restoration plans dependent upon the location of the restoration site and the lithology encountered.

In a discussion on succession, Lee et al. (1986) noted that although gorse does have the capacity to be a cover crop for seral (secondary succession) native species the density and the composition of individual species of the community will not approximate that of the local remnant community. The author hypothesised that the ground litter and bryophytes may have an impact on the succession in these sites. Others that have commented upon divergent trajectories influenced by the nurse species are Sullivan et al. (2007) who examined secondary succession in Wellington and Nelson, and Wilson (1994) in relation to regeneration at Hinewai Reserve, Banks Peninsula. With a different perspective is Williams (1983) in his study of secondary vegetation succession on the Port Hills of the Banks Peninsula. In that study the author described succession moved from broom (*Cytisus scoparius)* to elder (*Sambucus nigra*) and subsequently mahoe (*Melicytus ramiflorus*). Williams concluded that exotics are desirable species for re-establishment of native forest. These observations are pertinent to restoration when consideration is made regarding an interventionist or non interventionist approach. If a non-interventionist approach is considered then there is the possibility that the composition of the mature community may not mirror that of a non disturbed reference community. If the goal is to achieve that reference community the choice of nurse crop may be of significance.

3.3 Slope, Soil and Disturbance

Studies of the relationships between slopes and soil depth demonstrate how slope angle and the rates of erosion are bound together but vary with the geological formation. Regolith depth is attributed to “vegetation effects, recurrent slope failure as well as to the bedrock curvature, hillslope position, and slope angle” (DeRose et al., 1991: 489). The removal of vegetation will affect these factors as the slope angle will have adjusted to the presence of the “apparent” cohesion afforded the regolith by the root systems. Thus it will display a dynamic meta-stable equilibrium (Schumm, 1977) reflecting the historical boundary conditions. In keeping with the understanding that New Zealand exhibits high rates of sediment delivery to the ocean, Blaschke et al. (1992) concluded that while there is a comparatively rapid rate of turnover of soil in forests, under pasture the rate is higher. The rate of turnover describes the age of the soil in any one place and is determined by the frequency of disturbance events. In relation to the forest habitat, the rapid turnover rate indicated how important landslides are as disturbance agents.

A further study by DeRose et al. (1993) investigated soil loss from forested and deforested slopes and detailed the post-deforestation loss of soil. Such soil loss will affect the recovery of the site and impact on revegetation of mass movement scars. The study showed that as slopes evolve under the impact of continuing slope failure the higher regolith depth expected under forested slopes is replaced by a shallower regolith under pasture. The changed conditions may demonstrate evolution to an alternative stable state, though equilibriums are not the focus of the paper.

A number of authors have examined the effects of mass movement and loss of biological productivity at the site (Lambert et al., 1984; Blaschke et al., 2000; DeRose et al., 1995, Smale et al., 1997;) wherein studies are conducted in a variety of landscapes, mostly in mudstone geological settings. In the study by DeRose et al. (1995) the authors examined the consequences on the mudstone derived Taranaki hillslopes and found that on slopes 28-42^{o} on 40 year old scars biomass production was only 74% of uneroded levels. The finding was in relation to pastoral vegetation but may also have consequences for success in planting of native plants on degraded hillslopes and require particular strategies to address any adverse effect. These results contrast with the previously mentioned study by Smale et al. (1997) which stated that there was little difference in growth rates of kanuka between undisturbed pasture and mass movement scars in an East Coast site, highlighting the difference in species potential, substrate fertility variances found in different regions, and climatic differences.

Landscape dynamics and the frequency of disturbance is another subject considered in a New Zealand context. In his thesis, Blaschke (1988) considered the relationship between structure and dynamics of the main vegetation groups and individual species of the lowland steeplands of eastern Taranaki. The linkage between vegetation, topography, and soils was also examined. As part of the analysis the thesis looked at the floristic communities and the regeneration of woody vegetation following disturbance (principally mass movement i.e. deep seated landslides). In relation to the disturbance regimes successional pathways were found to be dependent upon topography, site history, location, and size of the disturbance area, but no rigid distinction between primary and secondary succession was discernable. The study, focussed upon the dynamics of ecosystems, also examined in detail the processes underlying vegetation and landscape change. It found a significant correlation between surface age and soil depth and that soil depth increases faster and continued longer under forest cover than under pasture. The model proposed for the landscape evolution is one that involves periodic evacuation of swales by landslides and refilling of swales by near-surface erosion.

The understanding of past processes is a valuable tool in determining goals and actions required in restoration projects. Glade (1997) conducted a review of literature relating to the frequency/magnitude of landslide rainstorm triggering events and the characteristics of the landscape. The outcome was a map of susceptibility to multiple occurrence regional landslide events over the terrain of the sites he studied given all endogenous and exogenous factors. The amount of data and time required to produce such a probability map would be enormous in a restoration context but does have direct ramifications to the success of restoration activity in relation to slope dynamics.

Studying disturbance in the riparian zone, Florsheim et al. (2008) reported on the importance of stream bank erosion as a natural geomorphic process and how the banks should not be viewed as static elements automatically needing stabilisation. In fact the erosion, when within its natural variability, is intrinsic to the ongoing integrity of the morphology of the channel, the invertebrates, and fish community. Preston et al. (2003) described how the riverbank constitutes an intermediate sediment storage site on the Ohura river system before the sediment is carried downstream in a secondary stage. It was concluded that bank storage is the main determinant of turbidity in the fluvial system, rather than the process/rate of hillslope erosion. This study highlights the need for a full understanding of catchments to determine cause and effect.

3.4 Sustainability of land use

The above discussion leads to the question of sustainable land practices and to this end Blaschke et al. (1992) conducted an investigation into New Zealand lowland steepland and the sustainability of agricultural land-use on such terrain. Landslide scars in forested catchments were surveyed and aging of scars was determined by examining tree rings and using chronosequence aerial photography. The same was undertaken in deforested land where it was easier to identify and age landslides due to greater information availability. The hillsides were then classified in terms of the percentage of hillslope failure and soil loss. Not only are valuable nutrients lost in situ, but the reduced soil depth and changed physical properties, especially in the erosional zone, may lead to chronic soil moisture deficit due to reduced water holding capacity. Additionally, the reduced capacity of the "farm" soil to hold moisture leads to altered discharge patterns to the stream, with sudden and increased peak flows which will have an effect on the stream morphology (Trustrum and DeRose, 1988). Blaschke et al. (1992) concluded that steep slopes greater than 42^{o} were unsustainable for pastoral agriculture given the high level of soil loss and should be retired from grazing, while slopes between 28 and 42 ^{o} may sustain low intensity grazing but that forestry may be more sustainable.

The rate of regional soil loss is also addressed by Crozier and Pillans (1991), in the Wanganui/Manawatu region. They conclude that given the return period of erosion causing rainstorms, loss exceeds soil formation on pasture. The denudation does not mean loss of soil from the system entirely, with most sediment being deposited in, at farthest, third order basins. It does, however, illustrate that with unchanged land use that the steeper slopes may trend in an evolutionary path towards an unproductive "badlands" state. Selby (1976) conducted a similar study in the south Waikato (on a greywacke lithology as opposed to mudstone/sandstone base of the Wanganui/Manawatu discussed previously). In the sites he studied the denudation rate, taking into account the frequency – magnitude of rainstorm events, is 1mm per year over the entire studied area.

Whilst the approach used by Blaschke and others looked at the productivity and the sustainability of pasture, Dymond et al. (2006) used a GIS model in order to classify susceptibility to erosion according to slope, land-cover and rock-type. The model was validated against results of the rainstorm in the Manawatu/Wanganui area in 2004, where it was found that 58% of erosion scars occurred on hillsides classified as susceptible. This model did not include factors such as areas of historical landslides which reduce probability of landslides (Crozier & Pillans, 1991; DeRose et al., 1991), or the influence of antecedent conditions (Crozier, 1986). An apparently unexpected result in the Dymond et al. (2006) study concerned the less than 30^{o} slopes deemed not susceptible to failure. The model classed slopes below a threshold angle, dependent upon the underlying parent material, as not susceptible. Instead, the probability of failure below 30^{o} was found to be approximately linear to the slope angle. In another analysis conducted by Hicks (1991) following Cyclone Bola on the East Cape in 1987, it was demonstrated that <10% of hillslopes under pasture remained uneroded, <20% of hillslopes were uneroded under pine forest and 33% of slopes were uneroded under indigenous forest.

These findings may all have some implications for restoration activity. For example, restoration activities in the riparian zone may be detrimentally affected without taking action higher in the catchment. Another implication is that since mass movement is usually found in concave settings the run-off is likely to be channelled into the bare site and cause further activation of its scarps. Alternatively, can the findings of Smale et al. (1997) that kanuka (*Kunzea ericoides*) is as likely to succeed in pasture as on the mass movement site be generalised. If so, is there need for concern?

3.5 Vegetation and soil stabilisation

In the last decade there has been some focus on attributes of indigenous species related to their effectiveness in enabling sustainable land use including erosion control. In a study by Marden et al. (2005) twelve species commonly found in riparian bank and slope zones were compared over a five year period in a controlled trial with data gathered in relation to biomass and root spread (mean maximum diameter). From this it was determined that the species could be effective in stabilisation of low-order streams, but would not be suitable for higher order situations due to the shallow nature of their root growth.

Czernin and Phillips (2005) discussed the root system of *Cordyline australis* (New Zealand cabbage tree) in relation to its effectiveness in stabilisation of river bank stabilisation. Growth rates, spread, tensile strength, pullout resistance and comparison with *Salix* spp. were made. While somewhat provisional, the study concluded that cabbage trees are not universally appropriate but may be useful in some circumstances such as lower order streams or at some distance from the main channel. Planting with *Phormium tenax* (New Zealand flax) along stream banks was suggested as it helped to provide ground cover during flooding and also to moderate local flow conditions. The obvious upside of using native species instead of introduced *Salix* spp. is the biodiversity benefit.

In the case of >10 ha actively eroding gullies in a study of the Waipaoa River catchment Marden et al. (2005a) concluded that the whole catchment should be re-afforested with fast-growing trees before the active gully was addressed. This prioritisation involved some control of water run-off into the gully before establishing vegetation in a highly active transportational environment. When the whole catchment was reforested the probability of effective stabilisation of eroding gullies was dependent upon gully size. For gullies <1 ha in area the success probability was >80%; for gullies 1 – 5 ha in area success probability was c. 60%; gullies of 5- 10 ha area the success rate was 50%. For gullies >10 ha mitigation by reforestation had not completely stabilised the gullies but in 40% of cases had halved the area of activity. These probabilities were calculated following digitisation of areas of erosion in GIS from a sequence of aerial photos of the whole catchment and measuring the changes in area over the period 1961 – 1988. The shape of the gully was also seen to be a determinant of successful restoration with linear catchments more likely to have successful treatment. Most of the afforestation in the Waipaoa River catchment uses the exotic *Pinus radiata* on unstable slopes while in other areas exotics commonly used are *Populus* spp. and *Salix* spp. (McIvor et al., 2009; Thompson & Luckman, 1993).

The scale of the mass movement in the described studies is far greater than encountered in my case study, but the implications related to the reactivation or continued activity of mass movement sites is pertinent. If the mass movement sites continue activity over a long period of time, or are susceptible to further failure, it may be of relevance to restoration priorities and to impact on downstream restoration activity. The use of exotic species with the intent of harvest does raise concerns about the period that these slopes are then vulnerable to renewed slope instability. Watson et al. (1999) state that there is an 8 year period where vulnerability exists. If other means of income can be derived, for example, carbon credits, there may be a case for use of indigenous forest to be used as part of the solution. A number of studies have investigated the properties of native species for this purpose (Phillips, 2005; Watson and Marden, 2005; Watson et al., 1999, are examples).

Chapter 3. Site Selection

1. Introduction

Ecological restoration is the practice of returning a tract of land that is in a degraded condition to one in which the ecosystem has integrity and functions in a sustainable manner (Society for Ecological Restoration International Science & Policy Working Group, 2004). A return of an ecosystem to conditions as described above, and which restores the biological community to an equilibrium resembling the situation prior to anthropogenic impact (an historical trajectory) (Palmer 2008) requires guidance by reference to a site which resembles the historical nature of the restoration site. It will be impossible to return the site totally to a pre-human impact state due to loss of species (McGlone, 1989; Atkinson and Greenwood, 1989). Thus, a clear articulation of the vision and objectives for the restoration site will be an integral part of guiding the search for a reference site. In this study the search for a reference site has been based upon the premise that it should be of a relatively undisturbed nature as suggested above, geographically close to the restoration site (to facilitate the project), and a similar environmental classification to the restoration site (to help ensure that conditions are similar) (Beauchamp & Shafroth, 2011).

A central interest in this study is the impact of pastoral land use and so the site selection emphasis is to locate sites with which to assess the changes. This section discusses the selection of a restoration site based upon the use of Geographical Information Systems (GIS) and national databases of land cover, environmental classes and, to a lesser extent, soils. In elaborating the discussion, one of the central questions of the study will be addressed, that is:

Can national databases be a useful tool in the process of selecting a reference site in an ecological restoration context?

The outline of this section is as follows: Firstly, a brief background is provided, followed by a description of the databases, and their relevance to the selection process. The GIS method is then presented in a step by step form. The results of the process are presented, along with a discussion of positive and negative aspects of the process and the outcome.

2. Background

The purpose of having a reference site is to guide the aims and objectives of a restoration plan. Consequently there is a need to locate a site that will have the same or, more likely, similar characteristics in terms of the desired floristic community composition as the restoration site. The focus in this study is upon the structure of the floristic community, but recognises this is only part of the ecosystem. Restoring the abiotic functions and floristic community structure first will enable other elements, such as fauna, to establish of their own accord. This is described by Palmer et al. (1997) as the "Field of Dreams" hypothesis. It is understood that the floristic assemblage, as discussed in the literature review, will be determined to a large degree by a number of abiotic factors including climate, geology, soil characteristics, and physiography. Conversely, vegetation has a feedback effect on some of these factors, so it is not a unidirectional function.

There have been various attempts using environmental factors to classify environments on a broad scale, i.e. areas of similarity and dissimilarity. Examples of such classification systems that exist in New Zealand are the ecological district classification (McEwen, 1987) which is a nationwide categorisation as is the Land Environments of New Zealand classification (LENZ) (Leathwick et al.,2002; Leathwick et al., 2003), and on a more localised basis, eco-domains (Gabites, 2002). This study looks at the use of electronic databases (detailed in following paragraphs) that contain environmental and climatic factors using GIS software in order to locate a reference site.

While there is some agreement about the importance of the relationship of abiotic factors to ecology, the process here is an exploratory one and it is recognised that criteria and variables other than those chosen here may be of greater significance in some circumstances. For instance, in this study it was considered desirable to investigate the effect that slope aspect has upon floristic community (distribution) due to evidence that aspect is a significant factor in vegetation distribution, for example, Bennie et al. (2006), Sternberg and Shoshany (2001) and Powell (2000). The slope parameter may not be applicable to every restoration project, particularly on easy to rolling slopes which may not produce strong gradients. Similarly, it was desired to investigate the effects akin to that of 'old field' impact, that is, the presence of invasive weed species, altered soil structure and chemistry, and absence of native species seed propagules (Hobbs and Cramer, 2007), specifically in relation to impacts of grazing activity. Consequently, a deforested farm site was chosen as a restoration site, requiring that the reference site would be one that has undisturbed forest vegetation. Thus the focus is on the effects of land use change from forest to pastoral farmland, and consequently the process outlined here may not be applicable to projects where this is not pertinent. Elements of the process will still be of use however.

Given time constraints, the study focuses on zero (upper catchment areas where ephemeral water paths exist) to first order basins (areas where a small stream flows consistently but does not have persistent inflow from other streams), the scale of which makes restoration practicable but even at this scale there may be specific geomorphic/vegetation significance (Sheridan & Spies, 2005). Large complex watersheds may be beyond the scope of most restoration scenarios. Although the method used here relates to small sub-catchments the process to choose a reference site is relevant to other settings and scales.

3. National databases

The method outlined in this section details the use of a number of national databases as the means to select a suitable reference site. The databases that are examined are the Land Environments of New Zealand database (LENZ), the Land Cover Database 2 (LCDB2), and the Fundamental Soils Layer (FSL). The selection process also uses aerial images as desk-based confirmatory tools in relation to the areas (polygons) created in the process of selection. What is presented to begin with is a description of environmental classification systems.

3.1 Land Environments of New Zealand (LENZ)

A common goal of nations is the desire to produce a system by which to classify the environment that exists within their borders. The purpose may be to support a number of managerial goals, e.g. land management, trends in the state of the environment, resource mapping, conservation of rare ecosystems, and ecological restoration. Consequently there are various attempts at their creation on a national basis, for example, LENZ (Leathwick et al., 2002). The LENZ classification was produced by the Crown Research Institute Manaaki Whenua-Landcare Research Ltd for the Ministry for the Environment. It is designed to provide a framework for conservation and land management purposes (Leathwick et al., 2002; Leathwick et al., 2003).

A feature that distinguishes LENZ from previous classification schemes produced for the New Zealand environment is the construction of the database with separate layers of data. User analysis can utilise all the data or, alternatively, elements of it individually. Furthermore, the classification is not based upon current land use and vegetation as defined by human activity but on data layers corresponding to environmental variables associated with mapped forest composition (Leathwick et al., 2002). In building the classifications, climatic data, soil attributes, and landform parameters were utilised. The process involved calculation of environmental distance from the measured points to interpolate the environment for which no data was available. The method is similar to international approaches to potential vegetation mapping, for instance that compiled by Kuchler (1964) for North America or similarly systems described for Australia (Thackway and Lesslie, 2005).

The analysis, classification, and output of the classification polygons were completed using ESRI® ArcView® 3.2. The results were produced at various levels of detail i.e. level 1 to level 4, with level 4 being the finest scale in a hierarchical classification. There is the added functionality of being able to map the underlying data layers separately. The numbers of classes that appear in each of the levels are 20, 100, 200, and 500. It is suggested that level 1 is useful at a national scale, level 2 at national to regional scale, level 3 at regional scale, and level 4 at regional to district scale or 1: 50, 000 (Leathwick et al., 2002). In this sub district scale study a level 4 layer incorporating all elements of the database was used. In practice, scales down to 1: 5000, and frequently lower, were used to analyse the detail at the sub-catchment size. It is recognised at such a fine scale the boundaries of the polygons (similarity classes) may not be totally accurate but this high resolution is necessary at sub-catchment scale.

The 15 underlying data layers are broadly classified as climatic, physiographic and soil attributes. The climate layers consist of measurements interpolated from climate stations across the country. The specific layers are: mean annual temperature, mean minimum temperature of the coldest month, mean annual solar radiation, winter solar radiation, October vapour pressure deficit, annual water deficit and monthly water balance ratio. The landform layer is solely represented by slope angle derived from a 25 metre digital elevation model.

The seven soil layers consist of drainage classes, acid soluble phosphorus, exchangeable calcium, particle size, induration (particle hardness), soil age and chemical limitations (to growth). The soil data comes from The New Zealand Land Resource Inventory (Lynn et al., 2008; Wilde, 2006) stored by Landcare Research which includes both fundamental soils data and land use capability information. It in turn relies upon about 40 different soil surveys in the North Island and 20 from the South Island (Leathwick et al., 2002) but is variable in data richness, quality and resolution. Leathwick et al. (2002) discuss the lack of robustness of the data due to the lack of ground-truthed data, particularly in certain areas. Consequently the soil layers receive a lesser (0.25) weighting in the calculations.

3.2 Land Cover Database 2.

The Land Cover Database (LCDB) is an initiative of The Ministry for the Environment (MfE). LCDB1 was completed in 2000 using SPOT satellite imagery acquired over the summer of 1996/97, whilst LCDB2 is derived from imagery acquired in 2001/2 from the Landsat 7 ETM+ satellite. The database is multifunctional in that it can be used in a number of applications such as state of environmental monitoring, forest and shrub-land inventory, biodiversity assessment, trend analysis and infrastructure planning. The database is freely available from the website http://koordinates.com and is used in a GIS environment to provide analysis in the aforementioned fields. In addition because there are versions with images gathered at different times, analysis can include a temporal setting. The imagery has been processed to produce ESRI shapefiles, meaning that raster surface data has been transformed into polygons based upon the spectral imagery of Landsat 7 data. The imagery, particularly of LCDB2, offers an advantage because the spectrum imaged includes the range outside human perception. Both automated and manual interpretation was used to generate the areas for the vegetation class polygons. The minimum mapping unit is one hectare which maintains compatibility with LCDB1.

As the LCDB2 user guide states the accuracy is within one pixel (15 m) except for areas with a paucity of control point’s e.g. mountainous native vegetation. The digitising of the boundaries of the polygons at a screen resolution of 1:15000 means that any use of the database at resolution less than 1:25000 causes a rasterisation of the polygon perimeters. This means that the line follows the pixellation of the screen rather than being smooth. Given the scale of the work in this research larger scale use was necessary however pixellation was not an impediment. The database results in a thematic classification of 43 different classes including indigenous forest, gorse, broadleaf hardwood, grass etc.

3.3 Fundamental Soils Database

New Zealand Land Resource Inventory (NZLRI) is one of the databases whose data was used to generate the LENZ classification. The Fundamental Soils Layer is a digital representation derived from the NZLRI work sheets, which in themselves are constructed from aerial photographs, by identifying spatial similarity due to surface geology, and also geomorphology and soils. These classes are of interest in this study for detailed confirmation since soil analysis is an integral element of the study. The FSL was simply used as corroboration of choices made given that part of the data is already embedded in the LENZ classification data as it gives finer detail relating to the soil types.

4 Outline of the methodology

In the technical guide to LENZ (Leathwick et al., 2002) there is a description of all the environments beginning with the level 1 environment and detailing the distinctions provided in the lower level classes. The classifications have been developed using mathematical environmental distance measures and these algorithms provide firstly a non hierarchical set of classes followed by a second stage hierarchical classification. The result is a dendrogram for each of the levels of the environments is produced. Figure 1 shows the dendrogram related to the predominant environment at Whareroa. A full description of the process is provided in the technical guide and it is not my intention to go into this in depth here.

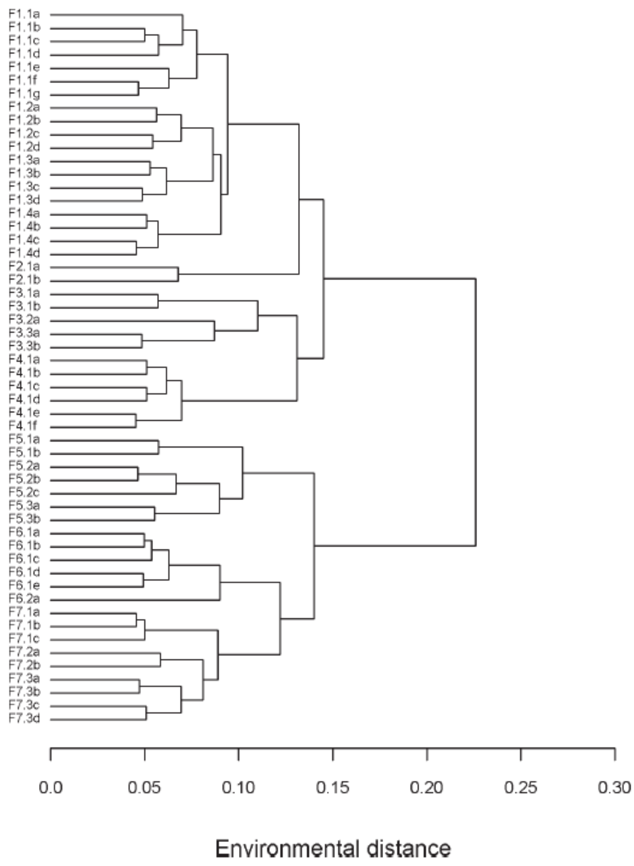

Figure 1: Dendrogram for F environments, (LENZ, 2005).

The guide can be downloaded in PDF form from Landcare Research website using the url: http://www.landcareresearch.co.nz/databases/lenz/products_techguide.asp.

The dendrogram is introduced so that it can be used to examine the similarity/dissimilarity of the various environments and the information can be utilised when examining the environments for suitability as a reference. This will be further explored in the discussion about the environments that specifically relate to Whareroa in later sections. The product of the LENZ classification is the creation of a map that situates each of the environments on the ground in New Zealand (refer to Figure 2**).** The LENZ digital data is used in the creation of the maps produced in this study (Figures 6 and 7).

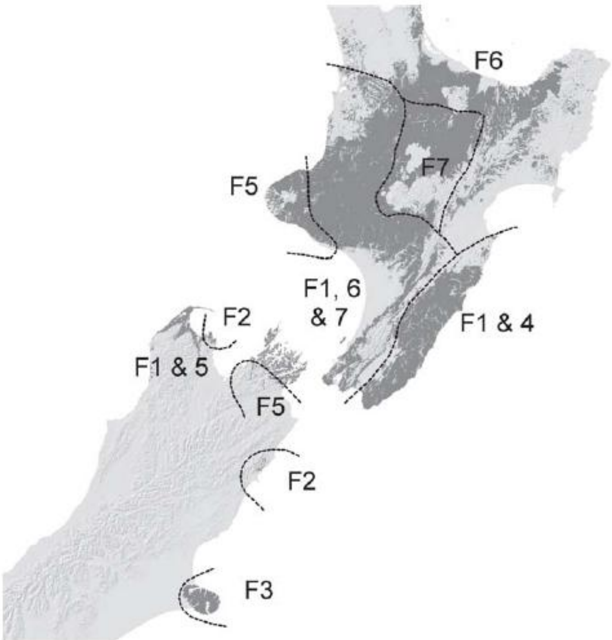

Figure 2: LENZ environments associated with Whareroa (LENZ, 2005).

It is not particularly useful to describe in general F environments given the scale of the study. More useful is the description given at level 2. At level 2 Environment F1 is described as the largest and most geographically diverse. The climate is mild with high solar radiation and slight annual water deficits. Soils are well drained and of low natural fertility. Further descriptions are provided in the analysis section. Another environment at Whareroa is C2, which is described as gently undulating inland plains with moderate vapour pressure deficits and low annual water deficits. Loess is the main parent material with another being alluvium. Other factors are the same as described above for F1.

4.1 ArcGIS method for selection of reference sites.

For this study the New Zealand Map Grid (NZMG) projection was used as the basis for the data. New Zealand Transverse Mercator (NZTM) is now the projection of choice in New Zealand but the digital aerial imagery received was in NZMG and was subsequently maintained because transformation to NZTM may result in distortions in the photography. The following is a step-by-step ArcGIS process used to identify a reference site and to choose the specific catchment of focus at the restoration site.

1. Add the databases to ESRI ArcMap i.e. LENZ level 4, LCDB2, FSL/NZLRI.

2. Add aerial photography sourced from Kapiti Coast District Council, i.e. r260503, r260602, r260603 (flown in 2002).

3. Add the NZ coastline polyline

4. Add Cadastral parcels.

5. Using the "select by attribute tool" select the Cadastral parcel for Whareroa Farm. The selection is exported as a new layer in ArcMap followed by removal of the original cadastral parcel datalayer.

6. With Whareroa delineated by the cadastral parcel layer it is overlayed on the LENZ level 4 layer to determine the classes which are present at the site (see Figure 3).

7. By examining the dendrogram (Figure 1) accompanying the Technical Guide it was decided to combine those classes that displayed close environmental distance in relation to classes found at Whareroa, and separately those which display greater environmental dissimilarity, so as to reduce the complexity of resultant map.

8. To undertake the action at step 7 the merge tool was used to merge F1.4a and F1.4b and to conflate F2-7 at level 3 with the results exported as a new layer in the map.

9. Now the full LENZ level 4 datalayer is removed as the additional information was not of interest and removing the layer helped reduce the complexity of layer information in the Table of Contents and processing time when queries are run.

10. The results of the above action identified all those areas that exist in New Zealand classified under those environments regardless of current landcover. To eliminate those areas that are not potential reference sites because they do not have forest cover the Indigenous Forest layer in LCDB2 was then selected by attribute and exported as a new layer.

11. Layers C2.1e, F1.4c and F1.4ab (those classes found at Whareroa) were then selected by location where they shared a line segment (i.e. where there was contiguity such that all 3 were found next to each other).

12. The Indigenous Forest layer was then intersected with the composite polygon and exported as a layer. The action results in a set of choices (or lack of) see (Figure 4) for a restoration site where the same three LENZ classes exist and are contiguous.

13. The NZ 25 m DEM was added to ArcMap.

14. Geoprocessing of the DEM with the Spatial Analyst tool was undertaken to produce a hillshade layer, slope layer, and aspect layer.

15. Sub-catchments within Whareroa were digitised within the Editor tool using the aerial images, aided by the hillshade and contour layer to produce polygons outlining the boundary of the watershed (see Figure 7). The result indicated the dendritic pattern and physiography of the sub-catchments used to search for similar shapes and physiography in the reference site.

16. The mapping indicated that two catchments would be suitable. Each of these catchments consisted of a single but different class that was completely dominant. Consequently the scope was re-widened providing a greater range of possible restoration sites than that portrayed by the analysis at step 12.

17. Therefore, intersection of the indigenous forest layer with each of the separate relevant classes (F1.4c, F1.4a-b, C2.1e) was undertaken and the layers exported. This increased the number of potential relevant reference sites as the constraint of contiguous environmental classes was removed (see Figure 5).

18. The FSL layer was added, detailing the soils underlying the various sites see (Appendix 3.5 & 3.7).

19. Selection was made given relevant consideration to the suitability of the forests and catchments and dendritic patterns at the potential reference sites in relation to the catchment classes identified at step 15, along with matching of the soils as displayed in the FSL.

Further description of the terms and tools used is included at Appendix 3.9.

5. Results

The objective of this section was to outline a procedure using national databases in a GIS environment, and to highlight a site that can be utilised as a reference site for a chosen restoration site. The final outcome of the process is produced by maps at Figures 6 and 7. Intermediate maps were produced as part of the process and these are described below.

Firstly, a map that contains the legal boundary shows that there are three main environmental classes when the cadastral parcel and the level 4 LENZ datalayer are displayed. These are F1.4c, F1.4b and C2.1e as can be seen in Figure 3 and in a regional context in Appendix 3.1. In the analysis F1.4a and F1.4b have been combined as these are joined at the same environmental distance (refer Figure 1). The merging is of no real consequence as in fact there is no F1.4a in the immediate area. Selection by location where these three environments shared a line segment was undertaken and merged as one layer. The result highlights any reference environment which may also hold the condition of proximity as found at Whareroa.

When the layer is intersected with the indigenous forest layer from LCDB2 the resultant map indicates very few locations where contiguity of classes occurs (refer to Figure 4).

The constraint of contiguity significantly restricts choices of reference sites. When the rule is relaxed and data are queried with the three environment layers intersected separately with the LCDB2 forest layer more options are afforded. The results are displayed in Figure 5 (also Appendix 3.2 and 3.3 for broader scale), which provides a greater range of choices for the selection of a restoration site. Also included in the appendices is the LCDB2 map for Whareroa (Appendix 3.4).

Examination of these maps reveals that there are very few areas where indigenous forest is found in the F1.4a or F1.4b environment and practically none in the C2.1e class. F1.4a and F1.4b are described as existing in lower elevation and less steep hillslopes while C2.1e is an alluvial flat environment with the consequence that these have more potential for intensive use and so have been totally modified. The 1.4c class has a wide range of possibilities as it corresponds to steeper and higher elevation land and consequently had lesser impact by land use change, that is, deforestation.

Examination of Whareroa Farm identifies two areas that were seen as potential sub-catchments for study (Figure 7). My original intent was to use the catchment Whareroa S1 but subsequent analysis revealed that it did not contain sufficient south facing slopes to obtain samples from (refer Appendix 3.6). Hence the catchment labelled Whareroa S2 was identified and utilised for the south facing sampling sites. The catchment labelled Whareroa N was identified as the possible catchment in the LENZ class F1.4a-b. The map at Figure 7 shows that the northern catchment is almost totally F1.4a-b environment. Similarly, the southern catchment also is totally dominated by one class, that is, F1.4c.

Referring again to Figure 5, of the potential reference sites that have F1.4a-b environments a pocket of forest in Waterfall Road is identified that is within close proximity of Whareroa, but is smaller in catchment size than the Whareroa north catchment. Additionally, a small part of Paraparaumu Scenic Reserve is also classified as F1.4a-b environment. Another option would appear to be Nikau Reserve in Paraparaumu. The F1.4c environments are numerous and those close by include Maungakotukutuku Valley, Paraparaumu Scenic Reserve and Hemi Matenga Reserve. These are highlighted in Figure 5.

Looking more closely at the restoration site choices it can be seen that the northern catchment coincided mainly with environment F1.4a-b and the southern with F1.4c. The potential reference sites for environment F1.4a-b were not suitable for vegetation sampling due to their small size with a consequence being that the area to perimeter ratio was small with concomitant increased edge effects (Fonseca and Joner, 2007; Murcia, 1995). Another factor in some cases was the degree of modification away from an undisturbed environment. Two potential selections within the F1.4a-b class were inspected on the ground, i.e. Nikau Reserve in Paraparaumu and a private block in Waterfall Rd, not far north of Whareroa. Whilst these had merits they also displayed some of the conditions described above. The southern catchment at Whareroa is classified as F1.4c and offered more choice of restoration sites as detailed in Figure 5.

Following site inspection it was deemed that Paraparaumu Scenic Reserve was the best option. This decision was made due to; 1) the presence of south and north facing slopes within the same catchment (see Appendix 3.8); 2) that the inclination of the slopes appeared similar to that of the southern catchment identified at Whareroa (Figure 6) and; 3) that there was a reasonable similarity in dendritic pattern. It is not to say that the other sites were devoid of these attributes but Paraparaumu was also suitable as a reference site because it has been a reserve for more than 100 years. Ground reconnaissance confirmed a diverse and seemingly mature forest assemblage and seemingly not disturbed by clearance, details of which have been outlined in the introduction.

Appendix 3.5 and 3.7 depict the fundamental soils layer from NZLRI for each of the sites. These figures show that the soil for Whareroa S1 and S2 is Makara Steepland and Paremata Hill soils for Whareroa N. At Paraparaumu it is evident that the major soil series type is Makara Steep phase, but on the south facing slope one transect appears to be located in a finger of Paremata Hill phase soil. Implications relating to the soil analysis is discussed later in this chapter and also in Chapter 5.

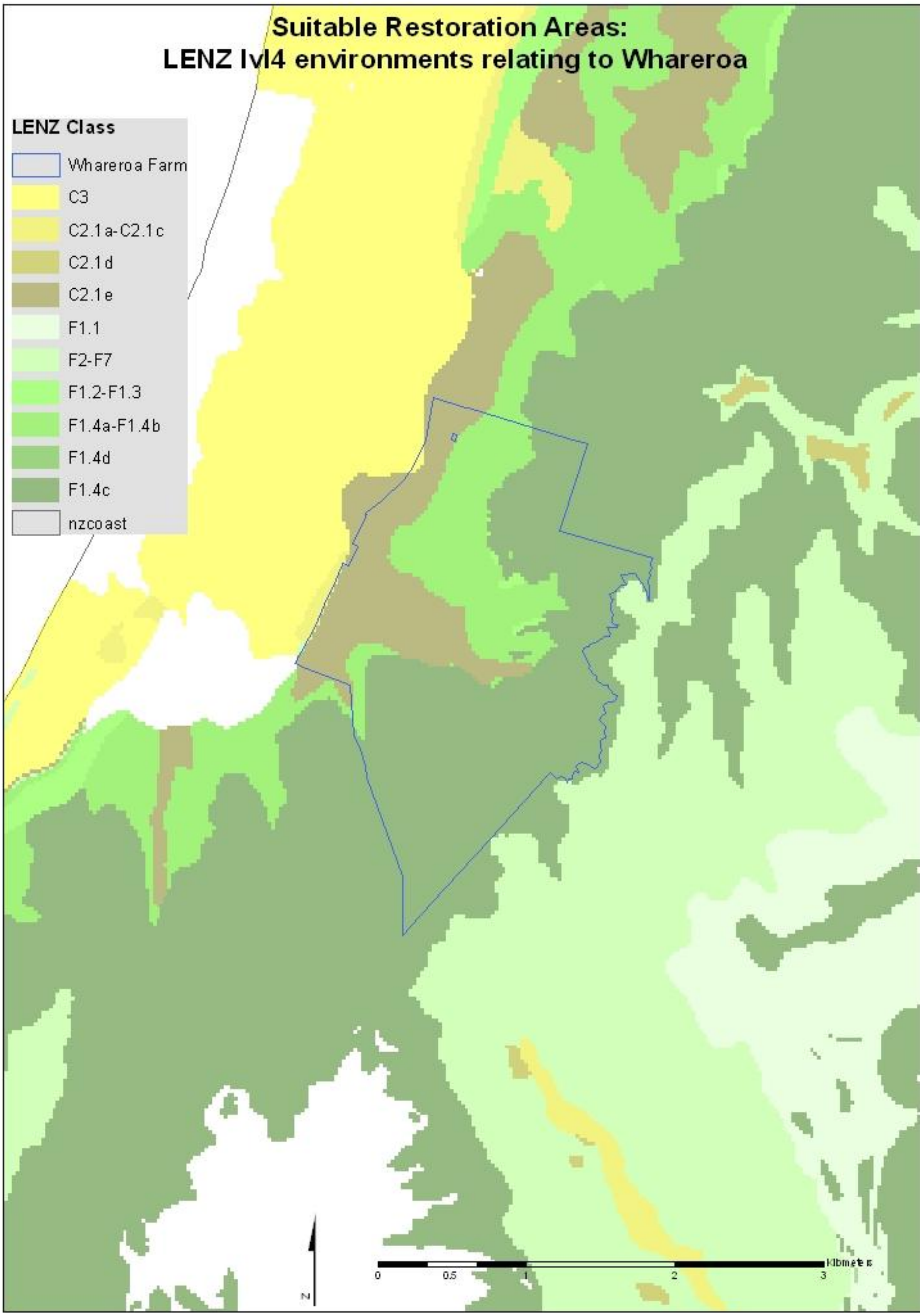

Figure 3: Whareroa cadastral boundaries and LENZ classifications.

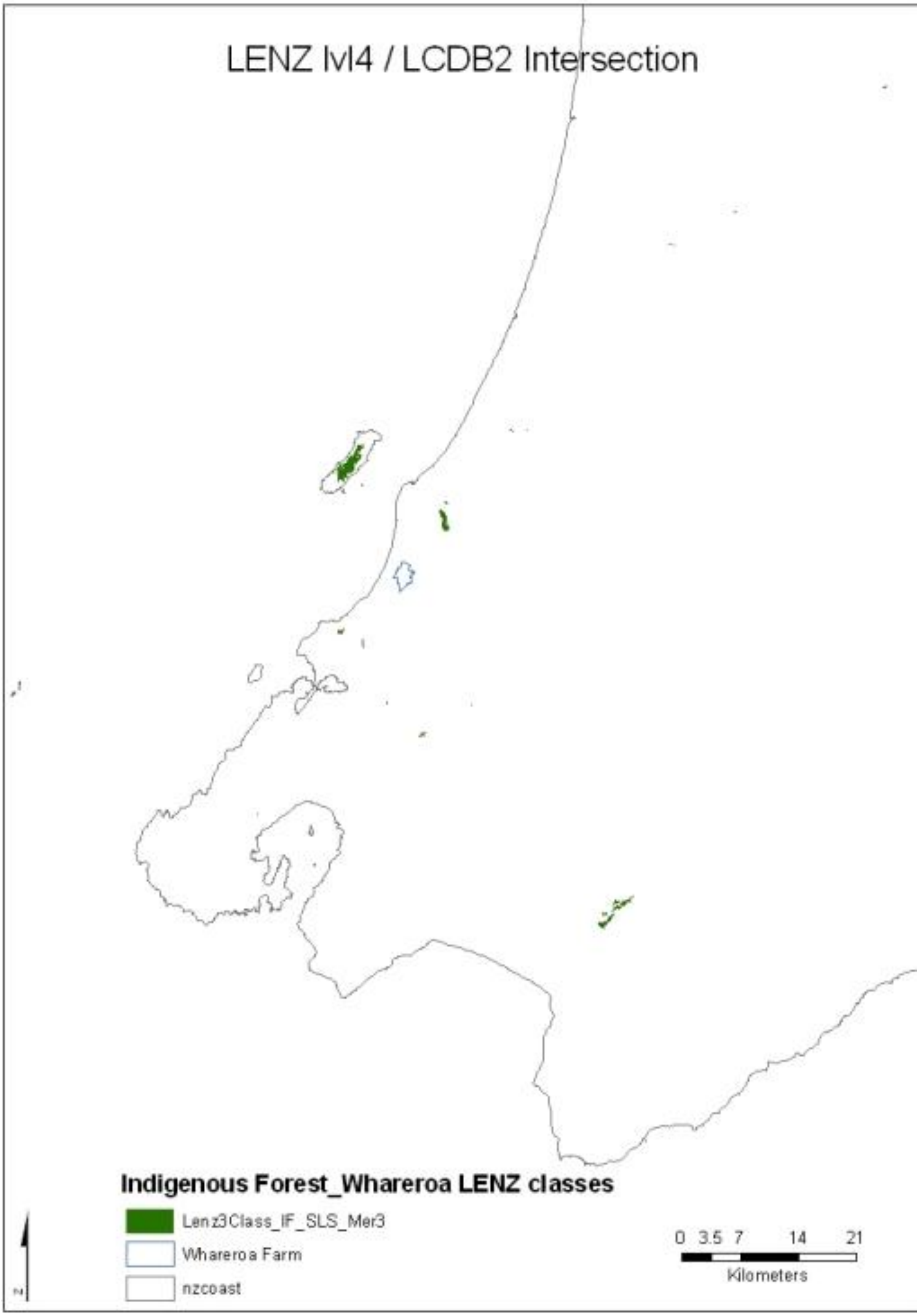

Figure 4: Merged LENZ classes as found at Whareroa, where the classes share a boundary segment, and also intersect with the indigenous forest class of LCDB2.

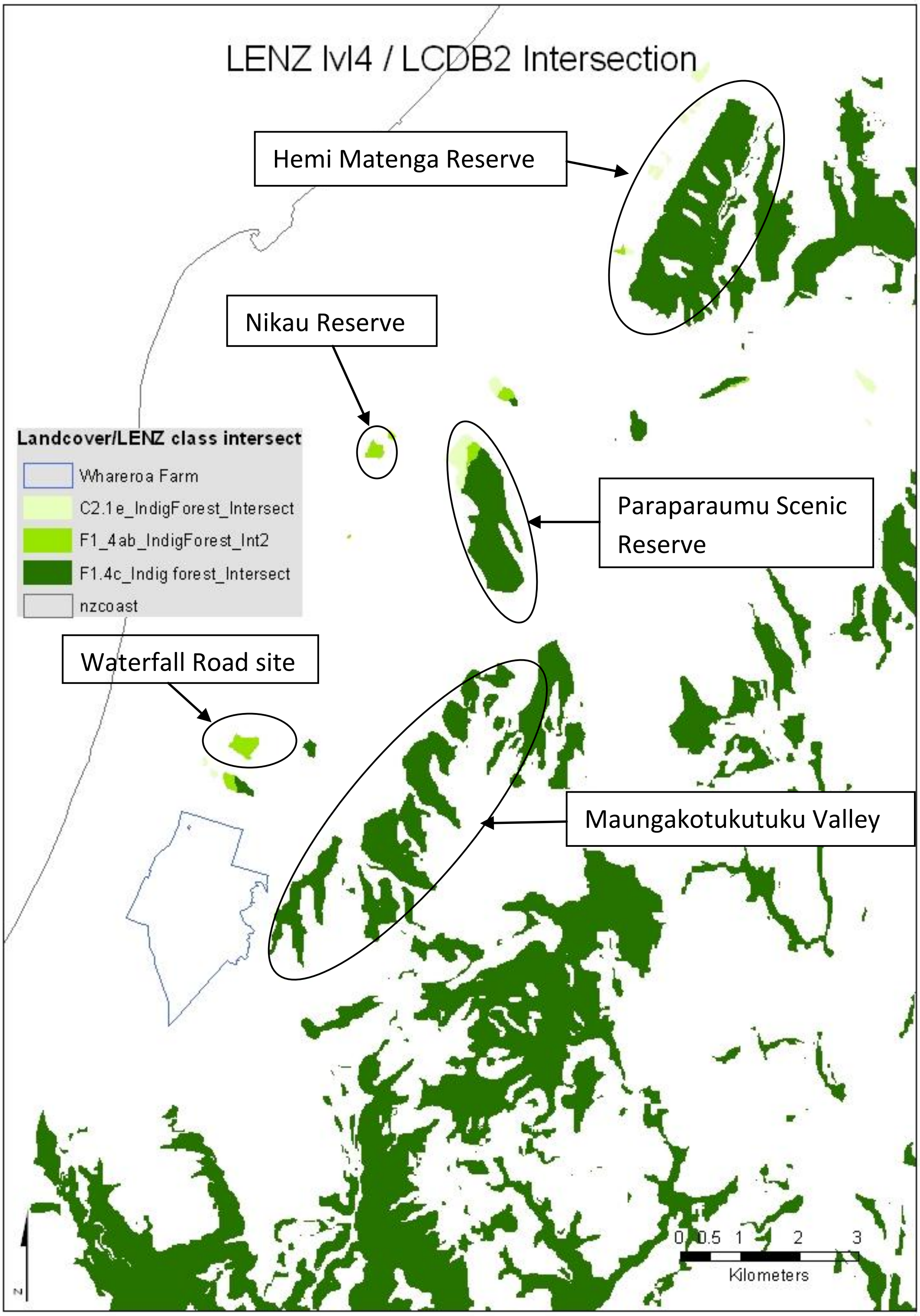

Figure 5: Separate LENZ classifications as found at Whareroa intersected with LCDB2 indigenous forest layer in the vicinity of Whareroa.

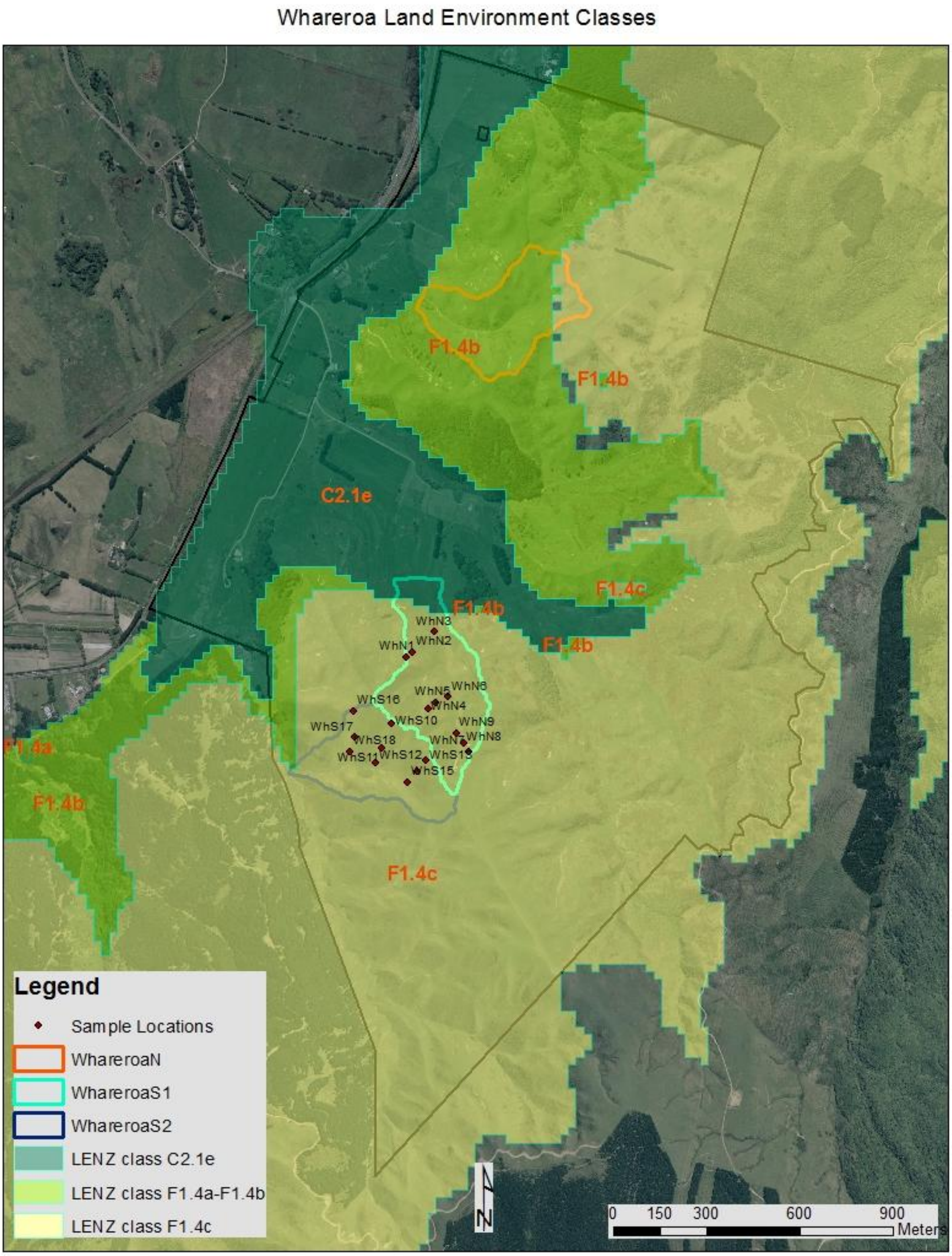

Figure 6: Whareroa Farm showing catchments, sample sites and LENZ classes.

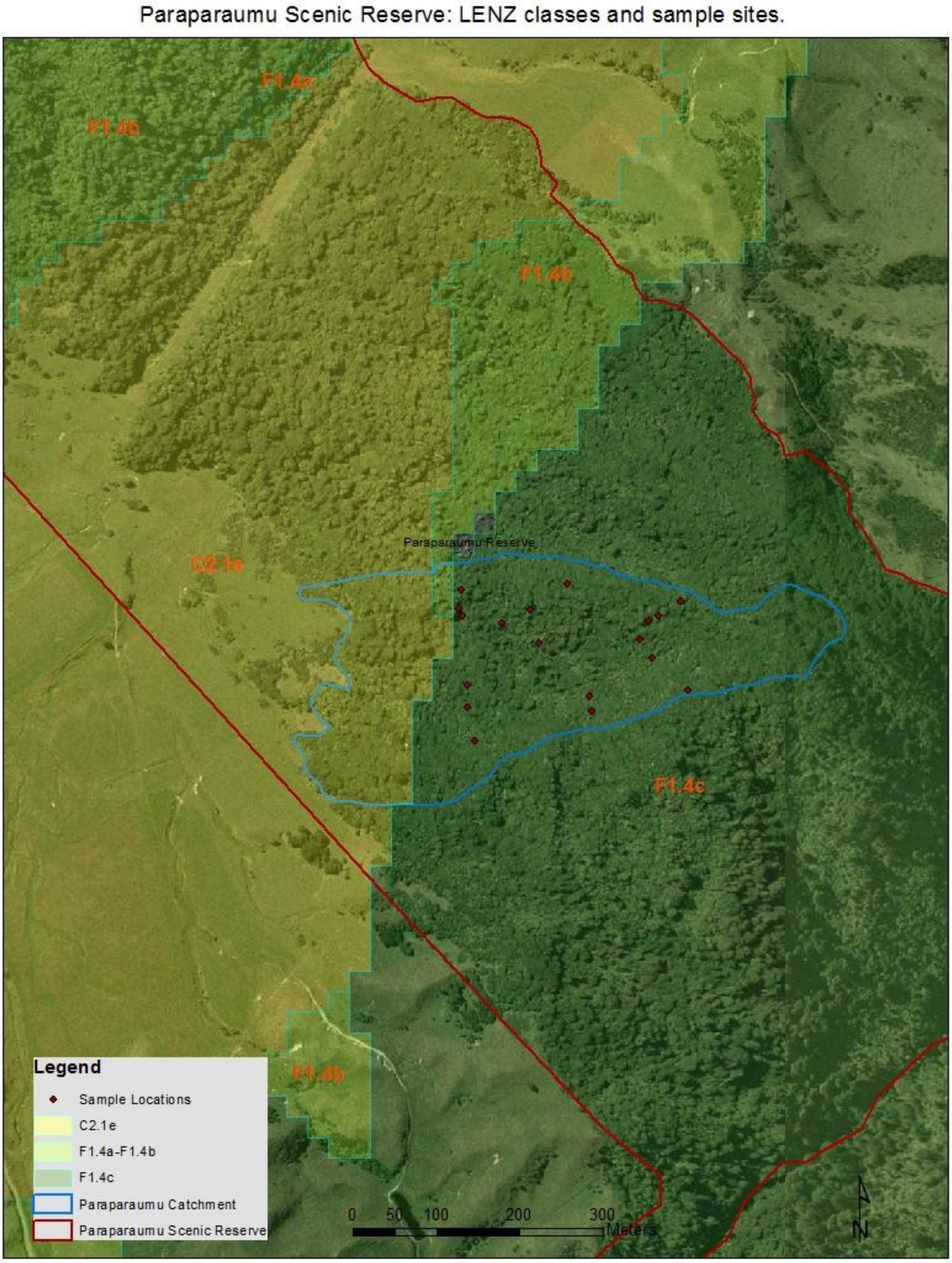

Figure 7: Selected gully system at Paraparaumu Scenic Reserve, showing the LENZ classifications and sample sites.

6. Discussion

The following discussion relates both to the merits of the use of the national databases and also the outcomes suggested by the GIS selection process. Firstly, although the output from GIS analysis may be viewed as being objective, subjectivity may be encountered at many levels. In this study the subjectivity remains where choice from a number of closely related reference sites is made and factors such as ease of access or whether the distance from the coastal salt air is perceived to be important. Another example involves the parameters used which are only a selection of numerous possibilities and the choices made here are, to a certain extent, subjective. Furthermore, it would have been possible to hone the selection further with more parameters e.g. proportion of catchment facing a particular direction or degree of slope over a certain inclination. The analysis was curtailed at a broader level and on the ground assessment used to make final decisions about the choice of sites to be used. Use of these databases with GIS could also be used simply as a confirmatory device where a practitioner may have sufficient knowledge and understanding to be able to select a reference site, that suitably reflects the characteristics and floristic composition one would expect to find at the restoration site.

The databases contain a large and complex amount of information, and the algorithms used to construct the polygons of the classes can produce some erroneous results. The LCDB is constructed from a mixture of automated selection and manual interpretation and either could introduce errors. It may be that budgets of the responsible agencies are insufficient to undertake the amount of ground truthing necessary to ensure all results are correct. In the case of the region under examination (thinking particularly of the Maungakotukutuku Valley) it appears that some LENZ areas are classified as F7 while the technical guide for F7 classification reveals that the environment is unlikely to be found in the Kapiti region. Craig Briggs, LENZ technician at Landcare Research, revealed that it would be possible to rerun the algorithm with different input which may produce "corrected" results (Briggs, pers. comm., 2010). These anomalies are a good reason to use other means to verify the results before finalising decisions based on the database information.

Another factor that is important and recognised by Leathwick et al. (2002) is that any datalayer which portrays distinct polygons of homogeneous environments is not a reflection of the real world, where very distinct boundaries between one environment and another do not exist, except in particular circumstances. It is more likely that a gradient of vegetation composition will be encountered such that a change will be indistinct. Although the methodology used here will find environments similar to the one being restored it is not the only means of finding similar environments using the LENZ database. It is also possible to use similarity/dissimilarity algorithms to accomplish the selection process based upon some measure of dissimilarity, for example, Gowers metric distance (Leathwick et al., 2002). The outcome of using the latter method is that no distinct areas are produced; instead a map with graded shading indicating environmental distance from the desired environment is produced. However, the method used here is a simple one where there is no need to have an understanding of the different algorithms or the need to have access to the particular version of ArcGIS 3.2 to run the environmental distance algorithm. Due to the simplicity of the process I have used, it may also better suit land managers and restoration groups. Another observation is that the classifications produced in LCDB2, being an automated process, does lead to erroneous assignments of land use to areas, as can be verified by examination of the map of Whareroa (Appendix 3.4).

The second part of the discussion pertains to the results of the GIS analysis. The methodology concurrently identified a specific sub-catchment within the restoration site and a range of potential reference sites. The process was one of feedback where analysis depicted the range of environments found at Whareroa which then constrained the selection of restoration sites, which in turn determined the focal sub-catchments at Whareroa. The need to focus on smaller sub-catchments was governed by the fact that the whole farm is 445 ha and too large to examine within the constraints of this study. Factors that were considered in selecting the specific sites over and above the environmental classes were slope aspect and slope angle which were analysed directly using GIS. Dendritic pattern was also considered, but is a more subjective visual assessment. Of the preceding factors aspect was considered the most important as the orientation of the slope would be expected to influence vegetation. Slope angle was more difficult to control for but was still employed as far as possible. One limiting element with regard to use of these factors at the scale of small catchments is the coarseness of the digital elevation model which is based upon a 25 m grid. The coarseness makes it difficult to be very precise in relation to slope angle and also to some extent, slope aspect.

The choice to use the southern sub-catchment(s) at Whareroa was driven mainly by the choices available as reference sites. Availability of choices of restoration sites may not be a factor in most ‘real’ situations and if the northern catchment at Whareroa was the restoration site then it would have been possible to utilise the reference sites discovered. The choice to use the southern sites at Whareroa was a compromise in that the north and south facing slopes lead to separate drainage catchments, with the preference being that just one drainage basin being involved. The decision was made as neither one had sufficient north and south facing slope options separately. But with other conditions being met e.g. soil type and environmental class the dual sub-catchment choice was still considered the best option for the study.

7. Conclusion

The above discussion relates to the use of site selection using national databases and GIS analysis. At the outset it seemed to an inexperienced user of GIS that it would be a difficult process. Over time it was revealed that simple analysis can easily identify the environments and, concomitantly, the potential reference sites required in an ecological restoration process. The process (and site selection results) provide confidence that the results from the ensuing analysis are robust and should stand scrutiny. It is a process that, given the tools, would be achievable by restoration groups interested in guiding their projects. Difficulties that may be encountered by local groups, but less so by regional land managers, would be the access to elements of the data, for example, the aerial images for confirmation of sites and the access to GIS software. Hopefully some form of access may be afforded through local government bodies.

In conclusion, while although there may be some doubts about elements of the national databases the process has shown that they can be used to further ecological restoration in relation to selection of reference sites. The outlined methodology is a relatively swift way to gain clarification of both general and specific locations that may be examined for potential as restoration sites. It produces clear and interpretable output for professionals and community groups alike. The selection of Paraparaumu Scenic Reserve has proven to be a very good choice as a template for Whareroa as will be outlined in other sections of the study. Other guides and information e.g. ecoregions and ecodistricts, geological maps, or soil classifications are available to confirm or validate the correct identification. Notwithstanding the provisos outlined it would seem that national databases used in conjunction with GIS will help in the selection of reference sites, (both for the knowledgeable and the not so).

Chapter 4. Vegetation: Pattern, abundance and relationships

1. Introduction

An intention of this thesis is to illustrate how an understanding of an ecosystem can be useful in clarifying the objectives of ecological restoration activity in a practical sense. With this framework, the reference site is the 'basket of knowledge' that reveals what a natural undisturbed environment might look like, plant associations, and which plants and which communities may be associated with which environmental gradients (factors). Can the 'basket of knowledge' effectively help answer the following question relating to the floristic assemblage and geomorphic elements?

Is there any significant difference in community floristic vegetation assemblage dependent upon hillslope location and aspect, and do the measured gradients influence the floristic assemblage?

Chapter three outlined the process by which a reference site was chosen and chapter five analyses the abiotic variables measured at the restoration site. The goal of chapter 4 is to outline the process and outcomes of the sampling of the reference site, Paraparaumu Scenic Reserve, in relation to the floristic composition and their relationship to the selected abiotic factors. The results of this enquiry, particularly the relationships between floristic composition, individual species, soil variables and geomorphic factors, are important as input for the prioritisation of restoration activity as discussed in Chapter 7.

The vegetation communities of the Kapiti Coast area have been described by Gabites (2002), McEwen (1987), and Stone (2010). In her eco-domains publication, Gabites (2002) states that the domains are clusters of areas of a homogeneous nature dependent upon their biogeoclimatic similarity. The section on Cook Strait ecological regions in Ecological Regions and Districts (McEwen, 1987) describes the vegetation of Paraparaumu Scenic Reserve as a remnant of regionally rare kohekohe forest but gives no more detail. In an assessment examining the effects of pest control (Stone, 2010:1) the forest is described as "predominantly coastal (kohekohe) and lowland (rimu-tawa-mahoe) forest".

Historically, Paraparaumu Scenic Reserve has been under crown care since 1906 (Anderson and Pickens, 1996) and for some time was monitored through permanent plots. An assessment of the reserve held by Department of Conservation, completed in 1983, notes that the fences to the north-east were not preventing stock from entry. It also notes that the forest for the study's sampled area is scattered emergent trees of tawa (*Beilschmiedia tawa*), rewarewa (*Knightia excelsa*), hinau (*Elaeocarpus dentatus*), rimu (*Dacrydium cuppressinum*) and, less frequently, miro (*Prumnopitys ferruginea*) and kahikatea (*Dacrycarpus dacrydioides*), whilst the dominant species is kohekohe (*Dysoxylum spectabile).*The understorey consists of supplejack (*Ripogonum scandens*), mahoe (*Melicytus ramiflorus*) and broadleaved shrubs, which is noted as sparse around the periphery due to grazing. The report gives a generalised understanding of the composition of the forests.

2. Data Collection

Chapter 3 outlined the selection of the sites and catchments and detailed the sampling locations in the convex creep zone, the mid-slope transportational zone and the footslope. In order to compare the environmental variables with the vegetation community the assemblage is surveyed centred upon these points. With this structure in place the sampling design is predetermined and can be described as a stratified design or even restricted random as described by Goldsmith and Harrison (1976) or stratified partial random (Allaby, 2003). While the structure is stratified the specific sampling points were random in that the specific points were very much a matter of being a choice out of many which were determined in the field, as long as it represented the chosen landform unit and aspect. Due to the small size of the catchments and dense canopy attempts to randomly select points in GIS and use the coordinates in a GPS to precisely locate the points was not successful. Therefore, it is not random in that a computerised random selection of a pair of coordinates was utilised. Such random sampling can be described as inappropriate for field work as some areas may be under or over sampled and so distort the results (Goldsmith and Harrison, 1976). Figure 1 depicts the sample points and transects.

The method of estimating abundance of species used in the Recce method of Allen (1992) uses cover classes for a range of structural tiers, and appears to be a suitable method for a quick, yet revealing, inventory of vegetation within quadrats. These tiers account for the emergent, canopy, sub canopy, shrub, ground cover, and epiphytes. Consequently the sum total of coverage can be greater than 100%. As shown in Table 1 the range of the cover classes is not equal but is loosely a logarithmic scale.

Table 1: Abundance values assigned to each of the Recce (percent) cover classes (Allen, 1992) and transformation value.

Recce cover classes	<1	1 – 5	6 – 25	26 – 50	51 – 75	76 – 100
Abundance value in this study	1	2	3	5	7	9

In this study the cover classes and tiers used are; ground (<0.3 m), shrub (0.3 – 2 m), lower sub-canopy (2 – 5 m), upper sub-canopy (5 – 12 m), lower canopy (>12 m), upper canopy (12 – 25 m) and emergent (>25 m).

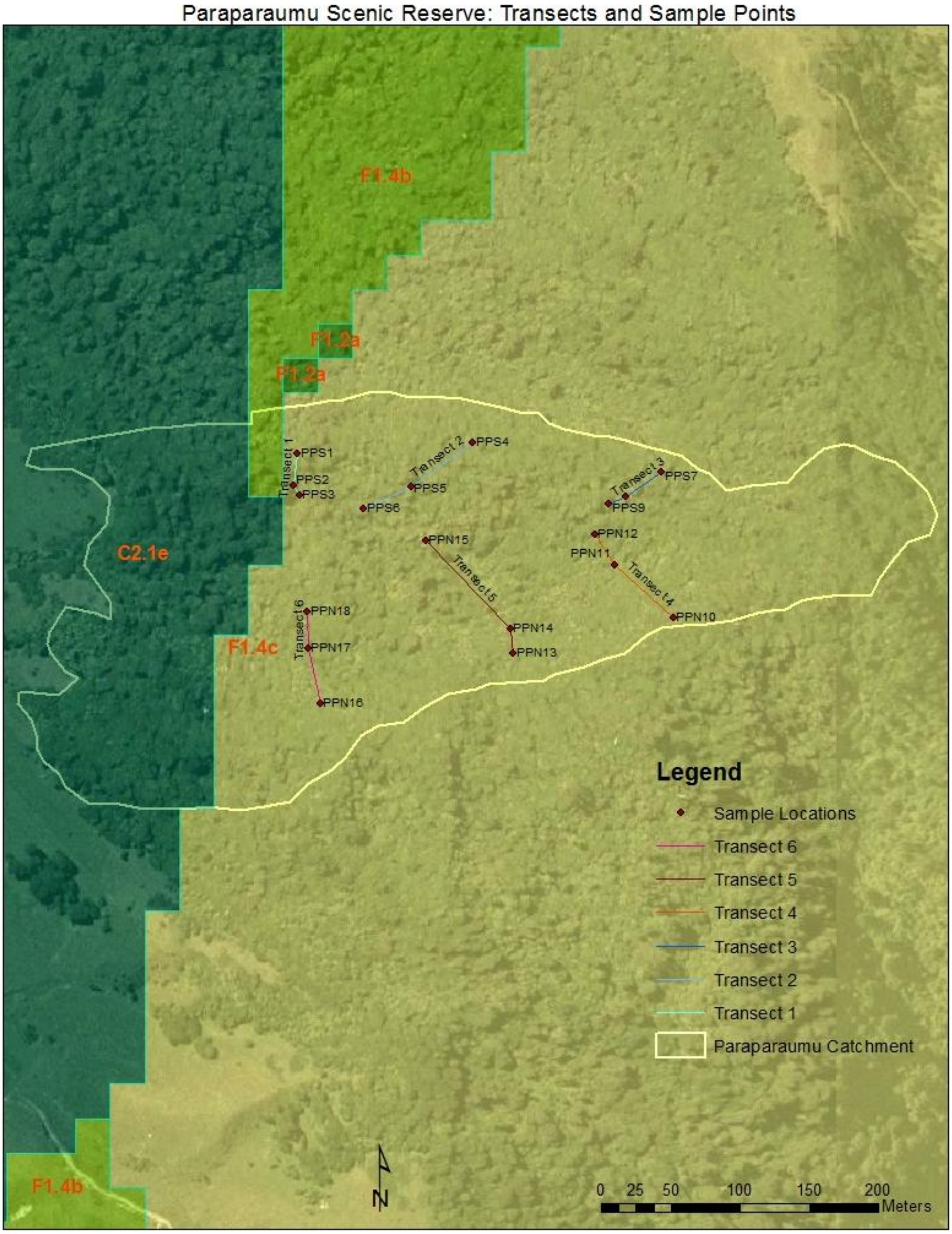

Figure 1: Paraparaumu Scenic Reserve study catchment with sample points and transects referred to in the text. The quadrats were centred upon the soil sample sites. The points were recorded by a Garmin etrex handheld GPS device, with the accuracy under dense canopy usually in the range of 11-14 m so the placement in this map may not be precise.

The quadrat size was chosen to be a rectangular 5 x 20 m, oriented with the long side parallel to the slope. While this may be on the small size for forest sampling, given the scale of the gully system being sampled it was considered sufficient. The shape of the quadrat was also chosen partly due to the small scale of the gully/valley under study. This meant that the narrow width ensured the sampling would stay within the chosen landform unit (and homogenous community, should there be one). It also maintained greater distance between quadrats down the slope on the particular transect than a square quadrat of the same area would have done, helping to minimise spatial autocorrelation. The edge effects concomitant with a large perimeter to size ratio is not likely to have an impact as the quadrats were within an undisturbed forest. Where necessary to ensure that the quadrats did not bridge from swale to spur the length was reduced and the width increased to maintain size unity. This was only required on one occasion (PpN14). Further detail in relation to quadrat selection is found in Appendix 4.7.

Table 2: Table of sample site codes, the symbol displayed in the graphical plots, transect number, aspect, and landform unit description

Site Code	Symbol	Transect no.	Aspect	Landform unit
PpS1	△	1	South	Convex creep zone (CCZ)
Pps2	▼	1	South	Mid slope transportational zone (MST)
PpS3	□	1	South	Footslope (FS)
PpS4	△	2	South	Convex creep zone (CCZ)
PpS5	▼	2	South	Mid slope transportational zone (MST)
PpS6	□	2	South	Footslope (FS)
PpS7	△	3	South	Convex creep zone (CCZ)
PpS8	▼	3	South	Mid slope transportational zone (MST)
PpS9	□	3	South	Footslope (FS)
PpN10	+	4	North	Convex creep zone (CCZ)
PpN11	■	4	North	Mid slope transportational zone (MST)
PpN12	○	4	North	Footslope (FS)
PpN13	+	5	North	Convex creep zone (CCZ)
PpN14	■	5	North	Mid slope transportational zone (MST)
PpN15	○	5	North	Footslope (FS)
PpN16	+	6	North	Convex creep zone (CCZ)
PpN17	■	6	North	Mid slope transportational zone (MST)
PpN18	○	6	North	Footslope (FS)

The raw data (collected during mid-November 2010) was entered into a spreadsheet with results from each quadrat separated into relevant tiers. An aggregate sheet was used to total the raw abundance of each species for the quadrat. The aggregate sheet was then transformed following the van der Maarel (1979) formula to provide a final abundance value. The transformed composite of abundance values for each quadrat (centred upon soil sample sites, refer Figure 1) was used as the input data matrix for the subsequent ordination and cluster analysis. A copy of the field sheet for recording data is at Appendix 4.8.

3. Multivariate analysis in the context of this study

3.1 Ordination: Indirect Gradient Analysis

There is ongoing debate in the literature regarding the merits of the various ordination methods. There is no intent here to canvas that debate in depth as it is beyond the scope of the study. Ultimately, to make an informed choice it is necessary to have both a very good understanding of the algorithms and the data that has been collected. Even then it is likely that the method used will not please everyone. This study is more exploratory than confirmatory and attempts to ascertain if the selected environmental gradients are explanatory or not. It is also acknowledged that the main gradients that explain the floristic assembly may not be among those measured.

The approach here is to look first at the ordination in an unconstrained way (Indirect Gradient Analysis) to reveal what the floristic data collected implies, without linear constraint to the environmental variables (Direct Gradient Analysis). Due to the lack of surety as to the structure of the data a number of ordination methods have been used. Non Metric Multidimensional Scaling (NMDS) has been used because of the lack of assumptions inherent in its use. Correspondence Analysis (CA) is also explored because it is based upon a unimodal response model which is seen as more ecologically relevant than the linear response model implicit in NMDS. Principal Component Analysis was also undertaken but the results are not explored in the main text but the output plots are included in the appendix (4.2).

In CA a graph is produced where axes stretch from the centroid in positive and negative directions. The first axis shows the gradient where the highest amount of variation is captured. The second axis is that which is orthogonal (uncorrelated) to the first while capturing the next greatest variation and similarly with the third axis and so on. In CA the relationships are explained by the proximity of the points, species and sites (refer to Appendix 4.1 for results and discussion). If a set of concentric circles were drawn centred upon a species or site score the presence of other sites or species within smallest circles would indicate the highest correlation and those within the largest circle the least correlation. Therefore, species that are close to a site will have higher abundances at that site than at sites elsewhere; the correlation decreasing with distance. Similarly two species found close together will be found in higher abundance together.

A criticism of CA is that a mathematical artifact causes an arch effect (Hill and Gauch, 1980). This causes the scores to be plotted resembling an arch due to a compression of the distances between scores at the ends of the first axis. Detrended Correspondence Analysis (DCA) adjusts for this phenomenom by segmenting the axis (detrending) and stretching the points according to the algorithm. DCA has also been criticised (Minchin, 1987) who states that there are problems with the outcomes even when there is a symmetrical and unimodal response.

NMDS is a rank order statistical method and does not rely on assumptions to ensure its validity; most notably it does not require a linear response or the Gaussian (unimodal) model. Output includes the value of stress which is the measure of badness of fit, the higher the number the worse the fit. Kruskal (1964) states that stress < 0.05 is excellent, 0.05 – 0.10 good, 0.10 – 0.2 fair, and > 0.2 poor and above this value would be unwise to interpret the results. When the algorithm is run no single outcome is produce and each run will produce an alternative plot. (The PAST software used in the study produces a result after 11 iterations (Hammer, 2011)). The axes are not in a particular order of importance and hence the association between the plot points requires examination to elicit trends and associations and inferences related to gradients. This method has been criticised by Kenkel, (2006) who states that the results are not superior to CA.

3.2 Ordination: Direct Gradient Analysis

Direct gradient analysis method Canonical Correspondence Analysis (CCA) has been utilised as it is a commonly used technique when response variables are fitted to explanatory variables (for example, in this study the geomorphic factors and soil nutrients). While this study looks at abiotic explanatory variables it is also necessary to consider that there are many other explanations or factors that influence floristic patterns, for example, (biotic) interactions, dispersal mechanisms, historical factors and random effects (Kenkel, 2006). Palmer (1993) reported that CCA stood up well under a number of testing circumstances that have been known to cause distortions in other methods such as DCA and CA, including noise in abundance data, highly inter-correlated abiotic variables and situations where not all explanatory factors are known. These conditions may be present in the data collected in this study.

3.3 Cluster analysis

Cluster analysis of species groupings is desirable as the method can elicit groups of similar species and sites and display them in a graphical form. The main distinction between cluster analysis methods is hierarchical versus non hierarchical. Hierarchical analysis is further broken into two main types; 1) divisive, and 2) agglomerative. With the divisive algorithms the species data is viewed as one large group and the algorithm examines the data for similarity/dissimilarity. It then divides them until there are as many as species counted, unless instructed to halt at a set amount of groups. The agglomerative method does the reverse. This study used hierarchical agglomerative cluster analysis performed with unweighted pair-group method using arithmetic averages algorithm (UPGMA) and based on Bray-Curtis dissimilarities. The algorithm was chosen due to the availability of the software and the distance method because it is robust and a commonly used measure for ecology (Gauch, 1982).

In the context of the study, cluster analysis is utilised to gain an understanding of species groupings and whether distinctions according to hillslope location or slope aspect are apparent. Distinctions may be drawn from the species abundance matrix constructed for Paraparaumu Scenic Reserve. If topographically constrained groupings are found the knowledge may be useful in plant selection and placement at the restoration site, Whareroa.

3.4 Data Management

PAST software (Hammer, 2011) freely available from the University of Oslo, at the web address: http//folk.uio.no/ohammer/past/ has been used in this study to investigate the data. A range of analysis types are available in this software which is a user friendly package with a graphic user interface (GUI). The species data used for NMDS ordination were log transformed and tier 6 was removed. The reason for removing tier 6 data is twofold. The first is that there were many instances of single seedlings that would have given rare species more weight than is reasonable. In many cases there were numerous seedlings of canopy trees whilst they were not represented in the intermediate tiers. It would seem that these seedlings are simply suppressed waiting on a disturbance that opens the canopy which may then allow growth to occur. Alternatively, they simply do not survive in the conditions that they find and so do not add to the diversity in a meaningful way. There is some loss in removing the layer as the ferns and allies that do not grow above 0.3 m are not represented and may in fact be indicator species. The second reason is that both the grasses and some ferns were difficult to identify increasing the possibility of error.

The log transformation of the abundance data was undertaken when NMDS was utilised due to the presence of many zeros in the matrix reflecting the presence of sparse species. The log transformation also reduced the influence of the few abundant species which may be seen as outliers in the ordination algorithm. CA and CCA automatically double centres by row and column (a standardisation or scaling technique) and so no log transform has been performed when using these techniques. The abiotic factors have been standardised through normalisation of the scores by dividing the mean by the standard deviation. The action removes the effect of the differing units of measurement and also the differing range and scale of the measured units.

The data relating to the environmental variables was entered into a data matrix for use in the ordination process (refer Appendix 4.6). When undertaking CCA it is understood that the procedure is best where the number of explanatory variables are reduced to the minimum. Although CCA may be seen as more a confirmatory tool, in this study the response to a wide range of variables is sought due to the unclear relationship of the two sets of variables. The intent of the vegetation inventory is to examine if there were any correlations between any of the abiotic factors measured at the restoration site which are outside their normal range as (see Chapter 5). Hence, CCA is seen as exploratory and so only highly correlated variables were removed i.e. total C which is correlated with total N, and porosity which is highly negatively correlated with bulk density (Appendix 5.5).

Removal of two variables still leaves quite a large number in the analysis, and it may be that further analysis could be taken with a reduced set following examination of the results of the initial ordination process. To limit the scope of the study this has not been undertaken.

4. Results

The full matrix of abiotic variables, geomorphic data and species abundance levels is shown in Appendix 4.6. Also in the appendices is a table of species with full names and descriptions (Appendix 4.9). Table 4 acts as a legend for the ordination graphs.

Table 3: Concise legend of site symbols specifically for ordination plots.

△	South facing convex creep zone	+	North facing convex creep zone
▼	South facing mid-transportational zone	■	North facing mid-transportational zone
□	South facing footslope	○	North Facing footslope

4.1 Non-metric Multidimensional Scaling (NMDS)

The statistical output for the site ordination (Figure 2) shows that the stress for a two dimensional plot is 0.1793 which is rather high and interpretation of the ordination should be undertaken with caution. Stress for the species ordination (Figure 3) is very high at 0. 3119. The level of stress is a measure of the fit for a 2 dimensional solution and given this weight indications are that more than 2 dimensions are likely to be accounting for the variance. However, while although reduction in stress will be achieved by increasing the number of dimensions analysed this reduction is not indicative of a better solution (Gauch, 1982).

It is also understood that the axes are neither ordered nor sequential. In fact the algorithm can give a different result for each run and it is possible for the solution to be stuck at a local optimum rather than a global one. Since the axes are not in a particular order the understanding of a NMDS plot is gained by examining the associations of the points, in this case the site scores which are grouped by Aspect and Hillslope Location. The distances between them are not necessarily a true indicator of the degree of association but the groupings do lend themselves to interpretation in a more general way. It is also possible to examine for trends or gradients.

It appears that the footslope locations while not closely clustered are grouped in the upper left quadrant (Figure 2). The clustering would seem to indicate a grouping of species which are more tolerant of lower light and higher moisture levels. On the lower left, widely spaced and apart from the balance of the data are PpS1 and PpS2, the upper slope and mid-slope of the south-facing ridge. These sample points are closest to the coalescing colluvial fan at the bottom of the ridge and may be influenced by the proximity to another ecosystem niche and soils class. The inventory for transect 1 shows tawa is present which is not usual elsewhere but common on the colluvial and alluvial parts of the environment (not sampled in this study). The MST and the CCZ of the north facing slopes are mainly contained in the lower left quadrant indicating a broad similarity of species. The CCZ for the south-facing slopes are not grouped but do display a very linear pattern diagonally across the plot. Again, this may indicate some sort of change in assembly from that at the bottom end of the spur to that at the top, though this may be due to other factors than distance from the colluvial assembly.

The plot for the species ordination (Figure 3) is transposed 180° compared with the site plot. This is simply a function of the algorithm and does not have an ecological meaning. Given the high stress function the species ordination is not analysed further. Analysis of species follows the Direct Gradient Analysis output.

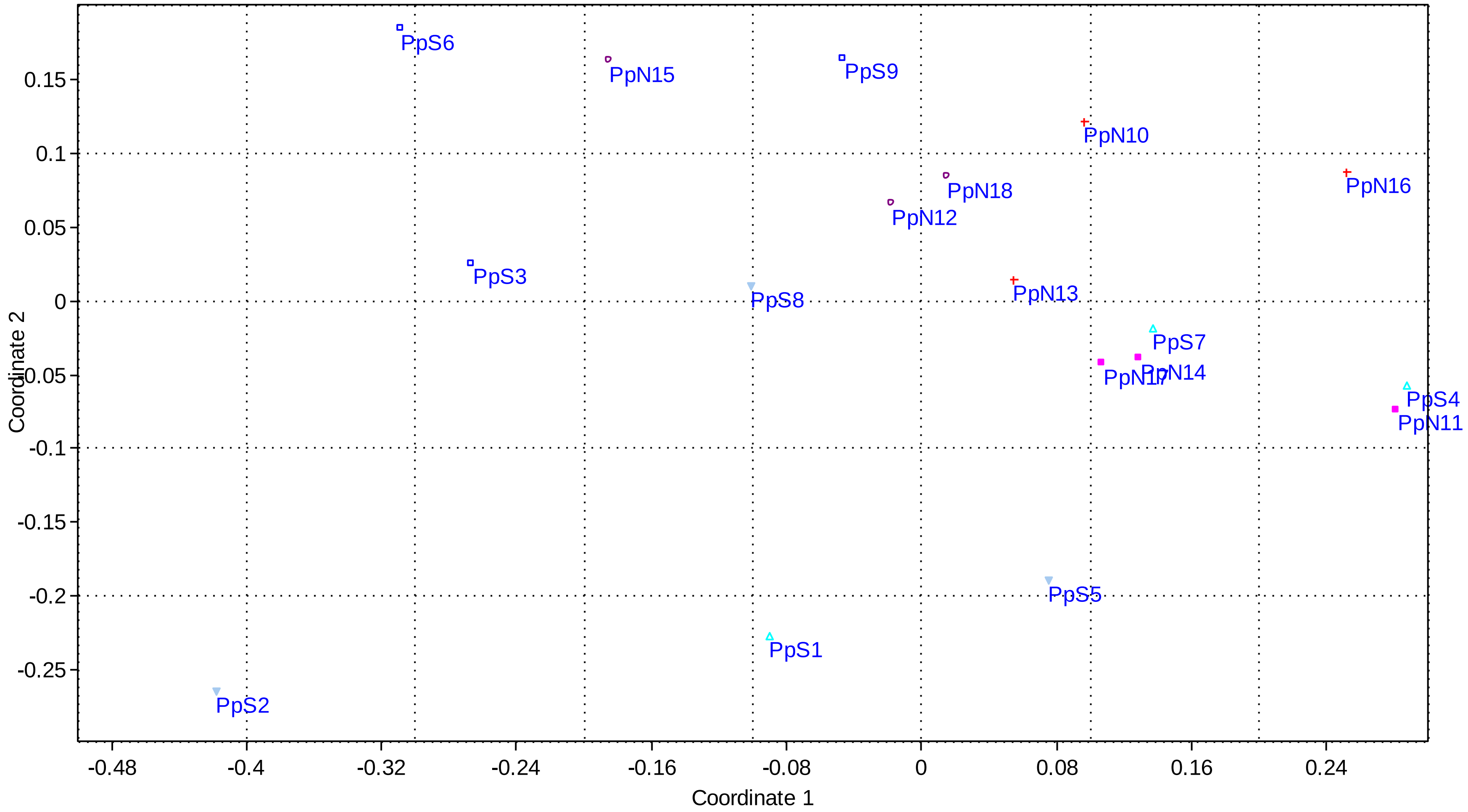

Figure 2: Site scores for NMDS using Bray-Curtis dissimilarity measure on Paraparaumu Scenic Reserve log transformed data showing axes 1 & 2 in a 2 dimension analysis grouped by aspect and hillslope location. Stress = 0.1793.

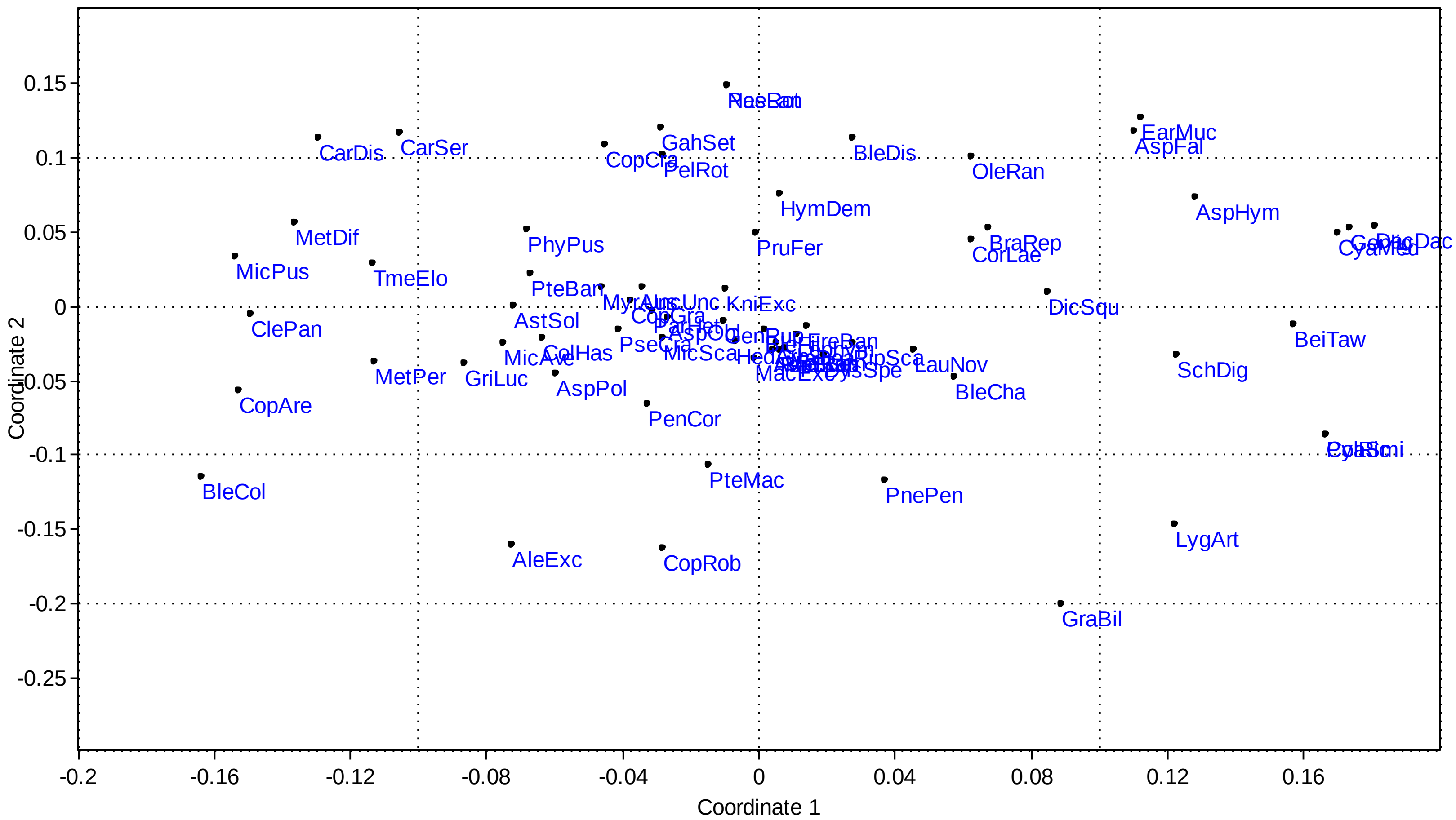

Figure 3: Species scores for NMDS using Bray-Curtis dissimilarity measure on Paraparaumu Scenic Reserve log transformed data showing axes 1 & 2 in a 2 dimension analysis grouped by aspect and hillslope location. Stress = 0.3119.

4.2 Canonical Correspondence Analysis (CCA)

CCA produces a linear combination of environmental variables which maximises the dispersion of the species scores. In doing this CCA chooses the best weights for the environmental variables and so no user input is required regarding weightings (ter Braak, 1995). Plots showing separate elements of the analysis are presented (Figures 4 – 7) to provide clarity as the complete triplot is a very dense graph to interpret. Figure 6 shows sites separately in order to show their relationship clearly. The data seems to be strongly associated with the first axis but the table of eigenvalues (Appendix 4.5) shows that it only accounts for 26% of the variation. The eigenvalue for the second axis is 22% of total variation. The ordination is similar to the indirect gradient analysis results.

Figure 4 displays the site scores while Figure 5 illustrates the abiotic ordination which shows that there is no single gradient that is totally dominant. The length of the line is a reflection of the strength of the gradient. The longest gradient is Hillslope Location which is also aligned closely to the first axis. The next strongest gradients are that of Slope and Total N. Two of these are landform variables and so is the next strongest which is aspect. As a group these may determine the first axis. Those most closely aligned to the second axis are C:N ratio in one direction and P, and pH to a lesser extent. Figure 6 is a triplot in which abiotic gradients, site scores and species scores are depicted. This ordination has been undertaken using scaling type 2 which emphasises the relationship of the species. Figure 7 is the ordination for the second and third axes. The ordination of the second and third axis combination appears to confirm that C:N ratio is the strongest and most closely aligned to the second axis. The third axis does not present a clear response that is decipherable. Interpretation of these plots can be found in the discussion section.

Table 4: Names of the abiotic factors used in the CCA analysis with abbreviations as displayed in the plots.

Gradient Plot Name	Full Name
BulkDens	Bulk Density
Sand	Sand
Silt	Silt
Aspect	Aspect
pH	pH
Olsen P	Olsen extractable phosphorus
Min N	Anaerobically mineralisable nitrogen
Total N	Total nitrogen
CN ratio	Carbon nitrogen ratio

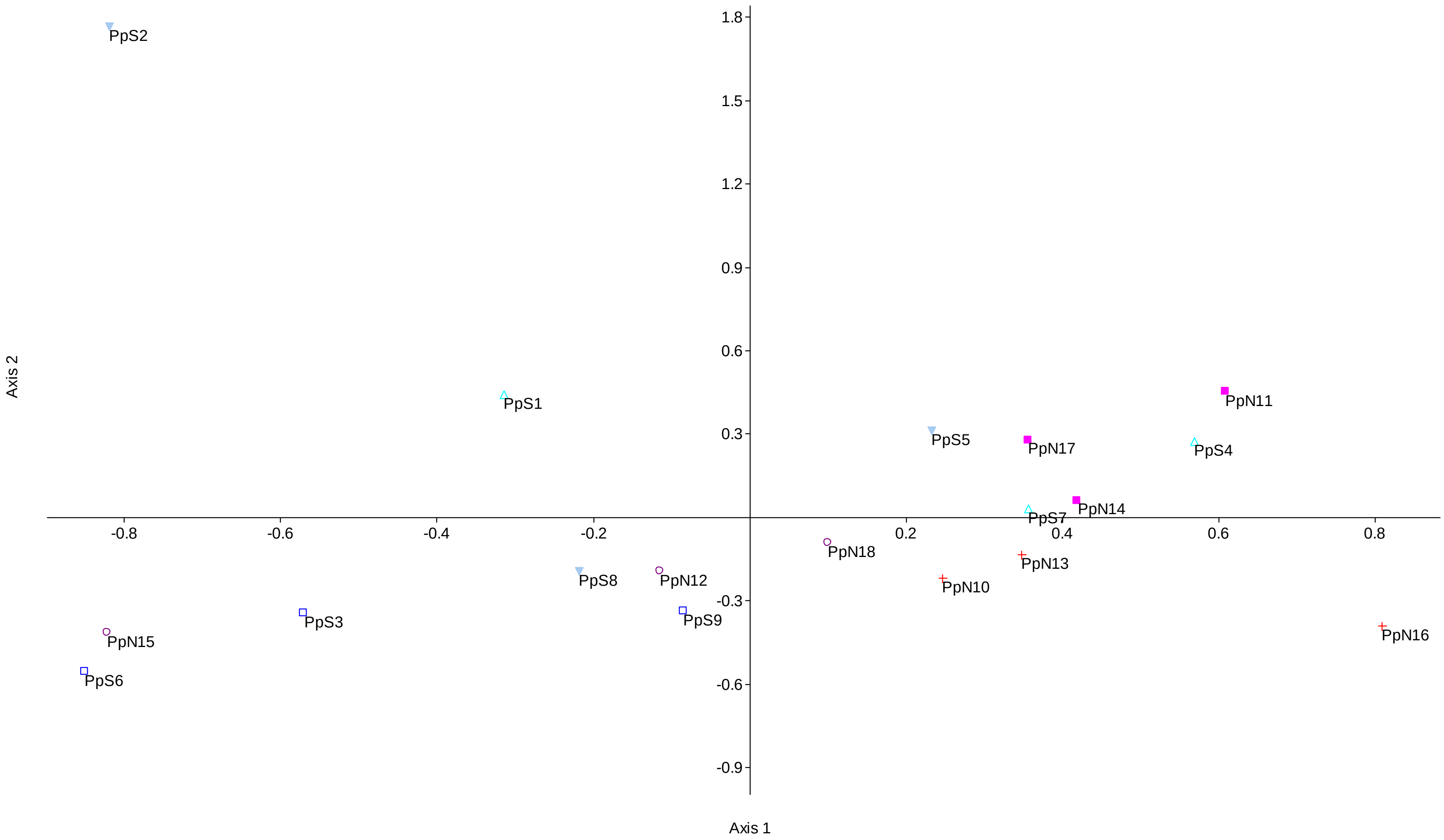

Figure4: CCA plot of axes 1 & 2 showing site scores for Paraparaumu data excluding tier 6 (groundcover < 0.3 m).

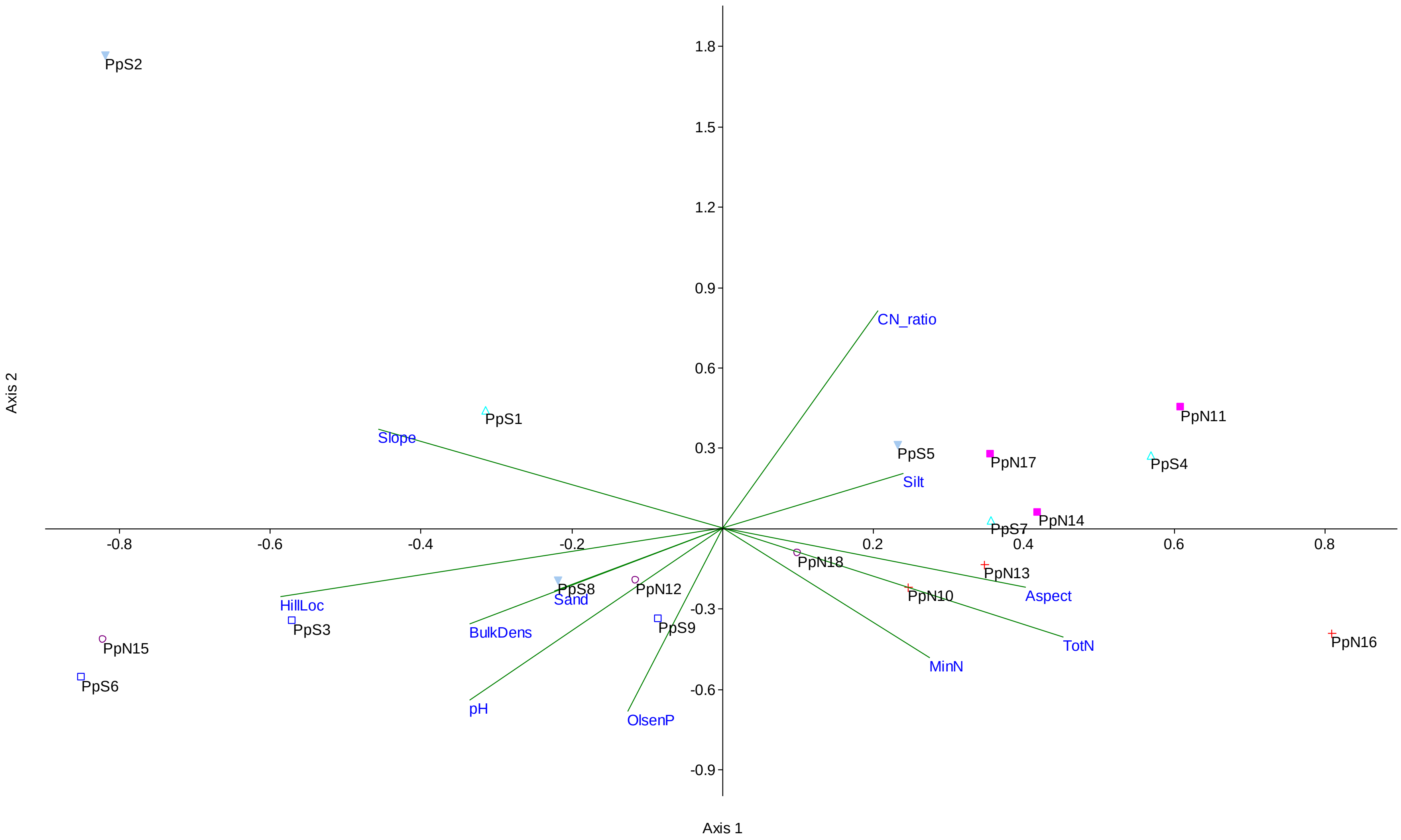

Figure 5: CCA biplot of axes 1 & 2 showing site scores and abiotic gradients for Paraparaumu species data excluding tier 6 (groundcover < 0.3 m).

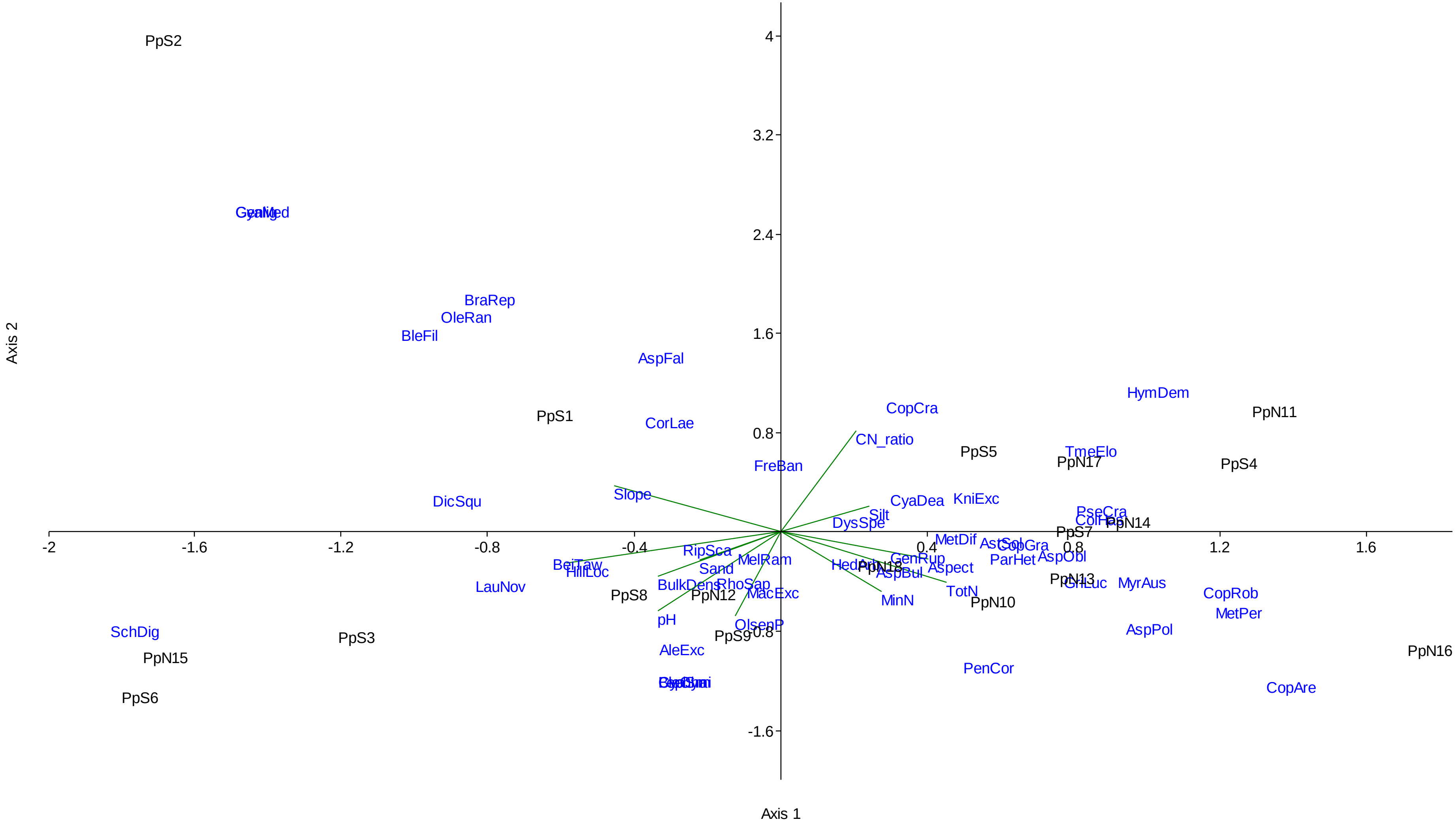

Figure 6: CCA triplot of axes 1 & 2 showing site scores and abiotic gradients for Paraparaumu species data excluding tier 6 (groundcover < 0.3 m).

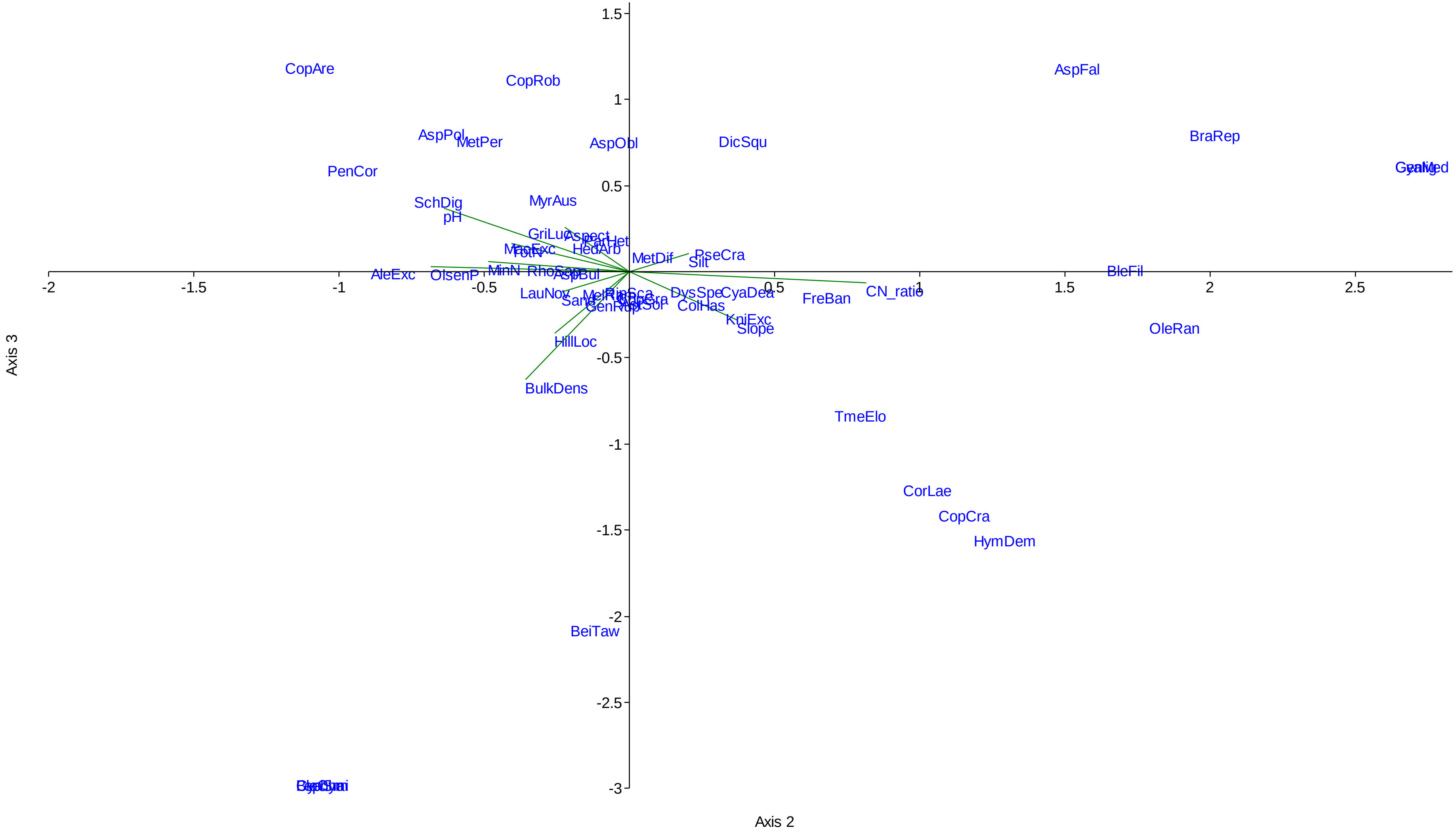

Figure 7: CCA biplot of axes 2 & 3 showing species scores and abiotic gradients for Paraparaumu species data excluding tier 6 (groundcover < 0.3 m).

4.3 Cluster Analysis

Figure 8 shows that there are few long stems in the dendrogram which means that separate assemblages are not strongly delineated. Groups have been identified that appear to show reasonable similarity and are outlined in different coloured borders. Some of the groupings suggested are related to landform units and physiography such as the group that can be identified boxed in red and is associated with the MST sites or south facing CCZ (refer Figure 8). Another group associated with landform units is that outlined in blue consisting of sites closest to the colluvial outwash fan i.e. sites PpS1, PpS2 and PpS3.

Alternatively, other groups do not appear clustered primarily due to landform unit associations. The group boxed in yellow has consistently higher abundances common over most sites and does not conform to landform unit associations. Pukatea (*Laurelia novae-zelandiae)* and kiekie (*Freycenetia banksii*)do not form "clumps" with other groupings but are "chained" to this group at quite a low amount of similarity. Also grouped at some distance in similarity is a pair of species (mamaku (*Cyathea medullaris*) and pate (*Schflerra digitata*)) which may be found more commonly in the MST or FS zones. It is also apparent that these species in this group are generally found in the higher tiers. The group boxed in green appears to be more common to the lower height tiers. One branch consists of species in the 0.3 – 2 m tier and the other branch is more common in CCZ and MST sites particularly those facing north which are larger shrubs or small trees.

The two way analysis graphs the sites concurrently with the species shows that three site groups are evident. Site cluster 1 consists of the CCZ and MST of transect 1 which is adjacent to the unsampled LENZ environment. Sub canopy species not abundant elsewhere appear in this transect as does tawa. However, the footslope site (also including tawa) clusters with other footslope sites (Site Cluster 3) and not Site Cluster 1. This indicates it is the presence and absence of other species influencing the group. Site Cluster 2 is a combination of CCZ and MST sites and contains no species in the group of species outlined in red. The largest group Site Cluster 3 are mainly FS and MST sites of both north and south facing aspect and seem differentiated from cluster 2 by the presence of species in the red species group, and conversely none in the blue species group. These groups may arguably indicate a species preference for specific positions on the slope catena.

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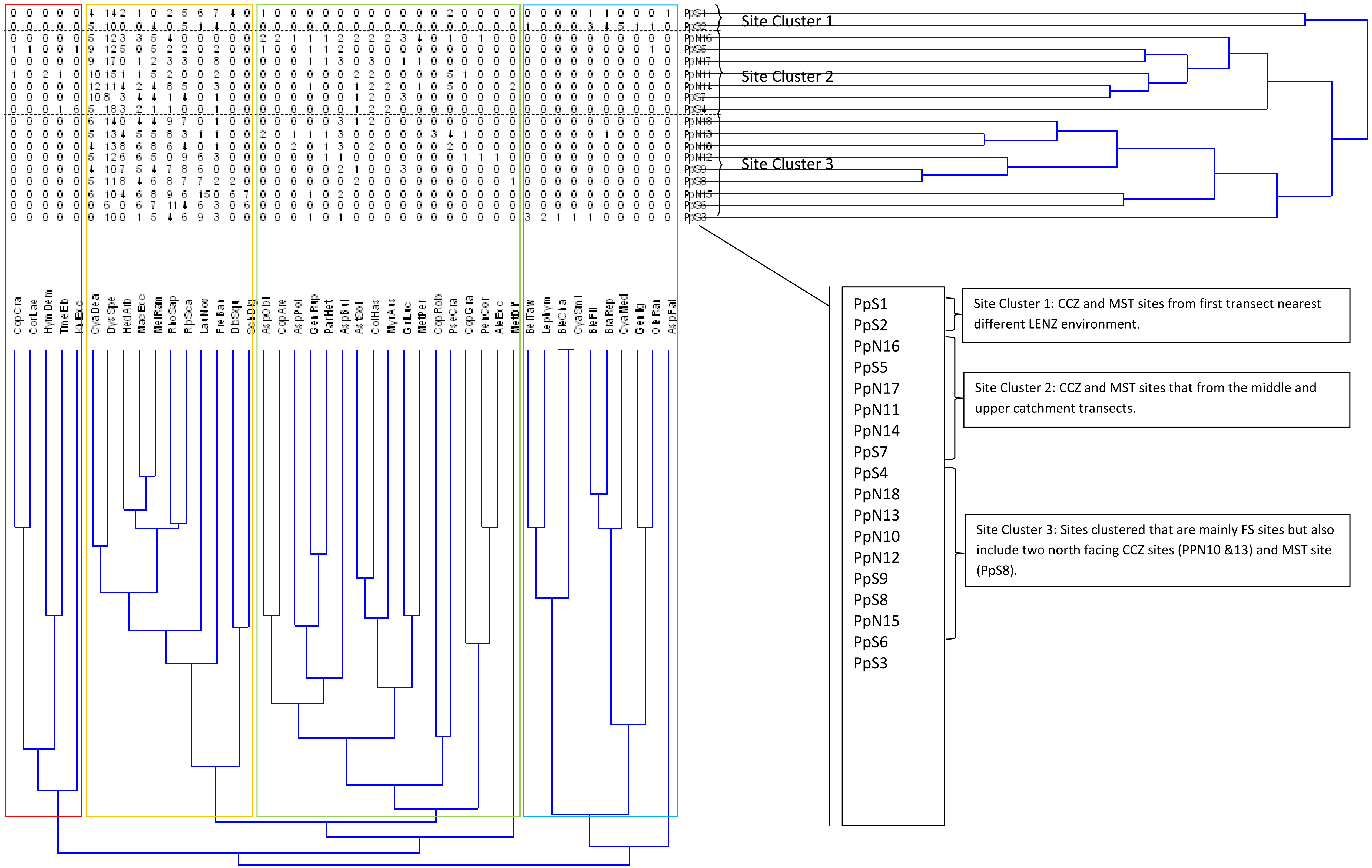

Figure 8: Agglomerative UPGMA cluster analysis for Paraparaumu data using Bray-Curtis dissimilarity measure. Two-way analysis showing abundance values, site, and species clusters

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5. Discussion

This study provided good evidence that landform variables influence floristic composition. Indirect gradient analysis using ordination and cluster analysis suggested that sites were grouped according to Hillslope Location. This clustering indicates a grouping of predominantly footslope sites and another of south facing CCZ sites and north facing MST sites. The conclusion was supported by direct gradient analysis but this indicates that hillslope location is not the only driver accounting for most of the influence with Slope and Aspect also having an impact. Hence, as a group, landform variables appear to be the main components influencing the first gradient and as such the drivers of floristic assembly. The second axis shows that the main driver is C:N ratio with Olsen P and pH having a lesser impact. The third axis indicates that Bulk Density may also impact floristic composition.

There is little in the literature where ordination has attempted to expain floristic composition dependent upon hillslope location and aspect in a small zero to first order sub-catchment. Examining a larger scale, Develice and Burke (1989) report that where vegetation does not form obvious communities that ordination and cluster analysis can identify groups, but that they may overlap in the environmental space. They found some communities may be located in positions unlikely without the influence of insolation, that is, some communities are found at higher altitudes where insolation is greater hence offsetting the altitude factor. Burns (1995) examined Waipoua State Forest and amongst other findings reported that there were significant differences between topographical units. They concluded the differences were due to increasing fertility between ridges or plateau positions compared with units lower on the slope catena. Vegetation patterns were concluded to be largely topographic and associated with soil fertility and moisture and altitudinally determined temperature and precipitation gradients (Burns and Leathwick, 1996). Other studies in a New Zealand context look at either very different environments, or are concerned with confirming hypotheses unrelated to this study and are generally examining a larger scale.

5.1 Do landscape variables explain patterns in community composition?

In CCA the percentage of variation of the first axis is only 26%, the second axis is 22% the third is 13% and the total variation for these 61% (Appendix 4.5). Although the vegetation analysis is intended to be exploratory and the number of samples is small permutation tests have been undertaken and reveal that the p-value for all axes is not significant. Alternatively, the amount of variation encapsulated in the axes whilst being small cannot rule out significance in an ecological sense (Gauch, 1982). Ter Braak (1986) also states that small eigenvalues may be of ecological importance and are more important than the species environment correlation.

The CCA plot shows that the factor Hillslope Location is the strongest gradient followed by Slope and Total N. This information is of note and may be important in guiding restoration. Hillslope Location (landform unit) is likely to have some correlation to insolation, as will aspect. Insolation might be suggested as an important gradient and further research regarding insolation is suggested. The noted gradients correspond to the results from the permutation tests showing that Slope and Hillslope Location were significant factors for a number of variables.

The cluster analysis (Figures 10 and 11) supports the notion of hillslope location being a driver of community assemblage. The evidence is only moderate given the short length of the stems and so small distances between groups, but still appears valid given the correlation with the direct gradient analysis. The species group outlined in red corresponds to CCZ and MST zones (Site Cluster 2) and another, outlined in blue, which appears to be associated with proximity to the colluvial outwash fan (Site Cluster 1). Site Cluster 3 is associated with footslope sites and this shows an absence of species that are found in abundance at the CCZ and MST. Although strong evidence of clusters based on individual landform units is lacking there is some evidence of clusters related to groups of landform units. This knowledge may be useful in applying to restoration at Whareroa.

Of the other variables, the plot shown at Figure 7 indicates that Bulk Density and Sand are correlated whilst Silt is negatively correlated with them. Higher measurements of silt can be seen to be associated with CCZ and MST whilst higher proportion of sand is associated with the FS possibly indicating that the silt is transported out of this part of the system with little ongoing storage. The response will be partly due to the steep and narrow nature of the gully system which does not have a large colluvial footslope.

Regarding the soil chemical variables, C:N ratio is also associated with mid and upper slope sites and is negatively correlated with Olsen P and pH, both of which have higher measurements in the footslope sites. Given the result it may be that phosphorous does accumulate in the lower slope which has an effect upon the pH. Slope angle is negatively correlated with Total N meaning the greater the slope angle the less the amount of Total N. This might be explained by the paucity of ground cover plants on the steep mid slope sections in combination with gravelly and mobile soil which could also be quite shallow. These factors may facilitate the rapid removal of N from the slopes. Higher levels of Total N and AMN are associated with the north facing upper slopes where slope angle is less.

In general, there appears to be a well defined group based on the footslopes whereas the other landform units are not as clearly delineated. It may be that a strong gradient hinted at in the ordination, not measured but correlated with hillslope location and aspect, is insolation. The importance of insolation is highlighted by DeVelice et al. (1988), DeVelice and Burke (1989), and Leathwick et al., (1995). Another explanation of distribution may lie in the complex of soil moisture and summer atmospheric moisture deficits (Leathwick & Whitehead, 2001). Again, their findings related to insolation and soil moisture but focuses more particularly on the availability of water. Dyer (2009) investigated a water balance approach based on moisture use and stress and found a physiographic pattern based on slope location and slope aspect which showed that highest rates of evapotranspiration were found on south facing slopes, then, ridges, valleys, and north-facing slopes (northern hemisphere orientation). South facing slopes and ridge tops experienced the highest moisture deficit.

5.2 Species-environment relationships

Given the results of the ordination it is difficult to establish distinct floristic communities. The result may be due to the small size of the catchment and the absence of distinct ecotones. However, in the cluster analysis some groups may be identified (Figure 10 and 11) arguably two of which may be seen as determined by landform variables whilst the others appear to be a clustering of more generally abundant species. Since the sampling has been completed within a single LENZ class it is not surprising that a relatively homogenous community is evident. Had a larger catchment been sampled possibly greater distinction may have been apparent.

Sheridan and Spies (2005) note that in their study of zero order basins in coastal Oregon that zero order basins have distinctive geomorphology and fluvial systems which produces distinctive plant associations with some species in the zero order basin being found in riparian zones elsewhere and others found in upland areas elsewhere. In this context, it is interesting to note that PpS8, Pps9, and PpN12 are mid to lower positions of transects at the top of the zero order basin whilst distinctly separate are PpS6 and PpN15 both mid transect footslope sites lower down in a first order basin position. Similarly, a group can be observed as north facing MST sites PpN14, PpN17 and PpN11. PpN18 is quite close (similar) to two north facing CCZ sites but this FS site is physically unlike the other FS sites being more open to the north at the base of a side gully.

Another feature worthy of comment relates to PpS1, 2 and 3 which are widely spaced but point in the same direction from the centroid. These sample points are closest to the coalescing colluvial fan at the bottom of the ridge and are on the boundary with a different LENZ class and soil series class (refer to Figure 1 in this chapter and Appendix 3.7). It is observable that a greater abundance of tawa is evident in that area and also that on the nose of the spur there is more kiekie which is reflected at these sites especially PpS2 and PpS3. Also of note is that the PpS2 quadrat partly encompasses a very steep section which is the result of an historical slip. Not only are there more mosses here but the understorey is reflected in the disturbance and may have some bearing on composition for the site. Tawa, along with pukatea, pate, and supplejack, have a close correlation to hillslope location.

Species scores at the centre and near the edges of a graph are not as robust as the mid-range scores (Kindt and Coe, 2005). Given that consideration it is still possible to find associations. For instance, it can be seen that pukatea, wheki (*Dicksonia squarrosa*), supplejack and pate are associated with the wetter footslope sites but is distant from red matipou (*Myrsine australis*) which is mainly found in greater abundance in the upper slope sites. Associated with the sites of the upper and mid-slopes can be seen *Collospermum hastatum*, an epiphyte, and silver fern (*Cyathea dealbata*) along with a cluster of other species possibly adapted to less soil moisture and/or increased light levels. These are factors not measured but which may be inferred in conjunction with the graphical arrangement implicit in the data.

The plot shows kohekohe, silver fern, and rewarewa in association with silt and negatively correlated with sand. The *Asplenium* species *A. bulberifum* and *A. polyodon* are correlated with the amount of Total N. These species and the others correlated with N may be species that will prosper during restoration due to enhanced levels of N at a grazing restoration site at the expense of those which are negatively correlated, for example, mamaku.

Common species kawakawa, mahoe, nikau have some association with the levels of P, and pH as well as the level of sand and bulk density. A species which looks negatively correlated to P is *Coprosma crassifolius* which may not succeed under enhanced levels of P encountered at a farm restoration site. Species such as *Coprosma robusta* and *Metrosideros perforata* are strongly correlated to north aspect and to increased levels of N. The level of P and the ordination may need to be treated with caution as at one site i.e. PpS9 the measurement was 29 µg/mL while the mean for Paraparaumu was 5.36 µg/mL. PpS9 was re-sampled and re-tested but the result returned was 26 µg/mL. There is no clear indication why the result is so different, but obviously it will have an effect on the ordination.

With regards to Figure 9, while the third axis accounts for a lesser amount of the eigenvalue it seems that the gradient that is most important is that of bulk density which is shown as correlated with hillslope location. It may be another factor that influences the spatial pattern of species. Of note is the clearer indication that C:N ratio is the variable that accounts for the majority of the variation in the second axis. It is noted that C:N is seen as an important soil fertility variable in the study of species composition in Northland gumland heaths (Clarkson et al. 2011). Strongly negatively correlated to C:N ratio was pH and Olsen P. Understanding the levels at the restoration site will help with implementation of actions required for successful revegetation.

6. Conclusion

Finally, has the process been successful in answering the questions posed to begin with:

1) *Is there any significant difference in community assemblage dependent upon hillslope location and aspect?*
2) *Do the measured gradients influence the floristic assemblage?*

The first can be answered, with some equivocation, that yes ordination can find species that prefer some locations both in a general sense and in terms of landform unit position. However, it is not possible with the data to state that specific community assemblages exist at the individual landform units sampled in this study. There is evidence of assemblage being classed into 2 groups, one predominantly of FS sites and the other of CCZ and MST sites more generally. There is no evidence to confirm broadly a relationship between community composition and aspect. It may be possible to perceive an insolation gradient given the closeness of PpN18, a footslope location which is open to the north, to upper slope locations and distant from other footslope locations which are not open, on the ordination plots. The stress of the NMDS analysis and the eigenvalues may indicate that an unmeasured gradient is the main driver at this sub-catchment scale.

Regarding the second question, the CCA ordination indicated that no individual gradient measured was found to be very strong and so one variable alone may not have a high degree of effect. It may be possible to suggest that a grouping of landform units and physiographic factors provides the strongest gradient influencing the floristic community. With regards to Total N and Olsen P, both chemicals suspected of being at enhanced levels on most agricultural land, the use and placement of species sensitive to their level of presence may need to be given some consideration in a restoration plan. In a different data set it may be possible to apply findings in a very specific way, so there is at least a theoretical yes to the second question. Regardless of the specific relationships in this study it is evident that the methods used here would be of assistance in ecological restoration projects in general.

The relationships between the floristic composition, individual species, the soil variables, and the geomorphic factors that are presented in this chapter have a role in determining restoration priorities. Identifying species associations with these variables will help determine whether or not attempts should be made to take remedial action if the variables are significantly different between the restoration and reference sites. If a significant difference is found but it is determined to be unpractical to remediate the situation then selection of species may be guided by the results of the ordination where associations with the environmental variables are analysed.

The results hinge on a large array of steps being undertaken correctly. The method of choosing the sampling sites is important and in this study the option of stratified partially random sampling was determined as a valid technique to ensure control of factors so as to be able to test the significance in the setting for restoration purposes. The study may have been improved if an importance value was used for the sampling technique, where not only estimates of cover were assigned to classes, but also specimens counted, and basal area calculated so as to give a robust measure of the abundance of species and so the assemblage. It would have required a much greater sampling effort and for this exploratory study not within its scope. Greater flexibility could have been achieved in the analysis of the data by using the R software but again the time taken to learn and confidently use R was beyond the scope of the study. The sample size is not large and so the results of species composition could be compromised. For example, no rimu have been recorded but are visible members of the community. So there could be improvements made in confirmatory studies if necessary. The degree of similarity between the different ordination methods and cluster analysis does however give reasonable confidence in interpreting the data and the results presented here would be useful in the restoration of Whareroa.

Chapter 5. Geomorphology and soil variables

1. Introduction

To begin it is important to briefly outline the relationship between soil science and geomorphology as these are simultaneously investigated. Soils develop on a geomorphological surface and Schaetzel and Anderson (2005) state that there is a feedback between landform and soils as both develop concurrently; soils reflect the geomorphology of their location and it follows that physiography reflects the influence of soil characteristics. Practically, the inference is that soil will have an influence on the susceptibility of soil to erosion and, conversely, slope failure is a product both of the parent material and the physiography as characterised by the evolutionary state of the location. With consideration to the relationship outlined above, the intent of this chapter is also to examine the factors associated also with soil/vegetation nexus. Ehrenfeld et al. (2005) echo the notion of feedback between landscape and soils in the relationship between soil and plants. Their examination of physical soil properties and chemical status also includes consideration of the inherent mechanisms, direction, scale, strength, and complexity.

In this study I compare soil variables (specifically, soil quality indicators) at both the restoration and reference site. Considered also are the significance of soil relationships with environmental (geomorphological) factors. Subsequently, the values of the soil variables are compared with values that the literature proposes are expected for indigenous forest. If conditions at the restoration site are determined to be outside their "normal" dynamic range, and if it is accepted the difference may be associated with land use change and introduced exotic species, consideration of the consequences to restoration is required. Of particular interest is the relationship of soil variables which are out of their normal range and indigenous floristic species. The relationship is considered more fully in the vegetation analysis section under the constrained ordination discussion and also in the synthesis chapter. While significant, it is beyond the scope of this study to discuss in detail the subject of thresholds, stable or altered states in relation to geomorphic processes in the context of the site. The question that the study attempts to answer is:

Can examination of geomorphological factors and soil variables point towards conditions that may require remediation prior to ecological restoration?

2. Background

Numerous soil parameters are used in studies in which relationships of abiotic variables, the environment and vegetation are examined (for example Basher and Lynn, 1996; Eger and Hewitt, 2008; Giltrap and Hewitt, 2004). In their research to find significant environmental characteristics which constrain vegetation distribution and productivity

Abella and Covington (2006) used the following geomorphic environmental factors; elevation, transformed aspect, slope gradient and terrain shape index, and also soil parameters; $CaCO_3$, texture, pH, organic C, total N. Other studies that have used a range of soil parameters include those of Palik et al. (2000), Dodd and Power (2007), Giltrap and Hewitt (2004).

A definition for soil quality indicators expressed by Hill and Sparling (2009: 32) is "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health". The project '500 soils' undertaken by Landcare Research (Sparling et al., 2004) looked at a selection of variables to outline the needs for various agencies when monitoring soil quality indicators. The minimal set being utilised were total C, total N, mineralisable N, soil pH, Olsen P, bulk density, and macroporosity which forms the basis of the set for this study. Hill et al. (2003) concur with such a set as a minimum and it also reflects the views of Doran and Parkin (1996). The "one size fits all" approach will have limitations. For example, if areas have been polluted heavy metals levels will not be captured (Cameron et al., 1998). A set of indicators produced for England and Wales includes copper, nickel, and zinc (Environment Agency, 2006).

Considering the significance of the exclusions in the Landcare Research set is beyond the scope of this study, but for a quick, cost effective analysis its use appears reasonable. Most information available focuses upon conditions found in an agricultural setting and there is a paucity of data pertaining to environmental levels of nutrients and even less relating to physical soil conditions in indigenous forest (Sparling and Schipper, 2004). Webb et al. (2000) and Taylor et al. (2010) provide a few relevant examples.

3. Dependent Variables

The above physical indicators can provide information on land use change and geomorphic processes under altered conditions, for instance as at the restoration site. Texture can also be used as an estimator of water-holding capacity so helping to provide proxy information. All give information in relation to the need for remediation if significantly different to the reference site and known expected ranges. The chemical variables have been chosen as the basis of soil quality indicators used in similar studies and by commercial laboratories. Tests on variables such as exchangeable calcium, cation exchange capacity and base saturation are important indicators which were beyond the capacity of the study budget.

Olsen soluble P has been questioned as a suitable means to test phosphorus in New Zealand and research has compared it with the resin P method (Saggar et al., 1999). The Olsen P extraction method was developed in the North America under alkaline soil conditions and may not be suitable for acid soil (McKie, 2006) as found under native forest conditions in New Zealand. Another concern is overestimation of the value in low

P soils, and underestimation if P is high or if lime has been recently applied (Curtin and Syers, 2001; McKie, 2006; Hill Laboratories, 2009). These concerns may be pertinent in making decisions regarding application, or not, of precise amounts of fertiliser. My interest was to check differences between undisturbed soil and agricultural soil rather than to make an absolute determination about the levels (Olsen P has been used such a context in the recent past, see Stevenson, 2004). Secondly, I wished to find if the agricultural soil was significantly outside the normal range, and the expectation was that it would be significantly different not just marginally different. Given these reasons and the lower cost the Olsen P test was utilised.

The variables chosen for measurement were constrained by the resources available. Extensive expensive laboratory tests were not possible, which restricted the number processed. Other measurements were deemed to be unachievable due to time constraints. Ultimately, the variables analysed are factors that govern vegetative growth and species composition, though they are not the only ones. Consideration was also given to physical properties and their relationship with changed land use.

Two variables that were not included in the final analysis but are of importance are water-holding capacity (WHC) and soil depth. The plan to measure the WHC was to use time domain reflectrometry (TDR) to obtain soil moisture content at two times of the year. The first measurement was made in the winter, the second to be completed in late summer. After the majority of the sites had been measured in winter it became evident that the measurement was unreliable when three very different readings were obtained from the same position. Previously only one reading had been taken from each point. The second reading was to have been taken at the driest time of the year, but it seemed that the soil would be too hard to drive the pins of the TDR meter into the soil without damage. An alternative was to have equipment in situ and take measurements but was beyond the scope of this study. A third alternative of measuring in the lab was also not possible as equipment to apply vacuum to the soil was not on hand.

The second variable planned but not used in analysis was soil depth. Due to the colluvial nature of the soil at the sites and the presence of large floating clasts, soil depth measured by rod was deemed too unreliable. Digging of pits was also determined to be an inefficient allocation of limited resources. The final range of environmental factors and soil variables that have been measured are tabulated below.

4. Factors (main effects)

The land use indicator or "site" factor is used to investigate changes in dependent variables due to land use change, that is, the clearance of native forest and replacement with grazing pasture. Inclusion of aspect is designed to examine; a) differences at the reference site resulting from the micro climate formed as a result of the amount of solar radiation falling upon the different slope aspects; and b) possible effects upon vegetation composition. Landform unit (shown also as hillslope location) was included to investigate if there are any differences between community vegetation compositions at different locations on a hillslope at the reference site and if erosion at the restoration site has caused any major changes along the slope catena. There are various examples of landform classification; the model used here is the Dalrymple et al. (1968) nine unit classification, chosen due to its wide acceptance in New Zealand.

My interest is whether there is significant difference in the soil variables between the convex creep zone (upper slope), mid slope transportational zone, and foot slope (colluvial depositional lower slope). A further question is whether there are correlations with the soil variables, hillslope locations and the vegetation composition? Slope angle may be seen as a factor or a variable. In this analysis it is treated as a covariate of the factors and not a factor as it is a continuous measurement, and used to examine if it influences the dependent variables.

Table 1: Factors and variables measured in this study.

Geomorphic Environmental Factor	**Measurement unit**	**Factor Type**
Site	n/a	Land use
Aspect (generalised as north or south facing)	n/a	Physical
Landform Unit (hillslope location)	n/a	Physical
Slope angle	degrees	Physical
Soil variable		**SQI Type**
Bulk density	mg/cm^3	Physical
Porosity	Vv/V	Physical
Texture	% sand, silt, clay	Physical
pH	pH	Chemical
Olsen soluble P	µg/mL	Chemical
Anaerobic mineralisable N (AMN)	Kg/ha	Biological
Total N	%w/w	Chemical
Total C	%w/w	Chemical
C:N ratio	n/a	Chemical

5. Methodology

The design is a stratified random design where sample points are controlled for site, aspect and landform unit, with the transect start point being of a random nature. Details are shown graphically in Figure 1.

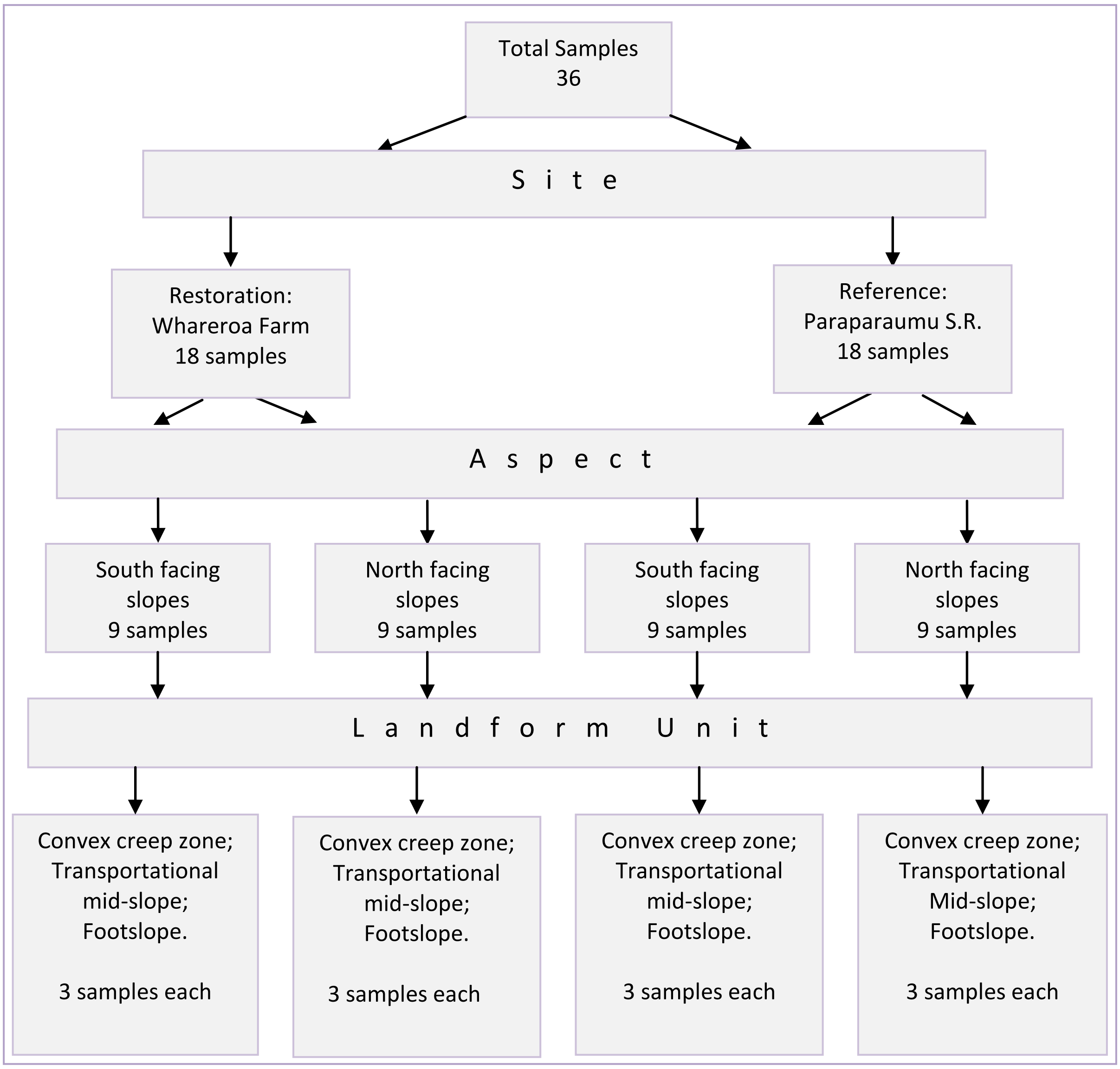

Figure 1: Schematic representation of the experimental design.

5.1 Sampling methods and data collection

Aspect: At each of the sample sites the aspect down the general line of the slope was determined by hand-held compass.

Slope angle: The slope angle was measured by Abney level between sampling points along transects.

Landform unit: Theoretically the landform units were determined by visual inspection and sample sites were spaced widely enough to reduce the effects of spatial autocorrelation, while maintaining the overall objective investigating a small scale sub-catchment. The terrain was such that the certain units were not evident or non existant, for example, the footslope in the steep parts of Paraparaumu did not exist with the slope falling directly into an active narrow fluvial channel. In such cases sample sites were chosen that approximated the footslope but more likely represent an alluvial toe slope.

pH: pH was measured in the field by the water method (Watson and Brown, 1998; Curtis and Childs, 2002) with equal amounts of soil and distilled water mixed in a container for 2 minutes. The mixture was left to stand for 5 minutes, remixed for one minute, left another one minute before being tested with a pH meter. The meter was calibrated prior to use with buffer agent for pH 4 and pH 7.

Soil sample: In the field, a metal cylinder 54 mm in diameter and 60 mm in length which, after removing the organic horizon, was driven into the ground to collect a sample of known volume from 0-100 mm depth. The sample was then wrapped in cling wrap and placed in a sealable plastic bag. From the sides of the hole created by the extraction of the core sample further loose material was collected by hand trowel and placed in a sealable plastic bag. At the end of the day samples were refrigerated at approximately 4° C whilst awaiting laboratory analysis.

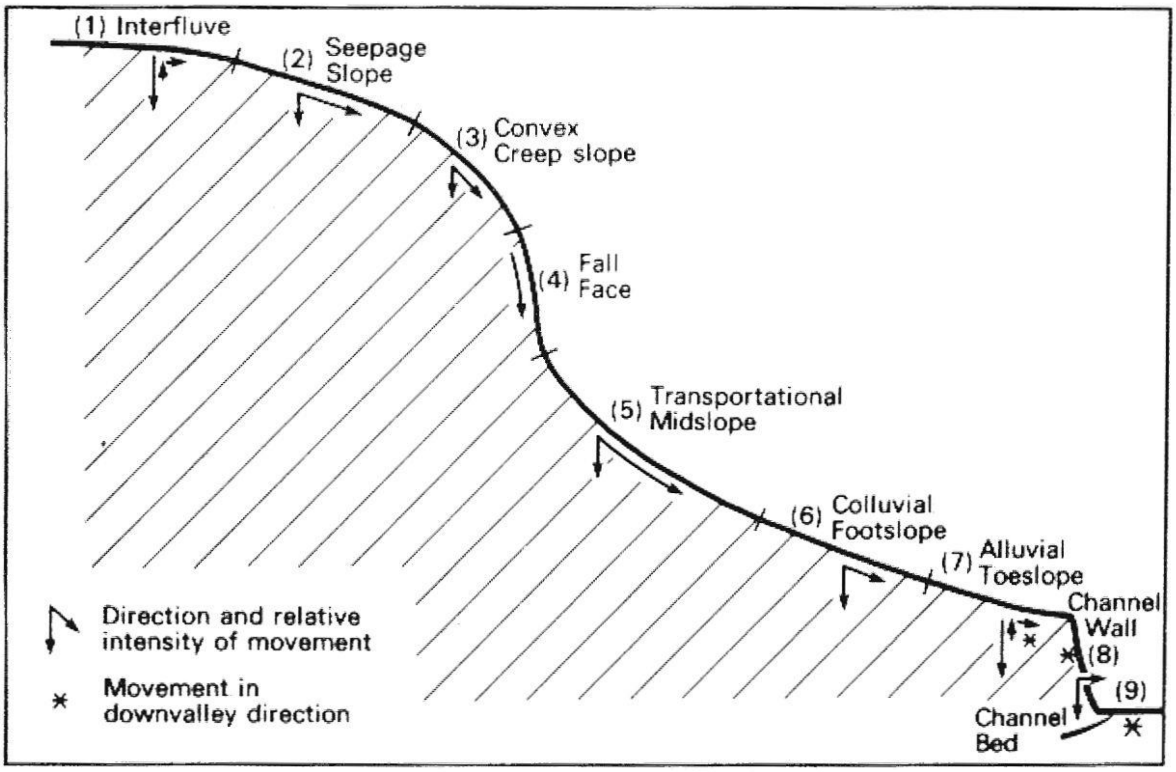

Figure 2: Nine unit landform description (Dalrymple et al., 1968)

5.2 Analysis methods

Bulk Density and Porosity

The analysis was conducted using methodology as per the NZ Standards NZS 4402: 1986 Tests 2.1 and 5.1.3. Briefly, the method involved weighing the moist core, drying the core in a furnace at 105° C for 24 hours, re-weighing the sample to find the dry bulk density, adjusted for the weight of the cylinder. Accounting for the density of water, at a measured temperature, the relative density and specific gravity of the soil was calculated to find the volume of the solid material and consequently the void ratio, and so the porosity measurement.

Texture (Particle Size Analysis)

Texture was measured using the Beckman-Coulter LS230 laser diffraction particle size analyser. The procedure used in this study was to sieve approximately three replicates of 5 gm of soil sample through a 2 mm sieve. The sample was then oven dried at 105°C for 24 hours. Subsequently, the batches of samples were weighed and placed in crucibles before being placed in the furnace set to 400°C to remove the organic matter. The weight of the first batch of samples was checked during the first firing after 4, 5, and 6 hours. Over the time measured there was no decrease in weight so subsequent tests were completed over a time period of six hours. The final method used coincides with Chappell's (1998) recommendations for removal of organic matter from soil samples.

Further sub-sampling was undertaken with an amount of approximately 0.5 g (with 3 replicates per sample) being placed in a mixture of 100 ml deionised water and 3% Calgon deflocculent. The mixture was left to stand for 12-18 hours to ensure the disaggregation of the particles. The wet sample was added to the particle size analyser wet module with the ultrasonic level set to 5 for 90 seconds, to complete disaggregation without fracturing the particles. Measurement of particle size was taken for 90 seconds with the pump speed set to 80. The model was set with a refractive index (RI) of 1.55 and the absorption coefficient (AC) to 0.1. Buurman et al., (2001) states that the RI of 1.56 is valid for quartz, clay minerals and feldspars whilst Campbell (2003) states RI for quartz is best set at 1.544. As greywacke is contains quartz and feldspar RI was set relative to these two suggestions. At times the analyser indicated that the obscuration was too high and so the solution was diluted reducing obscuration to within the window of 12- 20%.

Chemical analysis

The sample gathered at each site was initially prepared before sending to the ARL laboratory for processing. The initial preparation consisted of drying the material for 12 hours at 40°C, sieving through a 2mm sieve mesh prior to placement in pottles and shipment to the laboratory within 7 days. For details of the laboratory methods refer to Appendix 5.1.

5.3 Statistical analysis

Parametric statistical testing is not distribution-free but commonly three assumptions need to be met to validate the results: random sampling (independence in observational designs), constant variance and normal distribution. The last two of these can rarely be achieved in ecological studies (Legendre & Legendre, 1998) therefore alternative methods are required. Consideration of the alternatives to parametric statistical analysis e.g. non parametric alternatives to ANOVA or linear regression resulted in permutational multivariate analysis of variance being utilised.

For this study the freely available software known as Permanova written by Professor M. J. Anderson is used (Anderson, 2005). Permutation tests result in a permutational multivariate analysis of variance where the test statistic is a pseudo F statistic (not Fisher's F-ratio). It shares some similar ties with common ANOVA but differs from parametric methods in that the *P*-value is derived by randomly shuffling individual sampling units across treatments (McArdle and Anderson, 2001). The theory behind the process is that shuffling the results/observations between appropriate labels would not make a difference to the result if the null hypothesis of no difference was true. If there is a significant statistical difference it will be reflected in the *P*-value.

It is pointed out by Anderson (2001, 2001b) that Permanova (a permutation test technique) is not assumption-free, nor is it strictly distribution-free. Anderson states that in multi-factor analysis that Permanova is "semi-parametric" due to the testing of the interaction terms for which there is no non-parametric method. However, given that it relies on permutation to provide the *P*-values it can still be seen as distribution free. Furthermore, Permanova does not require constant variance but can be sensitive to differences amongst groups.

Debate exists regarding the independence assumption, particularly within the confines of a stratified sampling method. Ricotta (2007) and Lájer (2007) assert many ecological studies ignore the requirements of random sampling and that given Tobler's (1970) law of geography is present (all things are interrelated and close things more than distant ones), spatial auto-non-correlation and hence independence will be nearly impossible to achieve. Countering Ricotta and Lajer are Lepš and Šmilauer (2007) who state that Lajer's suggestion of only using exploratory statistics is impractical and that the requirements of independence in observational studies are different to controlled experiments. Legendre (1993) also suggests ways of utilising statistics in the face of spatial autocorrelation. These papers are largely concerned with ecological parameters; however, they also have an impact upon sampling of abiotic parameters. While there would definitely be some relationship between particles of sediment along a slope catena, the episodic nature of the movement of sediment would appear to be sufficient to give enough independence in the study and hence enabling use of more than exploratory statistics.

5.4 Statistical analysis design

The design of the statistical analysis is a 2 x 2 x 3 factorial design, where the factors are fixed and crossed. The 3 factors are Site (land use change indicator, i.e. Whareroa or Paraparaumu), Aspect (i.e. north or south), and Hillslope Location (landform unit). While although only 3 locations on a slope catena are sampled from the nine unit landform system the factor is considered fixed as there is no consideration given to generalise from the ones sampled. Slope angle, while although a factor, is analysed as a covariate because it is a continuous measurement. Interaction tests are automatically produced due to the crossed factor design.

The tests have been performed using raw data without transformation for a number of reasons. Firstly, no outlier is identified using Cook's distance (Cook and Weisber 1982) as having undue influence or leverage, that is, all are well under the significant coefficient of 1. Secondly, use of raw data means that the distance measure between the data points is retained thereby ensuring no loss of detail. Thirdly, although many of the variables do not display normal distribution, tests have shown that transforming the data does not change the significance status of the *P*-value.

Standardisation was performed using z score normalisation. No difference was found between z score normalisation and the outcome using the value divided by standard deviation. Euclidian distance was used as the distance measure as it is generally used for abiotic data in environmental studies (Legendre and Legendre, 1998) as shown in studies presented by Diadema et al. (2004) and Ernst and Rödal (2005). Permutation is performed on the residuals of the reduced model. Whilst not an exact test it is asymptotically exact and gives reliable results (Anderson & Legendre, 1999; Anderson and ter Braak, 2003). Permutation tests using raw data has Type 1 error close to α and does not need a large sample but is not undertaken with the presence of a covariable.

6. Results

Results are presented in tabular form (refer Tables 2 – 4). Table 2 presents results where values from both sites are tested simultaneously. Table 3 details pairwise comparisons where significant results are produced for the Landform Unit (hillslope location) which has three levels. Table 4 displays results from within-site tests. Results are significant where $P<0.05$ and where pairwise comparisons are discussed the *P*-value is the sequential Bonferroni correction value. The *P*-value is taken from the P Perm calculation where the number of unique values is high i.e. >95% or P_MC (Monte Carlo calculation method) where the unique values number is <95% (Anderson, 2005). Summary statistics are included at Appendix 5.3a-f grouped by sites, aspect and hillslope location, boxplots for dependent variables at 5.4a-d, *a posteriori* pairwise comparisons at Appendix 5.6a-c, and interaction plots at Appendix 5.7a-c.

With the landform units (hillslope location), group 1 is the convex creep zone, group 2 is the transportational mid-slope and group 3 is the footslope. With pairwise tests including site factor, group 1 is Whareroa and group 2 is Paraparaumu. With comparisons regarding slope aspect, group 1 is north facing and group 2 south facing. Values in bold indicate significance at the 5% level. The values stated are the permutation *P*-values not the Monte Carlo P as in all tests the number of unique permutations was high (greater than 95% of the 4999 permutations run with each analysis). Texture although it has a significant value pertaining to Landform unit is not shown in pairwise comparisons in Table 3 as it is involved in a significant interaction term.

Table 2: *P*-values from permutational multivariate analysis of variance of the Whareroa and Paraparaumu abiotic data.

	Factor (independent variable)			Covariable	Interaction			
Variable	Site (Si) (land use)	Aspect (As)	Landform unit (Hi)	Slope angle	Si x As	Si x Hi	As x Hi	Si x As x Hi
All	**0.0002**	0.3392	**0.0096**	**0.0002**	0.3384	0.0716	0.1572	0.8364
Bulk Density	0.0776	0.3068	0.1186	0.1350	0.2852	0.7418	0.8302	0.6590
Porosity	**0.0172**	0.1848	0.1618	0.1850	0.2416	0.5372	0.6952	0.6134
Texture	**0.0002**	**0.0236**	**0.0154**	**0.0090**	0.3800	0.3000	**0.0010**	0.6226
pH	**0.0002**	0.2354	**0.0312**	0.9892	0.8640	0.0916	0.8996	0.4418
Olsen P	**0.0032**	0.6246	0.0966	**0.0058**	0.2088	0.3470	0.4558	0.6260
Mineralisable N	0.3118	0.7420	0.2676	**0.0324**	0.4574	**0.0254**	0.9184	0.9898
Total N	**0.0122**	0.8148	0.3020	**0.0012**	0.3210	0.2120	0.4380	0.4972
Total C	0.3552	0.8076	0.2236	**0.0166**	0.3240	0.2346	0.3756	0.2034
C:N ratio	**0.0002**	0.7126	**0.0014**	**0.0002**	0.8986	0.1012	0.9090	0.2414

Table 3: Pairwise comparisons relating to Landform Unit (Hillslope Location) and the variables where significance has been indicated in the overall test and univariate situations.

Variable	Groups	t statistic	*P* Perm.	*P*-Value with Bonferroni Correction
Overall	(1,2)	1.1188	0.2740	0.5480
	(1,3)	1.0620	0.3376	0.3376
	(2,3)	1.6957	**0.0124**	**0.0372**
pH	(1,2)	0.0247	0.9804	0.9804
	(1,3)	2.0620	0.0510	0.1020
	(2,3)	3.5274	**0.0020**	**0.0060**
C:N ratio	(1,2)	0.4018	0.6878	0.6878
	(1,3)	2.2932	**0.0330**	0.0660
	(2,3)	2.2273	**0.0324**	0.0972

Table 4: Permutation Tests *P*-values with sites variables tested separately.

Variable	Site (land use)	Covariable: Slope angle	Factor: Aspect (As)	Factor: Landform unit (Hi)	Interaction: As x Hi
Overall	Wh	0.3538	0.0836	0.0578	0.7604
	Pp	**0.0046**	0.7192	**0.0180**	0.1496
Bulk Density	Wh	0.1880	0.1404	0.7256	0.7780
	Pp	0.1266	0.7432	0.1712	0.7430
Porosity	Wh	0.0778	0.1138	0.7570	0.8224
	Pp	0.1990	0.8038	0.1572	0.5660
Texture	Wh	0.4142	**0.0094**	**0.0024**	0.0814
	Pp	0.6572	0.2730	0.2428	**0.0470**
pH	Wh	0.8560	0.4980	0.4992	0.9128
	Pp	0.9656	0.3944	0.1432	0.9362
Olsen P	Wh	0.5054	0.1514	0.1968	0.4634
	Pp	0.3618	0.1826	**0.0372**	**0.0444**
Mineralisable N	Wh	0.7166	0.4248	0.1330	0.8868
	Pp	**0.0080**	0.8618	0.1794	0.9408
Total N	Wh	0.9428	0.4700	0.2278	0.8250
	Pp	**0.0056**	0.6686	0.4822	0.4020
Total C	Wh	0.7448	0.3686	0.4300	0.5752
	Pp	**0.0080**	0.6208	0.4944	0.2046
C:N ratio	Wh	0.1776	0.4674	0.2320	0.1664
	Pp	0.1384	0.8798	**0.0066**	0.4430

6.1 Overall multivariate test

The results show the factor Site is significant at P<0.0002 (refer Table 2). Landform Unit i.e. hillslope location with P<0.01 also indicated that hillslope location accounted for a significant amount of the variation measured which indicates different conditions amongst the measured units. Given that there are three levels of hillslope location a pairwise comparison revealed that the difference lies in the grouping (2,3) i.e. between mid-slope and footslope, P<0.0372 (Table 3). When the sites are examined separately (Table 4), Landform Unit at Whareroa is (marginally) not significant (P<0.0578) (if the confidence interval was relaxed then the result may have significance), whilst it is significant at Paraparaumu (P<0.0180).

Slope aspect is not a factor with significant variance in the results of the variables measured (Tables 2 and 4). The covariate, slope angle, is highly significant (P < 0.01, Table 2) in the test of all variables considered simultaneously. The variance due to slope angle is accounted for before the tests of the other factors and interactions are conducted. The situation regarding testing within-sites is similar to the hillslope location scenario where slope angle is determined to be a significant contributor to the variation of the measurements of the variables at Paraparaumu but not at Whareroa (Table 4).

Given that the multivariate tests revealed the relative importance of the factors and interactions in the overall test, univariate tests for each of the variables were undertaken and are discussed below.

6.2 Bulk Density

The tests showed that no factor is seen as a significant influence on Bulk Density, regardless of whether the sites are tested independently or not. The factor nearest to a significant result is Site (land use), $P<0.0776$, in the tests of both sites simultaneously (Table 2).

6.3 Porosity

Land use is the one factor that has a significant influence on Porosity ($P<0.0172$, Table 2) and as it has a strong negative correlation with Bulk Density (see Appendix 5.5) it is surprising that both are not in the same category. When each site is tested separately no factor is calculated as significant.

6.4 Texture

Permutation tests for texture used the percent of sand and silt value as determined in the laser diffraction analysis. The third element of texture, clay was not included as the three amounts would have totalled 100 percent and consequently the test algorithm would have malfunctioned. The test for Texture across both sites reveals that there is significant interaction between Aspect and Landform Unit ($P<0.0010$, Table 2). As Landform Unit has 3 levels, pairwise comparisons were tested among levels of Landform Unit within Aspect (Appendix 5.6c). The result showed no significant P-value associated with south facing aspect (level 2) after sequential Bonferroni correction, that is, no difference in texture between the hillslope locations. However, significant interaction was returned between all groups (i.e. (CCZ,MS), (CCZ,FS), and (MS,FS) on the north facing slope (level1). When examining tests among levels (that is, north and south facing slopes) of the factor Aspect within levels of Landform Unit, a significant difference lies in the Footslope (level 3) ($P<0.0024$).

The result for separate Paraparaumu samples shows Aspect by Landform Unit interaction significant ($P<0.0470$, Table 4). The pairwise comparison did not show any significant interaction for the factor Aspect given any of the 3 levels of Hillslope Location, that is, there was no significant interaction given north and south facing aspect and the creep zone, the mid transportational zone or the footslope (see Appendix 6). However, tests among levels of Hillslope Location within levels of Aspect showed within north facing aspect there is significant interaction in the groupings (1,2) ($P<0.0138$), that is, between creep zone and mid slope, and (1,3) ($P<0.0288$) between creep zone and footslope. The result indicates that whilst mid slope and footslope are similar the convex creep zone is different. Level 2 of Aspect (south facing) did not indicate any significant difference between any of the Hillslope Locations.

The results for Whareroa (Table 4) show that Aspect (by itself) was a significant factor in relation to Texture (P<0.0094) as is Hillslope Location (P<0.0180). Pairwise comparisons related to the three different hillslope locations did not, however, indicate differences attributable to any specific pairing (refer Appendix 5.6b).

6.5 pH

The results of the pH analysis (Table 2) showed that Site is significant (P<0.0002), which can be explained by the land use difference. Hillslope Location is significant with P<0.0312. The pairwise comparison (Table 3) shows that the significance lies with the difference in results for the mid-slope/footslope comparison (P<0.0060). The box plot (Appendix 5.4c) graphically illustrates the difference.

6.6 Olsen soluble P

Site is a significant influence (P<0.0032, Table 2) for Olsen P, again, seen as an indicator of the difference in land use and the application of fertiliser to the pasture. Also of significance is Slope Angle (P<0.0058, Table 2).

6.7 Anaerobic Mineralisable N (AMN)

Examining AMN, no main effects are found to be significant, but the covariate slope angle was, and also the interaction term Site by Hillslope location (P<0.0254, Table 2). The pairwise comparison for this interaction (Appendix 5.6a) shows that within levels of Hillslope Location that the footslope has different conditions between Whareroa and Paraparaumu (P<0.0348). Testing among the levels of Hillslope within factor Site, a significant difference between creep zone and mid-slope locations at Whareroa is indicated (P<0.0450). So whilst there is a difference between sites for the footslope, within Whareroa there is a difference between upper and mid-slopes, but not between other groups. These are graphically illustrated below in Figure 3.

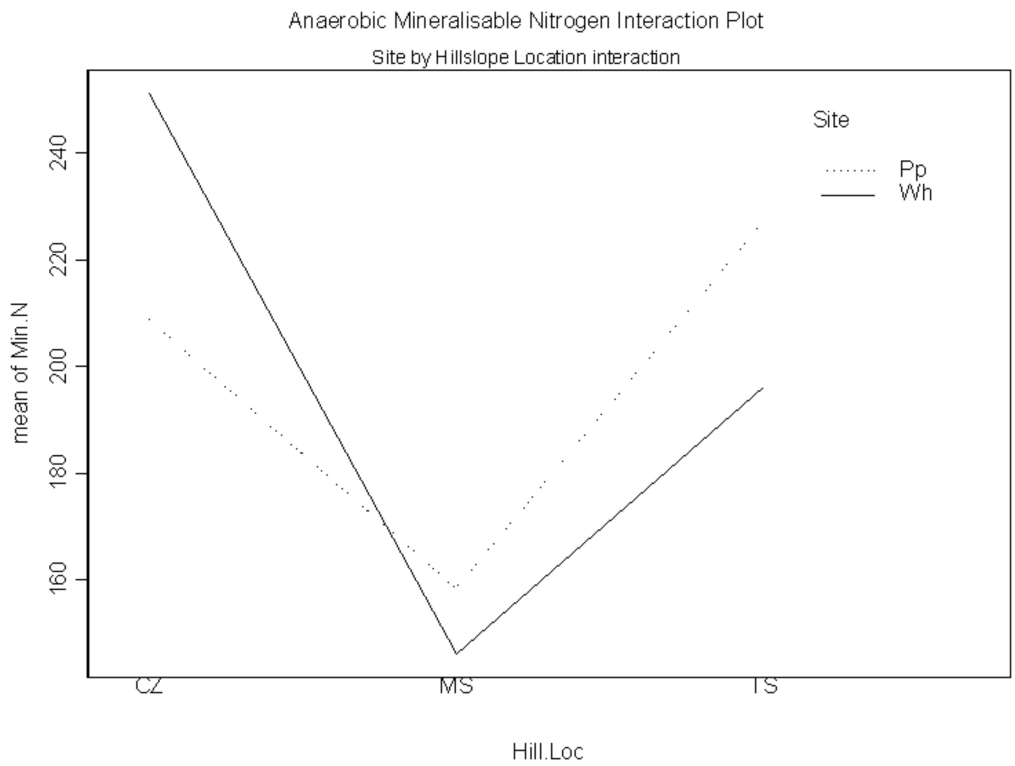

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Figure 3: Interaction plot for Anaerobic Mineralisable N: Tests among levels of Hill Location within levels of Site.

6.8 Total N

The factor Site (land use) was of significance to Total N (P<0.0122, Table 2). The only other factor that is significant is Slope Angle (P<0.0012, Table 2). Slope was also significant with the individual analysis for Paraparaumu (P<0080, Table 4). At Paraparaumu the slope angle is highest on average for the mid-slope and the mean Total N lowest (Appendix 5.4d).

6.9 Total C

The only significant factor of variation regarding Total C is slope angle (P<0.0166). For Total C Site factor was not significant implying there is no effect from land use.

6.10 C:N ratio

While the Site factor is not significant for Total C it is for C:N ratio (P<0.0002, Table 2). Landform Unit (Hillslope Location) is also significant (P<0.0014, Table 2). Pairwise comparisons (Table 3) of Hillslope Location indicated differences between creep zone and mid-slope as well as creep zone and footslope, indicating that the footslope is the place where the conditions differ. However, due to the multiple comparisons when the conservative sequential Bonferroni correction is applied both these levels of significance change to P > 0.05 (Table 3). Testing the sites separately Hillslope Location is indicated as a significant factor at Paraparaumu (P<0.0066, Table 4). *A posteriori* pairwise comparisons revealed that there is a significant difference between the creep zone and footslope ($P<0.0156$) and the mid-slope and footslope locations ($P<0.0188$) (Appendix 5.6b). Both results are shown with Bonferroni correction. The indication is that the footslope is significantly different. The boxplot (Appendix 5.4d) shows that the mean is lowest for the Footslope which may indicate that C is transported out of the system by fluvial action.

7. Discussion

The permutational multivariate analysis of variance shows that the factor Site (proxy for land use change) is significant at which in context means there is a difference between conditions at Whareroa and Paraparaumu, and that land use has a significant effect upon the measured variables. This is the strongest of the differences to be extracted from the data. When the sites are examined separately Landform Unit at Whareroa is (marginally) not significant ($P<0.0578$) (if the confidence interval was relaxed then the result may have significance), whilst it is significant at Paraparaumu ($P<0.0180$). The non-significant result for Whareroa may reflect the impact of increased slope failure producing changes in physical factors. Another cause may be alterations introduced by stock spreading nutrients more evenly over the slope locations and so removing the natural distinctions.

The lack of significance relating to the bulk density results may be due to the fact that land use at Whareroa has been one of extensive stock grazing rather than cropping or intensive animal management, and is a practice with relatively low impact on density, it is explainable.Further comment on bulk density is made in the section relating the measurements to the expected values for a forested soil.

Similarly, the comments relating to Bulk Density apply to Porosity given their correlation. Further, observation at Whareroa is that particularly during late autumn and winter, there is a lot of impact upon the soil by the stock, but given the steepness of the slopes it may be that compaction does not occur. Instead soil is trampled down the slope and the movement of the sediment may mean compaction does not occur. Sampling did not take place at points where stock congregate e.g. fence lines, gates, or night camps and these sites may reveal a different outcome for bulk density and porosity.

The results indicate difference of texture with regards to interaction of Aspect and Landform Unit (hillslope location) which is curious. Ostensibly, the significance of the interaction may be due to the difference in erosion rates on north and south facing slopes (refer Chapter 6), but the fact that only Footslope is different between north and south facing slopes confounds this conclusion somewhat. Also confusing is the fact that the within-site tests found the interaction at Whareroa was not significant. The results of the pairwise comparisons for the sites individually supports the conclusion that there is difference in texture in the hillslope locations tested on the north facing slopes in an undisturbed setting, but not on the south facing slopes. The statistical test was undertaken with clay removed as this was the least abundant of the particle sizes. It may be an improvement could be made by checking the results by removing sand and silt separately and re-running the test.

An explanation regarding the texture results may be that the difference is due to the tight grass sward at Whareroa compared with variable groundcover conditions at the different hillslope locations within Paraparaumu. Additionally, there is an observed difference in levels of mass movement at each of the sites, that is, medium to large translational slides at Whareroa and possibly movement due more to scree and overland wash at Paraparaumu which may explain the results. The analysis of erosion at Whareroa (Chapter 6) found that mass movement was heavily dependent upon slope aspect with north facing slopes the most susceptible. A combination of vegetation cover and slope aspect appears to be the cause of the statistical differences detailed here. This partly relates to the disturbance induced by conversion to pasture and the grazing regime imposed.

The results of the pH analysis can be explained by the land use difference and the hillslope location results may be due to the habits of stock and the concentration and transport of waste affecting soil pH at different locations (Haynes and Williams, 1999). The pairwise comparison (Table 2) shows that the significance lies with the difference in results for the mid-slope/footslope comparison. The box plot (Appendix 5.4c) graphically illustrates the difference, but it is difficult to understand why the mid-slope would be more acid than the creep zone or the footslope. Separate analysis of each site reveals that there is no significant factor for pH, so the main difference is between the sites and due to land-use, which may be significant in a restoration context.

It is a little difficult to understand why slope angle is a significant factor for Olsen P whilst Landform unit (Hillslope Location) is not, but it might be due to slope angle being a continuous variable and landform unit (Hillslope Location) is a categorical variable. The within-site analysis shows no factor is significant at Whareroa which may be due to the spread of manure by stock, though that explanation is the opposite of my remark regarding pH. At Paraparaumu, significance shows in the interaction term Aspect by Hillslope Location ($P<0.0444$, Table 4), that is, the effects are compounded by the combination. However, the measurement that was recorded for PpN12 was five times greater than for any other site sampled at Paraparaumu. A second sample was taken and tested which confirmed the high reading. It is this value which is influencing results and is rather inexplicable so no further analysis is attempted regarding the interaction term. Thus land use and slope angle appear to be the dominant explanation of the difference of Olsen P values found.

It is somewhat perplexing that the MS and TS means for Paraparaumu were higher than for Whareroa in the results for AMN. Possibly it has something to do with sampling only in the top of the soil horizon. The box plot (Appendix 5.4c) for hillslope locations at

Whareroa indicated the mean is lower for the mid-slope than the creep zone which may be a sign that there is an accumulation due to stock congregation on the flatter upper slope (Haynes and Williams, 1999) but once transport begins it moves rapidly off the steep mid slopes but does not accumulate in the swale. The midslope is also more prone to erosion compounding the situation. The result where Site is significant factor explaining Total N is understandable given the practice of adding fertiliser to pasture. Slope angle is also significant and may be explicable in terms of the transport and distribution of solute along a slope. In the separate tests of each site slope angle is not significant for Total N at Whareroa but is at Paraparaumu, which may indicate that the levels at Whareroa are more evenly spread but are not so under undisturbed conditions.

Studies do show that Total C under pasture has a relatively high level (for example, Ghani et al., 2009). In this study it can be seen that although Total C is relatively constant Total N does fluctuate with land use. For each of AMN, Total N and Total C the pattern is similar when viewing the within site analysis. Whilst there is no significant result at Whareroa slope angle is a significant factor for these variables at Paraparaumu. It may be argued that increased erosion and the influence of the stock at Whareroa reduce the natural patterns that are observed at Paraparaumu.

7.1 Relating the statistics to the values expected of indigenous forest

The discussion above relating to statistical significance illuminates part of the picture dealing with relationships between dependent and independent variables. It does not, however, reveal the actual measurements and their relationship with expected values or implications pertaining to practice at the restoration site. Statistically, there are differences between the reference and restoration site. The existence of differences in soil variables related to the Land Use factor, however, does not necessarily imply that land use change is the cause of the changes. The site selection process may have failed to find a complementary site to use as a reference but although the reference site is not a facsimile of the restoration site observationally and according to the LENZ classifications it does appear to be a good choice. The differences do appear to be much as is expected given the removal of indigenous forest and replacement with pasture. Studies that broadly examine these consequences were introduced in the literature review e.g. Dodd and Power, 2007; Smale, 1984; Smale et al., 1997; DeRose et al., 1995; Blaschke, 1998; and Lambert et al., 1984. In the following discussion physical soil variables are examined first followed by the chemical variables. Expected values are detailed in Table 5, page 98.

Considering bulk density, it is noted that for both sites that the measurement is in the upper part of the recommended range of the Land and Soil Monitoring guide (Hill and Sparling, 2009, Table 5) beyond which it begins to be a limiting factor for vegetation. In the guide, measurements in the range 1.2 – 1.4 mg/cm^3 are considered to be compact whilst above 1.4 mg/cm^3 soil is classed as very compact. Examining the summary statistics (Appendix 5.3a, e and f) for each site defined by landform unit, only the creep zone at

Whareroa is higher than the range recommended at 1.38 mg/cm^3. The situation may be because sampling points were within the proximity of a stock camp; alternatively, it could be a result of there being less landslide activity in the upper slope. Porosity is not considered here separately as it is strongly correlated to bulk density.

Makara soil (the soil series that Whareroa samples have been taken from) is defined by Bruce (2000) as usually being silt loam. He describes Ruahine Steepland (the soil which is described as a secondary constituent of the area that samples from Paraparaumu were taken) as being the same. The texture classification that is produced using the United States Department of Agriculture soils calculator (Figure 4) indicates the soil sampled is more of a sandy disposition than silty, with Paraparaumu more so than Whareroa. The details of the permutation tests in relation to texture have already been discussed above. Of consideration here is whether the different finding from the samples indicates a state that is not within the expected range or not. There might be three explanations for the difference between the study findings and the soil expected according to Bruce (2000). One is that the soils class boundaries may not be accurate at the scale of the study. The second is that the USDA calculator may have slightly different parameters for defining texture compared with the analysis given by Bruce. The third possibility may lie in different sampling and testing techniques between those used in the study and those which have informed the soil classes for these locations.

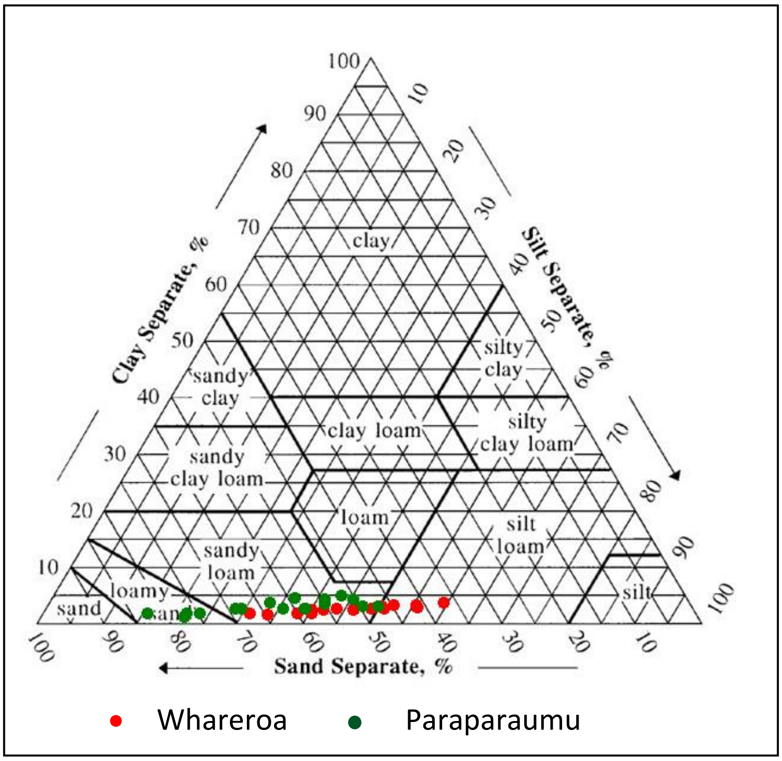

Figure 4: Texture triangle for soil samples from Whareroa and Paraparaumu (using United States Department of Agriculture (USDA) soils calculator).

Table 5: Comparison of measured variables and target ranges recommended in the literature and values from other studies.

Variable	Paraparaumu	Whareroa	Literature
Bulk Density	1.15 mg/cm^3	1.20 mg/cm^3	0.8-1.2 mg/cm^3 range (adequate); 0.7-1.4 mg/cm^3 (critical limits) (Hill and Sparling, 2009) 0.76 Mg m^{-3} (Sparling & Schipper, 2004) 0.84 Mg m^{-3} (Sparling et al., 2000)
pH	6.15	5.7	4-7 (optimal); 3.5-7.6 (critical limits for forestry) (Hill and Sparling, 2009) 5.36 (Sparling & Schipper, 2004) 5.86 (Sparling et al., 2000) 5.2 (Taylor et al., 2010)
Olsen soluble P	5.36 µg/mL (4.66mg/kg)	26 µg/mL (21.67mg/kg)	10-100mg/kg (adequate); 5-100 (critical limits for forestry) (Hill and Sparling, 2009) 11 µg/cm^{-3} (Sparling & Schipper, 2004) 8.9 µg/cm^{-3} (Sparling et al., 2000) 2.4 µg/g^{-1} (0-5 cm depth) (Sparling et al., 1994) 2.0 µg/g^{-1} (5-10 cm depth) (Sparling et al., 1994) 6.6 mg/kg (Taylor, 2010)
Anaerobic Mineral-isable N	198.11kg/ha (264 µg/cm^{-3})	197.83kg/ha (263.8 µg/cm^{-3})	40-120mg/kg (adequate); 20-175mg/kg (critical limit for forestry) (Hill and Sparling, 2009) 100 µg/cm^{-3} (Sparling & Schipper, 2004) 124 µg cm^{-3} (Sparling et al., 2000) 117 mg kg (Taylor et al., 2010)
Total N	0.32 %w/w (3.68 mg/cm^{-3})	0.45 %w/w (5.18 mg/cm^{-3})	0.2-0.6 % w/w (normal); 0.10 and 0.7 (critical limit for forestry) (Hill and Sparling, 2009); 3.48 mg/cm^{-3}(Sparling &Schipper, 2004) 4.39 mg/cm^{-3} (Sparling et al., 2000) 0.21% (0-5 cm depth) (Sparling et al., 1994) 0.11% (5-10 cm depth) Sparling et al., 1994) 0.45% (Taylor, 2010)
Total C	4.11 %w/w (47.27 mg/cm^3)	4.82 %w/w (55.43 mg/cm^3)	3.5-7 %w/w (adequate); <2.5 %w/w = critical limit, all land uses (Hill and Sparling, 2009) 56.5 mg/cm^{-3} (Sparling & Schipper, 2004) 72.3 mg/cm^{-3} (Sparling et al., 2000) 6% (0-5cm depth) (Sparling et al., 1994) 3.8% (5-10 cm depth (Sparling et al., 1994) 8.3% (Taylor, 2010)

Conversions for %w/w to mg cm^3 are shown at Appendix 5.2.

Considering chemical variables, Olsen P showed high values at Whareroa in comparison to that measured in native forest, but was within the optimum range recommended by Hill and Sparling (2009) for production forestry. King and Buckney (2002) in their study examined invasion of exotic plants in nutrient enriched urban bushland. The authors detail means of enrichment including stormwater, sewage overflow, fertiliser from gardens, and pets. The enrichment can be viewed as a disturbance, one which impacts on native species adapted to poor nutrient levels in the soil. Although not attributing the correlation of invasion with phosphorus alone, their ordination reveals that invasion and native community assemblage corresponds with the nutrient gradient including P and N. It seems the high value of P at Whareroa will have an influence on the species planted for restoration. It is also noted that P is a natural limiting factor in indigenous forest.

AMN is higher than the recommended level for a grazing drystock pasture setting (100-150 mg kg). It is also higher than the critical range for forestry (20-175 mg kg).The level is high at both Whareroa and Paraparaumu, and the result for Paraparaumu is odd and difficult to explain. It may be that it is some systemic sampling error, possibly in terms of time taken to have samples delivered to the lab for testing. It is recommended that samples should be in the lab within three days and analysed within one week (Wilde, 2003). Samples in this study were in a refrigerator within 3 days and dried within one week but it was longer than one week before analysis was completed. If the results are valid the impact a high level of plant available N has is uncertain, but with the levels of the chemical much higher than that naturally found in indigenous forest, there may be ramifications for floristic community assemblage.

Concerning Total N, the permutation tests showed a significant difference between Whareroa and Paraparaumu. The statistics show Whareroa having a higher mean than Paraparaumu, that is, Whareroa is 0.45% w/w; whilst at Paraparaumu it is 0.32% w/w. These results are within the bounds of the critical limits given by Hill and Sparling (2009), which are 0.10 and 0.7%, which relates to forestry, but in a production setting. Compared with the results from other indigenous forests the result for Whareroa is high, with the exception being that of Taylor (2010) and his study of Waikato forests. The AMN result is of more relevance as it shows the amount of N immediately available to vegetation.

The finding regarding Total C is consistent with some other studies (e.g. Murty et al., 2002 (in Australia)) that have found no soil carbon loss when forest soils are converted from forest to pasture. Conversely, Schipper et al. (2007) found in a set of seven soil orders in New Zealand that since conversion of scrubland to pasture there has been a decrease in soil carbon. Beets et al. (2002) revealed that in adjoining catchments in the Purukohukohu Experimental Basin near Taupo, New Zealand following conversion of pasture to *Pinus radiata* soil C declined during the first rotation. The measurement, however, is over the whole soil profile with no specific quantification for the 0-100 depth. Whilst important in general, as levels of C are similar in pasture and forest, it is likely that

Total C would not require undue consideration in a restoration project. However, understanding levels of N would be, due to influence upon community composition wherein undesirable species may be advantaged over those species desired, particularly those adapted to low N. The ordination in Chapter 4 helps understand associations between species and levels of soil chemicals.

The management requirements of a farm site will obviously have impacts on soil structure and also nutrient levels. The history of addition of fertiliser at Whareroa is not known. The farm has been operated by various agencies over the period following WWII, and the reversion to scrub of the upper and back slopes indicate that active fertilisation is unlikely to have taken place in the recent past, but the history of the current active farm from which samples have been taken is uncertain. The removal of farm subsidies by the government from the 1980's also played a role in the current situation. The current leaseholder states that it is not economically viable to apply fertiliser with today's market prices. Still, there is a historical legacy as indicated by the nutrient levels which correlates with studies such as Dodd and Power (2007).

Regarding levels of nutrient at Paraparaumu it is possible that although the forest has been a reserve since 1905 impacts from farming may influence the results. An unpublished 1983 report held by DOC details the condition of the reserve and states that due to the condition of the fences that the periphery of the forest was impacted by stock. Thus, extra nutrients may have entered the reserve due to stock excrement, but the quantity at the points where samples were taken is likely to be negligible given the difficult terrain. During my site visits, however, all fences encountered were robust, but the historical effect may remain. While there is no evidence, it may be assumed that drift from aerial topdressing may also have affected the reserve nutrient status. Stevenson (2004) notes the change in P levels in forest fragments in a hill country farm setting.

Other authors have also examined species composition change due to altered nutrient levels in a variety of ecosystems (Tilman, 1984; McLendon and Redente, 1991; Paschke et al., 2000; King and Buckney, 2002; Prober et al., 2002). Dodd and Power (2007) also examine the soil nutrient status, specifically P, which show high levels within retired pasture. They reveal also that Olsen P has reduced over the 20 year period of their study, but that the levels were still high. Stevenson (2004) also points to the distribution of nutrients to a forest fragment by transfer of dung when grazing is not excluded. The simple fact here is that the N and P measured here show larger quantities at Whareroa than Paraparaumu and this is likely to have consequences in relation to restoration.

Studies comparing succession through gorse to succession through native species, for example, kanuka, illustrate how soil nutrients can influence the successional trajectory (Sullivan et al., 2007; Lee et al., 1986). If restoration has an objective of floristic composition approximating an undisturbed reference site it would seem that nutrient levels which are outside the range of natural soils may need to be adjusted. In many situations action may be difficult, so active intervention to introduce the required species may be required after a given period of time when conditions have naturally altered. As some native species have a symbiosis with mycorrhizal fungi, helping with the uptake of nutrients in poor soils, high or low levels of phosphorus may inhibit the activity of these fungi (Amijee et al., 1989; Koide & Li, 1990). Another aspect is the function mycorrhizal fungi symbiosis has with roots upon the soil structure, in particular bulk density and porosity (Milleret et al., 2009). It is noted that addition of slow release fertiliser is carried out by some restoration practitioners when planting seedlings to aid in successful establishment and early growth. Such fertilisation in a farm setting may be a topic that requires some investigation to understand the benefits or drawbacks of the activity.

8. Conclusion

What is noteworthy here is that there are quantifiable and significant differences in relation to the soil parameters between a (relatively) undisturbed reference site and a restoration site. Whareroa displays much higher levels of Olsen P, Mineralisable N, Total N, whilst the C:N ratio and pH is lower than expected values for an indigenous forest. Whether these measurements are such that they display a level consistent with an altered stable state is unknown, but unlikely. It is more likely that with the removal of grazers and cessation of fertiliser additions that the chemical nature of the soil would slowly revert to a natural condition (Kirschbaum et al., 2008), but reversion is expected to take decades. The nature of the physiography is such that the steep slopes would see runoff carry some nutrient away.

However, as has been discussed, the alteration of the soil chemistry does influence the successional trajectory and so it may be that some intervention is required to guide succession in a desirable way. Action may include an ongoing periodic disturbance regime to interject desirable species amongst those that are undesirable but have dominated. Regarding the physical properties, in particular bulk density, the compaction at the restoration site was higher but not so extreme as to limit growth. The results for the north facing convex creep zone were near the critical point and this condition may need attention if active restoration was to be undertaken.

Returning to the central question of the chapter, using the methods outlined here the results show that elements of the soil can be identified that may require mitigation prior to biological restoration taking place. The results did not produce unexpected outcomes but quantifying the soil variables gives confidence to make specific decisions in a restoration plan, rather than making assumptions. For small community based projects the methods used may not be appropriate or necessary (though in most cases it would be beneficial). For larger scale projects, where land is being retired and active restoration employed, the cost of implementing this or similar processes would be minimal compared to the overall cost of such a scheme and would seem beneficial.

Chapter 6. Geomorphic analysis: Processes and form

1. Introduction

What imprint of land use change can be interpreted in the landscape? Change realised in the aftermath of the destruction of vegetation is immediately apparent; also that that signified by fresh landslide scars. What is less obvious in most circumstances is the change in the coarse architecture of the landscape, often masked by a longer time scale (Phillips, 1995). Occasionally there are events, such as a large storm, that produce a visual manifestation of the change with the production of multiple landslides, and these are pointers of this structural change. Usually, much change is unseen, unrecognised, or at best partially perceived. With the removal of the added cohesion provided by vegetation the geomorphological process of change may be accelerated. Viles (1988) and Thornes (1990) supply theoretical discussion on the influence of vegetation whilst DeRose et al. (1993) provide evidence of the effects of vegetation geomorphic processes on a catchment scale.

Disturbance is a natural phenomenon in the normal state of affairs and due to climate cycles the degree of vegetation cover of the landscape has been, and always will be, in a state of flux; a dynamic equilibrium (Strahler, 1952; Chorley, 1962). Compared to changes over geological time scales, human induced disturbance is not "natural" and given the impact disturbance has upon diversity, needs addressing where possible. While the emphasis of this chapter is to examine the catchment scale ramifications on geomorphology due to forest removal it is also recognised that other imprints of human activity exist, for example, through the alteration of chemical and physical soil parameters. Soil nutrients have been addressed in Chapters 4 and 5 and will be revisited in Chapter 7. The focus of this chapter is not to compare geomorphic process differences between reference and restoration site, but to examine processes at a disturbed site by mapping and analysing an historical erosion chronosequence and consider the connectivity of the slopes to the swales. The central interest in this section is captured in the question:

What are the means of interpreting geomorphological change in a disturbed environment and can they be usefully utilised in a restoration context?

2. Background

2.1 History shaping the future

The Davisian (Davis, 1909) interpretation of historical geography does not need to be divorced from the geomorphic process landform relationships and quantitative study as presented by those such as Strahler (1952), Chorley (1962) or Hack (1960). In fact, it is essential to consider these two differing outlooks simultaneously to gain a holistic and full understanding (see Preston et al., 2011). At Whareroa the history is reflected in the differential areas of loess deposits and its influence on the steepness and roundness of the topography. It can be found in the coalescing colluvial outwash fan, and the alluvial terrace. It can be seen in the incision of the fan by the fluvial systems exiting the slopes, and the escarpment of the Te Ramaroa fan, an artifact of the last sea-level high-stand c6500 years ago (Hawke and McConchie, 2006; Te Punga, 1962). Consideration of the processes involved in this historical setting may be understood given the differing timescales invoked in the differing outlooks. A discussion related to temporal settings and geomorphic processes presented by de Boer (1992) argues that the processes that are of significance on the large scale may not be as crucial on a small scale where instantaneous processes are of interest.

The anthropogenic removal of vegetation may have induced processes akin to those present at the time of post-glacial climate warming, when colluvium was transported from the slopes, although at different rates. As the forest re-cloaked the land, the depth of soils on the slopes would have increased and influenced the containment of sediment within the gully systems. The relationship between slope angle and soil depth would have adjusted in the presence of the added cohesion afforded by the root system of the forest vegetation (Marden et al., 2005; Blaschke, 1988). With sudden removal of forest and replacement with pasture there would have been an increase in slope failure due to the threshold angle of repose for slope stability being surpassed. Brooks et al. (1995) examine the links between climate, vegetation and pedogenesis and rates of erosion. Hence, the new conditions begin to reshape the land once more. With the activation of the product of past processes and conditions the future is being established (at least the medium term timescale). It is the feedback of processes and states induced by land use change that is of interest in this section of the study, bringing with it elements of Davis' (1909) and Gilbert's (1909) understanding.

2.2 Geomorphic dynamics and stable states: Process/form relationships

A brief foray into the theory of geomorphic dynamics and stable states is required to background the principles regarding whether land use change has caused irreparable or irreversible damage to the physical state of Whareroa. Ahnert (1987) looked at process-landform relationships attempting to bring together the different temporal scales of the process element and the landscape pattern in an open system framework. A stable state is described by Ahnert (1994) as one where constant process-form relationships (Ahnert, 1994) infer equilibrium and hence stable landscapes. In this case change in form is within the confines of the normal dynamic range (or dynamic equilibrium) of the processes operating at that time. An alternative perspective is offered by Schumm and Lichty (1965) where, given differing time scales, the landscape may be in differing stable states and equilibria; a sense of the meaning is conveyed in Figure 1. The bottom left illustration indicates that periods of sudden change of equilibrium (dynamic metastable equilibrium) are interspersed with times of dynamic equilibrium.

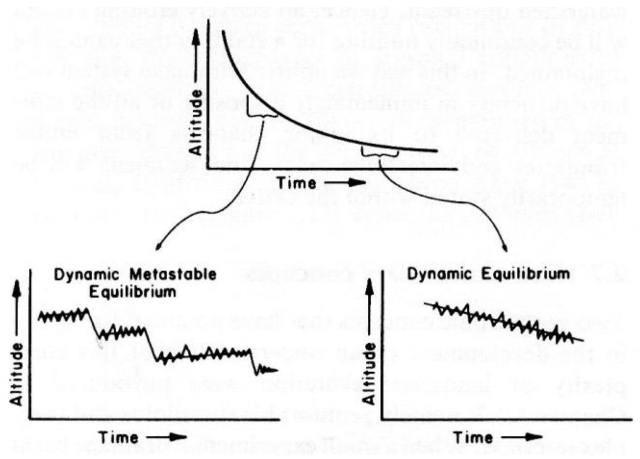

Figure 1: Equilibria and stable states as presented by Schumm and Lichty (1965).

Brunsden and Thornes (1979) look at the question similarly, but from the angle of sensitivity of the landscape, and produced the concept of a transient form ratio to describe the state of the landform (Figure 2).

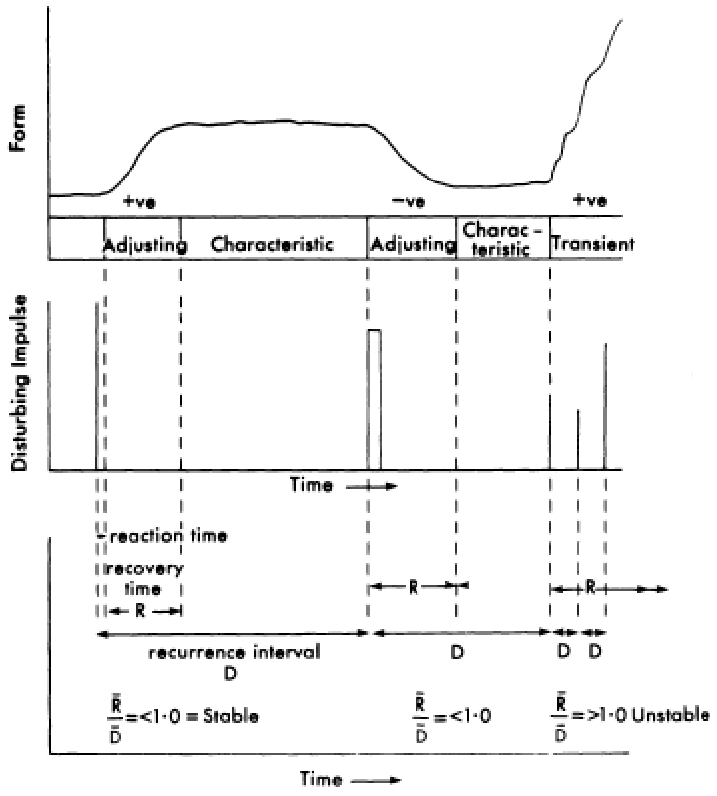

Figure 2: Graphical representation of transient form ratio and relative description of the state of the landscape (Brunsden and Thornes, 1979).

The transient period in Figure 2 is akin to dynamic metastable equilibrium. The graphical representation of Brunsden and Thorne's model also alludes to the unstable nature of the recovery and how it is not a smooth response but is quite unstable. This element is discussed by Crozier and Preston (1999), and termed the relaxation period, who present a model to illustrate the process (refer to Figure 3).

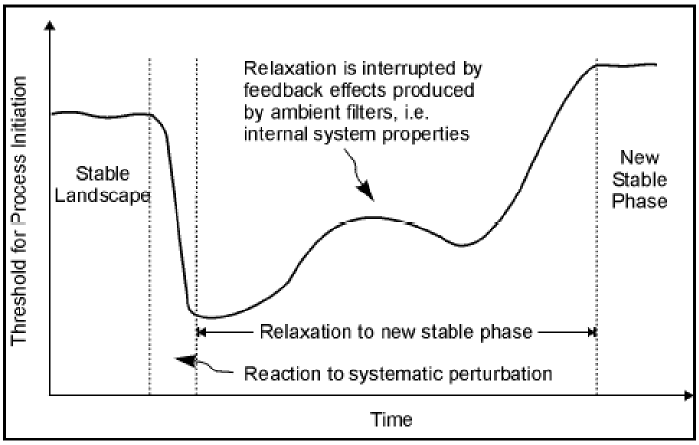

Figure 3: Graphical representation of the system response to perturbation (Crozier and Preston, 1999).

The frequency and magnitude concepts as discussed by Wolman and Miller (1960) and the relative work done by events of differing magnitude are also of significance when looking at the effects of removal of vegetation. Wolman and Gerson (1978) expand the concept and conclude that most work is done by a particular frequency of events of a moderate scale rather than large infrequent events in the long term. The above discussion does not encapsulate all of the key theories in relation to the concept of equilibria, stable states and perturbation, nor the debate about the veracity of the models. It is, however, a brief outline of some of the important elements in relation to the response of landforms and processes at Whareroa following the removal of vegetation.

2.3 Landscape evolution and consequences for ecological restoration

The above discussion leads to the question; in what state is Whareroa and have the conditions been altered beyond a threshold that has changed the equilibria at the site? Does the deforestation of the land increase the speed of a cycle within a stable state where the magnitude of the perturbation is still within historic thresholds; or is the level of perturbation causing the landscape to find an altered stable state? Looking at the evidence, are there signs of the evolution to a state which is stuck in the cycle of degradation? Hobbs and Harris (2001) examine the possibility of changed states and look to occasions when states may have changed due to thresholds being surpassed and implications for restoration activity. Figure 4 (reproduced again to help with the flow of the narrative) provides a clear graphical explanation combining responses related to changed conditions for both abiotic and biotic conditions. The Brierley and Fryirs (2000, 2005) method for assessment of restoration priorities and trajectories considers the intactness of the catchment in a similar way.

Selby (1993) discusses landscape evolution along with frequency and magnitude of extreme events and the effects that they have on the ongoing evolution of the small catchments. In such circumstances much sediment is not lost from the system through fluvial transport but is stored in depositional zones within the catchment (Preston et al., 2003). This has implications for landscape evolution. What may be more pertinent though is the frequency magnitude equation, given the apparent increase in erosion following deforestation. These factors and processes are background to the analysis and are implicit through the mapping of historic landslides.

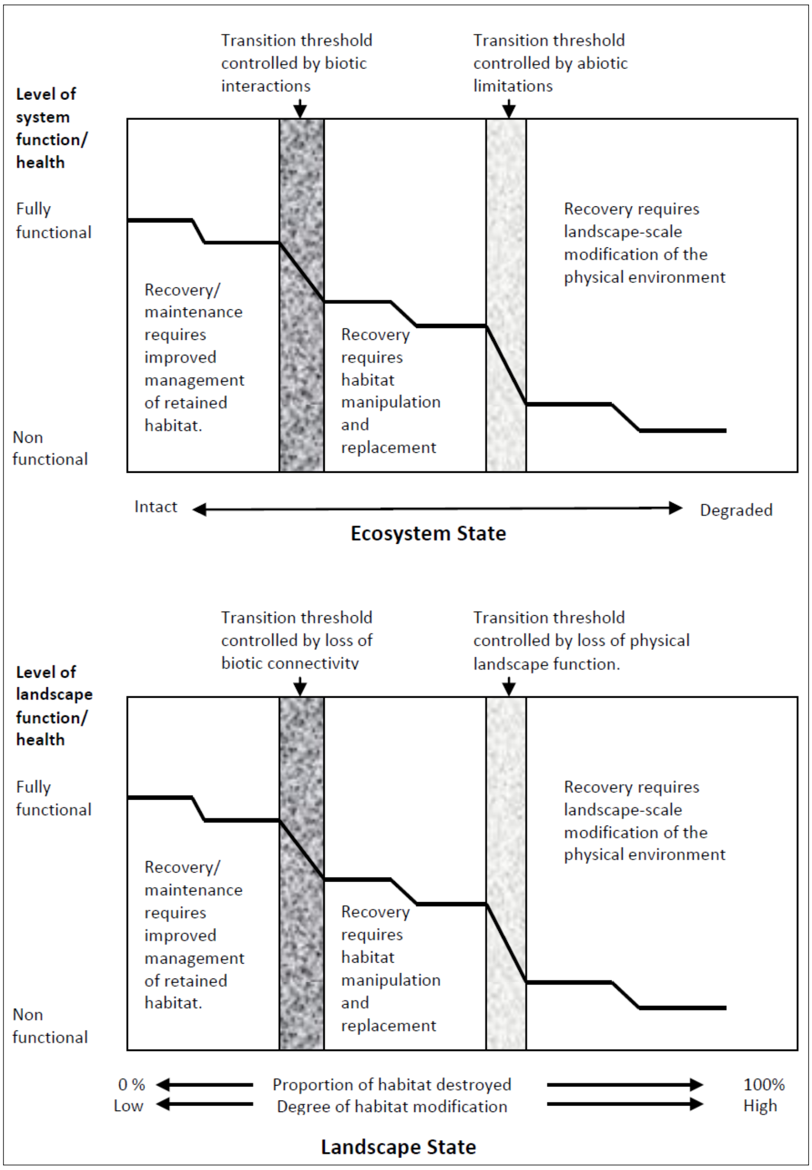

Figure 4: Biotic and abiotic thresholds at the ecosystem scale and the landscape scale with appropriate response action (redrawn from Hobbs and Harris, 2001).

3. Means of geomorphic assessment: A methodology relating to a 70 year chronosequence of mapped mass movement

The means of geomorphological assessment outlined in the following sections are:

1) Examining the pattern of mass movement over the past 70 years by mapping instances discernable in aerial photography (a chronosequence);
2) Analysing the occurrence of mass movement and its spatial relationship with;
    a. Prior mass movement,
    b. Slope aspect,
    c. Slope angle;
3) Examining the connectivity of slopes with the swale;
4) Investigating the erosion risk within the sub-catchment.

Using these analyses, combined with knowledge of the soil and abiotic factors outlined in Chapter 5, provides a means to make inferences regarding whether critical thresholds have been exceeded and consequently whether a (degraded) new stable state has been established. This process also gives insight regarding landscape evolution. With such information available, it is possible to make decisions regarding the prioritisation and potential effectiveness of restoration.

4 Historical erosion patterns; mapping the recent past at Whareroa Farm

4.1 Slope Failure Chronosequence

Aerial photos of Whareroa for the years 1942, 1952, 1962, 1977, 1988, 1998, 2002, and 2010 were obtained for analysis. The quality of the 1977 and 1998 photos was not good enough to be able to interpret mass movement clearly. Therefore, the analysis has been performed on the balance of six images. The 2002 image was received already orthorectified and so was used as the control photo to georeference the other photos. This process has been undertaken using the ESRI software ArcGIS. Georeferencing was required in order to locate the images in the same space as each other, according to spatial coordinates within the same projection system, which enables quantitative comparisons. Potential difficulties may be due to; 1) distortion, and 2) displacement (Paine and Kiser, 2003). Images produced at different times and taken from different locations of the same scene will have different qualities and factors affecting their faithfulness to the actual area and each other.

Ground control points were manually identified on each georeferenced image and matched to the same point on each of the other images. The process was complicated by the difficulty in identifying visible landmarks and matching them between images of varying resolution and quality. Another source of error arises in the transformation of each target photo to sit in the same space as the control photo. The ESRI ArcGIS software has a number of options for transforming the digital image of the photo. The appropriate choice depends on 1) the image quality and resolution, 2) the distortions introduced in the spatial extent during the original capture of the image and 3) the effect of the type of transformation- each warps or stretches the image in a different manner which in turn affects the accuracy of the alignment. For example, some transformations attempt to minimise errors near the control and target points, some preserve straight lines, others attempt to limit errors over the full spatial extent of the images.

As the intent was to map fine scale and precise representations of the erosion over a chronosequence of the same spatial location it was necessary to have reasonable accuracy at both the local and global scale. The areas of erosion were not used as points and so accuracy for space distant from the control/target points was required. Consequently, the adjust transformation was chosen. ESRI states "the adjust transformation optimizes for both global LSF and local accuracy. It is built on an algorithm that combines a polynomial transformation and triangulated irregular network (TIN) interpolation techniques". This adjust transformation requires a minimum of three control points. Approximately fifty points were matched in most cases. Points were clustered mostly near the part of the image that required best fit, i.e. the study catchment, and broadly, Whareroa Farm. Due to the factors identified above there is some degree of uncertainty related to the georeferencing. Specifically, the photo quality was problematic due to scale, graininess and lack of definitive points or markers that could be confidently identified across the series of photos. However, the degree of accuracy generally appeared to be within a metre.

4.2 Analysis of spatial relationship of mass movement

The georeferenced aerial photos were examined individually and the ArcGIS Editor tool used to digitise the perimeters of erosion for each year separately, thereby creating a multi part polygon layer. With each aerial photo the first task was to digitise erosion that had not been identified in the previous year's photo but which was not fresh mass movement, that is, it was visually evident but the ground was no longer bare. These were digitised and saved as a layer. Subsequent digitisation of fresh mass movement was undertaken as a separate layer. This digitisation enabled mapping of a chronosequence of erosion occurring between each pair of aerial photo dates. Once all aerial photos were completed the separate layers were added to a single map and merged into a single layer which allowed further analysis in conjunction with surface layers from a digital elevation model (DEM).

4.3 Spatial relationship of new mass movement with prior mass movement

The relationship of mass movement to previous locations of mass movement was analysed. This was completed by selecting by location where polygons from each successive period intersected a mass movement identified in a previous year. A buffer of 1.5 m was added to allow for any inconsistencies in the geoprocessing and georeferencing. Statistics pertaining to the year were extracted from the results of the above operations for the overall counts of mass movement, overall area of new mass movement, and also the amount of mass movement relative to the area of each class.

4.4 Spatial relationships between mass movement and the slope aspect and angle

ArcGIS analysis of the relationships was completed using the aerial images detailed above and also a digital elevation model extracted from the national DEM. The DEM has a resolution of 25 m pixels. The DEM was masked to the cadastral boundary of Whareroa Farm to reduce processing time. Subsequently, the symbology tool within the layer properties (accessed by clicking on the layer in the Table of Contents), was used to produce a slope layer with six classes. These classes are 0 – 7, 7.01 – 18, 18.01 – 28, 28.01 – 32, 32.01 – 42, > 42 degrees. These classes were chosen with regard to critical slope angles found to be of significance concerning mass movement with greywacke substrate (Dymond et al., 2006; DeRose et al., 1993). An aspect layer was also created from the DEM; refer to Table 1 for classification.

Table 1: Slope aspect class

Aspect	Degrees	Reclass. Value
Flat	-1	0
North	0 – 22.5	1
Northeast	22.5 – 67.5	2
East	67.5 – 112.5	3
Southeast	112.5 – 157.5	4
South	157 – 202.5	5
Southwest	202.5 – 247.5	6
West	247.5 – 292.5	7
Northwest	292.5 – 337.5	8
North	337.5 – 360	1

To explore the spatial relationships the aspect and slope angle layers derived from the 25 m DEM were reclassified into classes with specific discrete values. The reclassified value for aspect is shown in the third column of Table 1. Subsequently, they were converted from raster format to vector shapefiles and, next, each separate class was selected by attribute using the selection menu and saved as a separate layer. This action allowed the merged erosion layer to be selected by location where the centroid intersected each of the classes of slope and aspect. From the resultant selection statistics could be extracted and analysed.

To discover the relationships when slope angle and aspect are analysed simultaneously a new set of re-classifications was undertaken for both layers. With an understanding of the separate analyses gained from the first phase of analysis the slope angle classes were modified as follows: 0 – 7 and 7.01 – 18 were given the value of 10, 18.01 – 28 was reclassified as 20, 28.01 – 32 reclassified as 30, and slope angle above 32 was given the value of 40. The new aspect and slope layers were then summed using the Plus tool in the Math toolset of the Spatial Analyst extension. This action results in a distinct value for each slope/angle aspect class with which a more detailed analysis can be undertaken (see Figure 8).

4.5 Considering connectivity of slopes to the fluvial system

DEMs can be utilised to understand the level of hydrological connectivity of the slopes to the fluvial channel and hence the impact of sediment from slope failure upon the riparian zone. The scale of the national DEM produces a twenty five metre pixel. To obtain an understanding at the scale of small zero order basins the 25 metre resolution is too coarse. To address the problem a fine scale DEM was created from data personally collected at the site. The creation consisted of walking approximately parallel lines one metre apart across the slopes of a chosen part of the gully system with a hand held Trimble Geographic Positioning System (GPS) device. The data collected consists of x, y and z coordinates for each one metre travelled and gives an elevation datum for each point recorded (see appendix 6.0 for a map of the points). Due to New Zealand's global position, satellite geometry was sometimes less than optimal and signals were periodically lost. The microtopography also caused signals to be lost occasionally. A summary of the precision for the points provided by the device shows that the lateral position error average to be 0.120 m and for the vertical point the average error to be 0.059 m.

The data from the GPS was downloaded as points into ArcGIS. DEMs were created using the Inverse Distance Weighting (IDW) interpolation method with a power setting of 0.5. Four DEMs with different resolutions were created, that is, 0.5 m, 1 m, 2 m, and 5 m. Root mean square errors for all were ≈ 0.3 m. Subsequently, hillshade, slope, and aspect layers were produced for use in the analysis. From the ArcGIS Toolbox the Toolkit for hydrology was used to obtain the flow accumulation over the DEM after any sinks (pixels with no outlet) were filled. The algorithm tracks the path of convergence of overland flow across the DEM by examining each pixel and calculating the relationship based on the elevation data. With a flow layer created, a flow accumulation map can be produced to analyse the degree of connectivity and the location of barriers, buffers or blankets that may reduce the connectivity.

4.6 Erosion risk analysis

The preceding mass movement chronosequence analysis will provide pointers regarding the location where erosion has occurred in the past and judgements may be made given this information regarding the susceptibility of future erosion. The information comes as a group of discrete elements that we need to view separately and interpret to make prognoses. Over a long period of time there have been models produced to map erosion and quantify soil loss. The Universal Soil Loss Equation is an example which has been incorporated into a GIS environment (for example, Gitas et al., 2009; Shi, 2002) to analyse erosion. Other models are discussed in the literature review.

A method that is contained in a Toolbox that operates in an ESRI ArcGIS environment is Polyscape (Jackson et al., in review). Polyscape is a land management toolkit containing multiple tools with which to map, investigate, analyse and manage landscapes. Embedded in Polyscape is the Compound Topographic Index (CTI) (Thorne et al.,1986) which takes into account the erosive potential of three factors; overland flow magnitude, slope, and overland flow concentration. A formal definition is:

CTI = A˙ S˙ PLANC

Where A = upslope drainage area (m^2) (after sink areas have been accounted for); S = local slope (m/m); and PLANC = planform curvature (1/100 m). A acts as surrogate for overland flow magnitude and upslope drainage as they have been seen to be correlated. PLANC is a measure of landscape convergence and hence overland flow concentration.

The CTI has been utilised in this study as it operates in a known GIS environment with a user friendly interface with which to input the data. Polyscape script co-opts separate algorithms within ArcGIS, for example flow direction and accumulation, and slope angle calculations amongst others, and also introduces CTI into an integrated package. CTI incorporates default parameters (based on European conditions) that relate to geomorphic processes intrinsic in water flow and sediment entrainment as defined above. The output, amongst other information, is an erosion risk layer that provides classes corresponding to high, medium or low risk of erosion.

In the CTI erosion tool there is opportunity for user input via the minimum and maximum values in separate fields. The values entered are an arbitrary integer, with the defaults being 2 for the minimum and 5 for the maximum. Besides using the default setting two other sets using alternative CTI in relation to the 2 m pixel DEM were run i.e. 500 minimum, 1000 maximum; and 2000 minimum, 10000 maximum. Additionally, DEM's of 0.5 m, 1 m, 2 m, and 5 m were used, to examine the usefulness of fine scale DEM's in a restoration context.

5. Results

Figures 5a and 5b show the composite view with the polygons colour coded for each separate year mapped. The digitised map of erosion for each of the aerial photos can be found at appendices 6.5a – 6.5g. For the 1942 photo the imprint of mass movement which are no longer bare are identified with the prefix 'pre'. The same prefix was used for the 1952 aerial where imprints of mass movement not coinciding with an observed scar on the previous aerial map were identified. With intervals between photos usually being ten years or greater it is likely that these are instances of mass movement that happened early in the interval where vegetation had recovered. Some of these sites are unlikely to be identified. The maps with slope aspect and slope angle along with the digitised mass movement sites are at Appendix 6.6.

Figure 8 shows a map of the combined aspect and slope layer. Histograms that are derived from the data of the intersection of the mass movement and the DEM layers are shown in Figures 6, 7 & 9. These show that there is no strong trend indicating more mass movement assocated with previous mass movement. The histograms relating to slope angle show that there is a threshold at 18° after which the susceptibility is relatively constant up to 42°. Regarding slope aspect the results show that mass movement is more prevalent from the west sector around to the north-east sector. Maps of flow accumulation and erosion risk as produced by Polyscape are also presented in Figures 10 a-h and Figure 11. These illustrate the information with different levels of resolution. A set of comparisons of using different input CTI parameters is produced (Figure 12) to investigate their effects on the output. The flow path maps give a clear indication of the likely path of overland flow in rain events through this zero order basin. The maps of erosion risk do not provide a clear picture of risk using the input parameters at the scales used.

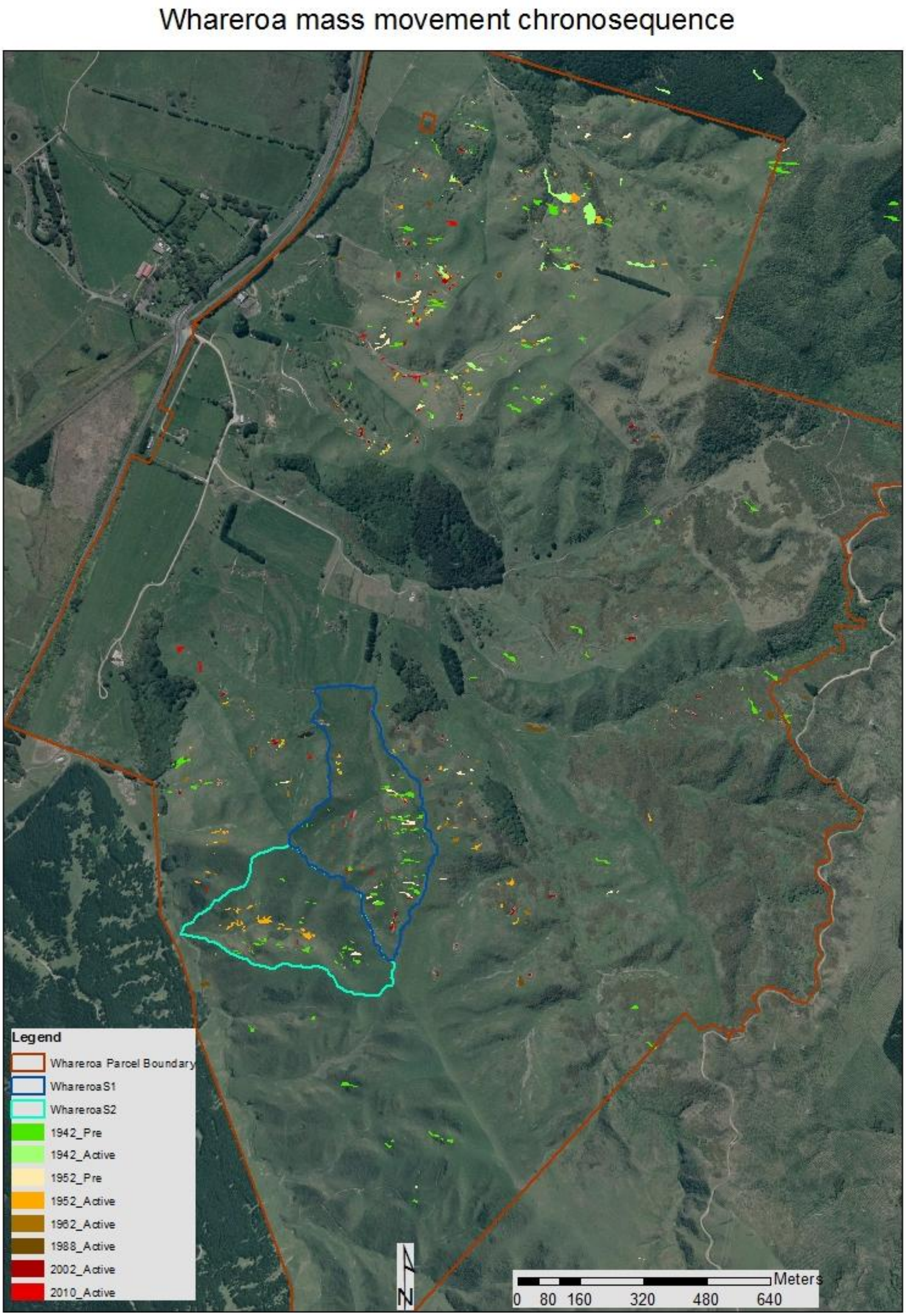

Figure 5a: Chronosequence of mass movement for the whole area of Whareroa Farm, from aerial photos for periods 1942, 1952, 1962, 1988, 2002, and 2010, including the sub-catchments from which soil samples were taken at Whareroa Farm.

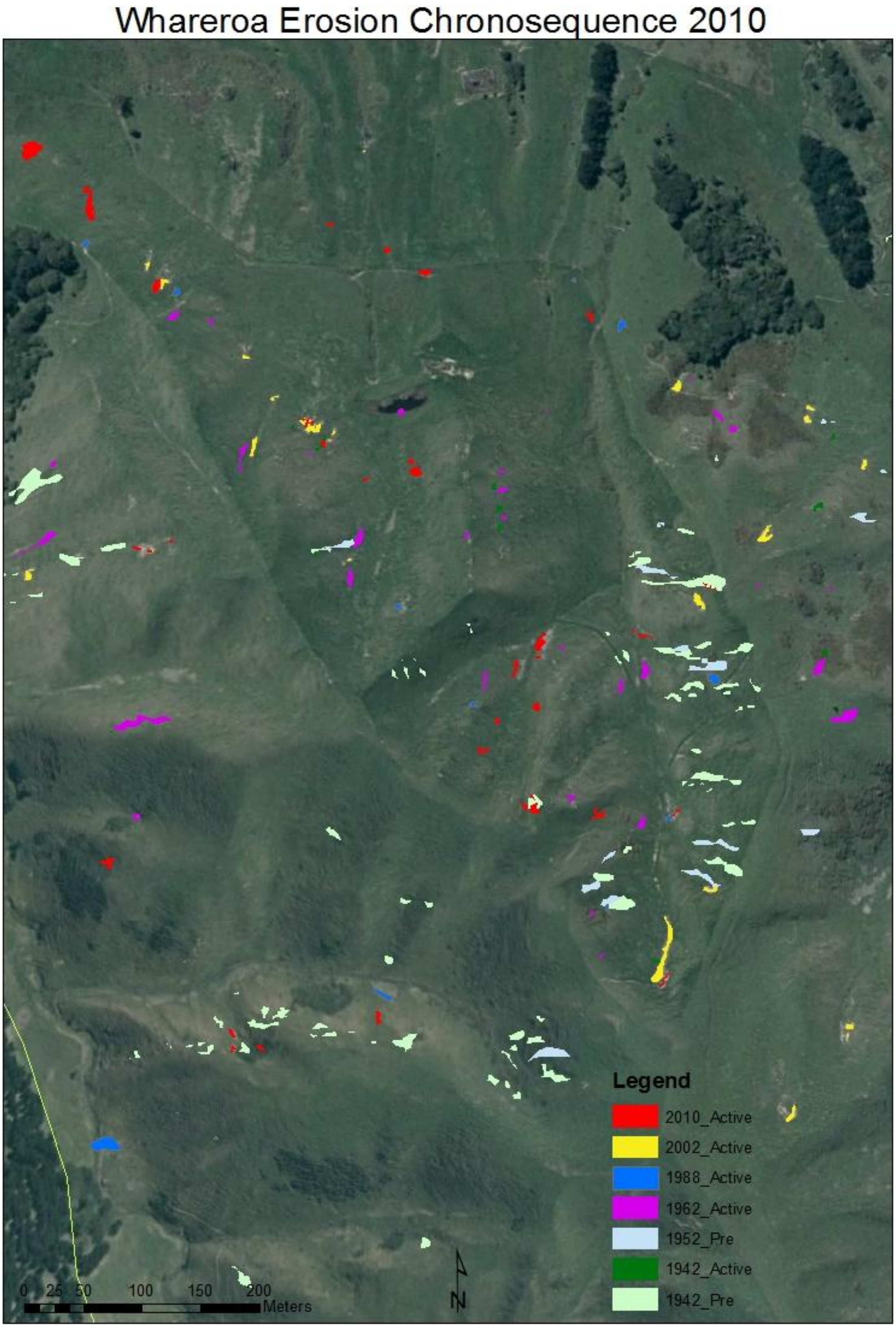

Figure 5b: Mass movement mapped from aerial photos for periods 1942, 1952, 1962, 1988, 2002, and 2010, showing the sub-catchments from which soil samples were taken at Whareroa Farm.

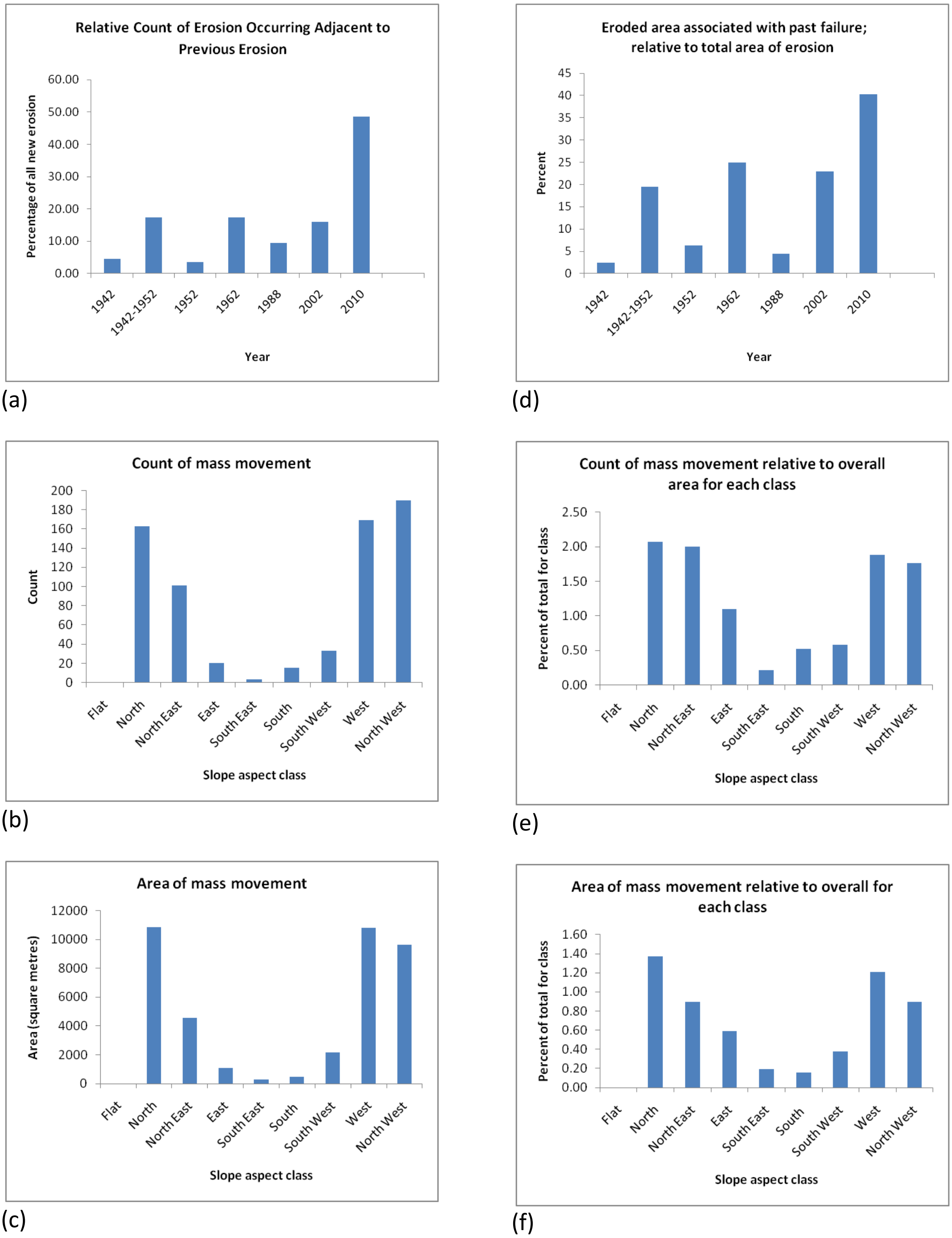

Figure 6: (a) & (d) Mass movement associated with previous mass movement sites; (b) & (e) counts of mass movement per slope aspect class; (c) & (f) area of mass movement per slope aspect class.

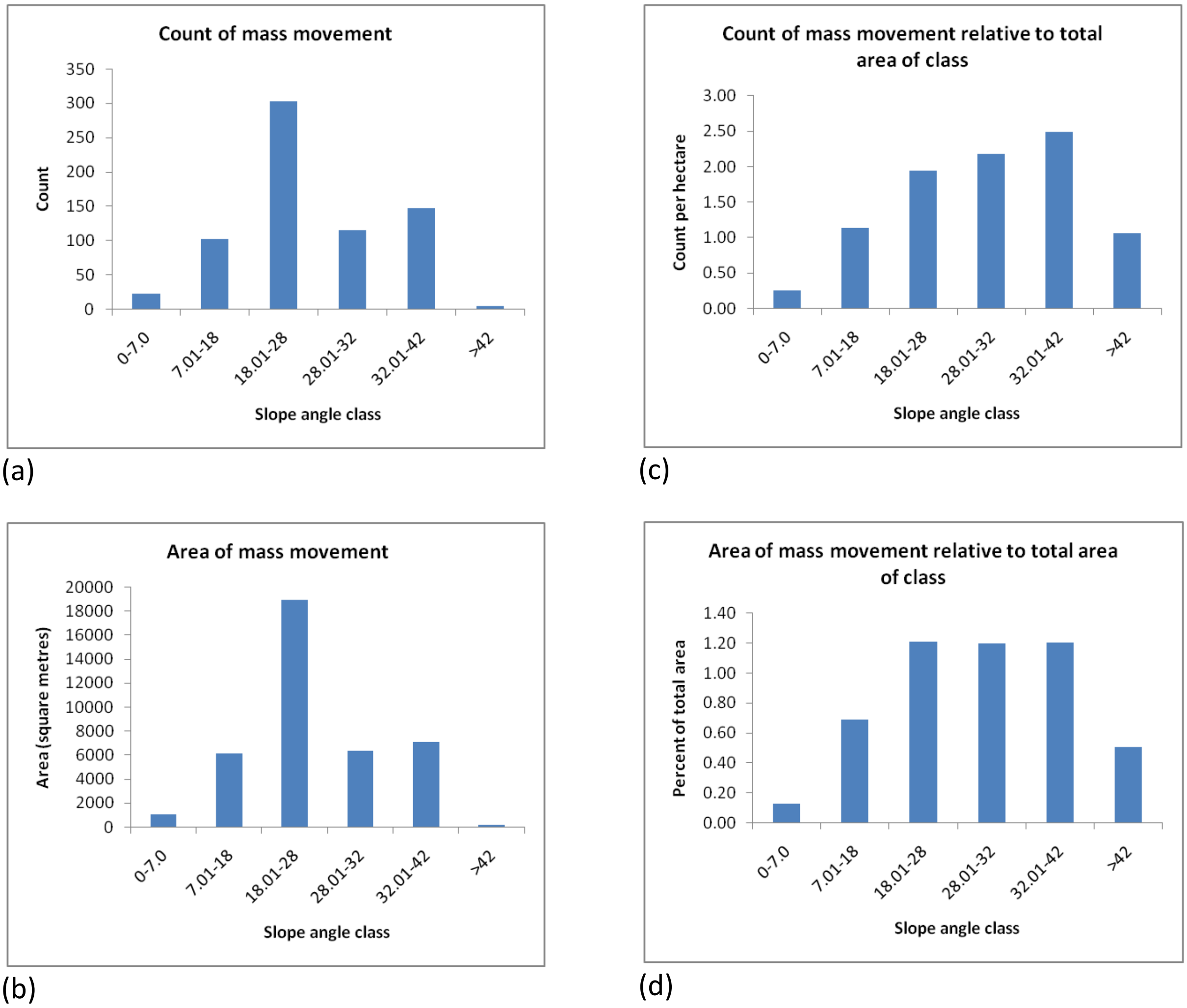

Figure 7: (a) & (c); count of discrete mass movement per slope angle class: (b) & (d); area of mass movement per slope angle class.

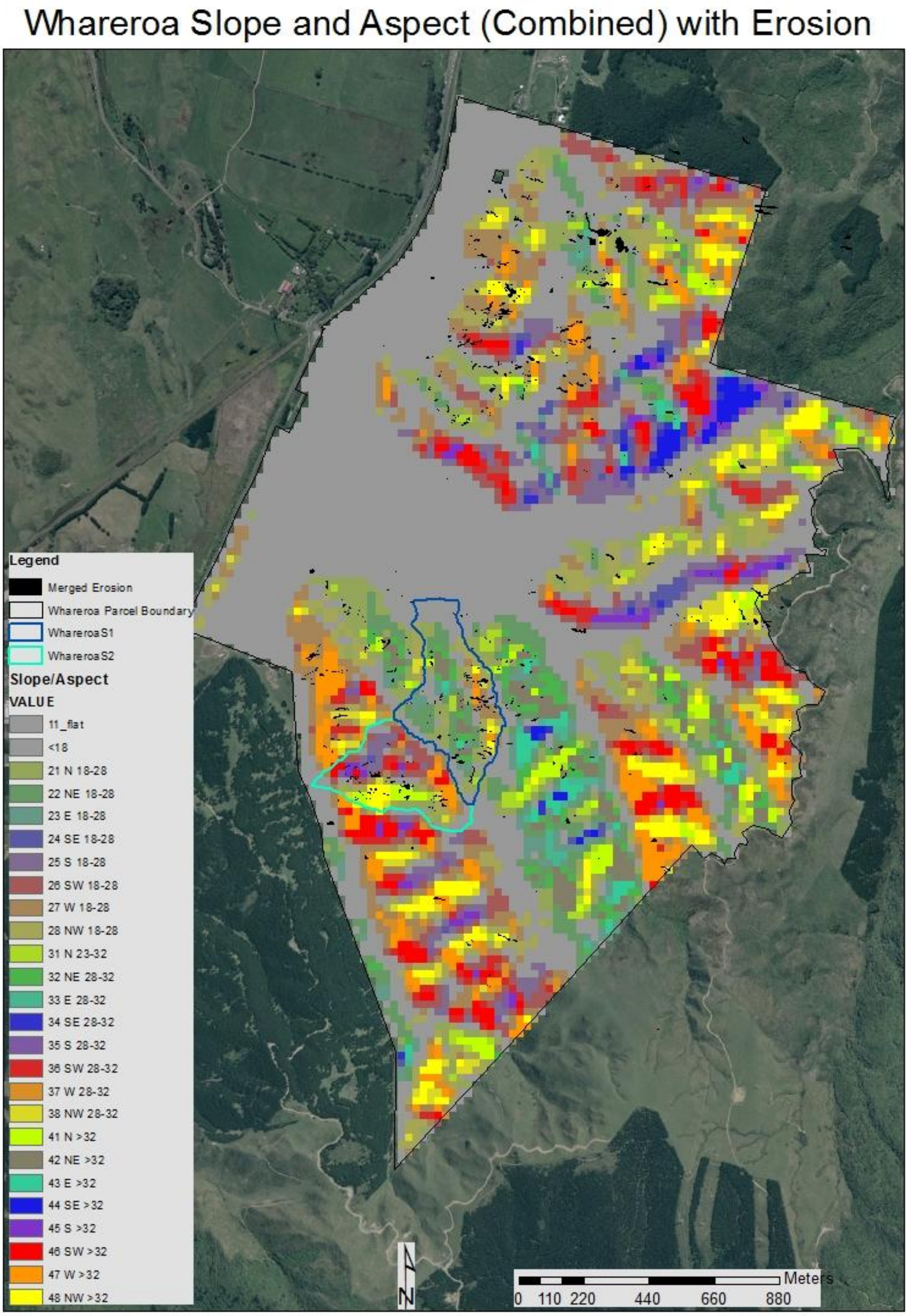

Figure 8: Map of the aspect and slope layers added together to form a layer with distinct pixels for each slope class and aspect class. The slope angle classes are 18-28°, 28 -32°, and >32°. Less than 18° is not analysed and coloured grey.

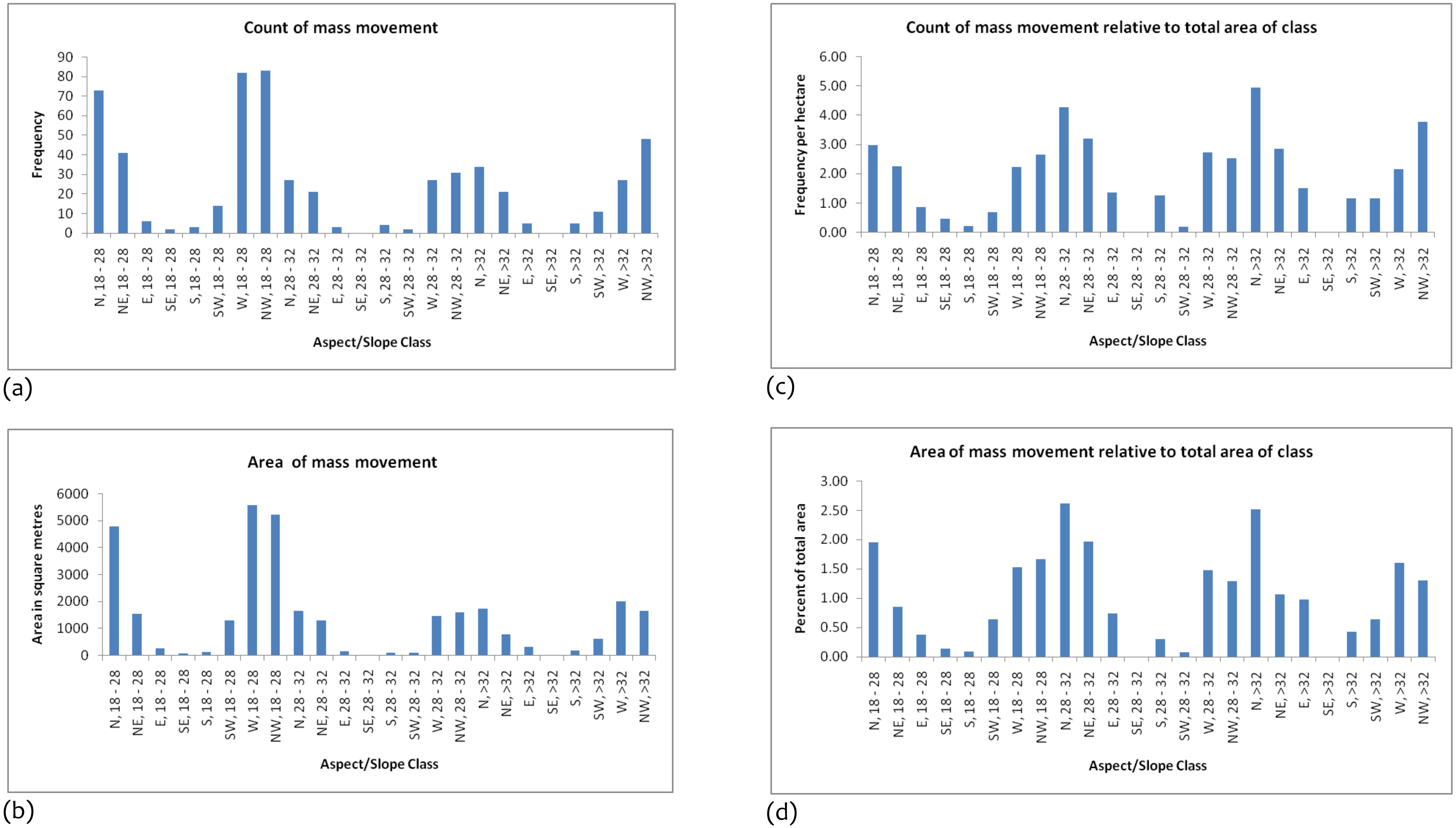

Fig 9: Aspect and slope layers added together to produce statistics related to each combination pertaining to the frequency and area of mass movement. Slope classes below 18° were removed as the earlier analysis identified these as being less susceptible and due to the small area within the >42° class this was combined with the 32 - 42° layer

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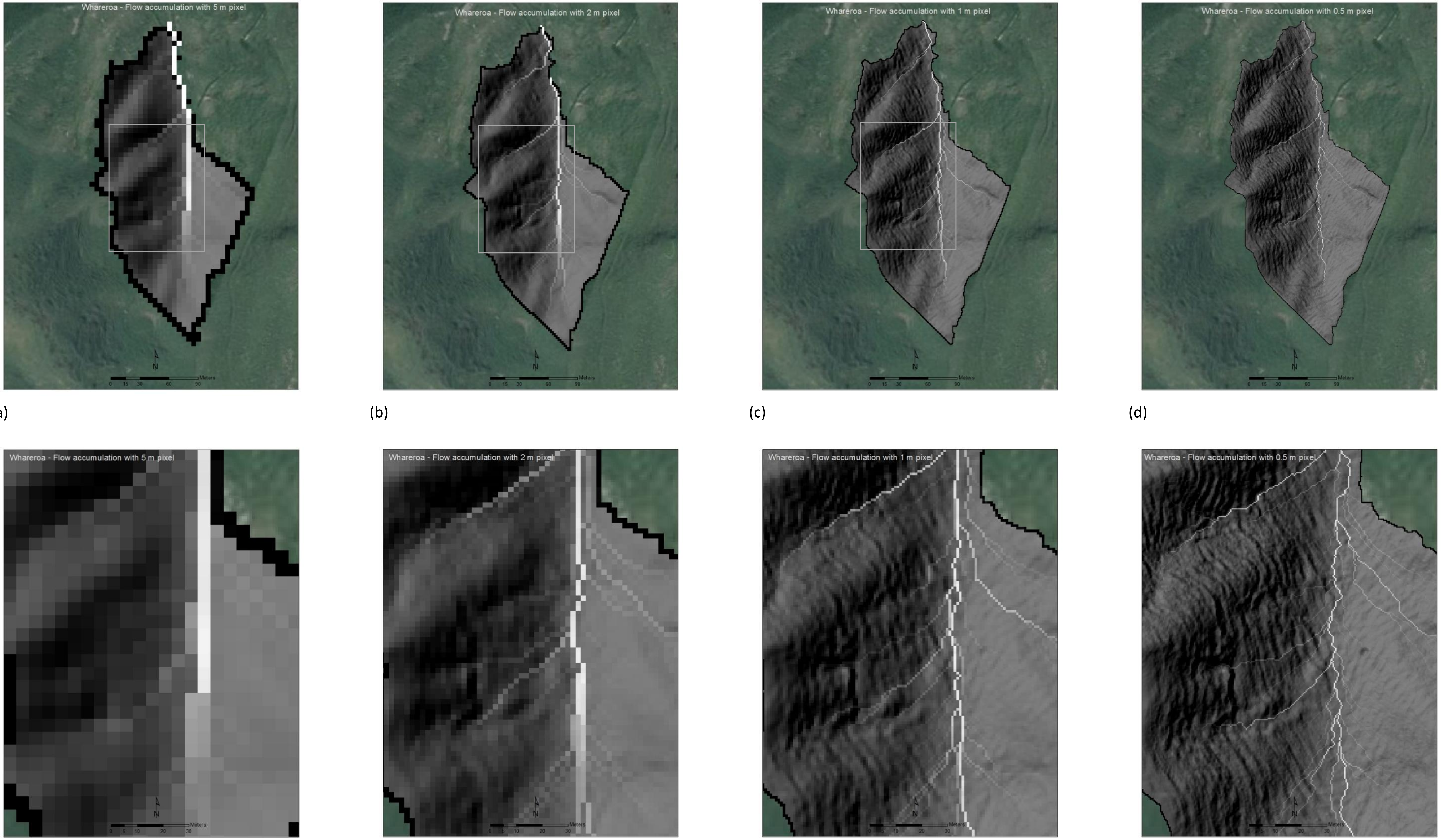


(e) (f) (g) (h)

Figure 10: Flow accumulation surface maps illustrating the results produced by differing DEM resolutions. The bottom row displays a close up of the area inside the rectangle in the image directly above. Each resolution has benefits, with the 5 m pixel in (a) providing a good coarse general understanding whilst that of 0.5 m pixel in figure 10b shows details including paths around colluvial deposits in the swale and the erosion trails on the slopes.

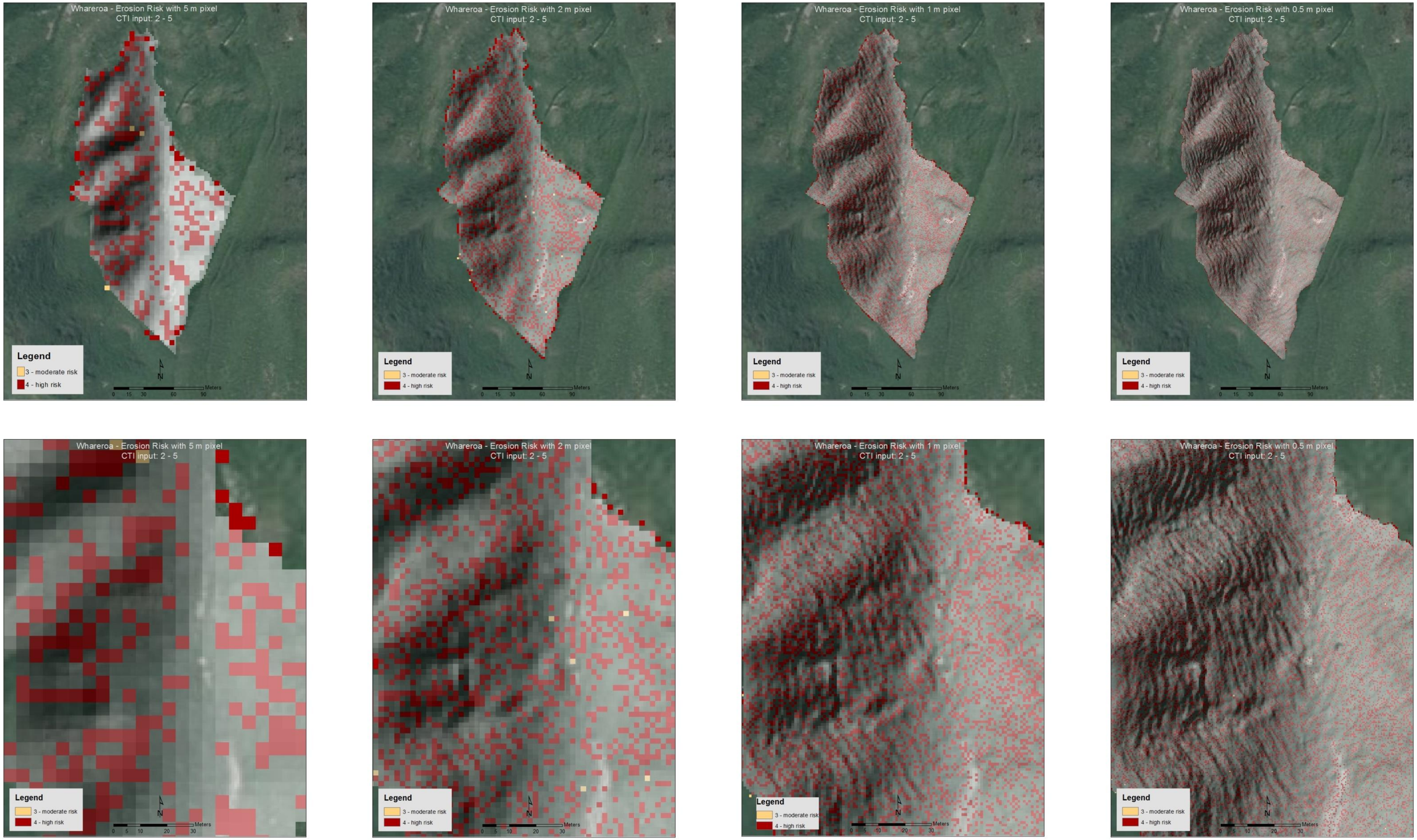


Figure 11: Map of erosion risk produced using Polyscape with DEM's of different scale with default CTI index of 2 for the minimum and 5 for the maximum. The top row shows the whole sub-catchment with the lower row a sub-set in close up. It can be seen that ostensibly there may be some information in the coarse 5 m pixel images that could direct action to specific areas. Ground truthing would then discover if these are in need of prioritisation to ensure stability of the slope. The finer scales DEM are very dense and difficult to interpret. The fact that there are few areas of moderate as opposed to high risk may suggest that the parameters in Polyscape for this scale of catchment and topography may not be suitable.

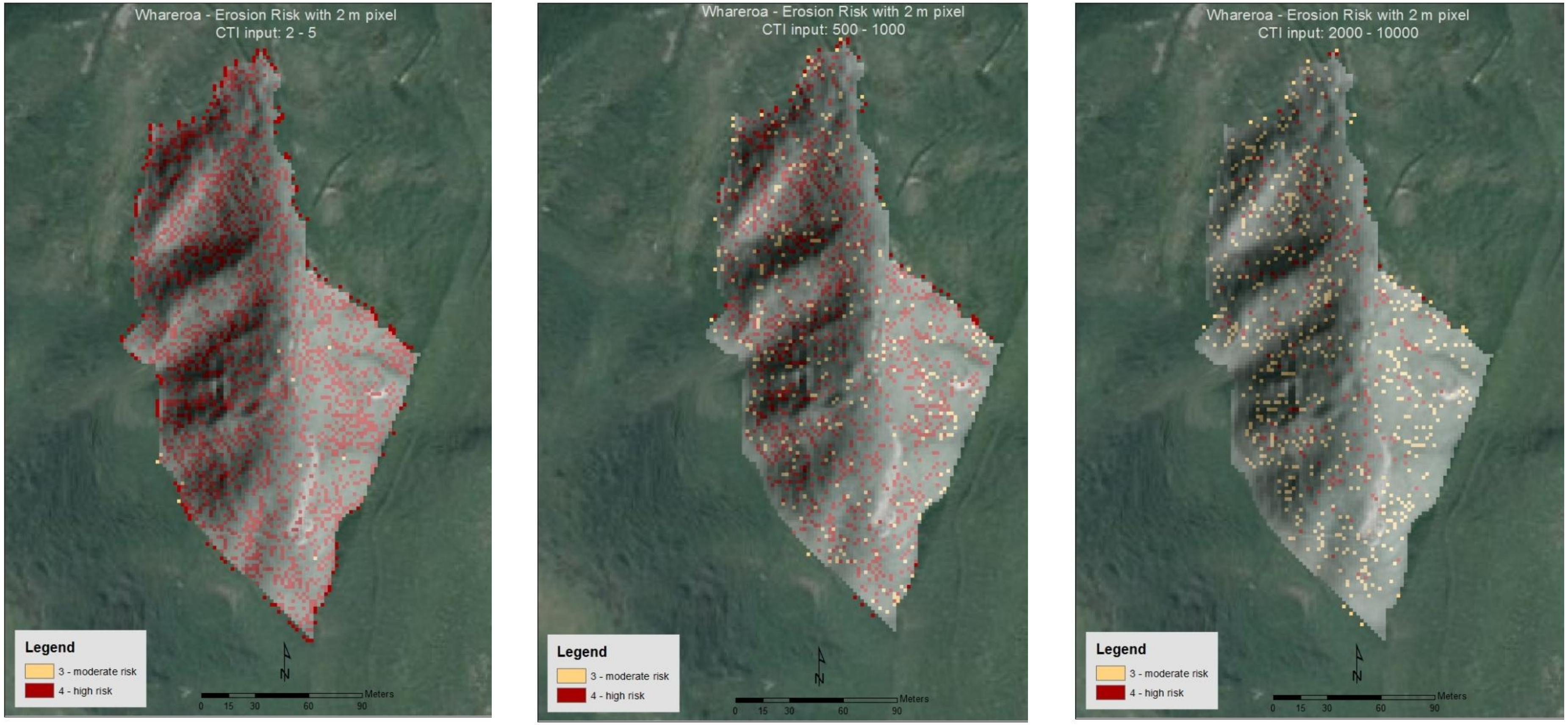
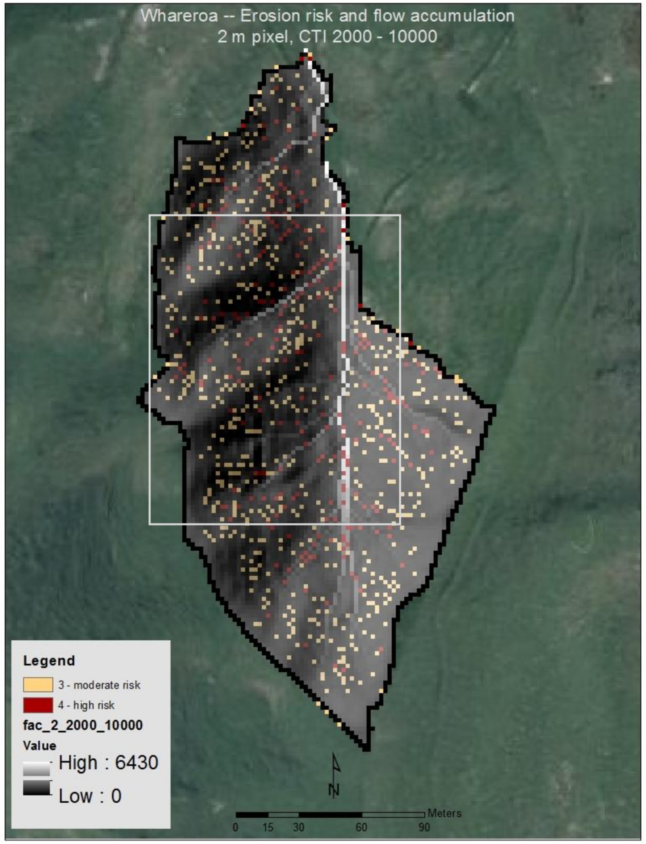
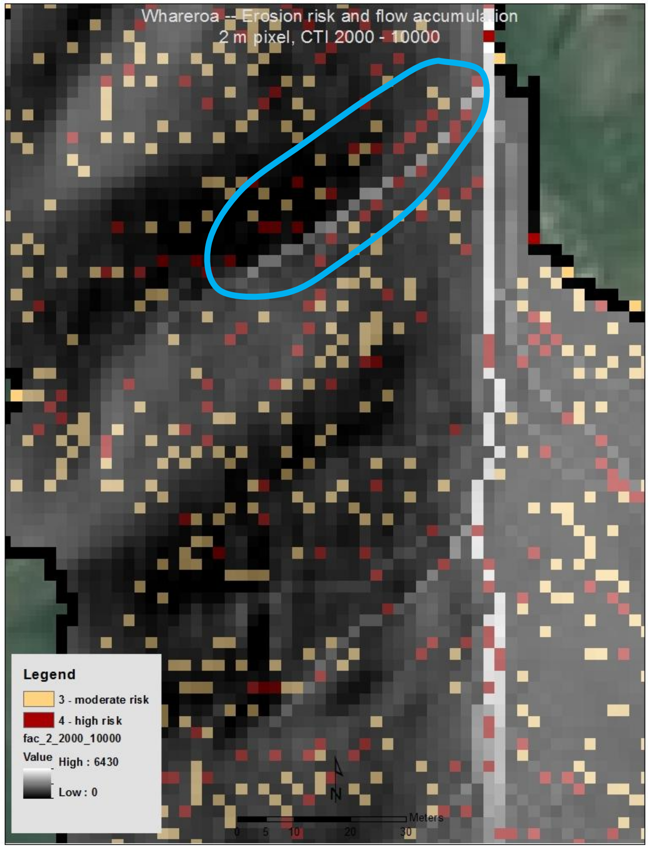


Figure 12: Illustrates erosion risk comparison using 3 different CTI index input values in an attempt to discover if there is a set that may better suit the conditions at this site than the default settings.



(a)



(b)

Figure 13 (a & b): (above) Flow accumulation layer underlying the erosion risk layer at the 2 m pixel resolution; the close up (13b) is indicated by the area in the rectangle in the figure to the left.

6.Discussion

A number of issues need to be articulated before discussing the results. Firstly, some aerial photos were easier to interpret than others. For instance, the 2010 aerial was at a higher resolution and had greater clarity and this meant that it was easier to identify instances of mass movement. Consequently there will be variability in identification of mass movement for each of the years examined. The second factor is the difficulty of correctly georeferencing aerials where there are few easily identifiable markers that can be confidently cross referenced between aerials with decadal time differences. As a result absolutely true registration may not have occurred across the whole image and hence working at the fine scale is a challenge and may affect the results. These factors are background to the following discussion.

6.1 Slope failure chronosequence

In order to use a larger sample size, mapping of mass movement was carried out over the whole Whareroa Farm not just the gullies from which soil samples were taken. The 2010 aerial photo did not cover the whole of the farm and so the outlying areas could not be mapped. It is also acknowledged that the photos are not orthorectified except for the 2002 aerial. Consequently, the unrectified images may be distorted to some degree even though the strenuous georeferencing was undertaken to ensure the precision of points that were most critical.

The chronosequence of erosion, by mapping of visible mass movement sites over the last six decades, revealed that the percent of slope failure associated with the scarp of previous slope failure averaged 16.7 percent (refer to Table 1, Appendix 6.3). The histogram at Figure 6a and Figure 6d indicates that for the 2010 year there is a much higher level of association between new and previous sites (the histograms for the raw data is shown at Appendix 6.1). This may be due to either the higher degree of clarity and resolution for the 2010 aerial, or the comparatively short time frame between 2002 and 2010, meaning more exposed surface remained visible. Alternatively it may be that a number of intense rain events happened between 2003 and 2010. Hence recovery (revegetation) of previous scarps may not have taken place prior to the next event and so had less cohesion provided by root systems. It is possible that it is a combination of these explanations. When the 2010 data was removed the average becomes 11.38 percent.

The total area of new erosion associated with previous mass movement relative to the total area of mass movement showed high amounts for four of the periods; being approximately 20 percent or greater (Figure 6d). However, the count and area (Figure 6a and 6d) has a very similar distribution and do not support an argument that failure on the edge of previous mass movement is greater than on completely new sites. Disregarding the anomalous result for 2010 there does not appear to be a pattern of increased mass movement indicating an acceleration of erosion when the mass movement is relativised to total area. There does appear to be a trend when examining the raw count data but the trendline is not strong with $R^2 = 0.60$ ($y = 3.9643x - 4.2857$, see Appendix 6.2). Removing the 2010 data reduces the result to $R^2 = 0.55$ ($y = 1.6571x + 1.8667$, see Appendix 6.2). Though the correlation is not strong, the results of both the counts and the area are surprising as from my observation there does not seem to be the level of association depicted in the statistics between past and new mass movement.

The overall area of mass movement is 4 ha or only 0.89 percent of the total area of Whareroa (446.6 ha) for the whole period analysed (Table 2, Appendix 6.3). The amount of erosion identified, however, may be under estimated due to identification difficulties induced by the decadal intervals between aerial photos and their low resolution. Whilst recognising these pitfalls the eroded area is still a small amount for a 70 year period. On the other hand, 4 ha of mass movement is a large area when considered in isolation and when considering the loss of production from such an area (DeRose et al., 1995; Smale et al., 1997), as detailed in earlier chapters. If the situation is emulated at Whareroa even the mass movement from the earliest (1942) aerial photo will not have returned to pasture productivity levels maintained prior to the failure.

Further analysis might be needed to make strong statements as to the evolutionary patterns. Analysis might include comprehensive soil depth analysis for both north and south facing slopes which may give a better picture of whether dynamic equilibrium has changed to a state of thinner soil depth. This general hypothesis is supported by Trustrum and DeRose, (1988) and also illustrated by Crozier and Pillans (1991). Rosser and Ross (2011) reported on the differential soil depth between eroded sites and uneroded sites. Soil depth at eroded sites (40 years after slope failure) was found to be one third that of sites not eroded. Comparing north and south facing slopes with the differing rates of slope failure (discussed later) may give some indication. Calculations of convexity and concavity (planform curvature) of the slopes may also be a method to determine evolution but would need a longitudinal study (a continuous study over a long period of time) to reveal trends (Istanbulluoglu et al., 2008).

6.2 Slope failure, slope aspect, and slope angle

The results for the analysis on relationships between slope aspect and mass movement (see Figures 6b, c, e, and f) indicated there are distinct patterns whether investigating the raw data or relative to total area. There are higher amounts of erosion on northerly facing rather than southerly facing slopes corresponding with previous New Zealand publications (for example, Crozier et al., 1980). The pattern was particularly striking in the raw data with high count and area statistics for the north, northwest and west sectors. When the relativised area analysis is examined there were some changes to the pattern, (Appendix 6.4 details the actual area at Whareroa in slope and aspect classes). For instance, the aspect northeast becomes significant. It is also noted that the northwest sector was not as predominant when it might be expected to be, given the prevailing weather pattern is from the northwest for the location. Compounding the impact of the prevalent weather is the fact that these aspects are also likely to have a relatively large diurnal range in daily temperature. Both these factors may be implicated in mass movement likelihood. A further consideration is that the shadow on the south facing slopes in some aerial photos is such that it may mask some detail. From observations in the field it does appear that south facing slopes have fewer instances of mass movement.

Could this be a sign of slope exhaustion, a sign of the mass movement having removed most available sediment? To gain greater insight further work would be needed in relation to the soil depth and slope curvature patterns. Other possibilities to explain the pattern may include the direction of specific rain events of low frequency but of high magnitude, or possibly antecedent conditions which may be influenced by the time of the year that a rain event occurred (Eyles et al., 1978). Regardless of the causation, the raw data showed the magnitude of mass movement per se, whilst the relativised data indicated the locations most susceptible to mass movement. The preceding knowledge is relevant to the restoration priorities that may help to minimise future slope failure and so that the risk of damage to down-slope planting and riparian biota is reduced. While a quantitative analysis of the reference site has not been undertaken after much time spent in the area completing the vegetation inventory and taking soil samples it is evident that there is less observable mass movement.

The analysis of the relationship between slope angle and mass movement (Figure 7a – d) revealed that the results are similar across both the count and area data. The slope class 18 – 28° had the highest magnitude of erosion. The result, however, is partly due to the fact that the catchment has a high proportion of area within this class (Appendix 6.4). When the results were relativised, 18 – 28° is similar to the 28 ° - 32 ° and 32 ° -42 ° classes. This indicated that while most of the mass movement is associated with 18 ° – 28 ° class, it was no more susceptible than the steeper classes. While the classes have been chosen following their recognition as critical thresholds it seems that any slope above 18° is equally susceptible at Whareroa. Such a conclusion is a curse and blessing. It helps in that there does not need to be differentiation of slopes that are moderately steep and above, but is a problem in that the target area is that much larger. That the >42° class was not as susceptible may be due to there being less material in-situ to be eroded.

When the aspect and slope layers were reclassified and added together it was possible to look in finer detail regarding the associations (Figures 9a-9d). The analysis helped to pinpoint locations of mass movement magnitude and susceptibility more precisely. The analysis confirmed that the west to north sector in the 18 – 28° slope class had the highest magnitude given the raw data. When the data is considered relative to the area of each class a similar pattern occurs to the separate analyses above. The same aspect classes were important but now the 28 – 32° and > 32° slope classes were also of importance for both the frequency data and the area data. These data clearly highlight quantitatively where erosion has occurred. It may also indicate the locations that may be susceptible in the future if material is still available for mass movement to be instigated.

In light of the comments made in the discussion above concerning the slope failure chronosequence, the fact that only a small percentage of the whole farm is affected by mass movement leads to the conclusion that exhaustion of material from these slopes is unlikely to be complete. The highest percentage for any class was 2.61 percent for the North 28 – 32° class which seems to support this conclusion. It would appear, therefore, that the slope/aspect results may serve as a reasonable tool with which to base prioritisation of slope stabilisation planning. The analysis gives guidance with regards to the areas with the greatest impact from mass movement and also those that are most susceptible. One note of caution in interpretation of the results is that the coarseness of the 25 m DEM is not the most useful scale at which to undertake this analysis. Unfortunately it is the only one available for this area. The general susceptibility for erosion, given slope angle, is supported by the erosion risk analysis presented in the following discussion.

6.3 Sequential evolution or stochasticity?

If it is not possible to illustrate an unequivocal pattern of erosion happening in a sequential manner based upon previous locations of failures then how can the pattern and likelihood of erosion occurrence be understood at Whareroa? That there is no clear pattern of progression of mass movement sites sequentially up a slope seems true but there is certainly a distinct pattern of generalised locational likelihood. The mapping and the statistical analysis of erosion clearly indicates that sites facing from west to northeast, in general, are more likely to fail. Many other studies discuss the impact of aspect on vegetation and erosion; disparate examples were detailed by Bennie et al. (2006) regarding the English chalkland grasslands and by Weaver (1991) in southern Africa. The effect (of aspect) may be due to the prevailing wind direction accompanying large storm events. Alternatively, it may be a product of increased weathering due to the greater diurnal range of temperature associated with northerly aspect. It could be argued, therefore, that there is some concentration of erosion but not a sequential pattern. It might be seen as stochastic episodic events happening at random, but with a higher likelihood within certain slope aspects and inclinations upon the hillsides.

The results relating to the overall amount of erosion suggests that there is no severe landscape degradation happening, systematically or randomly. My subjective observation would be in accordance with the quantitative results, and an evolutionary trend towards a 'badlands' state is not suggested. The graphs detailing the temporal erosion do not show a trend towards increased erosion, particularly if the 2010 data is discounted (for reasons discussed above). It is also pertinent to remember that the location has had a long period of disturbance possibly as far back as the 1850's, as outlined in the introduction. An alternative hypothesis may be that a large degree of material has been transported off the slopes in the period between 1850 and 1940, that is, prior to the time period studied here. While signatures of past erosion are observable in the landscape these have over time reverted from bare soil to sites with vegetation. Further study may confirm a tendency towards thinner soils but the situation does not appear to be irreversible. If the slopes were to continue to be grazed with the same intensity for years to come the recovery may not continue. If soil depth is a major control (Crozier et al., 1980) then the cycle may continue albeit at a different rate.

If the imposition of thinner soils is a long term proposition, the sustainability of grazing land use practice is questionable. DeRose et al. (1995) and Smale et al. (1997) stated that productivity has not increased above 80% on mass movement sites within a period of 40 years but my literature research did not reveal similar studies in relation to sites with greywacke parent material. Smale et al. (1997) indicated that growth on erosion sites was different between Taranaki mud/sandstone country and that of the east coast, with the inference that underlying fertility of the bedrock is the determining factor. Rosser and Ross (2011) provided an update that correlates with these earlier studies whilst examining Wairarapa hill country. It may be that it is even slower at Whareroa due to lower fertility given the parent material of the soils is greywacke. Whichever the case, it would appear that a hypothesis of hillslopes moving irretrievably to a (degraded) new stable state is not supported by the evidence at this juncture. It is likely that the conditions are altered, particularly on northerly facing slopes, but not so significantly that it is impossible for the situation to be reversed. Restoration is likely to take longer than otherwise might be the case though.

6.4 Susceptibility of future slope failure

The mapping of erosion in this study looks only at the last 70 years due to lack of data availability prior to this but records show that the land was leased from local Maori by a Mr MacKay in 1876 (Carkeek, 1966). In the introductory chapter land use history was touched on and it appears that land was already cleared of forest at that time in parts of the area. Much erosion will have therefore taken place following the original removal of vegetation, particularly after root systems rotted away, removing the cohesion that they provided. Carson and Petley (1970) presented the issues pertaining to threshold hillslope angles given the structure and texture of the regolith. Hence, the picture provided by the mapping of erosion is only partial, and does not illuminate earlier erosion patterns, locations and severity, all of which cloud the discussion pertaining to the future.

The above data shows that new mass movements occurring on the periphery of previously failed sites is within the range of 10 – 20 percent of all erosion. This leaves 80 – 90 percent occurring in other locations. It would still seem that the scarps of the mass movement sites are susceptible because they are much steeper than the surrounding slope angle and often the head of the scarp is situated in a position where the soil depth is relatively deep. An aspect that may be worthy of future investigation is whether the product of mass movement (translational slumps, that is, a detached landmass which moves downslope along a planar surface) is transported further when it is a reactivation of a previous mass movement site. The trail formed by the earlier mass movement may facilitate the movement of the sediment entrained in the new occurrence. Alternatively, the path including the longitudinal dykes created may hinder the entrainment of sediment in subsequent instances mass movement.

If soil has been relocated or sediment transported out of the sub-catchment then there may be implications for the success of any active planting interventions. The research into replenishment of fertility on mass movement sites (DeRose et al., 1995; Smale et al., 1997) focuses upon pasture growth but fluctuations in nutrients will also affect growth of native forest species as reflected in the seral stages in natural disturbance (Blaschke, 1988; Blaschke et al., 1992; Smale et al., 1997). In a restoration project, the ongoing successful maintenance of a desired successional trajectory may be impeded by the presence of large areas of degraded soil. The fact that at least 11 percent of erosion occurs in association with the presence of prior mass movement, while not high is still of some significance for restoration practice. It is possible that this figure may be higher as it was very difficult to interpret the 1962, 1988 and 2002 aerial photos for mass movement that had occurred during the time between photos but was no longer visible because the scar had been re-grassed. Had the 1977 aerial photo been interpretable this may have altered the data significantly, due to the large rainstorm event in the Wellington region in December 1976. With this in mind, consideration of the stabilisation of erosion may be of benefit in a restoration context. If species that are normal native colonisers are planted on and around mass movement sites this will help with stabilisation and prevention of further mass movement, if the plants become established before another damaging rain event occurs.

6.5 Modelling erosion susceptibility

There are models which predict the slope failure susceptibility, for example, the factor of safety equation. Slope angle is one element of the equation, whilst another is soil depth. Collins et al. (2004) proposed a vegetation-erosion model with implications for landscape evolution, taking into account the cover and cohesion that vegetation applies to slopes. For restoration groups without the access and knowledge of numerical models on-site observation may prove sufficient. Once a site has undergone mass movement that particular site is unlikely to experience further failure until soil depth has reached a critical level wherein erosion is possible again (Crozier et al, 1980). A contradictory factor is that of loss of toe support to the area surrounding the scarp of a mass movement site, which can lead to reduced shear strength and increased vulnerability.

Mass movement scars are visible in the landscape and so could be targeted without numerical analysis. Consideration of the sites and situation of mass movement, the level of toe support available to scarps, the soil depth (by observing the relative wilting point of the pasture and its location), the slope aspect and angle can all be undertaken without technical sophistication. Such observation will provide information relating to the propensity for mass movement to occur with the implication of risk to restoration success locally and further afield due to the entrainment of sediment in the fluvial channels.

A quantitative approach is the utilisation of the CTI algorithm within a GIS environment which calculates erosion risk. A very brief explanation was given in the methodology section. In this study, I have produced mapping of the erosion risk using the default CTI setting for each of the resolutions investigated in the flow accumulation set. The CTI settings are values that take account of other factors controlling soil erosion; specifically, soil and vegetation. The values represent critical thresholds. Values pertinent for the subject area may need local knowledge or experimentation to calibrate with observation or other empirical evidence. Unfortunately without such calibration the values entered are rather arbitrary and may need further work and comparison with other methods to determine a sufficiently robust correlation.

Whichever scale DEM is used (in this study) utilising the default CTI values the outcome does not give a particularly useful demarcation of target locations within the sub-catchment. Risk appeared to be spread reasonably evenly across the landscape (Figure 11). Conversely, the calculated risk may present a true picture of the reality as the mapping of historic erosion found comparatively high rates of erosion on north facing slopes, which this map captures. That it does not seem to delineate different slope angle susceptibility may be due to the fineness of the DEM, that is, a coarser resolution may be advantageous for uncovering the risk potential. The statistical analysis showed all slopes over 18^{o} to be susceptible to erosion so the picture displayed may be reasonable.

Certainly the 5 m pixel resolution gives more guidance than the finest resolutions, and may be useful to some extent in directing further investigation on the ground to the general areas of high risk identified. Areas where mass movement scarps are present and soil is deep may be areas prioritised for revegetation. Close examination of the combined erosion risk and flow accumulation maps would suggest that the areas close to the convergent flow paths may require some attention. For example, the close up map of the 2 m pixel version (Figure 13b) shows some pixels of high risk parallel to the flow path, and could provide a lead for further on-site investigation.

The parameters within the algorithms of Polyscape are built upon the settings for landscapes in Europe and so the model may need 'tuning' for New Zealand conditions. To test if altering the CTI setting produced 'better' or at least different results two further analyses were conducted. The default setting is 2 minimum and 5 maximum. The integers used as a test are arbitrary and so the first alternative used 500 as the minimum and 1000 as the maximum, whilst the second used 2000 minimum and 10000 maximum. The former (Figure 12b) reduced the total area of risk with a thin wide spread but no visibly clustered areas. An increase in the moderate risk pixels is evident. The latter (Figure 12c) reduced the risk prone area further and the balance of risk swung further towards moderate rather than high. The default setting found almost no medium risk areas (Figure 12a). It is not possible to interpret the results of any of the maps of this site with any confidence without further research into the parameters underlying the algorithms.

A possibility might be that for New Zealand conditions in steep sub-catchments erosion risk might be explained by slope angle alone (with consideration of thresholds dependent upon the basement geology or soil type). Another consideration may be that the model will not predict the susceptibility given the prevalent types of mass movement encountered in New Zealand. To confirm its effectiveness or otherwise it may be possible to test the model by creating a fine scale DEM for the south facing sub-catchment. Given the statistical difference found in the rates of erosion between south and north facing slopes the model should reflect the differential.

6.6 Buffers, barriers, blankets, and connectivity.

The creation of the fine scale DEM resulted in an ability to analyse the topography in the small scale catchment studied. Of particular interest is the level of hydrological connectivity, and by inference sediment between the slopes, the swale, and subsequently the fluvial channel. Connectivity has been analysed by using the flow accumulation tool embedded within Polyscape (ArcGIS also provides this tool separately). While I have not presented an analysis at the 25 m national scale DEM the coarseness of the 5 m analysis (Figure 10a and 10e) illustrates that 25 m pixels would be inappropriate. For the scale that is studied the 2 m pixel scale is as coarse as would be useful (Figure 10b and 10f). Conversely, there is probably no extra detail that can be usefully extracted from the 0.5 m pixel image (Figure 10d and 10h) than the 1 m pixel version (Figure 10c and 10g).

The maps indicate that fine scale DEM have the potential to be a means by which buffers and barriers to hydrological flow are identifiable. If buffers were present the paths that the flow takes may have pointed to their precise location. Buffers can be identified due to the raised elevation near fluvial channels produced by overbank flooding and the creation of levee like contours. A buffer may also be represented by wide low angle toe-slopes. Blankets which give a smoothing of the surface will be difficult to identify using this means but may be inferred from other information relating to loess or volcanic ash presence. Barriers may be found in steep zero order basins possibly as rocky outcrops and more pertinently in the study site, from rafted colluvial deposits found downslope from mass movement sites. They all represent areas that reduce the hydrological, and to some extent, the colluvial connectivity (Fryirs et al., 2007). Connectivity in this context may not be a desirable property due to the effects of sediment on downstream environments and in terms of flashiness of downstream flooding.

The maps of the flow accumulation showed that in this quite narrow and linear sub-catchment that the concave side gullies are closely connected to the main swale running south to north in the centre of the map. There are no true buffers that would hinder the flow in a rainstorm event. What can be identified are the particular overland flow paths and their confluence with the main gully swale. These confluences and their surrounds may be areas that need artificial buffering to prevent sediment reaching the swale and so the fluvial environment. Buffering may be simply achieved by allowing lank grass to grow in the swales which will help trap overland flow sediment and to some extent nutrient solute. Buffering from the effects of a large translational mass movement and the subsequent transport of the sediment may need hard engineering to prevent entry into the main swale, until slopes have been stabilised and the swale substantially revegetated. Evidence of rafted blocks from previous slope failure can be most readily identified in the 1 m and 0.5 m pixel images.

It is recognised that barriers may only be a barrier given a particular set of rainfall circumstances. With a rain event of sufficient magnitude these forms may not act as barriers because the saturated ground conditions (from antecedent rain) and/or intensity of rainfall may overwhelm the barrier effect. It may be that if natural barriers/buffers were artificially augmented (for example, logs laid on the ground in the path of the flow or sediment fence traps) and side gully/swale confluences were revegetated the degree to which they continue to act as a point of disconnect to the downslope fluvial system may be enhanced. The artificial barrier may help to protect the natural barrier (woody vegetation) until it is established. These confluences of side gullies and the main swale may be considered as another type of priority planting site.

7. What are the means of interpreting landscape change related to land use change and can they be usefully utilised in a restoration context?

This section has served to highlight a number of methods by which an assessment of a site can be made by looking at the geomorphology and interpreting different aspects of GIS output. The mapping of sequential mass movements from historic aerial photography assisted in understanding and quantifying the relationships between previous and new mass movement. Those results can be some of the factors considered when planning restoration.

The mapping and analysis techniques have not been able to clearly detect the existence of a systematic evolutionary pattern in the landscape. The analysis would suggest that no threshold has been crossed where the landform/process relationship has moved into a degraded alternative stable state. Such a situation is not easy to quantify but the fact that pasture has redeveloped on mass movement bare surfaces may be a sign that continued erosion is not causing a transition to another state. This depends upon whether active intervention has been implemented to re-grass the sites and the levels of nutrient available. The fact that the eastern slopes (those removed from active grazing) are regenerating through a gorse successional phase also suggests no evolutionary change. Other types of approaches were mentioned in the discussion section which may provide other avenues of enquiry.

The analysis of the frequency of mass movement according to slope aspect and angle does provide information about the likelihood of the location of ongoing slope failure, where landcover is pasture. The results are conclusive in pointing to the slope aspect and angle most susceptible to mass movement. This information can clearly be an important input to decision making processes within an ecological restoration plan. It would appear that revegetation of northerly facing slopes would be a priority based upon the fact that mass movement occurrence there is more frequent on the > 18^{o} slopes. It appears that this is the threshold slope angle at this site. Slopes steeper than 28^{o} when considered relative to the overall area of the class are no more susceptible. Revegetation of south facing slopes will probably occur more easily and may not need direct intervention given the higher constancy of conditions, and probability of greater water retention in the soil. Considerations relating to the likelihood of thinner soils on mass movement sites will also be needed amongst other analyses. The quantitative understanding of locations of erosion susceptibility, when considered in conjunction with other biological considerations of restoration, will provide greater confidence in making choices about prioritisation of restoration.

The mapping of the connectivity of the slopes to the swale provides further evidence of the impact mass movement may have on downslope and riparian areas. The fine scale (2 m) DEM provides the means to clearly identify areas of confluence and increased flow accumulation. In a zero order basin the confluence between side gullies and the main swale may be areas that require action to reduce the hydrological connectivity and so reduce the level of sediment transport. Although not illustrated in the study catchment, areas where connectivity is identified as being lower (buffers) may be augmented with artificial barriers and restoration planting (again) to reduce the connectivity of sediment with downslope areas. The mapping using the fine scale DEM suggests that it is useful in catchments of this size to identify areas that may have some priority in a restoration plan. In its current form the CTI erosion risk algorithm does not provide a clear understanding of erosion risk in a steep zero order basin under New Zealand conditions. At the moment it would seem that erosion risk may best be inferred from the historic mapping of erosion as illustrated earlier in the chapter which clearly does provide clear statistical insights.

In general, it is suggested that the methods detailed in this chapter can provide valuable information which will be of practical useful benefit for restoration practice in the type of environment studied. The methods require access to information that may be difficult for private landowners or community groups to access. The software utilised may also be a barrier to implementation. It is understood that archival aerial photos are available from Archives New Zealand at reasonable price and that Geophysical and Nuclear Sciences may lend aerial photos and so it is not impossible to obtain these. Access to sophisticated GIS software is limited due to cost. Some freeware is available that may complete some, if not all, the tasks undertaken here, but have not been tested. Another option may be for regional and local councils to provide access to a license for the ESRI software. Fine scale DEMs are becoming available for more areas of New Zealand which may be of sufficient scale to undertake analysis at the sub-catchment scale. Alternatively, photogrammetry provides another possible option for constructing fine scale DEMs. Many of the results pertaining to susceptibility of erosion dependent upon slope aspect and angle correlate with other studies and while it would provide less certainty the results of this study and others may be extrapolated to other sites, if the methods described here are unachievable. On-site inspection and analysis may also be sufficient to a trained eye.

Chapter 7. Synthesis and Conclusion: Geomorphology informing restoration practice

1. Introduction

In the previous chapters I have outlined a number of landform factors and soil quality variables which have influence on the landscape following the change of land use through deforestation. By examining the differences between a (relatively) undisturbed reference site and disturbed restoration site useful information is gathered that is important for the planning of restoration (see Chapter 5). The identification of variables that are significantly different between the sites helps give an indication about the geomorphic condition of the restoration site. Variables known to be significantly different can be compared with expected values, as understood from the literature, to help establish if the variables are outside of their normal dynamic range.

The abiotic variables identified can also be related to the floristic community at the reference site to gain an understanding of the possible significance upon the distribution and abundance of the community (Chapter 4). An assessment of the physical geomorphic condition of the restoration catchment can be added to the multifaceted approach to provide a fundamental background to the planning of a restoration project (Chapter 6). Other factors not focussed upon here will also be important, for example, the presence of rare species/ecosystems, distance from propagules, vectors of dispersal, and the matrix of the space about the restoration site; not forgetting the energy, will, and resources of the human community involved.

Having completed measurement and analysis of a large complex set of data a final question remains to be answered, which is:

Is there a practical and useful way to relate geomorphic understanding to ecological restoration prioritisation?

2. Background: Any guiding lights?

This study has been structured to present separate elements of a process to investigate the condition of a disturbed restoration site but contains minimal interaction between these elements. As a result there are distinct packages of data, output, information, and interpretation. Each package is quite discrete and the isolation causes difficulty when trying to determine broad restoration goals. The information produced in this study is useful detail that may determine the objectives which make up the goals, but less useful for the overarching direction. In this chapter I outline and explore a method that synthesises the distinct packages of information in a practical framework that can be utilised to make logical decisions in restoration practice.

Frameworks for assessing the environment exist, but following a literature search I am not aware of structured analysis in a restoration context which includes systematic consideration of the geomorphic factors, particularly relating to hillslope processes. In the literature review I outlined a range of studies that discuss frameworks and models for ecosystem assessment including some which invoke a geomorphic element. Included was a brief outline of River Styles® (Brierley and Fryirs, 2005). In this chapter I introduce more detail of this system, produced to examine the geomorphic condition of river systems, and use the basis of it to extend the concept to an application centred upon the whole area of a zero to first order sub-catchment.

Previously, I discussed research that presented various models and systems that have been utilised in identifying, mainly, areas that are seen as having conservation value. These approaches did not detail the mechanics or utility of practical restoration planning and prioritisation particularly in the context of a small catchment. An approach that does not rely solely on quantitative data or computer models and seems relevant to catchment-based ecological restoration is that presented by Brierley and Fryirs (2000, 2005). Furthermore, it does contain elements that are useful in planning and prioritisation at a catchment scale. The development of the system results from a collaboration with the New South Wales Department of Land and Water in order to produce a management tool (Brierley et al., 2002).

The author's approach includes assessment, analysis, and restoration prioritisation of reaches of the fluvial system from a geomorphic perspective. This is the most developed and detailed model that I have discovered, and is also communicated in a style which is assimilable. Although the scale of the case study catchment in the Bega Valley, southern New South Wales used to present the approach is much larger than the scale examined in this study there are elements that are applicable. Scale is not necessarily important anyway as the concept is multi scale, and the framework has been applied to assess most river catchments in New South Wales (Brierley et al., 2011). The concept behind the framework is that a river should be of a style in keeping with or "appropriate" to its geomorphic surrounds. The setting may be a mountain range, a fan environment following disgorgement from the highland areas or a floodplain setting. The author's state that in each landscape unit the river, given consideration to the underlying geology, should reflect certain characteristics or "styles" down to the reach scale and smaller. Hence, varying spatial case is encompassed.

The approach that is adopted is to check the appropriateness, that is, the degree of divergence from the expected, through a set of procedures for each section and reach of the river. If it is found not to be appropriate, and that it is disturbed to some extent, then further analysis is undertaken to assess whether it is resilient and may return to a natural state or not. It may depend on the position in the continuum of the river and how much impact from upstream sources may potentially be imposed. The assessment helps to make priorities for restoration and land use decisions. Considerations include whether there are rare species or ecosystems that need restoration and (in general) the recovery potential given a limited amount of resources that society has at its disposal. Although the system was designed and elaborated under Australian conditions it has been utilised in New Zealand (Reid et al., 2007).

At the broadest level, River Styles is a set of procedures in which to frame a catchment scale geomorphic understanding of river forms, processes, and linkages. The task is to capture the catchment character and behaviour, its condition, and adjustment capacity to disturbance. It is hierarchical wherein cascading scales are nested. It is described as a four-stage framework (Brierley and Fryirs, 2005; 249); these are:

Stage one: Catchment-wide baseline survey of river character and behaviour.
Stage two: Catchment-framed assessment of river evolution and geomorphic river condition.
Stage three: Assessment of the future trajectory of change and geomorphic river recovery potential.
Stage four: River management applications and implications: Catchment-based vision building, identification of target conditions and prioritisation of management efforts.

While this framework primarily focuses upon river analysis it does consider linkages with the surrounding landscape but does not examine the condition of that landscape much beyond the riparian zone and floodplain. All the same, it encompasses a wide-ranging and detailed consideration of catchment scale processes and forms. In the following section I consider ways in which this may be adapted to a systematic approach to investigate the condition of a sub-catchment with the focus on the sediment stores that are the slopes, fans, and alluvial terraces. My aim is to gauge the equilibrium, the degree of degradation, the recovery potential, and the priorities from a geomorphic perspective. This does not aim to be a quantitative assessment, but quantitative results of analysis already undertaken can be used in the process of judging the conditions.

3. Catchment-based geomorphic assessment: A proposed extension of the River Styles framework.

My proposition is that this broad framework may work equally for analysis of the catchment with a focus upon the contributing hillslopes (the majority of the catchment). It is obvious that there are significant differences in the temporal setting and rate of processes within a fluvial system and that of hillslope landforms. Nonetheless, it is still feasible to apply a basic framework that is constructed from River Styles. The proposal is not intended to be a full working model, simply a basic enunciation of a possible guidance system of use at a small catchment scale. I am not trying to emulate the multi-scale approach of River Styles but even at the scale in this study the connectivity between landscape components is of prime concern.

Considering the stages detailed above for the fluvial system and applying a structure for hillslopes the following adaptation is proposed:

Stage one: Whole catchment survey of landforms and behaviour or processes active in (and between) landforms.
Stage two: Assessment of slope evolution and hillslope physical condition, including soils, with comparison to expected parameters.
Stage three: Assessment of the future trajectory and recovery potential of the landforms and hillslopes.
Stage four: Interpretation with management applications and implications: catchment-based vision, including target conditions and prioritisation of action.

Each of the above stages has multiple elements and steps within them. Within the structure of this thesis I have undertaken what is called for in stages one and two in the previous chapters. This is not to say that I have used the same methodology nor have I completed the same analysis. But there is not the scope to cover the suggested pattern of enquiry outlined in River Styles in this thesis. What is of interest at this juncture is the two latter stages, that of elucidating recovery potential and hence informing restoration prioritisation (Figure 1). To expand upon the stages described above a flow chart is presented. Again, this is as outlined by Brierley and Fryirs (2005).

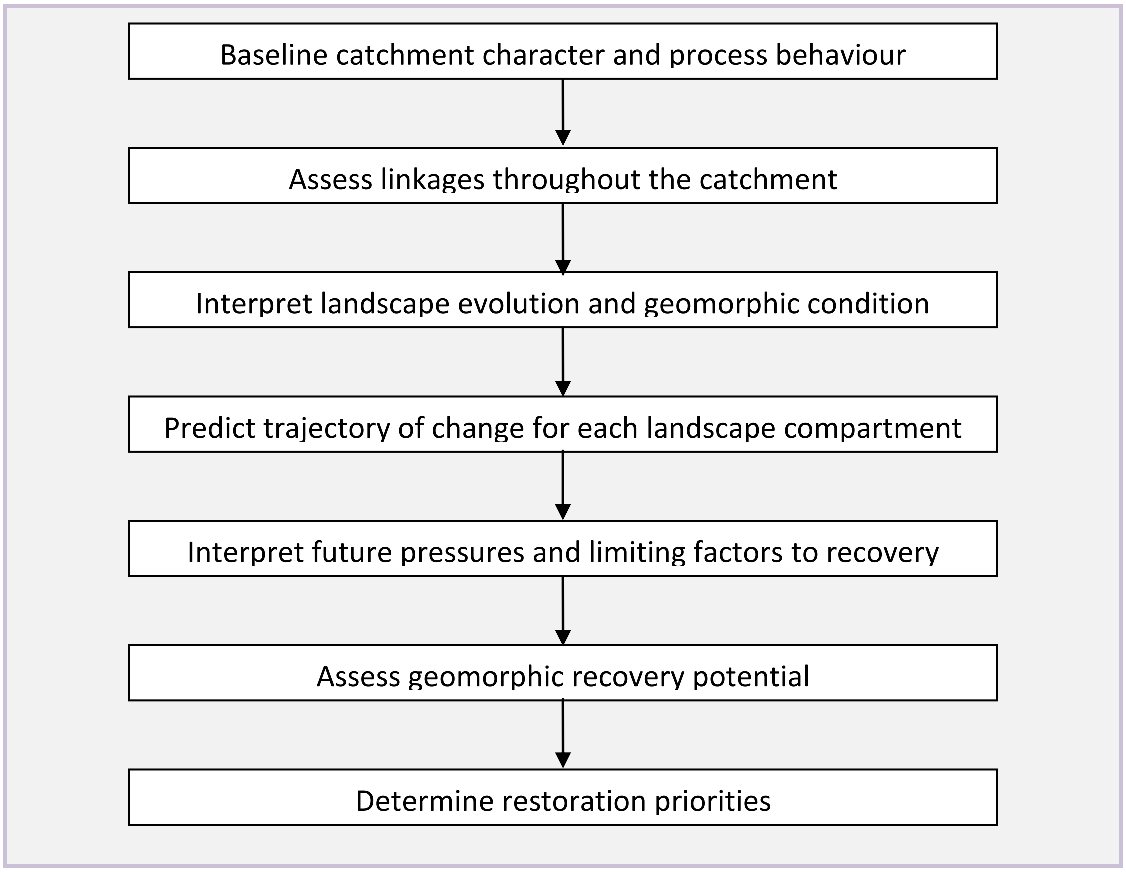


Figure 1. Steps to assessment of catchments and prioritisation of restoration (Brierley and Fryirs, 2005).

To clarify and explain the process I will make reference to this case study and the results already presented. Of the steps detailed in Figure 1, the first is covered in part by the introductory chapters and subsequently the process behaviour is considered in Chapter 5 where geomorphology and soils are discussed, Chapter 6 pertaining to geomorphic processes and to some extent in Chapter 4 on a vegetation analysis. The second step regarding linkages has been considered in Chapter 6. Connectivity also needs addressing in terms of biological linkages (of remnant patches, to distant intact forest, of the matrix and the presence of seed dispersers and in terms of seed bank presence).

Of step three, landscape evolution has been considered in Chapter 6 and geomorphic condition is discussed below. Future pressures have not been a central consideration but it is acknowledged in discussions on resilience with regard to climate change. Before limiting factors can be articulated I will canvas the condition of the catchment, which also provides background and data for the assessment of geomorphic recovery at step 6. Finally, the determination of priorities is presented.

3.1 Geomorphic condition

The following discussion is necessary as it provides input to the assessment of limiting factors and also recovery potential. The discussion is framed by one of the steps which inform Stage 2 (outlined earlier), and is:

Assess the condition of the catchment components and their functional capacity and assess levels of intactness.

This assessment may be completed by a combination of observational and quantitative approaches. To illustrate this, by mapping and delineating each of the components of the catchment it may be possible to determine to what extent a gully or spur is affected by erosion. Delineation may be possible by using readily available maps in the field as long as they are at a fine enough scale. Similarly, using aerial images in GIS software, digitally mapping erosion of hillslopes makes possible calculation of the area of erosion and which slopes are more vulnerable to ongoing slope failure, dependent upon slope aspect or angle. This was shown in Chapter 6. The information gathered by either means can be used to make an assessment as to whether each landscape component is in good, moderate or poor condition as compared to a reference condition.

In the case of a stream it may be the proportion that is undergoing active erosion of its banks. Another measure may be the extent (width, depth, length) of incision of streams on a colluvial fan. Such measurements when compared to measurements from a reference site may help estimate the relative condition. In consideration of an ephemeral swale the soil parameters may be the most pertinent aspect to inspect, so the level of nutrients or the physical texture and the relationship to a reference may provide data to determine the condition. For example, in this study a number of the soil variables are significantly different to the reference site measurements and at least two, total N and Olsen P, are well outside the range reported in other studies for native forest and thus they may be seen as poor in the condition description. This is reported in Chapter 5. As these are also are variables that influence floristic vegetation (refer Chapter 4) they may be of particular importance.

A table may be produced for each of the identified landform components as suggested by Brierley and Fryirs (2005; 317). This is a matrix "developed to assess the condition of a reach", whereby the practitioner assigns ticks or crosses in answer to the table of "desirability questions" constructed for each style as shown in Table 1. In their guidelines, the authors' state that three ticks signify good condition, two ticks or crosses signify moderate condition, and three crosses signify poor condition.

Table 1: Matrix displaying template for assessment of a theoretical geomorphic river condition (Brierley and Fryirs, 2005).

Geomorphic river condition	Channel attributes	Channel Planform	Bed Character
Good	✓	✓	✓
Moderate	✓	×	✓
Moderate	×	✓	×
Poor	×	×	×

3.2 Recovery Potential

Although the River Styles framework was created for river management a similar set of principles would be a reasonable template for consideration of other components of the landscape. It would be possible to have a nested hierarchical model making it suitable for large and small scale analysis. A flexible format may be required for landscapes beyond the riparian zone since the cascade of process/form relationships are not necessarily commensurate with a fluvial system, nor are the rates of the processes similar between the two. Firstly the definition of recovery potential is presented. Recovery potential in River Styles is divided into three classes which fit reasonably well for all landform components and are detailed in Table 2.

Table 2: Definitions for high, moderate and low recovery potential of the geomorphic condition as presented by Brierley and Fryirs (2005; 327).

Term	Definition
High Recovery Potential	Landform is in good geomorphic condition and is located in a position where the potential for deleterious impacts is minimal. These landforms or compartments are commonly found in upper parts of catchments.
Moderate recovery potential	Landform is either resilient to change but in moderate or poor geomorphic condition, or is in good condition, but sits downstream of a poor condition reach. The potential for off-site impacts and limiting factors propagating into the landform compartment is high.
Low recovery potential	Landform is in poor geomorphic condition, is sensitive to change or sits at a position in the catchment where pressures and limiting factors are likely to have negative off-site impacts that will impact directly on the future condition of the reach. Often these landform compartments sit in the most downstream sections of the catchment, where the cumulative effects of disturbance are manifest.

The definition for the specific levels of recovery potential is particularly meaningful for a fluvial situation and the transport system that it entails. In a New Zealand hillslope and associated landform context I think that it is still useful as there is connectivity within slopes and in most cases impacts affect areas down-slope not up-slope, e.g. deposition of colluvium following a mass movement event. Within a hillslope complex lateral geomorphic connections or adjacencies may also have some effect but they may be quite localised, for instance, the edge of a mass movement scarp. An exception, though not relevant to this case study, would be aeolian processes and sand dunes. Lateral connection is to some extent addressed in the decision tree (Figure 2) by the question related to the isolation of the landform. It may be that this decision tree could be further amended to take more account of the condition of adjacent landforms and the active processes or limiting factors found there.

In an ecological context the lateral consideration is important in terms of edge effects related to the patch (remnant) size and shape. Regarding the situation at the Whareroa sub-catchment study site (refer Figure 3) this is not a consideration as there is no presence of native vegetation to account for. However, if the case study was examining the areas adjacent to the current study where remnant patches of bush are present then lateral adjacency would need to be factored into landform condition and recovery potential.

The decision tree that Brierley and Fryirs (2005) present gives a logical stepped process by which to arrive at decisions regarding the recovery potential of the element under examination. I have transposed the word "reach" with "landform", for landform component (for example, gully, spur, ridge, colluvial fan, alluvial terrace etc), and it is evident that the tree is a useful tool to aid decision making. The questions presented in the decision tree relating to resilience or sensitivity will need to be assessed in relation

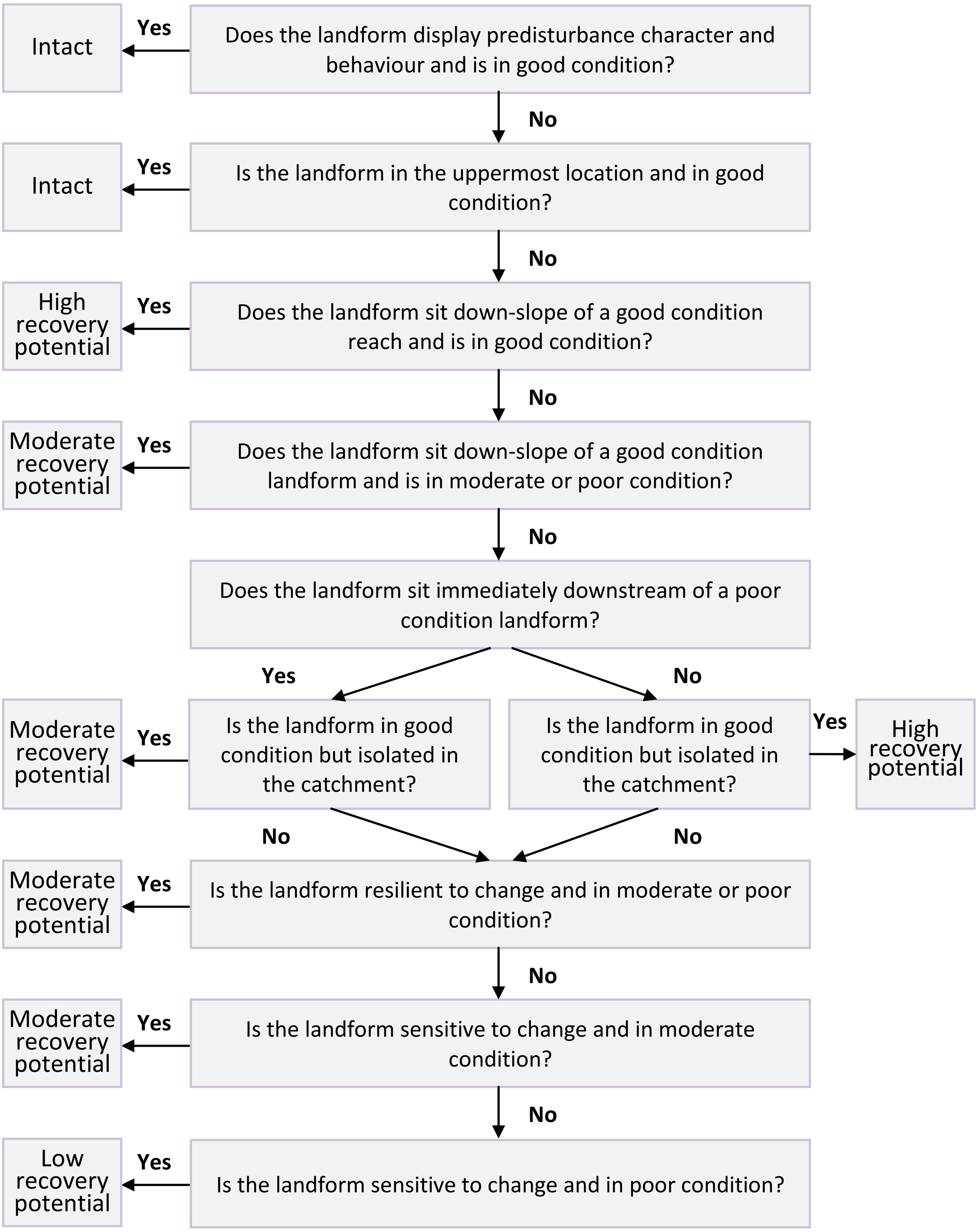


Figure 2: Landform condition and recovery potential decisions tree (adapted from Brierley and Fryirs, 2005: 340).

to each landform component. For each there will be different boundary conditions and measuring sticks. For example, a wetland will be very sensitive to the alteration of drainage patterns and hydraulic connectivity. Slopes will differ in sensitivity depending upon numerous factors including susceptibility to slope failure due to geology, soil parent material, slope aspect and angle or presence/absence of vegetation. Resilience may be greater in those components less sensitive or which respond well to the removal of the stressor.

Figure 3: View into gully system at Whareroa Farm used as the study site (Photo: Cooper, 2010).

3.3 Assessment of geomorphic recovery potential

To limit the scope I have reduced the amount of contributing analysis that accompanies Brierley and Fryirs' backgrounding for assessment of recovery potential. This is not to say that it would not be valuable in another context, but it is beyond the scope of the study. In this section I outline a sequence of steps that will provide a means by which geomorphic recovery potential can be assessed that is pertinent to this study. It is adapted from River Styles® and is used as the framework to make conclusions following the assessment of recovery potential. The purpose is to methodically consider the likelihood of the geomorphic system, and each of the landform components, to recover from a degraded state and for the site to return to a pre-disturbed equilibrium. The steps that direct this analysis are:

1) Determine the trajectory of change; does it lead to recovery, continuing degradation or an altered state.
2) Assess the capacity for the component condition to adjust or revert to the pre-disturbance state.

3) Determine if there is the presence of indicators which are out of balance, and whether the stressors can be adjusted so the trajectory of change moves towards recovery.
4) With respect to the indicators that have been determined to be outside the range of expected values, as understood from the reference condition, what is the likely impact upon a recovering native floristic vegetative community assemblage?

Each of the steps articulated above will now be discussed with reference to Whareroa Farm.

1) Determine the trajectory of change; does it lead to recovery, continuing degradation, or an altered state?

With an interpretation that involves Whareroa Farm, given the ongoing land management, the trajectory is one of maintenance of a degraded state but still marginally within the normal dynamic equilibrium. With continuing increased disturbance (due to the lack of woody vegetative cover) over a long time period a new (degraded) stable state may be induced, one with a reduced equilibrium soil depth. An altered stable state is unlikely to be an immediate concern as indicated by the geomorphic analysis in Chapter 6. Conversely, unless there was a change of land use, recovery is not a likely scenario without intervention in the short term.

2) Assess the capacity for the component condition to adjust or revert to the pre-disturbance state.

The recovery potential is dependent upon limiting factors that operate within the catchment. Limiting factors can be seen as factors that restrict the potential of the landform to be mobilised in a direction towards recovery of form and processes associated with a pre-disturbance state. Limiting factors for restoration may include:

- Chemical alteration of the soil
- Active erosion (which is outside the normal range)
- Absence of a seed bank for recovery to take place spontaneously
- Distance from seed propagules, or absence of vectors of dispersal
- Presence of invasive organisms e.g. pasture sward, browsing animals etc.
- Human activities
- Political and economic policies
- Social attitudes

Limiting factors such as these have both a direct and indirect impact on recovery potential. For some, such as active erosion, the severity of the erosion will establish the recovery potential as may the location within the catchment. Another consideration would be the time frame it may take to stabilise the erosional process and how much effort it would take. Less obvious may be the presence, and consequences, of pasture due to its ability to prevent some species of plants establishing via windblown seed. In a situation such as this, the eventual conclusion regarding recovery potential may then be framed by the vision of the restoration project and the expectations concerning the community assemblage. The use of species unable to compete with exotic or invasive plants is debateable. A similar type of choice may be presented with regards to species suitability in association with sites of mass movement.

3) Gauge whether there are methods to adjust conditions or indicators which are out of balance.

Considering the indicators that have been determined to be outside the range of expected values as understood from the reference condition what is the likely impact upon a recovering native floristic community assemblage? In the analysis of soil variables it was concluded that there were significant differences in the levels of soil chemical levels between the restoration site and the reference site. Subsequent examination comparing them with what is expected or found in other native forest sites found total N and Olsen P to be highly enhanced at Whareroa in the landform units sampled (refer Chapter 5). I have detailed this in earlier chapters, here I discuss remediation feasibility.

Kulmatiski and Beard (2006) investigated the use of activated carbon, in part, to decrease the mineralisation of N and P (among other things) in a shrub-steppe setting in Washington, USA. This was a small field trial where all vegetation was killed with herbicide followed by raking activated carbon into the soil and subsequent reseeding with a mixture of species. The results showed greatly reduced levels of N and P. The effect on native grass species was to increase their abundances with the expectation that this trend would continue due to their perennial life history compared to shorter lived exotics. While this may not be generally feasible in terms of labour and cost, such strategies may be suitable in some circumstances.

Similarly, Prober et al. (2005) attempted to restore the balance of the nutrient cycle in Australian open woodlands with the addition of sucrose and alternative fire regimes to encourage native grass and discourage exotic species. The author's results, while preliminary, showed encouraging signs that species preferring a low nitrate state were benefitting. A similar study by Paschke et al. (2000) in an American plains setting demonstrated similar findings. Others discussing mitigation of high nutrient levels and advocating adjustment by addition of carbon are Heneghan et al., (2008) and Bleier and Jackson (2007). Examining a different strategy, Curtin and Syers (2001) found that the addition of $CaCO_3$ (lime) to some soils in New Zealand reduced the amount of P in the soil by adsorption to Ca. In doing so the soil pH is increased as well and this provides an additive affect. The above indicates that it may be possible to reduce nutrient levels but the cost and/or amount of effort required may be an impediment.

Physical factors that are out of normal dynamic range will be particularly difficult to adjust in steep terrain. For instance, bulk density has been found to be at the fringes of being a limiting factor for vegetative growth, especially at north facing convex creep zone sites (Chapter 5). What may be possible on easy or rolling land is not feasible in steep sites, where ripping or ploughing are not options. In these circumstances other approaches may be necessary, including not attempting active restoration. Similarly, texture is found to be different between the restoration site and the reference site, but there is unlikely to be a way to adjust the relevant proportion of sand, silt and clay. Instead of mitigating for either of these physical soil elements it is suggested that careful species selection may be the only alternative if active planting is attempted. The ordination in Chapter 4 gives insights into the relationship between soil physical and chemical parameters and species which will be useful in guiding selection.

4) Considering the indicators that have been determined to be outside the range of expected values (as understood from the reference condition) what is the likely impact upon a recovering native floristic community assemblage?

While this step does not directly address a geomorphic question alone it is important to consider the relationship with community assemblage. The literature shows that certain nutrients are limiting factors in New Zealand indigenous forest. The main one cited is phosphorus. Enhanced nutrient levels do seem to have an effect on the composition of secondary regeneration (Sullivan et al., 2007; Wilson, 1994; Williams, 1983). This may have a negative effect if desired species of the restoration community are particularly adapted to nutrient-poor conditions and are out-competed by unwanted species tolerant of higher levels of nutrient. In a general sense, the heightened level of nutrient in the fluvial system is another issue that may need addressing during restoration of streams, wetlands or lakes. At Whareroa there may also be some effects induced by soil texture alterations following erosion processes changes but other than noting the correlations in the ordination I have been unable to locate affirmation of this finding and with this lack of corroboration any recommendation would be unwise.

4. Geomorphic condition and recovery potential analysis: Application to Whareroa Farm case study.

Having presented and discussed the various elements of the methodology related to geomorphic condition and recovery potential this section demonstrates the method as applied to the separate landscape components of Whareroa Farm restoration site. The tables display the assessment of geomorphic condition while the recovery potential is determined by following the decision tree. In contrast to River Styles, which only contains three parameters, the condition assessment table for terrestrial landscape components contains between three and five parameters. Also the assignation of the geomorphic condition varies from River Styles. If the landform component has one tick the condition is deemed poor. If there are two - three ticks dependent upon the number of parameters considered for the landscape component it will be moderate or good. If all components are ticked the condition is good. A parameter such as soil may be difficult to assign to a class as it may be considered as poor condition due to enhanced nutrient status and be very shallow too. The depth of the soil may, none the less, be a natural condition so there is an ambiguity in that case. In the analysis of each of the landscape components I have detailed the reasoning behind the decisions in an attempt to take such ambiguities into account.

With consideration of the conditions at Whareroa and given the data collected and analysed, table 3 shows an assessment of a convex spur.

Table 3: Assessment of geomorphic condition of a convex spur landform component.

Geomorphic condition	Soil	Vegetative cover	erosion	Channel incision	Stream Bank Stability
Poor	×	×	✓	n/a	n/a

Figure 4: Image showing drying pattern of north facing spurs in early summer (Photo: Cooper, 2010).

Figure 5: Soils on side spur indicating the shallow depth on this landform component (Photo: Cooper, 2010).

Soil is seen as being in a less than desirable state for two reasons; firstly, due to the enhanced nutrient levels found (Chapter 5), and secondly, the observation that these areas dry early in summer (Figure 4) indicating a shallow depth (Figure 5) and consequently low water-holding capacity. If this analysis was to consider each separate spur in both north and south facing catchments it may be that the drying effect is not as severe in the south facing aspect. There is no native vegetation, but no or little erosion. Observation of the pattern of regeneration in the retired parts of the farm (Figure 6) shows that spurs are the least likely, or alternatively the last, area to have woody vegetation. In comparison, at Paraparaumu Scenic Reserve forest canopy height is less than other landform units, possibly a reflection of the soil/environment nexus. Hence, the condition of the spur at Whareroa may not be far from a natural state. This would

Figure 6: Pattern of revegetation on the eastern sector of Whareroa Farm showing the ridge tops being the last landscape component to be revegetated (Photo: Cooper, 2010).

point the assessment of the condition to the moderate classification.

Using the decision tree the conclusion would indicate a low recovery potential. This may be so for the short to medium term but in the longer term conditions will be such that native vegetation could be successfully returned once regeneration around them reduced the exposure of these areas to solar radiation and winds.

With respect to a side gully an assessment may follow table 4

Table 4: Assessment of geomorphic condition of side gully landform component.

Geomorphic condition	Soil	Vegetative cover	erosion	Channel incision	Stream Bank Stability
Poor	×	×	×	✓	n/a

Figure 7: Gully erosion on eastern spur (Photo: Cooper, 2011).

Figure 8: Active side gully erosion (Photo: Cooper, 2011)

Soil is seen as poor due to the altered nutrient levels, though this is not necessarily a problem for vegetative growth but may be a potential problem for species composition. Vegetation cover is a grass sward with thistle and gorse interspersed, not native vegetation. Erosion is concentrated in this landform component and evident in the convergence swales and side walls, (Figures 6 and 7) but there is no channel incision. Although there is one desirable attribute, no channel incision, in a zero order or first order basin this condition is not likely to be found as the flow accumulation is not great enough to cause channelisation. Hence, instead of considering this landscape component moderate I consider it poor. Turning to the recovery potential, my assessment would be that, at the seventh question, the landform is resilient to change by virtue of the fact 1) that grass returns to mass movement scars and 2) that on the slopes of the farm which have been fenced off from stock woody reversion is taking place successfully. Therefore there is moderate recovery potential.

The third major component of the restoration site is the ephemeral swale.

Table 5: Swale of major tributary side gully.

Geomorphic condition	Soil	Vegetative cover	erosion	Channel incision	Stream Bank Stability
Moderate	×	×	✓	✓	n/a

Soil and vegetative cover are as discussed above. There is little erosion of significance except for one of quite large size near the head of the main swale. There are no isolated channelised sections before the knickpoint, from which point the discussion happens under the stream component. The swale is not an erosional area normally, rather one of transport and deposition. Deposition is evidenced by instances of rafted blocks of debris from mass movement events in the contributing side gullies. Water-holding capacity of the soil appears reasonable as observed in Figure 4 which shows the difference between the desiccated spur tops and the green swathe in the concave elements of the catchment in early summer (refer Figure 4). This landform can be reasonably described as in moderate condition and ostensibly it may be expected to have high recovery potential. However, the decision tree (questions 5 and 6) indicates that due to it being below a landform of poor condition (the gully above) the recovery potential is reduced to moderate. This last point is a good cue for consideration of what types of management could be implemented to ameliorate the situation and will be discussed later.

Figure 9: Rounded U shape of side gully with scree fields present (Photo: Cooper, 2010).

The state of the stream that exists in the lower part of the sub-catchment has not been a focus of this study, due to limitations in time. Thus, no measurements have been undertaken. The following is a reflection on the conditions based on observation.

Table 6: Geomorphic condition assessment for the first order stream.

Geomorphic condition	Soil	Vegetative cover	erosion	Channel incision	Stream Bank Stability
Poor	×	×	×	×	×

Figure 10: First order stream incision with bank instability illustrated (Photo: Cooper, 2011).

Figure 11: Stream incision and surrounding vegetation (Photo: Cooper, 2011).

The soil is assessed as poor though it may not be reasonable to infer from sites tested in other locations of the catchment. As discussed above there is no native vegetation, though some sparse gorse exists but not with an effective shading habit. Erosion is quite common on the bare steep banks. There is deep incision; more than seems reasonable for the size of the contributing catchment (see Figures 2, 10, and 11). The banks display evidence of frequent collapses, particularly in the lower segment. Along the length of channel inspected there is no evidence of bedrock so there is no constraint or confinement to the continued incision. These observations indicate the landscape component is in poor condition.

Only some parts of the fluvial channel at Paraparaumu have been observed due to difficult access. In this undisturbed environment there are sections where there is little vegetation, possibly due to the nature of the loose gravelly scree and soil and heavy shade. Conversely, in some places where there are narrow alluvial terraces ferns can be quite dense. This commentary on Paraparaumu Scenic Reserve is to acknowledge that given the rocky colluvial nature of the fans at the bottoms of the side gullies that stable vegetated channels may not be a natural thing.

Use of the decision tree produces an ambiguous result. The landscape component sits downslope of both moderate and poor elements. If the component was isolated from other elements by moderate condition elements (by way of restoration action, involving replanting) then this could be interpreted as moderate recovery potential and action implemented at a second or later stage.

This section has presented a general framework which is an interpretation of the River Styles framework and illustrates its use by examining the site at Whareroa. It demonstrates that it is useful even at the zero to first order basin scale, and seems likely that it would be of greater assistance for larger scale work, for example, large pastoral hill country farms and higher order stream catchments. It does clarify information that might otherwise be lost in the plethora of options and data that surround ecological restoration. It does so by simplifying the understanding of the general condition, which in a hierarchical analysis could be scaled to individual landform components. It is somewhat subjective but much of the background to the classification can be of a quantitative nature, providing more certainty. Completing the analysis above helped me to have a higher level of confidence about the nature of the landscape, its condition and recovery potential, and overturned some earlier notions regarding priorities.

5. Catchment based restoration prioritisation assessment.

Overarching the prioritisation activities is the vision that is developed for the restoration project. Without knowing what the spark for the project is and what eventual outcome is desired it is not possible to plan and prioritise the envisaged work. Having an inspiring vision sets the scene for the ensuing aims and objectives. If there were unlimited resources prioritisation would not be an issue. It is extremely unlikely that limitless resources will be the case, and so to obtain the best return for the labour and financial cost with a high rate of planting success in the short term, and a healthy and desired community within a functioning ecosystem in the longer term, prioritisation is required.

Stepping back for a moment, the debate regarding intervention or spontaneous rehabilitation is pertinent (for instance, Prach and Hobbs, 2008). This has been touched on in discussions regarding the successional trajectories and eventual community composition in Chapters 2, 4 and 5. It may be that following an analysis of the site, in certain circumstances, the decision is to allow “nature to take its course” that is, the do nothing option. However, with one aim being to speed up the recovery through successional phases and another being to guide the restoration to a “more natural” community composition than may eventuate if the site is left to its own devices given its disturbed state, an active restoration intervention is often chosen. In most cases the project will be too large to achieve in one fell swoop. Even if it is possible to complete in one specific intervention success may be compromised as a sequential pattern of restoration may be required to ensure success of the establishment of later successional species. Additionally, abiotic conditions may need correction to restore some ecosystem processes prior to revegetation as suggested in Hobbs and Harris (2001) model (Figure 4, page 107).

Thus it will be necessary to prioritise the work. As already conveyed in this thesis the amount of information can be daunting, the magnitude of work huge, and the complexity of the data confusing. Brierley and Fryirs (2005) detail an ordered sequential prioritisation assessment for a restoration project which assists in reducing the complexity. This follows the philosophy of conservation first and restoration next. I have adapted the sequence slightly to read as follows:

1) What identified rare species or ecosystems are present?
2) Take action on strategic areas that may assist with the recovery of downstream or adjacent areas.
3) Act on those areas where success is likely to be achieved
4) Consider the more difficult challenges.

By reference to the restoration site I describe each of the sequential steps, from highest to lowest priority, below.

1) What identified rare species or ecosystems are present.

This study has focussed upon geomorphic elements of the environment which impact on the floristic abundance and community. The study site is a farm gully in pasture with no woody vegetation except gorse. In a more general situation the first priority would be to conserve any rare or important species or ecosystems. Consideration of threatened species/ecosystems could also be prioritised. If restoring all of Whareroa Farm, then if one of the remnant forest patches was found to have an uncommon instance of mature northern rata on the Kapiti/Horowhenua lowlands or an endangered land snail, the remnant forest may be the first priority. Returning to consideration of the gully system studied there are no such instances, though Whareroa Stream does sustain populations of native fish in the lower reaches in Queen Elizabeth Park (Palmer, 2008). If the fish population was a target of restoration then the upper catchment would need prioritisation consideration due to the hydrological connectivity with the lower stream reaches. By focussing on the study site alone, there are no rare species identified and so no prioritisation necessary. If the site was considered in terms of its classification as a coastal lowland ecosystem it would be considered to be rare, particularly on a regional basis. This is borne out by the fact that the site selection process produced very few possibilities as reference site choices for the less steep, loess hillslopes (LENZ environment F1.4a-b) and virtually none for the colluvial footslope/alluvial terrace environment (LENZ environment C2.1e).

2) Take action on strategic areas that may assist with the recovery of downstream or adjacent areas.

Even allowing for the input of the quantitative assessment that informs the preceding framework elements, deciding on strategic areas is more arguable than consideration of rarity. If there are rare species in the stream channels, even if they are at some distance, the riparian zone in the upper reaches may be seen as strategic. When the slopes are subject to erosion this becomes more significant. Earlier I have outlined the geomorphic condition and the recovery potential for various components of the landscape. That earlier analysis demonstrates that the swale is susceptible to up slope processes, and this is linked quite closely within a small catchment to the first order stream (as demonstrated in Chapter 6). Following this logic it may be that although the swale was determined to be of “only” moderate recovery potential, the fact that this is the ephemeral transport zone to the active channel it would be a priority to restore.

The fact that it is downslope of a poor condition landscape compartment, the side gully(s), which are well connected (Chapter 6) means that physical barriers may be required to help reduce the amount of sediment reaching the swale and impacting on restoration plantings there. In some mature plants this may not be an issue as some New Zealand species have adapted to such conditions and have adventitious roots which may sprout from buried stems and trunks (Burrows, 1963; Wardle, 1963). For new restoration planting complete burial may be possible where adventitious roots are unlikely to be a saviour. Fox et al. (2006) make a case for placing barriers in their study of a Mediterranean forest following fire. Artificial barriers or sediment trap fences may be required until the planted trees are significant enough to resist, to some extent, the depositional processes of mass movement activity.

Barriers that reduce the connectivity of the slopes to the swale will help to reduce the particulates but there may still be some nutrient solute that escapes into the fluvial channel (Parkyn, 2004). Parkyn (2004) advised that the width of the buffer is critical, needing to be 10 – 13 m width, which filters the particulates but not all the solute. It may be in this zone, which is most easily worked, that carbon addition to the soil is considered. In light of these facts it would seem that the swale is a strategic area, one that would be relatively easy to successfully restore as a priority. By revegatation of this zone the roughness level of the surface will be increased in turn reducing storm surface flow. Hence the peak velocity of water discharge into the stream channel is lessened possibly reducing erosion of unstable banks. Restoration of the swale then acts to protect a downslope component of the landscape.

Figure 12: Knickpoint of main gully showing some erosion (Cooper, 2011).

Other zones that may be critical are the stream banks. Since the length of the stream in the study area is not large this may be another feasible project which might also be seen as a strategic area with moderate recovery potential. The research that shows that streambank erosion can be a prime source of remobilised sediment (Preston et al., 2003) within the fluvial channel would lend weight to action in this zone. Stabilisation may be undertaken as a second stage in following years once the swale area above the stream is established thus reducing the magnitude of the run-off which is likely to improve the chances of stream bank stabilisation. Although it may be difficult to stabilise the banks, action could be taken to improve the quality by ecological engineering. This may take the form of rip rap, providing toe support and reducing undercut by the action of the water, placed under steep active eroding banks. Also barriers (logs, boulders) could be utilised to reduce velocity and simultaneously create refugia for aquatic stream life, keeping in mind the stability of the banks. The knickpoints (Figure 12) representing the beginning of the active first order channel should receive attention as stabilisation will prevent upslope migration.

3) Act on those areas where success is likely to be achieved

In terms of the catchment studied the swale and riparian zone of the fluvial channel have been seen as strategic and may also have moderate to good recovery potential given that waterholding capacity appears to be enhanced in this zone. These areas are also the convergence zone for moisture so plantings would be able to survive dry hot summers with greater chance of success. Additionally, knickpoints and seep points (Figures 12 and 13) which may have a tendency to erode could be prioritised if not at the strategic level then at this third level. Success may be enhanced due to the intrinsic water availability.

Another component of the landscape to fit in this category would be the contributing side gullies. While these were categorised as poor condition, it was also seen that they should have moderate recovery potential. These are the areas of most erosion and any scars with steep scarps would be of particular concern (refer Figure 7 and 8) and require stabilisation with plantings. Further levels of prioritisation may take into account the slope aspect and angle which was the focus of Chapter 6 along with the erosion susceptibility analysis. This analysis highlights the north facing aspects being susceptible to erosion and also the worst affected by past erosion. Most of the side gullies will be of steep angle and it may be difficult to differentiate as all north facing slopes above 18° are susceptible. The side gullies areas may be acted upon after

Figure 13: Seep near bank of stream with tendency to collapse into stream bed and so create pressure on the opposite bank by flow diversion and subsequent undercutting (Cooper, 2011).

barriers have been engineered at the entry point to the swale of the main gully.

Where considering gullies with chronic active erosion other strategies may take precedence. Instead of attempting to plant the swales the whole slope beyond the active area may need to be the priority. This is the strategy introduced to reduce the ongoing erosion from major gullies in the Mangatu Forest on the East Coast (Marden et al., 2005). It highlights that not all situations will have the same approach. In the case of the study site there are no large scale aggressively active sites. However, mass movement scarps that may be susceptible to ongoing erosion are evident (Figure 8 is an instance) and so action to stabilise these may be considered at this point.

4) Consider the more difficult challenges.

Landscape components that would seem to be the most challenging are the north facing upper slope and spur tops (refer Figures 4 and 5). Their location means that they experience the full brunt of the desiccating and predominant north westerly winds and the full sun. These sites dry out earlier than other locations which reflect the low soil moisture holding capacity which may be due to the shallow soil of the narrow tops. This may not be the case for the south facing ridges but observation of the naturally regenerating areas of the farm seem to confirm the ridge/spur tops return to woody vegetation last.

This section on a prioritisation strategy has outlined a path by which the complexity of data may be plugged into a framework that helps to logically place the information into a restoration planning context. What has been described in no way reflects a restoration plan, but does provide a structure that may help to inform a restoration plan. The framework is based, very closely, on Brierley and Fryirs River Styles® (2000, 2005) framework, but only includes a fragment of the investigation that their system encompasses. The scope of their framework is so large that it has not been fully explored here, but I think that the essence for application to hillslopes is the emphasis on geomorphology, the connectivity of components of the landscape, and also the structure with which to guide decision making. The structure that is utilised here could be expanded and also tightened along with a deeper explanatory accompaniment. Inclusion of elements of the biological parameters such as biological corridors, patches, seedbanks, and dispersal agents will also have to parallel the investigation detailed here. None the less, I believe that it is been useful in the final analysis and with some further consideration could be a valuable tool for geomorphic assessment of restoration sites beyond the riparian zone.

6. Conclusion

The aim of this thesis was to examine how geomorphology may inform ecological restoration practice. Besides reviewing the literature a case study was undertaken focused upon a zero to first order gully system at Whareroa Farm. To provide information for this examination 5 core questions were posed. In Chapter 3 I investigated the use of national databases in a GIS environment to determine if this was a robust method to select a reference site. Using ArcGIS software with its inbuilt tools this process was reasonably simple with no need to resort to computer language script. The result was successful and without this method I may not have chosen the site that I did. Certainly, from anecdotal conversation Paraparaumu Scenic Reserve was not a target, but proved to be a very good reference for Whareroa Farm.

The selection of a comparable site was important to ensure that results related to differences in soil variables between the restoration site and the reference site, and the significance of explanatory geomorphic factors was meaningful. Also a robust site selection was required in order to give weight to results regarding vegetation abundance and composition and the relationship with soil variables and geomorphic factors. Without ensuring the reference site was a true template for the restoration site the information contained in the balance of the study would have been devalued. While the study does not approach the issue of species selection for the restoration site the relationships provide important input for that stage of a restoration project.

Chapter 4 examined the relationship between the floristic vegetation community composition, its abundance, and selected environmental gradients (geomorphic factors and soil variables). Soil samples were collected from chosen landform units and a group of indicators that may influence vegetation was measured. Centred upon the soil sample sites vegetation abundance was estimated within defined quadrats. The data were analysed by the use of ordination techniques to reduce the complexity of the data cloud and to elucidate the main relationships. From this I found that the most influential gradients were hillslope location (landform unit), C:N ratio, total N, and slope angle.

With consideration of the soil variable and geomorphic condition as measured at Whareroa I discussed how the knowledge of the relationships displayed by the ordination may be translated into practical application in a restoration context. Particular emphasis was placed upon the relationships between floristic assembly and physical and soil factors that are outside their normal range at Whareroa. In the restoration prioritisation process decisions will need to be taken to either; a) take action to return the factor to its normal range; or b) amend the species that may be chosen for the site given the abnormal condition of the factor.

Associated with the vegetation analysis described above, Chapter 5 examined soil variable values at Whareroa Farm and Paraparaumu Scenic Reserve, the differences between the sites and the relationship with a set of independent geomorphic factors. Soil samples were collected at the reference and restoration sites and analysed to assess the differences that may be explained by land use change, slope aspect and angle, and hillslope location. This found significant difference in soil variables dependent upon some of the factors, with the land use factor being strongly associated with significant differences in the measurements, as was slope angle and, (for fewer variables) also hillslope location. Slope aspect did not have a significant effect upon the variables other than soil texture. The mean values were outside the range of expected values for an indigenous forest soil, particularly for total N, anaerobically mineralisable N, Olsen P, and pH. This chemical state will have an influence on the species composition in a restoration context and may need addressing where possible. The data collected, when interpreted within the model (Figure 4, Chapter 6) that Hobbs and Harris (2001) produced, indicates the abiotic element of the ecosystem requires, if not remediation then specific strategies to address the disequilibrium of soil chemicals, prior to biological restoration.

The geomorphic condition at Whareroa Farm was analysed in Chapter 6. Here I was interested in the sub-catchment's susceptibility to erosion. To achieve this I analysed a chronosequence of six aerial images covering the period 1942 – 2010, by mapping the visible instances of mass movement. Analysis was carried out which identified patterns and provided information about the physiographic location of these events, and which also identified the susceptibility regarding future occurrences. While the total area of mass movement in comparison to the whole farm was not found to be very high, concentration of erosion was found to be strongly dependent upon slope aspect (west to northeast) and also to slope angle, with slopes greater than 18° showing propensity for failure. No strong correlation was found between instances of new mass movement and sites of previous slope failure. This information can be utilised when considering prioritisation of the restoration activity.

A fine scale DEM was produced which was used to examine the hydrological connectivity of the slopes with the swales and subsequently the fluvial channels. This indicated that the sub-catchment was well connected with few buffers or barriers to sediment reaching the channels from the slopes. This knowledge can be seen as having ramifications for downstream restoration activities undertaken to improve stream quality. It also provides valuable information that helped to reach conclusions about strategic sites for restoration and assisted with prioritisation decision making.

Finally in this chapter I have presented a framework based directly upon the River Styles® framework of Brierley and Fryirs (2005). The intent of the framework is for a geomorphic analysis to guide river management and restoration. The structure used in my analysis is a simplified version produced so that a logical method of utilising the information gathered in the preceding investigation can be usefully applied to decision making within an ecological restoration plan. While I don't proclaim this interpretation to be fully realised (a job outside the scope of this study) the structure was of value to take the accumulated disparate information and produce a means of prioritising action that would be of value as input to a restoration plan. It may simply confirm perceived wisdom, and also when considering nature's own practice, produce results that mimic it.

Hopefully that is so. At least it may give some guidance in situations where there are many problems to tackle with limited resources.

The analysis of geomorphic condition and recovery potential helped to identify strategic locations in the restoration site. The understanding brought by quantifying the degree of connectivity of sediment between slopes and streams, along with the knowledge of ecology, indicates that strategic points that reduce the connectivity would be a high priority for restoration activity. These sites may be seen to have more priority than riparian restoration downstream due to the effects of sediment (and chemical solute) transportation. The assessment framework is qualitative so subjectivity is introduced but much of the background input is quantitative and having a structure helps to reduce the complexity intrinsic in ecological restoration and so improve decision making.

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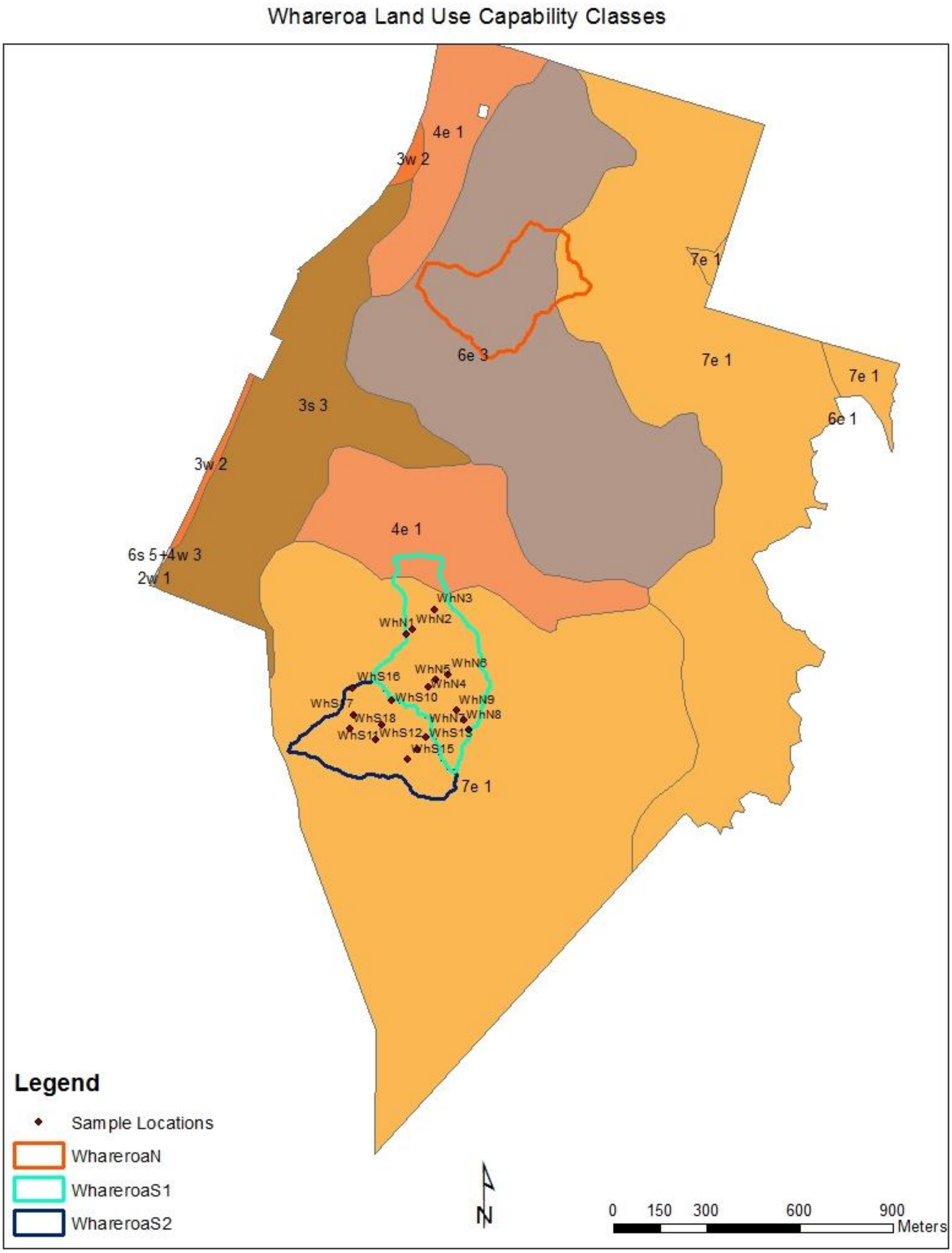
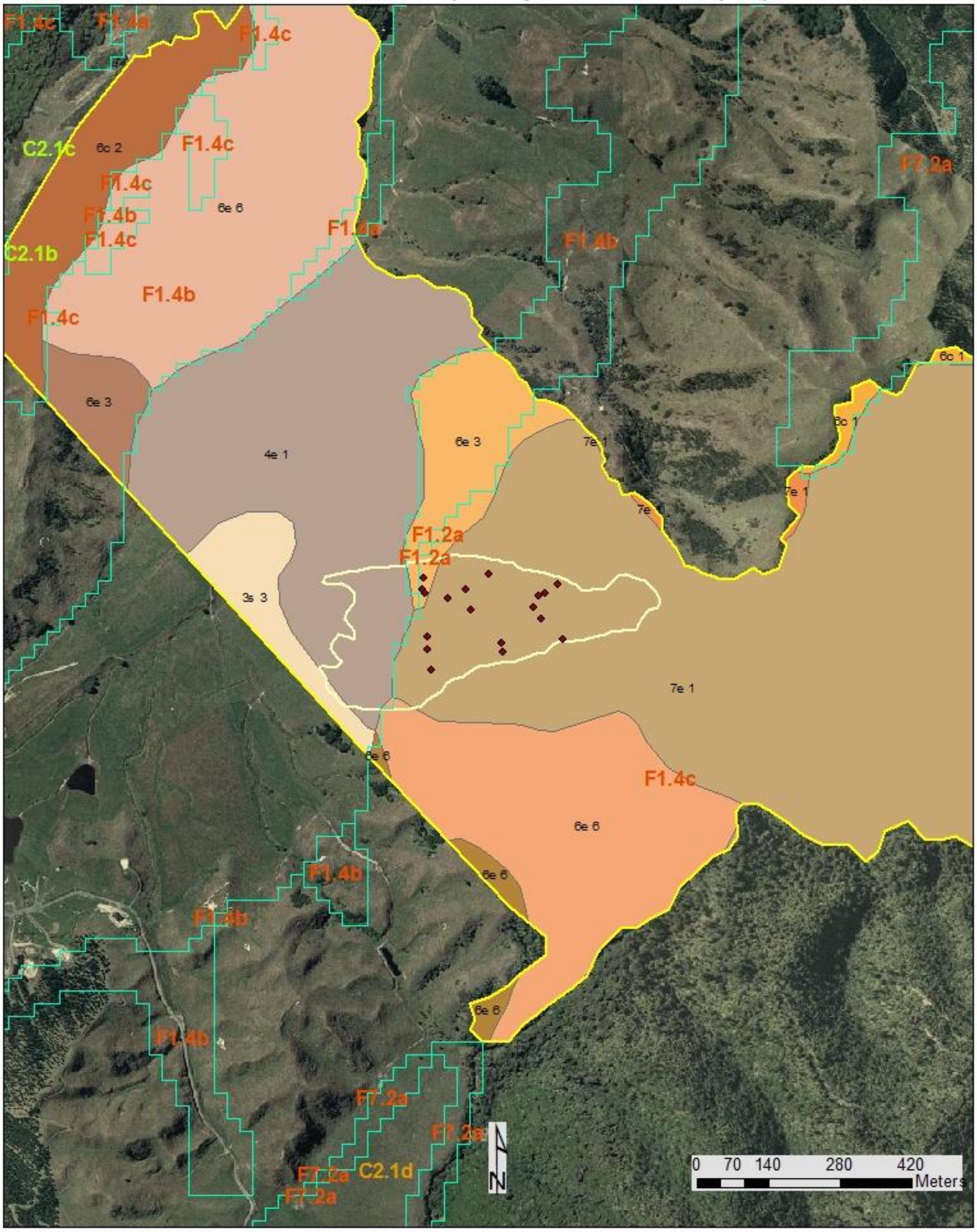
Note for the appendices: The first number of each appendix relates to the relevant chapter of the main body.

Appendix 1.1: Land use capability class map for Whareroa.

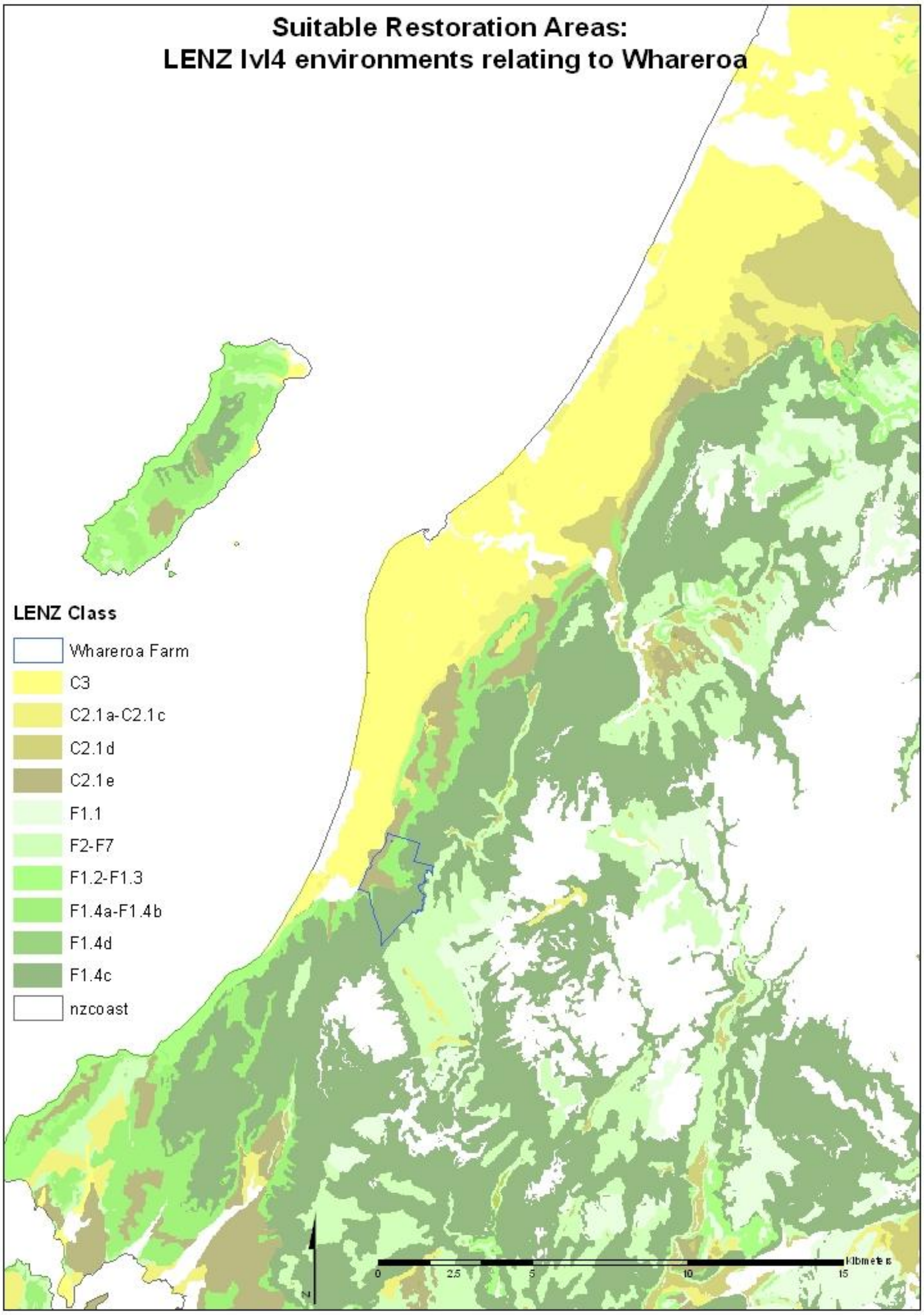


Appendix 1.2: Land use capability classes for Paraparaumu Scenic Reserve.

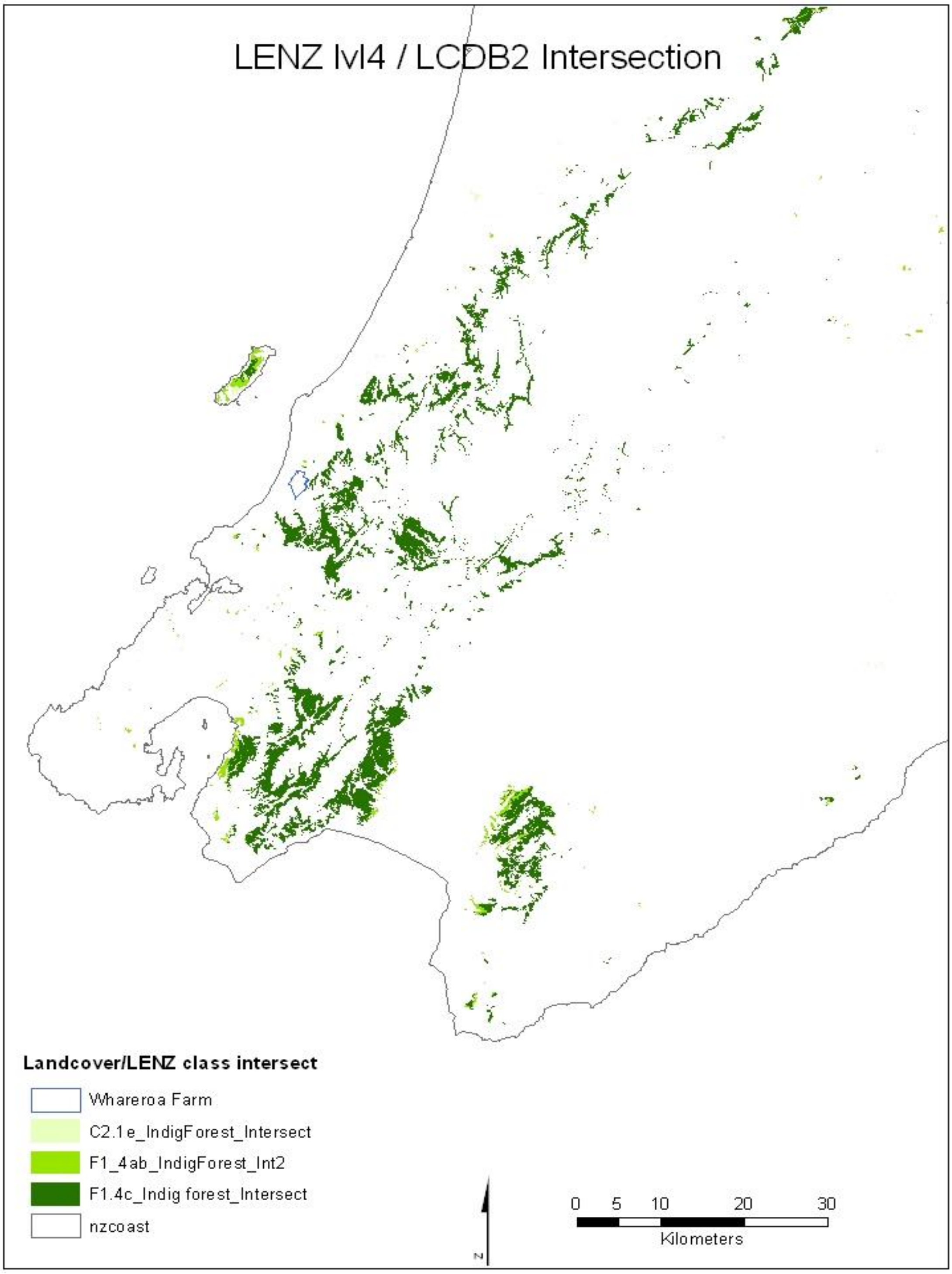
Paraparaumu Scenic Reserve:
LENZ classes, land use capability class and sample points



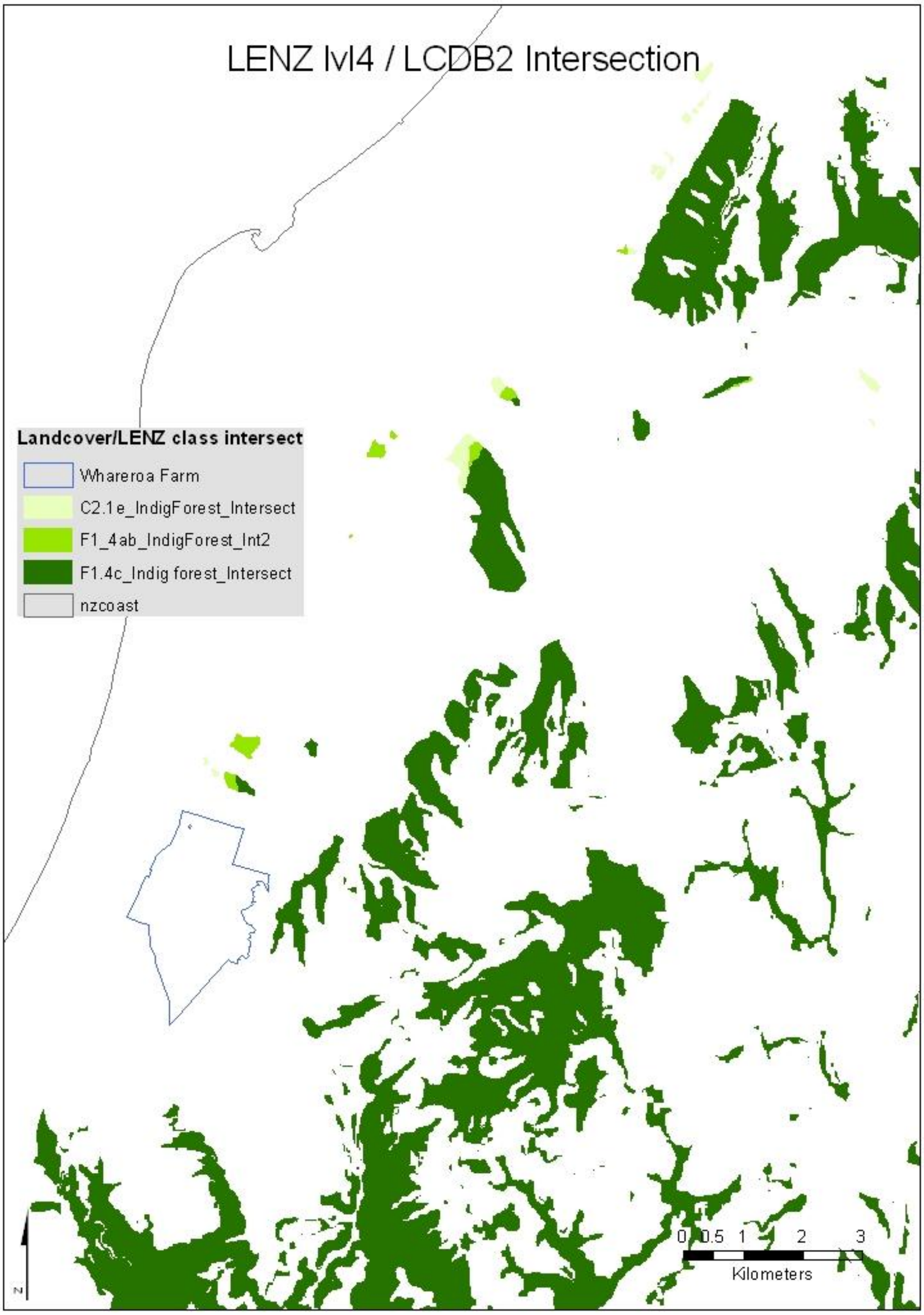
Appendix 3.1: LENZ classes for lower west North Island, New Zealand.



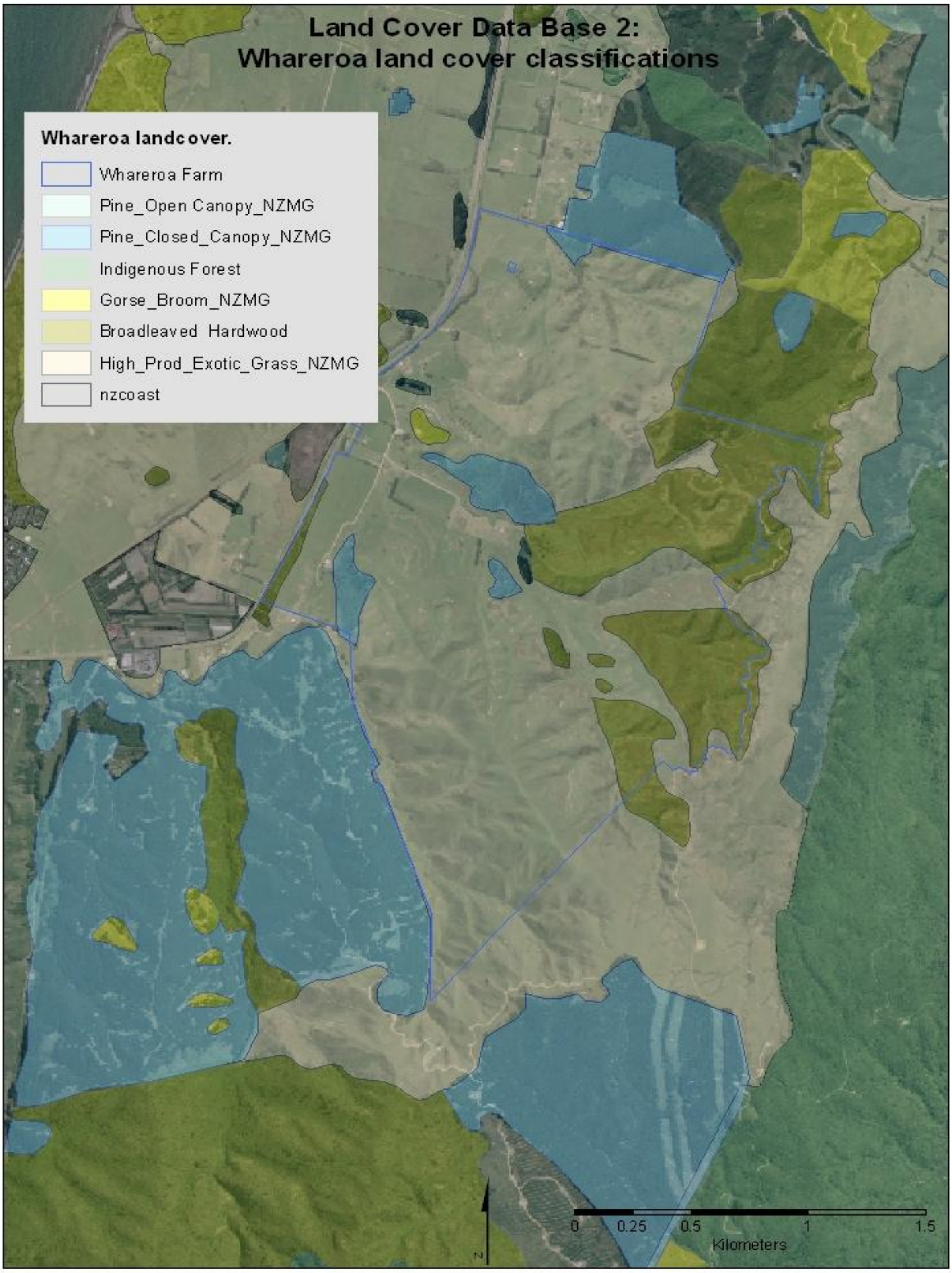
Appendix 3.2: Intersection of LENZ layers corresponding with those found at Whareroa Farm and where indigenous forest is current land cover.



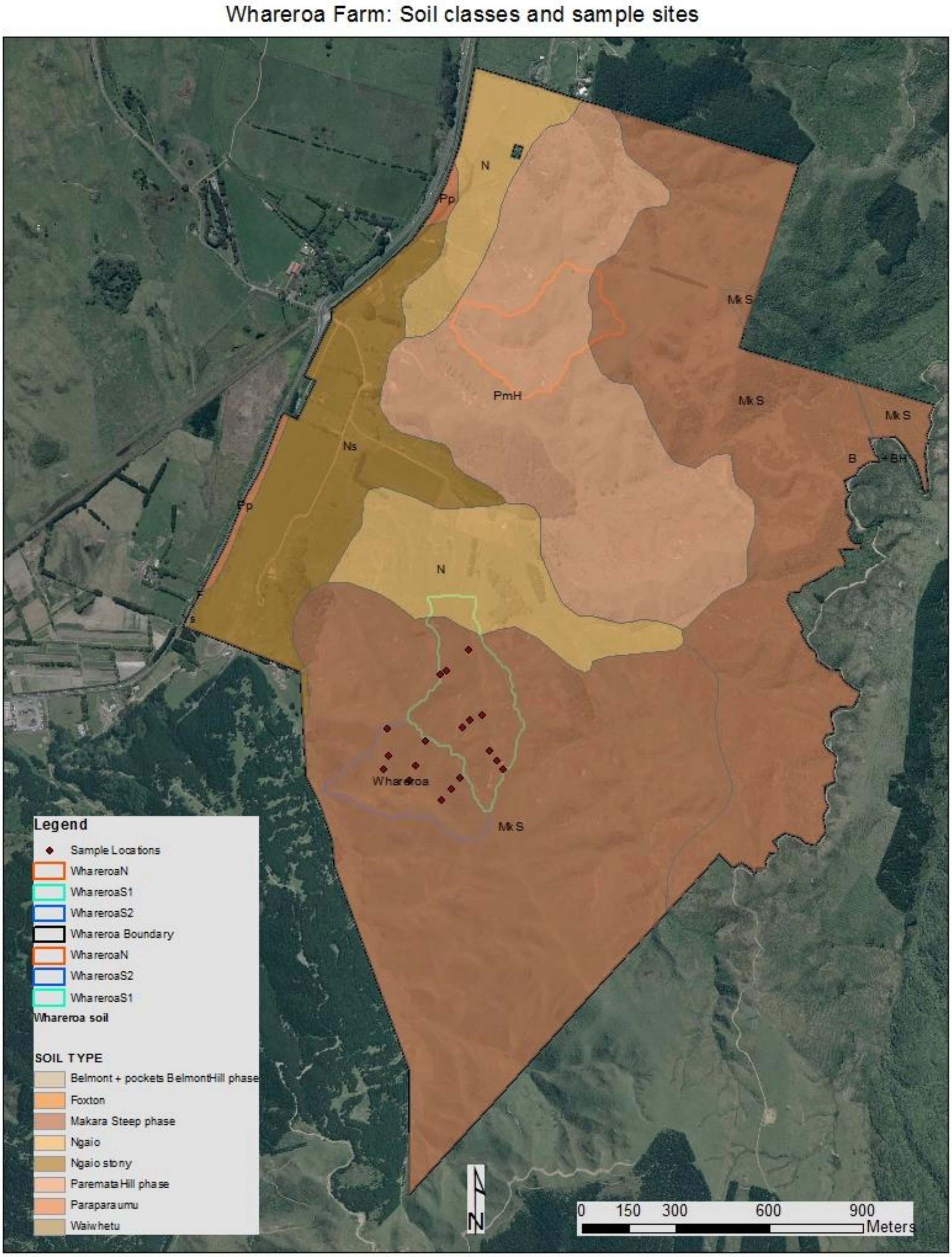
Appendix 3.3: LENZ environments as found at Whareroa and where indigenous forest currently is the landcover, inland Kapiti Coast.



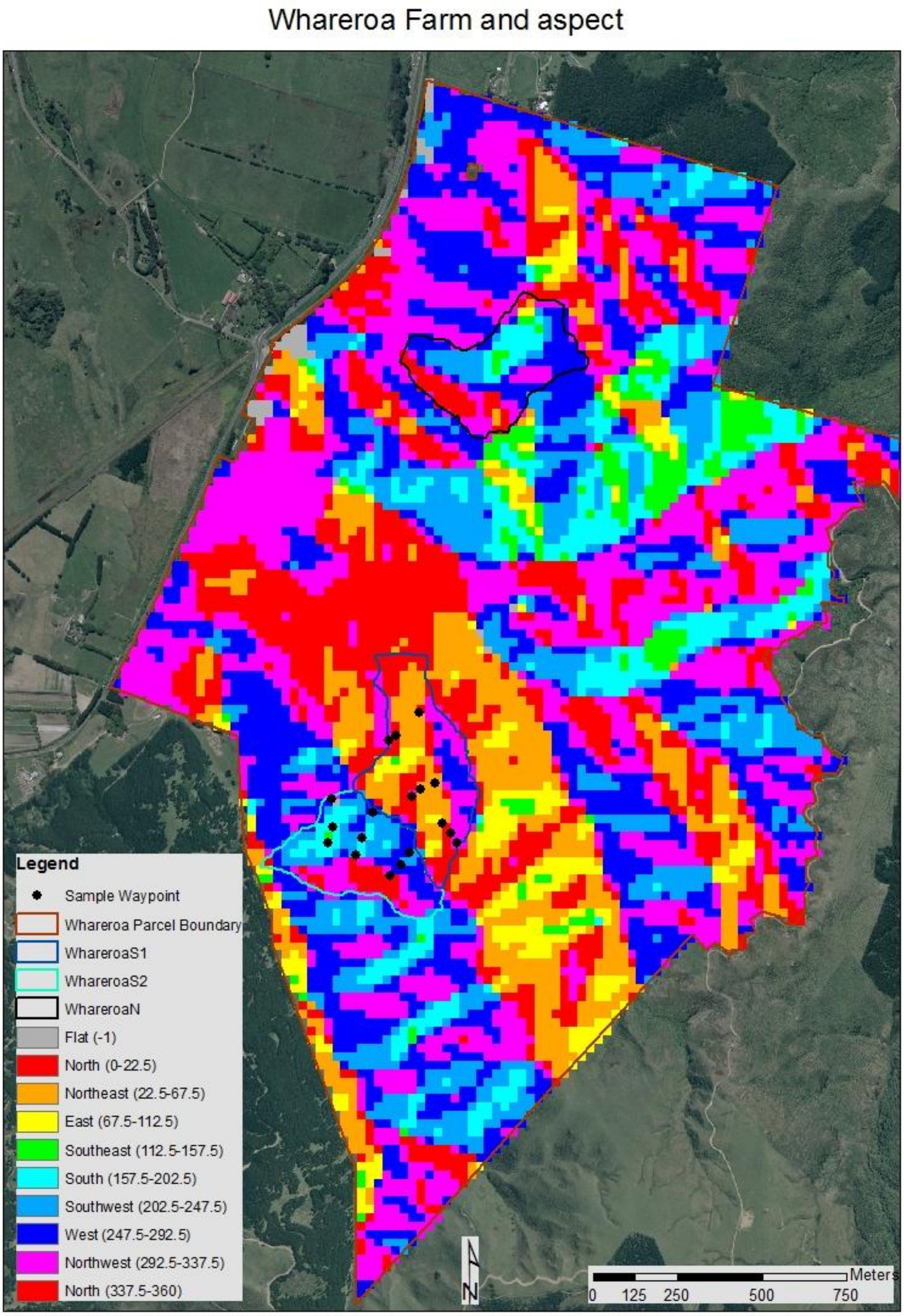
Appendix 3.4: Landcover polygons generated from LCDB2, for Whareroa Farm and surrounds



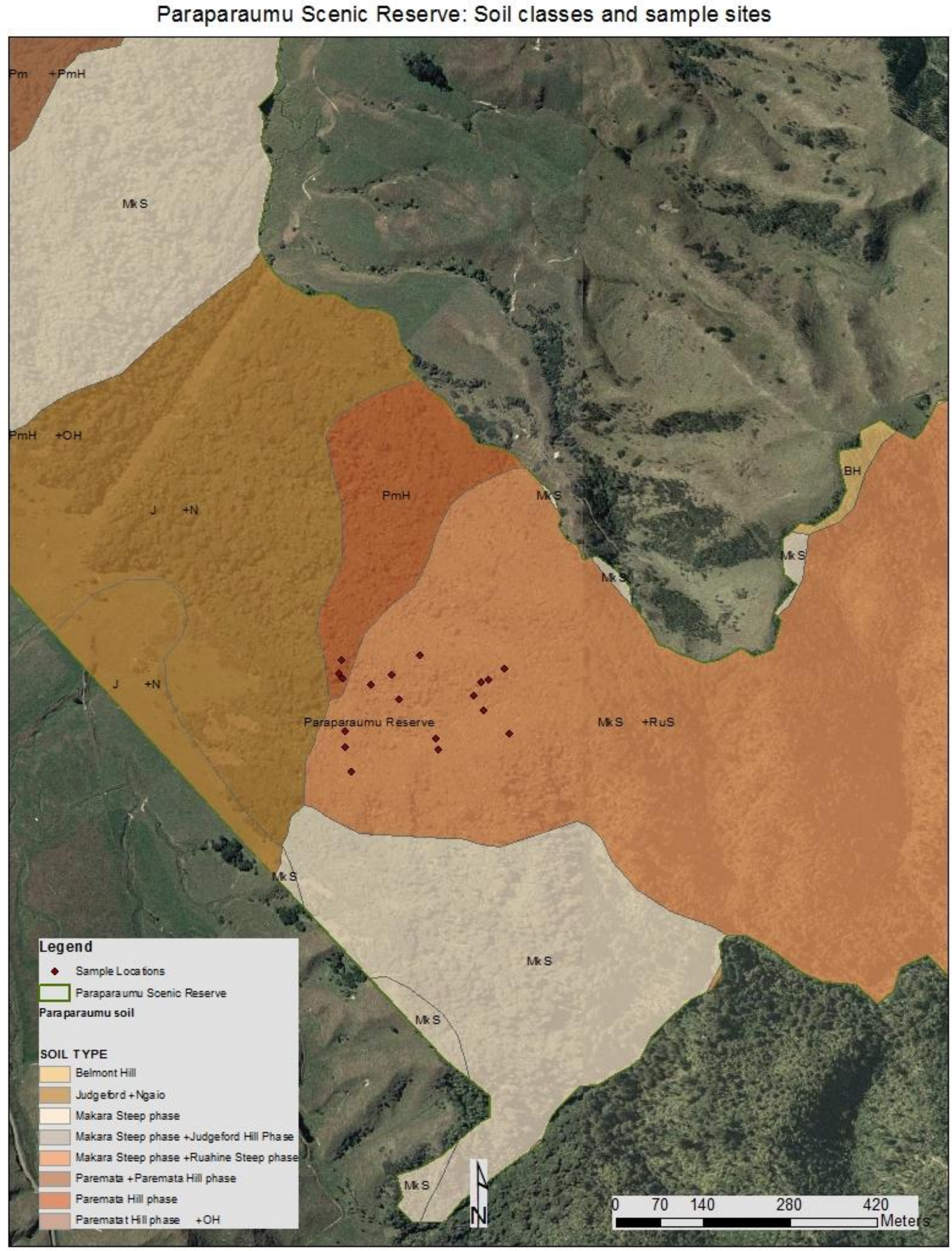
Appendix 3.5: Soils as generated from Fundamental Soils Layer of the NZLRI database for Whareroa Farm.



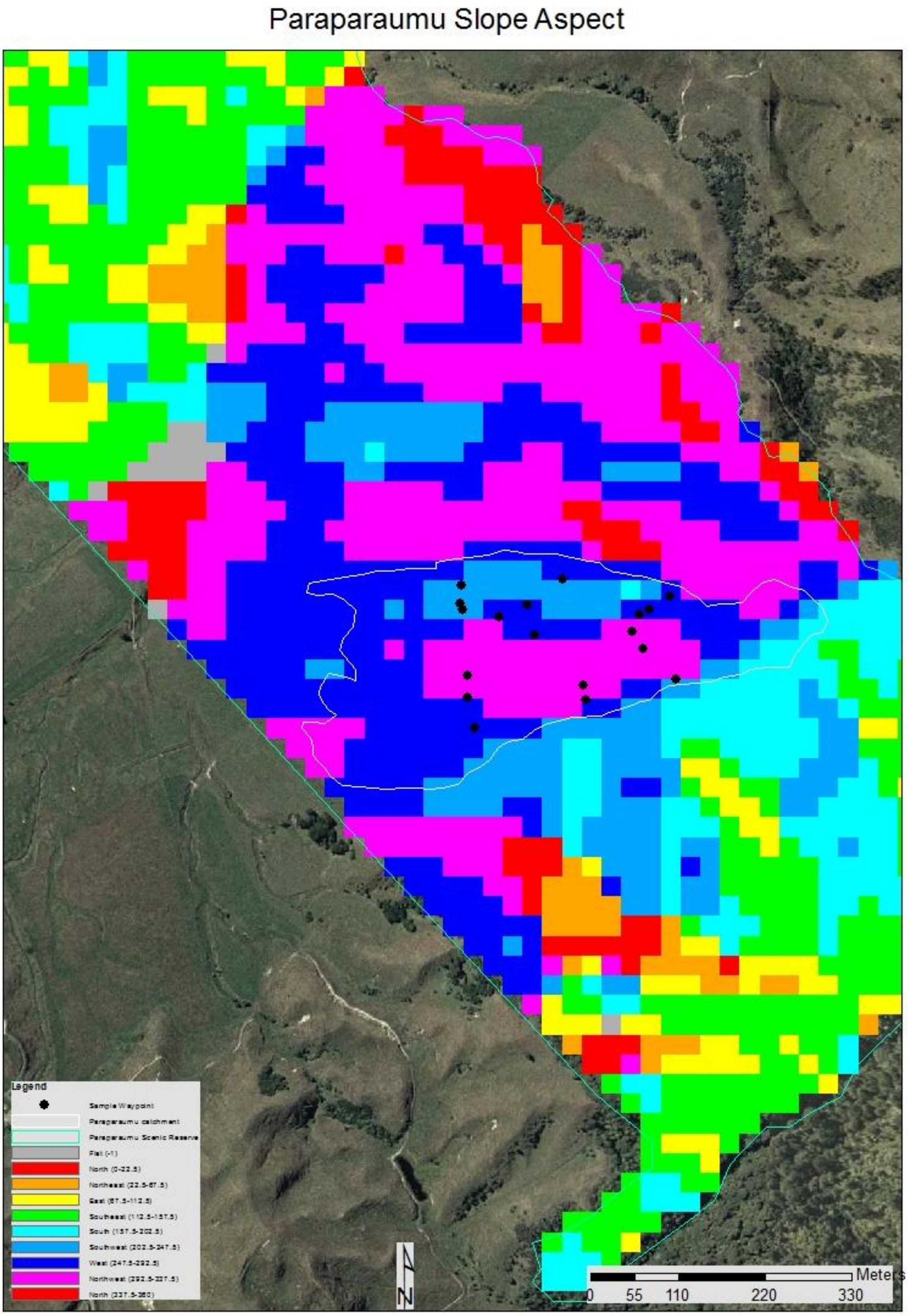
Appendix 3.6: Whareroa Farm and aspect as generated from national 25 m DEM, with catchments outlined and sample points.



Appendix 3.7: Soils as generated from Fundamental Soils Layer of the NZLRI database for Paraparaumu Scenic Reserve.



Appendix 3.8: Paraparaumu Scenic Reserve with aspect as generated from national 25 m DEM, with catchment and sample points



Appendix 3.9: Explanation of geoprocessing actions in ArcGIS

Spatial analysis allows data to be examined to find information that is pertinent to the study. The following are the list of commands used with an explanation of the purpose of the query.

'Select by attribute': Within the Selection menu 'Select by Attribute' operates with Standard Query Language (SQL) which uses attributes, operators and calculations to highlight features of interest. The query is entered in a dialogue box and the data is then highlighted in the map. If required this data selection can be saved as a new distinct layer. A standard query used in this analysis would follow the expression: "Level 4 classification" = F1.4c, once the LENZ layer has been activated and "Method" set to "Create a new selection". The result is a layer highlighting the polygons classified as f1.4c, which can be exported as a new distinct layer.

'Select by location': This spatial query, accessed from the same menu as 'select by attribute', allows selection of features based on their location relative to other features. In the query used during this analysis the argument used was where two sets of polygons share a line segment (which is essentially the sharing of two vertices).

Merge: Allows for the data from multiple sources to be combined in a single new output shapefile. This method has been used to produce a layer in which the three chosen LENZ classes are combined where they are contiguous (following the identification by the Select by Location where a line segment is shared spatial query is used). The merge tool is found in the Data Management tool set.

Intersect: Features or parts of features from different layers which share the same space are selected and are produced as an output shapefile. In this way the features of the LENZ classes selected by the above methods can then be intersected with the LCDB2 database attribute 'Indigenous Forest' to identify possible reference sites where intact forest is found in environments that are existant at Whareroa.

Digitisation: Refers to the act of creating a new feature from a layer that is already added to the map. Examples in this study are the polygons defining the catchments under consideration for the restoration site and also the reference site. This requires the use of the Editor tool and adding vertices around the watershed of the catchment thereby outlining its extent. Once saved this creates a new polygon feature.

Appendix 4.1 Correspondence Analysis (CA)

Whilst CA is different in the dissimilarity measure and algorithm used in NMDS and PCA (see Appendix 1a, and 2a and 2b respectively) the pattern of site associations is similar although there is a rotation (an arbitrary artifact) of the comparative axes. In the data from the study catchment it seems that the general relationships are depicted in a similar manner regardless of the underlying model, that is, linear or unimodal. There is also a similarity to the pattern as produced in CCA as shown in the following sections.

Referring to Figure 1, the points making up Transect 1 (see Figure 1 of main body of chapter 4), i.e. PpS1, PpS2 and PpS3 are widely spaced in the ordination but can still be seen generally as a group in the right half of the plot. Taking the overall plot trend there appears to be an arch effect one of the weaknesses of CA and reason that detrended correspondence analysis was introduced. If those extreme points are removed, the balance of the sites trend from footslopes (FS) clustered together mostly in the bottom right quadrant to the mid-slope transportation zone (MST) and convex creep zone (CCZ) sites in a loosely linear pattern towards the upper left quadrant.

The CA plot (Figure 1) shows the site scores alone for clarity of interpretation. Examination indicates that some of the pairs are very similar, for example PpN15 and PpS6 which are both FS sites of the middle transects almost share the same point. Another closely clustered set of sites is that including PpS9, PpN12 and PpS8. These are sites found in the upper transects (closest to the head of the valley) of which two are FS and the other MST. Figure 2 shows the species scores and hence relationships and Figure 3 illustrates the relationship between the site scores and the species scores.

In Figure 2 species scores are presented alone. These show the species relationships and the most common species with high abundance, for example, *Dysoxylum spectabile*, *Geniostoma rupestre* and *Melicytus ramiflorus* are located at the centroid. Uncommon species are placed on the perimeter, for example at this site, *Beilschmiedia tawa*. This being found only at the first transects. Figure 3 combines both the site and species scores and shows correlations of the species abundance and the sites where they are abundant. For instance, Collospermum hastatum has high abundance at PpN11 but is not correlated with PpS2 which is distant on the graph.

The eigenvalue (the measure of variation) scores are included at Appendix 4.3. The table shows that the first and second axes are very similar scores meaning they are of nearly equal importance and hence it is theoretically difficult to establish the dominant gradient. This may be better inferred from the CCA plot in this case study. They are also quite a small proportion of the overall variation.

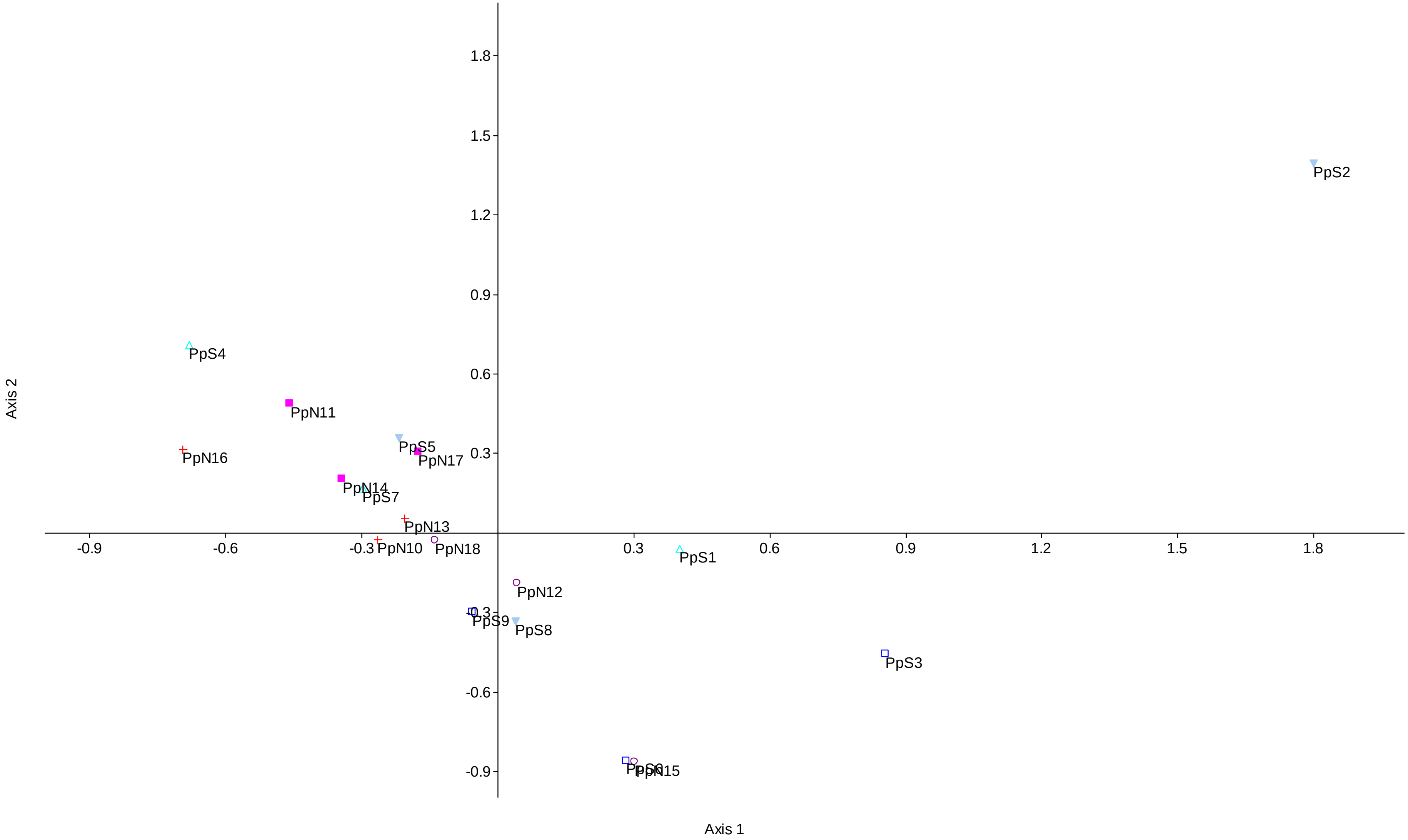


Figure 1: CA site score plot using raw data, excluding tier 6 (groundcover < 0.3 m) showing axes 1 & 2.

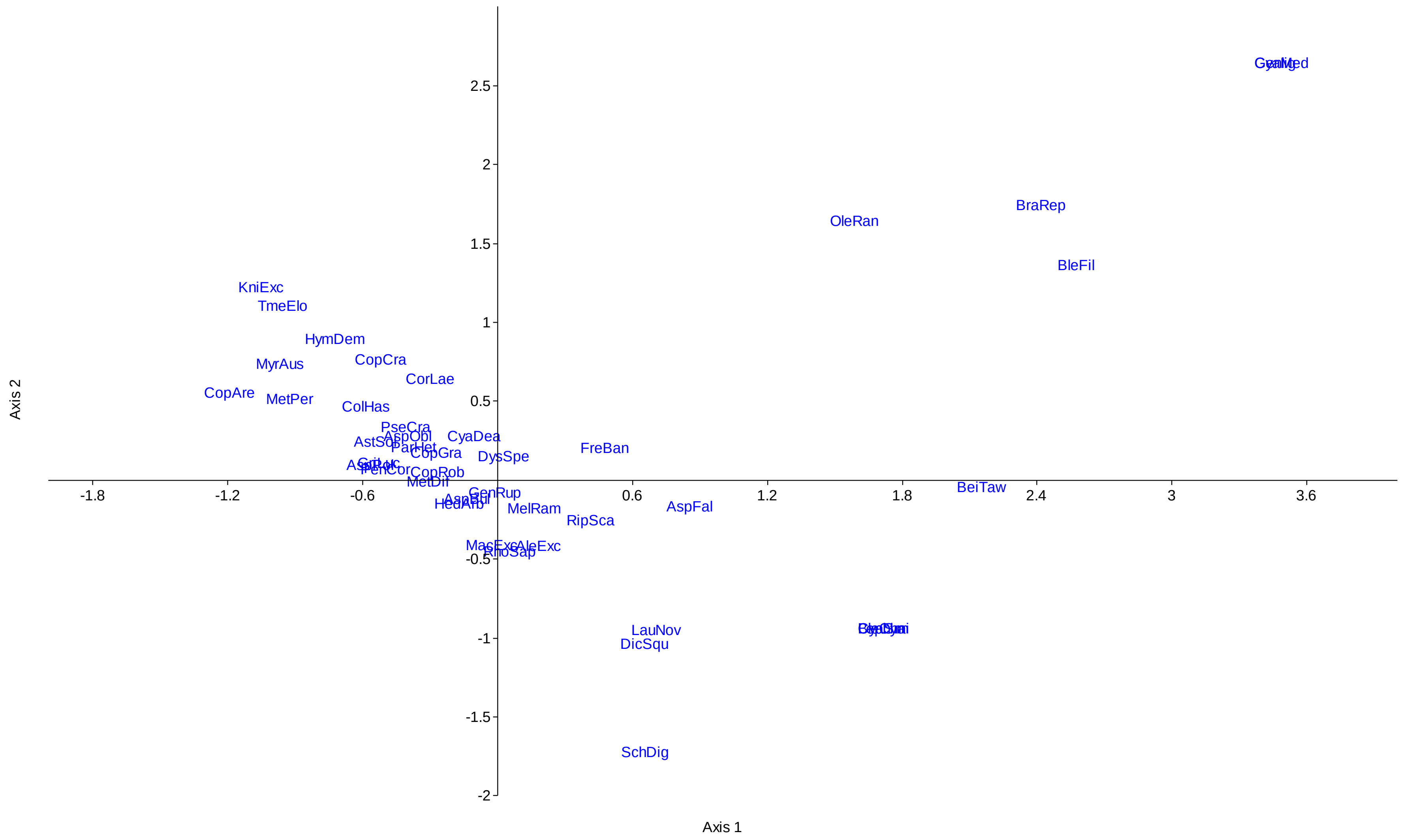


Figure 2: CA plot; species scores using raw data, excluding tier 6 (groundcover <0.3 m) showing axes 1 & 2.

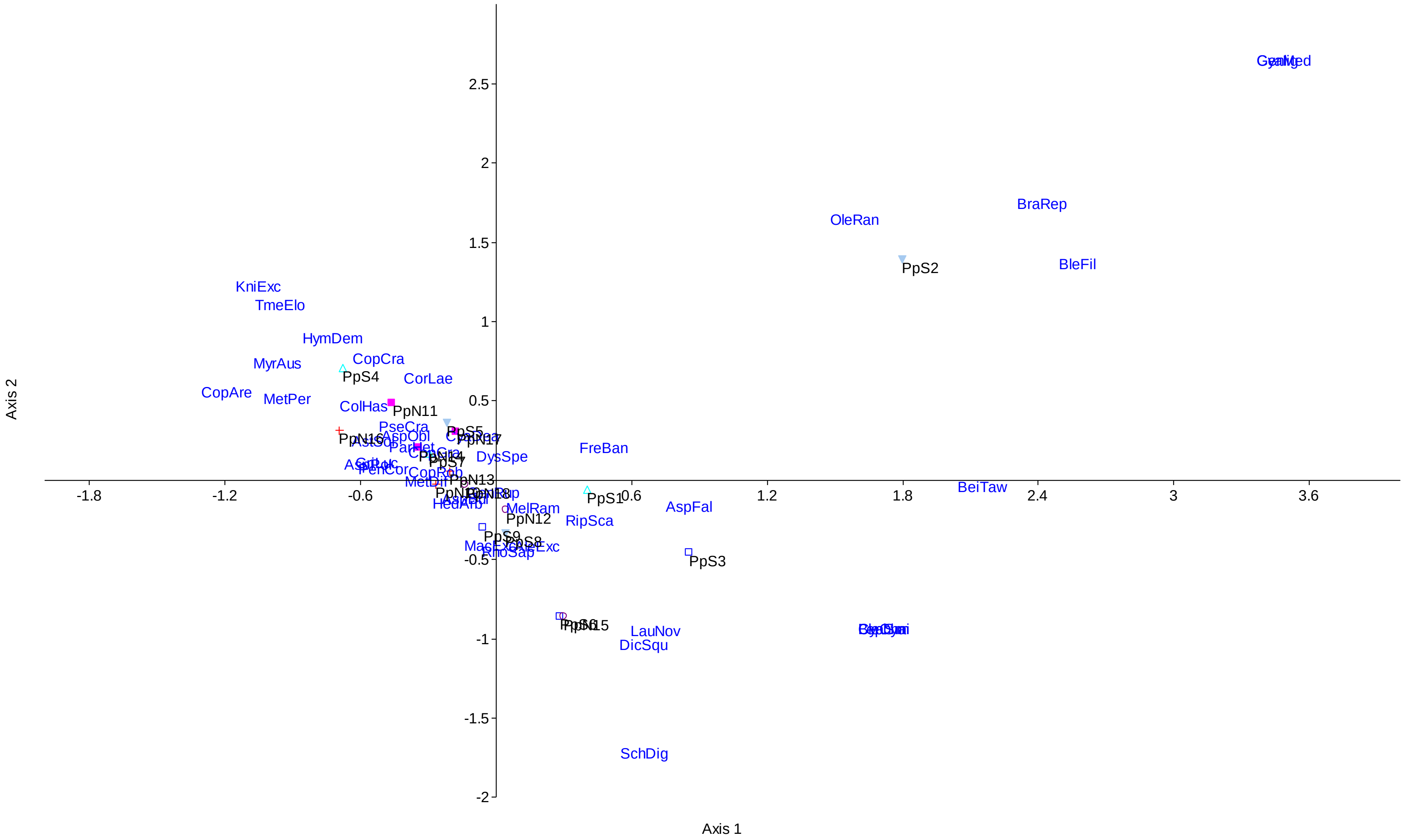


Figure 3: CA plot with sites and species using raw data excluding tier 6 (groundcover < 0.3 m), showing axes 1 & 2.

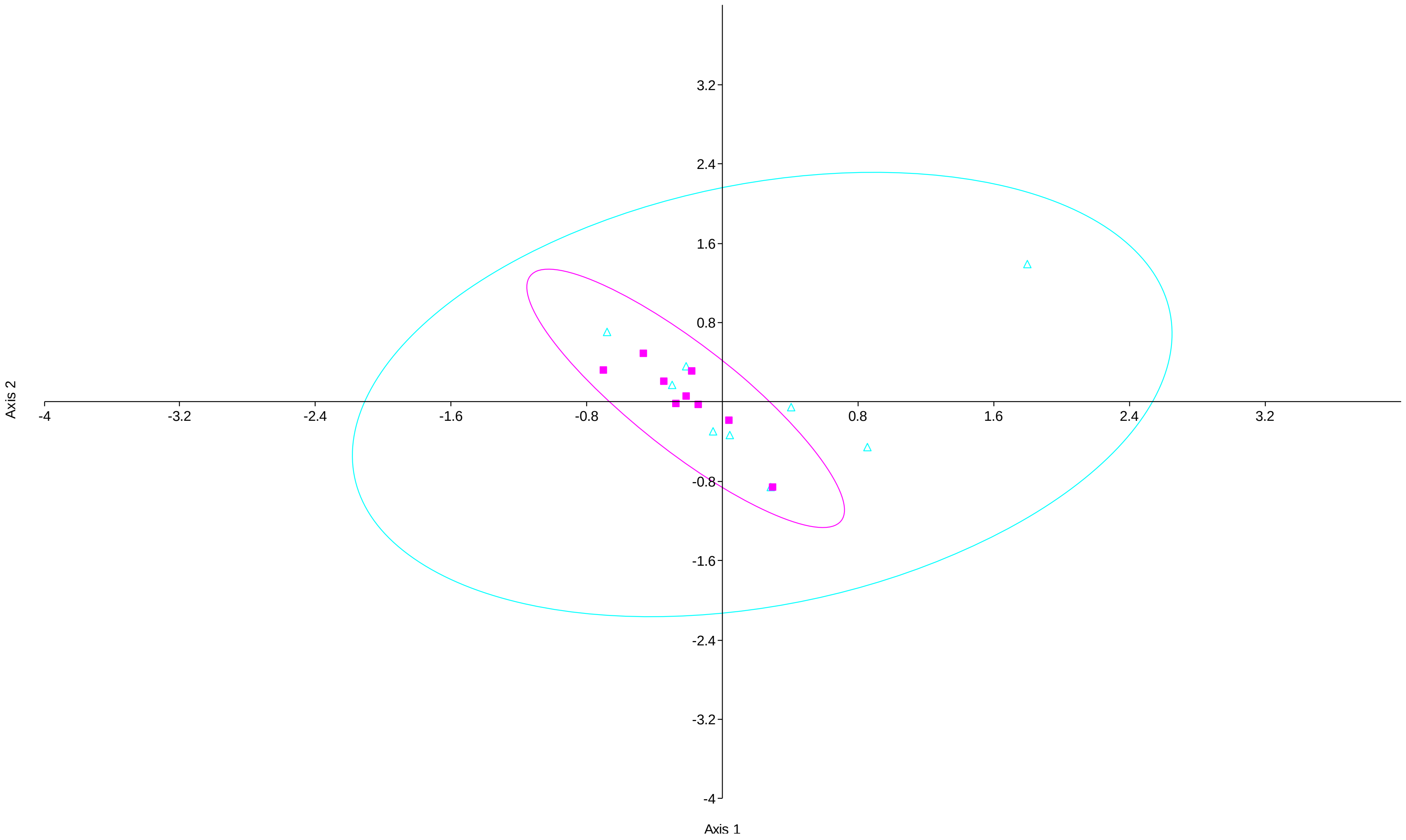


Figure 4: CA plot of raw data excluding tier 6 (groundcover < 0.3 m) with data grouped by aspect and depicted with symbols. 95% confidence ellipses for north and south facing slopes.

Appendix 4.2: PCA

Principal Component Analysis (PCA)

There is debate as to the appropriateness of ordination methods using linear response model for biotic data. The purpose for its use here is to examine the differences with other ordinations including NMDS (a rank order method) and also to CA which utilises a unimodal species response model. It is recommended by Palmer that gradient length be checked first by undertaking a Detrended Correspondence Analysis before using PCA. However, this ordination method has been criticised as giving distorted results due to the nature of the detrending process and rescaling procedure. The intent, then, is to see how close the results of the PCA and NMDS are upon visual examination.

The biplot (appendix 2a) includes the species data which is an advantage over NMDS. Both PCA and NMDS reveal 'latent' or unknown gradients for which hypotheses may be constructed and possibly tested with further research. The inclusion of the species scores in PCA adds to the understanding of the ecosystem as they can be associated with the site scores. Further with PCA gradient strengths can be estimated.

The first component is the gradient where the highest amount of variation is captured. The second component is that which is orthogonal to the first while capturing the greatest variation and similarly with the third component and so on. The ordering of the axes, unlike NMDS, helps with the understanding and consideration of the latent (unknown) gradient which is inferred by the plot. The ordination plot at appendix 2b is introduced as it is easy to read when the site scores are displayed alone.

Results

In general, the PCA biplot coincides with the NMDS plot and the ordination helps with the understanding of the relationship between the sites and the species. At one end of the first component is found sites that are predominantly footslope sites whilst at the other end are the upper slope convex creep zone and mid slope sites. The second component seems to span a change from the transect sites closest to the coalescent colluvial footslope to a mixture of sites at the head of the system. This appears to be in accord with the NMDS plot though the angles and distances between sites are not necessarily identical. This should not be of great concern as the NMDS is not a final solution and each iteration will produce a different pattern.

When interpreting PCA plots the angle from the centroid will determine the degree of correlation or otherwise. For instance, the angle between 7 finger (*Scheflera digitatus)* and mamaku *(Dicksonia squarossa)* is small indicating these two species are found in association with each other within the quadrats measured. Their abundance is likely to be greatest at sites PpS8 and PpS9 while they are negatively correlated with sites at 180° and so their abundance is less in that direction and uncorrelated with sites PpS1 or PpS2, PpN10 and PpN13. The length of the line indicates the degree of the gradient, that is, a large range in abundance if the line is long or a short gradient if the line is short.

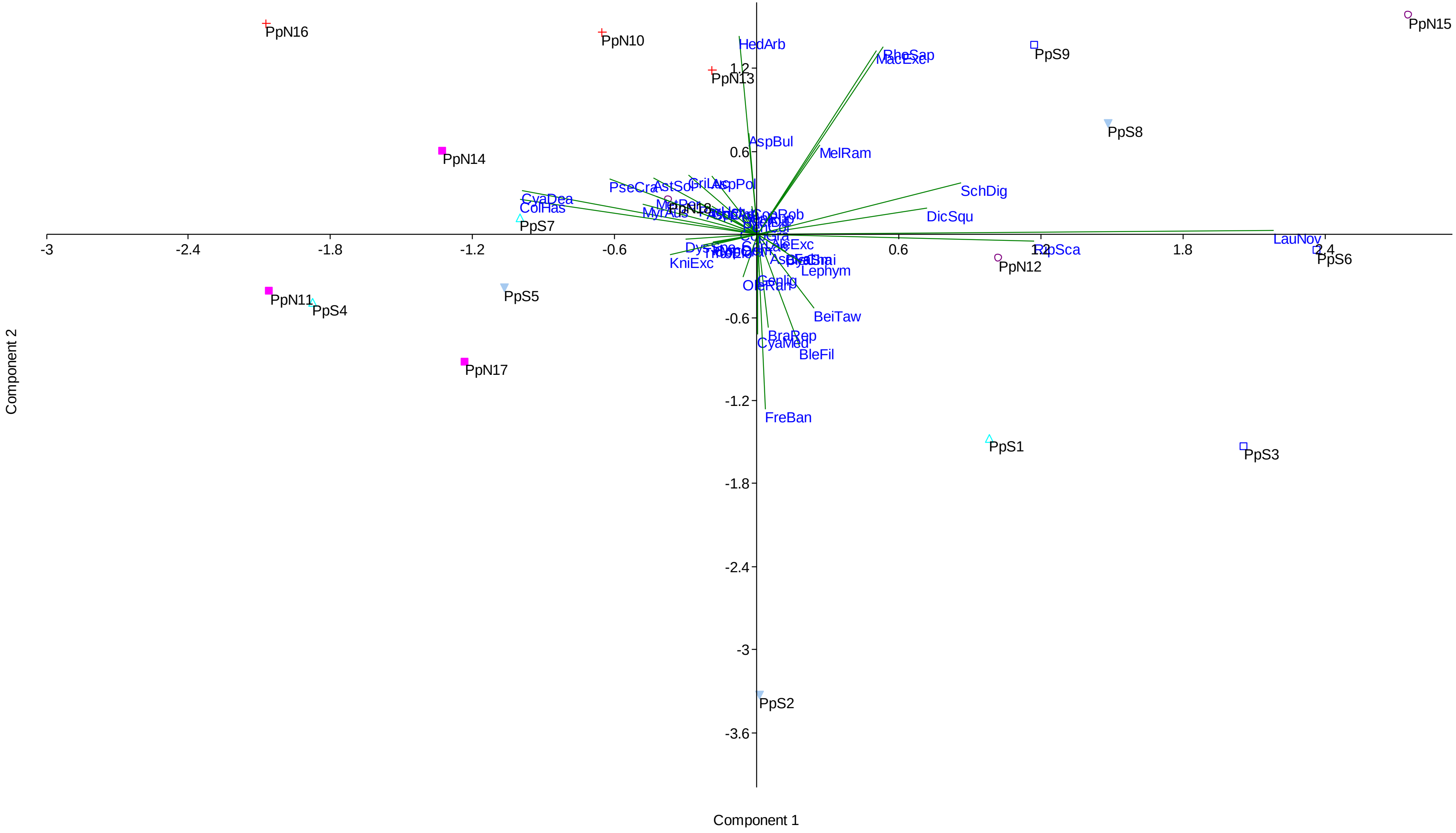
The apices of the species scores show the amount of range of the species. So for instance the longest line is that of pukatea (*Laurelia novaezealandae*) which indicates that it is dominant in some sites but absent in others. At a 180° angle to pukatea is kohekohe *Dysoxylm spectabile* inferring that these two species are not correlated. Kohekohe would be the dominant species by far but is common at most sites and so the line to the apice is not very long. The angle between it and rewarewa (*Knightia excelsa*) is very small and so these two species are often found together, but rewarewa is not a very abundant species being found in the seedling tier with the occasional mature emergent. So although the lengths of the species lines are similar they contribute in the assemblage in very different ways.

Nikau palm (*Rhopalastylus sapida*), kawakawa (*Macropiper excelsum*) and mahoe (*Melicytus ramiflorus*) can be seen as closely correlated and are generally expected to be common and the range seems to be medium. In some sites these have a large coverage whilst in others a small coverage, mahoe is less common. They appear to be associated with the wetter sites rather than the dry upper slopes. Another group includes 7 finger or pate (*Scheflera digitatus*), wheki (*Dicksonia squarrosa*) and supplejack (*Ripogonum scandens*) which are closely correlated and associated with the lower slope sites where light is less and moisture greater.

In the other direction of the plot and towards the sites of the upper and mid-slopes can be seen *Collospermum hastatum*, an epiphyte and silver fern (*Cyathea dealbata*) along with a cluster of other species adapted to drier poorer soils. Ostensibly, an interpretation of the first component may be that the hillslope location is of importance. However, underlying that are a number of factors that may also be of significance, for example, soil moisture, degree of diurnal range, differing amounts of insolation, or degree of soil fertility related also to soil depth.

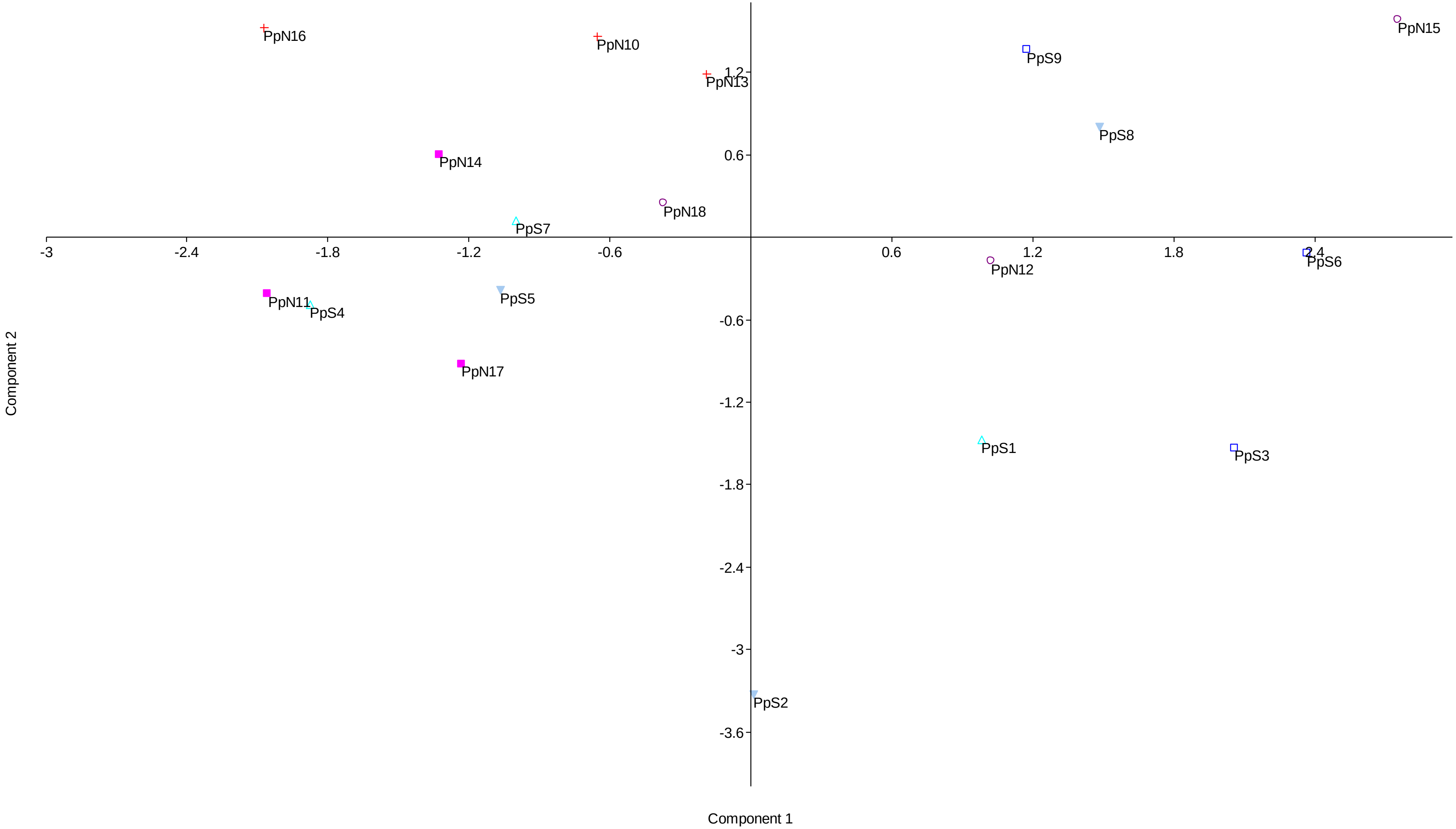
A final comment relates to the somewhat anomalous arrangement of PpS1 and PpS2 but which may be accounted for the unusual abundance of tawa and kiekie (*Freycenetia banksii*) at these two sites. This may be due to the proximity to the colluvial fan and the assemblage found there. It is observable that a greater abundance of tawa is evident in that area and also that on the nose of the spur there is more kiekie which is reflected at these sites especially PpS2. Also of note is that the PpS2 quadrat partly encompasses a very steep section which is the result of an historical slip. Not only are there more mosses here but the understorey is reflected in this disturbance and this may have some bearing on the nature of the ordination for this site. A biplot for components 2 and 3 is included in the appendix (4a, 4b) but as this is difficult to interpret it would be more guesswork and so is not discussed. As is shown in chapter 4 the same general pattern found in NMDS and PCA is also revealed in the CA plot.

Appendix 4.2a: PCA biplot



PCA-ordination diagram for components 1 & 2 of log transformed Paraparaumu Scenic Reserve data from the variance-covariance matrix using the singular value decomposition algorithm; species represented in lines, sites with symbols and text. Tier 6 (groundcover < 0.3 m) removed.

Appendix 4.2b: PCA biplot



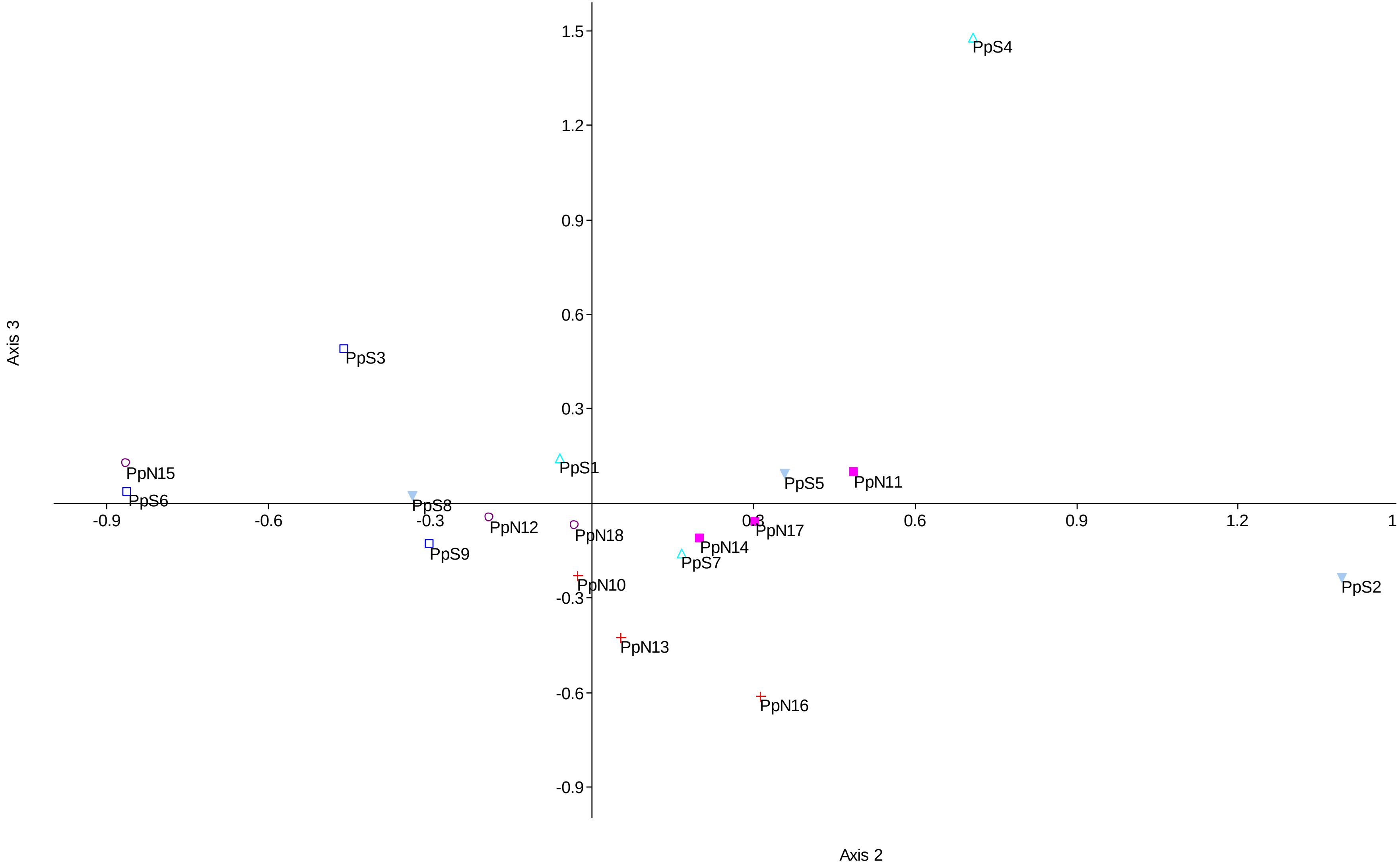
PCA-ordination diagram for components 1 & 2 of log transformed Paraparaumu Scenic Reserve data from the variance-covariance matrix using the singular value decomposition algorithm; sites with symbols and text. Tier 6 (groundcover < 0.3 m) removed.

Appendix 4.3: CA eigenvalues

Table 2: Table of CA eigenvalues for each of the axes and percent of variation captured in each axis.

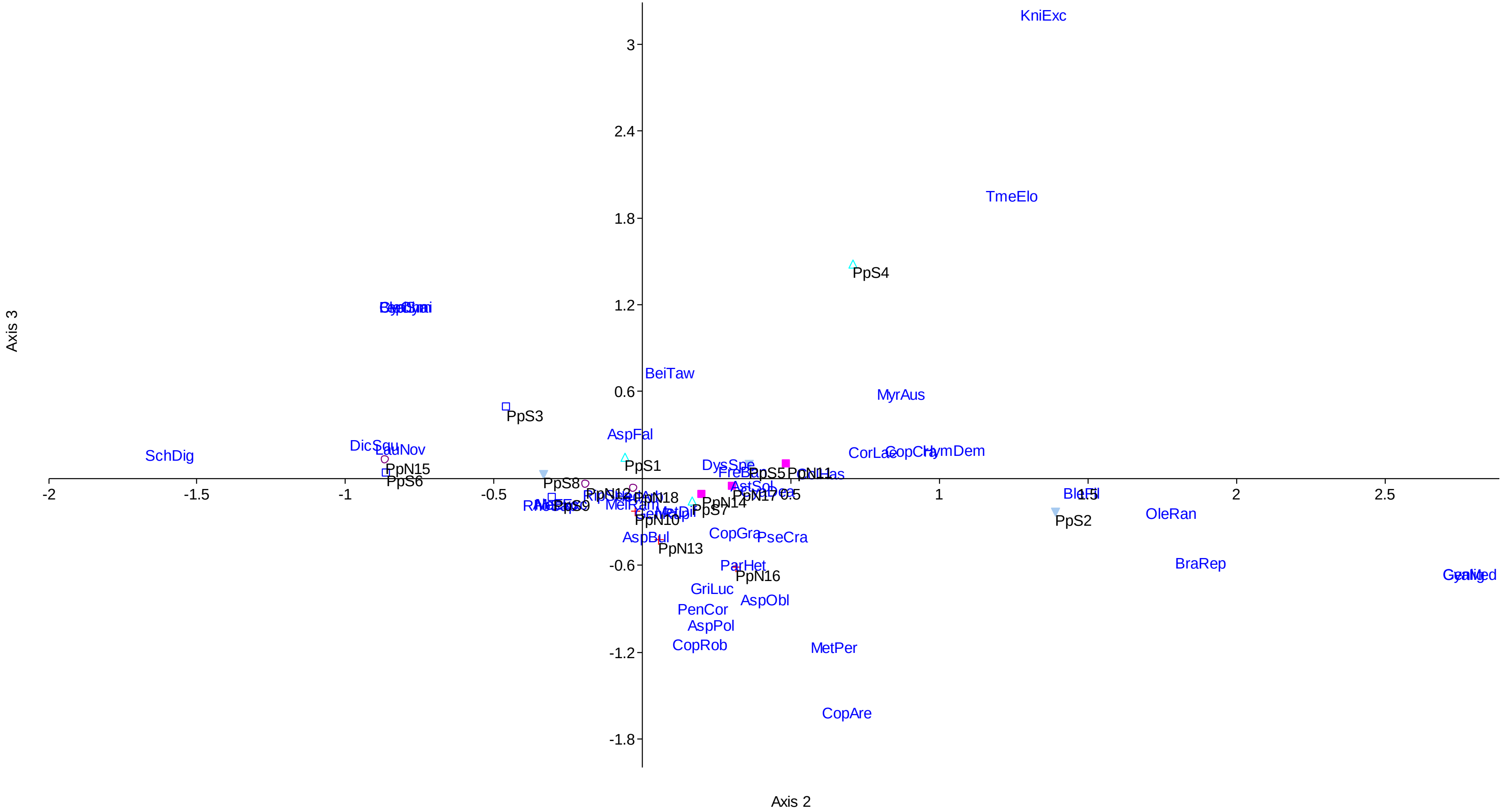
Axis	Eigenvalue	% of variation
1	0.284755	18.601
2	0.266172	17.387
3	0.154177	10.071
4	0.137652	8.9917
5	0.121752	7.9531
6	0.0941378	6.1493
7	0.0884235	5.776
8	0.0806666	5.2693
9	0.0646638	4.224
10	0.0614122	4.0116
11	0.0517527	3.3806
12	0.0399097	2.607
13	0.0298145	1.9476
14	0.02062	1.3469
15	0.0181173	1.1835
16	0.0099435	0.64953
17	0.00690073	0.45077

Appendix 4.4a: CA plot for second and third axes.



CA site score plot on raw data without tier 6 (groundcover < 0.3) axes 2 & 3.

Appendix 4.4b: PCA biplot for second and third axes



CA biplot on raw data without tier 6 (groundcover < 0.3) axes 2 & 3.

Appendix 4.5: CCA eigenvalues

Table 1: Eigenvalues assigned to the axes of the CCA plot, with percent of variation for each axis.

Axis	Eigenvalue	%
1	0.22323	25.52
2	0.19211	21.96
3	0.11378	13.01
4	0.084562	9.667
5	0.074986	8.572
6	0.056565	6.466
7	0.048564	5.552
8	0.036202	4.139
9	0.025782	2.947
10	0.018953	2.167
11	1.0036E-05	0.001147

Table 2: Table of eigenvalues for CCA constrained ordination with p-values for the axes from permutation tests.

Axis	Eigenvalue	p-value
1	0.2232	0.522
2	0.1921	0.13
3	0.1138	0.638
4	0.08456	0.912
5	0.07499	0.718
6	0.05656	0.938
7	0.04856	0.804
8	0.0362	0.818
9	0.02578	0.776
10	0.01895	0.506
11	1.004E-05	0.312

Appendix 4.6: Abiotic Data for input for constrained ordination.

Sample	Aspect	HillLoc	Slope (°)	BulkDens (mg/cm^3)	pH	OlsenP (mg/ml)	MinN (Kg/ha)	TotN (%w/w)	Total C (%w/w)	C:N ratio	Sand (%)	Silt (%)
PpS1	PpS	CZ	23	1.01	6.02	3	159	0.29	4.43	15	68.49	28.00
PpS2	PpS	MS	47	1.01	5.67	0.5	52	0.14	2.23	16	59.61	35.54
PpS3	PpS	TS	36	1.47	5.99	5	209	0.28	3.46	12	78.99	19.55
PpS4	PpS	CZ	29	1.07	5.89	3	212	0.28	3.61	13	55.48	40.54
PpS5	PpS	MS	31	1.21	5.69	2	197	0.30	4.35	15	77.81	20.02
PpS6	PpS	TS	47	1.45	6.99	8	46	0.11	1.18	11	86.69	11.59
PpS7	PpS	CZ	33	1.20	6.04	4	207	0.38	5.28	14	59.52	37.45
PpS8	PpS	MS	36	1.14	5.86	4	252	0.26	3.18	12	54.12	40.66
PpS9	PpS	TS	27	1.04	6.40	6	311	0.54	6.20	11	60.26	36.83
PpN10	PpN	CZ	20	1.15	6.37	4	173	0.31	3.97	13	69.48	27.52
PpN11	PpN	MS	42	1.21	5.38	2	88	0.24	3.85	16	68.51	28.42
PpN12	PpN	TS	24	1.34	6.58	9	244	0.34	3.81	11	55.26	40.00
PpN13	PpN	CZ	22	0.96	6.15	4	268	0.37	4.7	13	75.33	22.48
PpN14	PpN	MS	34	1.16	6.62	4	276	0.47	5.96	13	47.76	48.83
PpN15	PpN	TS	34	1.10	6.87	3	224	0.34	4.18	12	62.29	34.58
PpN16	PpN	CZ	23	1.01	6.36	5	234	0.42	5.1	12	72.41	25.00
PpN17	PpN	MS	36	1.07	5.55	4	85	0.25	3.92	15	50.83	44.47
PpN18	PpN	TS	26	1.09	6.30	3	329	0.39	4.74	12	50.04	46.56

Appendix 4.6 (continued)

Species data for ordination, no tier 6, abundance value transformed (van der Maarel).

	Ale Exc	Asp Bul	Asp Fal	Asp Obl	Asp Pol	Ast Sol	Bei Taw	Ble Cha	Ble Fil	Bra Rep	Col Has	Cop Are	Cop Cra	Cop Gra	Cop Rob	Cor Lae	Cya Dea	Cya Med	Cya Smi	Dic Squ
PpS1	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	4	0	0	4
PpS2	0	0	0	0	0	0	1	0	3	4	0	0	0	0	0	0	5	5	0	0
PpS3	0	1	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	0	1	0
PpS4	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	5	0	0	0
PpS5	0	2	0	1	0	0	0	0	0	0	0	0	1	0	0	1	9	0	0	0
PpS6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PpS7	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	10	0	0	0
PpS8	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	0	2
PpS9	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0
PpN10	0	3	0	0	2	0	0	0	0	0	2	0	0	0	0	0	4	0	0	0
PpN11	0	0	0	0	0	2	0	0	0	0	2	0	1	1	0	0	10	0	0	0
PpN12	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5	0	0	0
PpN13	0	3	0	2	1	0	0	0	0	1	0	0	0	1	3	0	5	0	0	0
PpN14	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	12	0	0	0
PpN15	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6
PpN16	0	2	0	2	1	2	0	0	0	0	2	2	0	0	0	0	5	0	0	0
PpN17	0	3	0	0	0	0	0	0	0	0	3	0	0	0	0	0	9	0	0	0
PpN18	0	3	0	0	0	1	0	0	0	0	2	0	0	0	0	0	6	0	0	0

Appendix 4.6 (continued).

	Dys Spe	Fre Ban	Gen Lig	Gen Rup	Gri Luc	Hed Arb	Hym Dem	Kni Exc	Lau Nov	Lep Hym	Mac Exc	Mel Ram	Met Dif	Met Per	Myr Aus	Ole Ran	Par Het	Pen Cor	Pse Cra	Rho Sap	Rip Sca	Sch Dig	Tme Elo
PpS1	14	7	0	0	0	2	0	0	6	0	1	0	0	0	0	0	0	0	2	2	5	0	0
PpS2	10	4	1	0	0	0	0	0	1	0	0	4	0	0	0	1	0	0	0	0	5	0	0
PpS3	10	3	0	1	0	0	0	0	9	2	1	5	0	0	0	0	0	0	0	4	6	0	0
PpS4	18	1	0	0	0	3	0	6	0	0	2	1	0	0	2	0	0	0	0	1	0	0	1
PpS5	12	2	0	1	0	5	0	1	0	0	0	5	0	0	0	1	1	0	0	2	2	0	0
PpS6	6	3	0	0	0	0	0	0	6	0	6	7	0	0	0	0	0	0	0	11	4	6	0
PpS7	8	1	0	0	3	3	0	0	0	0	4	4	0	0	0	0	0	0	0	1	4	0	0
PpS8	11	2	0	0	0	8	0	0	7	0	4	6	1	0	0	0	0	0	0	8	7	0	0
PpS9	10	0	0	0	3	7	0	0	6	0	5	4	0	0	0	0	0	0	0	7	8	0	0
PpN10	13	1	0	0	0	8	0	0	0	0	6	8	0	0	0	0	1	0	2	6	4	0	0
PpN11	15	2	0	0	0	1	2	0	0	0	1	5	0	0	0	0	0	0	5	2	0	0	1
PpN12	12	3	0	0	0	6	0	0	6	0	6	5	0	0	0	0	1	1	0	0	9	0	0
PpN13	13	1	0	1	0	4	0	0	1	0	5	5	0	0	0	0	1	0	4	8	3	0	0
PpN14	11	3	0	1	0	4	0	0	0	0	2	4	2	1	2	0	0	0	5	8	5	0	0
PpN15	10	0	0	1	0	4	0	0	15	0	6	8	0	0	0	0	0	0	0	9	6	7	0
PpN16	12	0	0	1	3	3	0	0	0	0	3	5	0	4	2	0	1	1	1	4	0	0	0
PpN17	17	8	0	1	1	0	0	0	0	0	1	2	0	1	0	0	1	0	0	3	3	0	0
PpN18	14	1	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	9	7	0	0

Appendix 4.7

Quadrat shape and size

The size and shape of the sampling area is also a matter of debate. Traditionally square plots or quadrats have been utilised (Goldsmith and Harrison, 1976; Dale, 1999). Others warn of using elongated plots that might include more than one group of plants (Kenkel et al., 1989). Meuller-Dombois et al. (1974) discuss the required size for a variety of ecosystems and state that for forest communities the minimum should be 200 – 400 m^2. In other studies, for example Burns (1995) chose unfixed sampling areas simply ensuring that the minimum area was in keeping with minimal area concept (see also Miller, 2004). In the literature relating to the 'Recce' rapid reconnaissance method Allen (1992) advises that the size should reflect the structure of the vegetation. Otýpkova and Chytrý (2006) investigated the effect of plot size on ordination and determined that size did influence results with smaller plots producing less stable results. The above discussion outlines the complexity of ecology and differing methods and opinions.

Measurement of the species composition

The question of what to measure corresponding to vegetation, and how to measure it, is another matter to clarify and confirm prior to sampling. In general, there are three different categories: Density, dominance or frequency. Density is the number of individuals found per unit area, dominance could be measured by using the basal area or crown coverage percentage per unit area, and frequency is the fraction of sample quadrats in which the species is found (Goldsmith & Harrison, 1976). These authors go on to state that the relative values for each of these measures can be combined to produce an importance value which is utilised in statistical testing and ordination.

Of the above three categories two are quantitative while the third, dominance (also termed abundance), can be quantitative or semi-quantitative. If the presence or absence of a species or basal area is the value measured this will be quantitative while using percent cover is semi-quantitative. The cover class method determines the value with an estimation of the canopy area projected vertically upon the ground as a percentage of the total quadrat area. To some this is seen as a weakness due to the inherent subjectivity and variability due to the perception of different observers. A version of the coverage percentage method uses cover classes which can be a variety of scales, for example the phytosociology Braun-Blanquet scale or Domin scale. Using such methods helps to smooth out errors of estimation by giving a breadth to the class of assignation, but does introduce loss of information.

Standardisation of data

There are those who advocate that log linear transformation should take place (Kenkel et al., 1998; Mead, 1988; Limpert et al., 2001) with an objective to convert the data to a normal distribution and allow for valid parametric statistical analysis to be undertaken. Jackson (1997) warns against data being relativised or standardised as this may ruin the intrinsic patterns and associations. During the analysis of the abiotic factors outlined in Chapter 3 it was determined that log, square root, or inverse transformation of the data did not result in normal distribution. Consequently in the multivariate analysis no transformation was undertaken on the abiotic data. However, where measurements are in very different units and scales (as seen in environmental abiotic variables), normalisation (a form of standardisation) is required and has been employed. The method used is dividing the standard deviation by the mean. The resultsof the permutation tests showed no difference between the above normalisation method and that of using z scores.

The species data has been log transformed not only due to the large number of zero values but also to ensure that the occasional species with large abundance values are not treated as an outlier in linear models (Digby and Kempton, 1987; Mead, 1988) and be overly dominated by large abundances in unimodal models (McGarrigal et al., 2000). The logarithm of zero is undefined and so in this analysis the value of the smallest observed value, which is one, has been added to the matrix prior to log transformation (Legendre and Legendre, 1998; McCune and Grace, 2002).

Multivariate analysis

Multivariate analysis is the analysis of data where there may be both multiple explanatory and response variables. Contrasting to univariate analysis, all variables are examined simultaneously to extract significant relationships.

Ordination

Ordination is one example of multivariate analysis, but what is it? “Ordination or scaling methods achieve an efficient and optimized low-dimensional representation of a complex data structure by emphasizing and bringing to the forefront underlying trended variation while suppressing ‘noise’ ” is how Kenkel, (2006: 668) summarises Gauch’s (1973) definition. Kenkel (2006: 664) also paraphrases Legendre and Legendre (1998) with a less technical explanation; “specifically, the objectives of multivariate data analysis are to summarize associations among species and to elucidate species responses to environmental factors”. Alternatively, ter Braak (1995; 91) describes ordination as “the collective term for a group of multivariate techniques which arrange sites along axes on the basis of data on species composition”.

The above highlight the different aspects of ordination including the reduction of complexity, the species environment interaction and the graphical output. In the graphical output the axes are an arrangement of the data so that those sites or species most similar are plotted in proximity while those dissimilar are distant in the plot.

However, there are many differing methods which have different strengths and weaknesses, with debate continuing as to the most effective and in which situations. The complexity is such that it is beyond the scope of this thesis to explain this debate in detail but a very brief overview is provided.

Indirect Gradient Analysis describes an ordination where the data is ordered dependent upon the data itself, and can be displayed in any number of axes (gradients). This plot represents the intrinsic pattern of the data itself. An overlay of an ordination of environmental gradients can be compared to the species data in a secondary step to examine if there are any correlations. Direct Gradient Analysis analyses simultaneously environmental data and species data, but the species data are constrained by the ordering of the environmental data and ordered as a best fit of this data. This is also known as constrained ordination. This type of ordination will not reveal any hidden environmental gradients as the species data is constrained specifically by the environmental data input and so if important environmental gradients have not been measured they will not be revealed. However, if there is a hypothesis wanting to be tested regarding the relationship between measured environmental variables and species then this method is used.

Two other aspects are important in ordination. Firstly, the algorithms of different methods use different species response models, these being 1) a linear response model, and 2) a unimodal response model. These models can be found in both Indirect and Direct Gradient Analysis. Secondly, some techniques are metric and so use specific similarity measures e.g. Euclidean distance or alternatively chi square distance, whilst others are semi or non-metric e.g. Bray-Curtis distance. There is robust debate about the efficacy of all of these parameters which is only touched upon in this study. It is common that more than one ordination method will be used on one data set so as to investigate different aspects of interest and also as a confirmatory device. That is the case in this study.

Cluster analysis

An additional multivariate technique is cluster analysis which includes classification as one type. These techniques attempt to collect and identify members of a group dependent upon their similarity. Classification refers to clustering with a training set of data, while cluster analysis uses raw data only to provide the groupings. There are two main sorts of cluster analysis; non-hierarchical and hierarchical. The first does not attempt to place the groups in any relationship with each other whilst the latter is specifically designed to illustrate the relationships dependent upon similarity within groups and dissimilarity between groups. Hierarchical clustering will provide a dendrogram (graphic tree display) which details the groups and levels of similarity.

The second grouping of methods depends on whether the algorithm is agglomerative or divisive. The latter divides the whole set of data (one cluster) into separate smaller groupings. The former starts with each member as separate cluster combining them until a pre-determined number is found. The cluster analysis method used was UPGMA (Unweighted Pair-Group Method using Arithmetic Averaging), an agglomerative method.

Appendix 4.8: Field Sheet for vegetation inventory for each quadrat.

Field Sheet: Vegetation description

Quadrat No.………………………………………………. Page No.……………………………………

Date: …………………………Recorded by: ……………………………………………………………

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

	Tier 1	**Tier 2**	**Tier 3**	**Tier 4**	**Tier 5**	**Tier 6**
	> 25 m	**12-25 m**	**5-12 m**	**2-5 m**	**0.3 – 2 m**	**< 0.3m**
Overall Cover						
Tier 7						
epiphytes						

Appendix 4.9: Floristic species list for Paraparaumu Scenic Reserve

Code	Scientific binomial	Common name	Family	BioStatus
AleExc	*Alectryon excelsus*	*Titoki*	Sapindaceae	Endemic
AnaLan	*Anarthropteris lanceolata*	*Lance Fern*	Polypodiaceae	Endemic
AspBul	*Asplenium bulbiferum*	*Hen and Chicken Fern*	Aspleniaceae	Non-endemic
AspFal	*Asplenium falcatum*	*Spleenwort*	Aspleniaceae	Indigenous
AspObl	*Asplenium oblongifolium*	*Spleenwort*	Aspleniaceae	Endemic
AspPol	*Asplenium polyodon*	*Spleenwort*	Aspleniaceae	Non-endemic
AstSol	*Astelia solandri*	*Perching Lily, Kaiwharawhara*	Liliaceae	Endemic
BeiTaw	*Beilschmiedia tawa*	*Tawa*	Lauraceae	Endemic
BleCha	*Blechnum chambersii*	*Lance fern, nini, rereti*	Blechnaceae	Non-endemic
BleCol	*Blechnum colensoi*	*Colensos hard fern, peretao, petako*	Blechnaceae	Indigenous
BleDis	*Blechnum discolor*	*Crown fern*	Blechnaceae	Endemic
BleFil	*Blechnum filiforme*	*Thread fern, climbing hard fern*	Blechnaceae	Endemic
BraRep	*Brachyglottis repanda*	*Rangiora*	Asteraceae	Endemic
CarDis	*Carex dissita*	*Forest sedge*	Cyperaceae	Endemic
CarSer	*Carpodetus serratus*	*Putaputaweta, marble leaf*	Grossulariaceae	Endemic
ClePan	*Clematis paniculata*	*White clematis, puawhananga*	Ranunculaceae	Endemic
ColHas	*Collospermum hastatum*	*Kahakaha*	Liliaceae	Endemic
CopAre	*Coprosma areolata*	*Thin-leaved coprosma*	Rubiaceae	Endemic
CopCra	*Coprosma crassifolia*		Rubiaceae	Endemic
CopGra	*Coprosma grandifolia*	*Kanono*	Rubiaceae	Endemic
CopRob	*Coprosma robusta*	*Karamu*	Rubiaceae	Endemic
CorLae	*Corynocarpus laevigatus*	*Karaka*	Corynocarpaceae	Endemic
CyaDea	*Cyathea dealbata*	*Silver Fern, Punga*	Cyatheaceae	Endemic
CyaMed	*Cyathea medullaris*	*Mamaku*	Cyatheaceae	Non-endemic
CyaSmi	*Cyathea smithii*	*Katote, soft tree fern*	Cyatheaceae	Endemic
DacDac	*Dacrycarpus dacrydioides*	*Kahikatea*	Podocarpaceae	Endemic

DicSqu	*Dicksonia squarrosa*	*Wheki*	Dicksoniaceae	Endemic
DysSpe	*Dysoxylum spectabile*	*Kohekohe*	Meliaceae	Endemic
EarMuc	*Earina mucronata*	*Bamboo orchid, peka-a-waka*	Orchidaceae	Endemic
FreBan	*Freycinetia banksii*	*Kiekie*	Pandanaceae	Endemic
GahSet	*Gahnia setifolia*	*Mapere, Gahnia, Giant Gahnia, Razor Sedge*	Cyperaceae	Endemic
Genlig	*Geniostoma ligustrifolium*	*Hangehange*	Loganiaceae	Unknown
GenRup	*Geniostoma rupestre*	*Hangehange*	Loganiaceae	Non-endemic
GraBil	*Grammitis billardierei*	*Common strap fern*	Grammitidaceae	Indigenous
GriLuc	*Griselinia lucida*	*Puka*	Cornaceae	Endemic
HedArb	*Hedycarya arborea*	*Pigeonwood*	Monimiaceae	Endemic
HymDem	*Hymenophyllum demissum*	*Drooping filmy fern, Irirangi, Piripiri*	Hymenophyllaceae	Endemic
KniExc	*Knightia excelsa*	*Rewarewa*	Proteaceae	Endemic
LauNov	*Laurelia novae-zelandiae*	*Pukatea*	Monimiaceae	Endemic
Lephym	*Leptopteris hymenophylloides*	*Crape fern, Single crape fern, Heruheru*	Osmundaceae	Endemic
LygArt	*Lygodium articulatum*	*Mangemange*	Schizaeaceae	Endemic
MacExc	*Macropiper excelsum*	*Kawakawa*	Piperaceae	Endemic
MelRam	*Melicytus ramiflorus*	*Mahoe*	Violaceae	Non-endemic
MetDif	*Metrosideros diffusa*	*White rata*	Myrtaceae	Endemic
MetPer	*Metrosideros perforata*	*White rata*	Myrtaceae	Endemic
MicAve	*Microlaena avenacea*	*Bush rice grass*	Poaceae	Non-endemic
MicPus	*Microsorum pustulatum*	*Hounds tongue, Kowaowao, Paraharaha*	Polypodiaceae	Indigenous
MicSca	*Microsorum scandens*	*Fragrant fern, Mokimoki*	Polypodiaceae	Indigenous
MyrAus	*Myrsine australis*	*Red mapou, red matipo, mapau, red maple*	Myrsinaceae	Endemic
NesLan	*Nestegis lanceolata*	*White maire*	Oleaceae	Endemic

OleRan	*Olearia rani*	*Heketara*	Asteraceae	Endemic
PaeRot	*Paesia species*		Dennstaedtiaceae	Indigenous
ParHet	*Parsonsia heterophylla*	*New Zealand jasmine, kaihua*	Apocynaceae	Endemic
PelRot	*Pellaea rotundifolia*	*Button fern, tarawera*	Pteridaceae	Indigenous
PenCor	*Pennantia corymbosa*	*Kaikomako*	Icacinaceae	Endemic
PhyPus	*Phymatosorus pustulatus*	*Hounds tongue, Kowaowao, Paraharaha*	Polypodiaceae	Indigenous
PnePen	*Pneumatopteris pennigera*	*Gully fern, Feather fern, Piupiu*	Thelypteridaceae	Non-endemic
PolRic	*Polystichum richardii*		Dryopteridaceae	Endemic
PruFer	*Prumnopitys ferruginea*	*Miro*	Podocarpaceae	Endemic
PseCra	*Pseudopanax crassifolius*	*Lancewood*	Araliaceae	Endemic
PteBan	*Pterostylis banksii*	*Tutukiwi, greenhood*	Orchidaceae	Endemic
PteMac	*Pteris macilenta*	*Sweet fern*	Pteridaceae	Indigenous
RhoSap	*Rhopalostylis sapida*	*Nikau Palm*	Arecaceae	Endemic
RipSca	*Ripogonum scandens*	*Supplejack*	Smilacaceae	Endemic
SchDig	*Schefflera digitata*	*Pate*	Araliaceae	Endemic
TmeElo	*Tmesipteris elongata*	*Fork fern*	Psilotaceae	Indigenous
UncUnc	*Uncinia uncinata*	*Hookgrass*	Cyperaceae	Non-endemic

Appendix 4.10: References for Chapter 4 appendices.

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Appendix 5.1: Measurement method for soil chemicals as advised by ARL Ravensdown Ltd.

AMN (Anaerobic Mineralisable N)

This procedure estimates the total amount of ammoniacal nitrogen produced on incubation of soil under water-logged (i.e., anaerobic) conditions at 40oC for seven days. The available ammonium ion is then leached from the soil by 1.7 M KCl. The available ammonia in the filtered extract is then determined by the reaction of ammonia with hypochlorite and phenol, catalysed by sodium nitroprusside, to form an intensely blue compound, indophenol (Hinds & Lowe, 1980). The value obtained for this test is an indication of the soil's nitrogen availability index. The nitrogen concentration is determined by flow injection analyser.

Total N/TotalC

Total carbon and nitrogen is analysed using the combustion method (LECO CNS-2000). The combustometric analysis for total carbon and nitrogen is truly quantitative and provides a very accurate and rapid result. The CNS-2000 analysis involves three stages: purge, burn and analyse. The sample is loaded into a ceramic boat and placed into a purge chamber of the horizontal furnace. The chamber is purged with oxygen to remove atmospheric gases. The boat is pushed into the furnace, oxygen is allowed to flow directly onto the sample and combustion takes place at 1050-1300°C. The resultant gaseous products are collected in the ballast chamber. The gaseous product is then used to purge and simultaneously fill the carbon and sulphur IR cells, as well as the 10 mL sample loop. The 10 mL aliquot of the gaseous product is then passed over hot copper, to remove excess oxygen and to reduce the oxides of nitrogen to their molecular form. Finally, the gas is scrubbed of residual moisture and carbon dioxide using anhydrous magnesium perchlorate and sodium hydroxide respectively. The nitrogen is measured using a thermal conductivity detector and individual IR cells detect carbon.

Olsen P method of measurement.

- 30 minute 0.5 M pH (8.50) Sodium Bicarbonate extraction and flow injection analysis
- Soil prepared to a 2mm sieve size and air dried at 60 degrees.
- LLD = 1 expressed as Olsen-soluble P ug/mL

Appendix 5.2: Conversion of w/w values in table 5.

An example:

Total N = 0.32 % w/w on a sample with a density of 1.15 g/ml (note: this is what is reported on ARL reports for each sample under volume to weight - it is not a field measurement therefore not ideal, but an approximation)

= 1.15 g/ml = 1150 mg/cm^3
= 0.32 mg/100 mg (because % out of 100)
= now need to convert mg to cm^3
= from density we know that there is 1150 mg /cm^3
= therefore in 100 mg will fill .0869 cm^3 (100mg/1150mg)
= result =
= 0.32 mg/.0869 cm^3
= 3.68 mg/cm3 (convert .0869 to 1 by multiplying by 11.5)

Convert to kg/m3

= 3.68 kg/m3 (conversion is 1:1)

Appendix 5.3a: Summary Statistics

```
All data
                BulkDens

     Min:    1.26000000
 1st Qu.:    1.41000000
    Mean:    1.50305556
  Median:    1.51000000
 3rd Qu.:    1.58250000
     Max:    1.78000000
 Total N:   36.00000000
   NA's :    0.00000000
Std Dev.:    0.13155812
 SE Mean:    0.02192635
LCL Mean:    1.45854269
UCL Mean:    1.54756842
Skewness:    0.04840365
Kurtosis:   -0.77654723
----------------------
```

```
All data
                Porosity

     Min:    0.370000000
 1st Qu.:    0.547500000
    Mean:    0.573611111
  Median:    0.580000000
 3rd Qu.:    0.612500000
     Max:    0.660000000
 Total N:   36.000000000
   NA's :    0.000000000
Std Dev.:    0.059095699
 SE Mean:    0.009849283
LCL Mean:    0.553616003
UCL Mean:    0.593606219
Skewness:   -1.360429775
Kurtosis:    2.897900791
-----------------------
```

```
All data
             Sand..vol

     Min: 37.50000000
 1st Qu.: 49.55500000
    Mean: 57.56400000
  Median: 56.32000000
 3rd Qu.: 63.78000000
     Max: 86.69000000
 Total N: 36.00000000
   NA's :  1.00000000
Std Dev.: 11.51113635
 SE Mean:  1.94573717
LCL Mean: 53.60978632
UCL Mean: 61.51821368
Skewness:  0.57100549
Kurtosis:  0.05929709
---------------------
```

```
Site:Wh
                BulkDens

     Min:    1.31000000
 1st Qu.:    1.53250000
    Mean:    1.57444444
  Median:    1.57500000
 3rd Qu.:    1.64750000
     Max:    1.78000000
 Total N:   18.00000000
   NA's :    0.00000000
Std Dev.:    0.11459505
 SE Mean:    0.02701031
LCL Mean:    1.51745767
UCL Mean:    1.63143122
Skewness:   -0.54142798
Kurtosis:    0.55491324
----------------------
```

```
Site:Wh
               Porosity

     Min:    0.37000000
 1st Qu.:    0.54000000
    Mean:    0.55777778
  Median:    0.56500000
 3rd Qu.:    0.59500000
     Max:    0.64000000
 Total N:   18.00000000
   NA's :    0.00000000
Std Dev.:    0.06273713
 SE Mean:    0.01478728
LCL Mean:    0.52657934
UCL Mean:    0.58897622
Skewness:   -1.52804501
Kurtosis:    3.80188323
-----------------------
```

```
Site:Wh
            Sand..vol

     Min:  37.500000
 1st Qu.:  45.767500
    Mean:  51.903333
  Median:  51.690000
 3rd Qu.:  58.275000
     Max:  67.700000
 Total N:  18.000000
   NA's :   0.000000
Std Dev.:   8.599831
 SE Mean:   2.027000
LCL Mean:  47.626738
UCL Mean:  56.179929
Skewness:   0.142604
Kurtosis:  -0.830706
--------------------
```

```
Site:Pp
               BulkDens

     Min:    1.26000000
 1st Qu.:    1.35000000
    Mean:    1.43166667
  Median:    1.41500000
 3rd Qu.:    1.47750000
     Max:    1.68000000
 Total N:   18.00000000
   NA's :    0.00000000
Std Dev.:    0.10820732
 SE Mean:    0.02550471
LCL Mean:    1.37785643
UCL Mean:    1.48547690
Skewness:    0.56272634
Kurtosis:    0.20207893
```

```
Site:Pp
               Porosity

     Min:    0.45000000
 1st Qu.:    0.57000000
    Mean:    0.58944444
  Median:    0.60000000
 3rd Qu.:    0.62000000
     Max:    0.66000000
 Total N:   18.00000000
   NA's :    0.00000000
Std Dev.:    0.05218431
 SE Mean:    0.01229996
LCL Mean:    0.56349380
UCL Mean:    0.61539509
Skewness:   -1.21068234
Kurtosis:    1.81814457
```

```
Site:Pp
             Sand..vol

     Min:  47.7600000
 1st Qu.:  55.2600000
    Mean:  63.5576471
  Median:  60.2600000
 3rd Qu.:  69.4800000
     Max:  86.6900000
 Total N:  18.0000000
   NA's :   1.0000000
Std Dev.:  11.3480750
 SE Mean:   2.7523125
LCL Mean:  57.7230053
UCL Mean:  69.3922888
Skewness:   0.5068122
Kurtosis:  -0.6624754
```

Appendix 5.3b: Summary Statistic

```
All data
                   Silt

     Min:  11.590000000
 1st Qu.:  33.685000000
    Mean:  39.294000000
  Median:  40.000000000
 3rd Qu.:  47.190000000
     Max:  58.480000000
 Total N:  36.000000000
   NA's :   1.000000000
Std Dev.:  11.020080121
 SE Mean:   1.862733520
LCL Mean:  35.508470031
UCL Mean:  43.079529969
Skewness:  -0.522853936
Kurtosis:  -0.003616688
-----------------------
```

```
All data
                   Clay

     Min:  1.4600000
 1st Qu.:  2.6000000
    Mean:  3.1428571
  Median:  3.1200000
 3rd Qu.:  3.5350000
     Max:  5.2200000
 Total N: 36.0000000
   NA's :  1.0000000
Std Dev.:  0.8839569
 SE Mean:  0.1494160
LCL Mean:  2.8392073
UCL Mean:  3.4465070
Skewness:  0.4313687
Kurtosis:  0.1358977
--------------------
```

```
All data
                Olsen.P

     Min:  0.500000
 1st Qu.:  4.000000
    Mean: 15.680556
  Median:  7.500000
 3rd Qu.: 19.750000
     Max: 76.000000
 Total N: 36.000000
   NA's :  0.000000
Std Dev.: 18.853250
 SE Mean:  3.142208
LCL Mean:  9.301533
UCL Mean: 22.059578
Skewness:  1.809663
Kurtosis:  2.718662
-------------------
```

```
Site:Wh
                 Silt

     Min:  30.0200000
 1st Qu.:  39.2750000
    Mean:  45.1255556
  Median:  45.4100000
 3rd Qu.:  50.7375000
     Max:  58.4800000
 Total N:  18.0000000
   NA's :   0.0000000
Std Dev.:   8.0457780
 SE Mean:   1.8964081
LCL Mean:  41.1244843
UCL Mean:  49.1266268
Skewness:  -0.1566762
Kurtosis:  -0.7918805
---------------------
```

```
Site:Wh
                     Clay

     Min:   1.94000000
 1st Qu.:   2.53500000
    Mean:   2.97166667
  Median:   3.10500000
 3rd Qu.:   3.40750000
     Max:   4.02000000
 Total N:  18.00000000
   NA's :   0.00000000
Std Dev.:   0.59410090
 SE Mean:   0.14003093
LCL Mean:   2.67622724
UCL Mean:   3.26710609
Skewness:  -0.09900126
Kurtosis:  -0.89259534
----------------------
```

```
Site:Wh
                 Olsen.P

     Min:   5.0000000
 1st Qu.:   8.2500000
    Mean:  26.0000000
  Median:  18.0000000
 3rd Qu.:  39.5000000
     Max:  76.0000000
 Total N:  18.0000000
   NA's :   0.0000000
Std Dev.:  21.6224284
 SE Mean:   5.0964553
LCL Mean:  15.2474193
UCL Mean:  36.7525807
Skewness:   1.0617435
Kurtosis:   0.2023984
--------------------
```

```
Site:Pp
                 Silt

     Min:  11.5900000
 1st Qu.:  27.5100000
    Mean:  33.1194118
  Median:  35.5400000
 3rd Qu.:  40.5400000
     Max:  48.8300000
 Total N:  18.0000000
   NA's :   1.0000000
Std Dev.:  10.5127467
 SE Mean:   2.5497156
LCL Mean:  27.7142562
UCL Mean:  38.5245674
Skewness:  -0.4428271
Kurtosis:  -0.5821019
```

```
Site:Pp
                   Clay

     Min:   1.4600000
 1st Qu.:   2.9100000
    Mean:   3.3241176
  Median:   3.1300000
 3rd Qu.:   3.9800000
     Max:   5.2200000
 Total N:  18.0000000
   NA's :   1.0000000
Std Dev.:   1.1034212
 SE Mean:   0.2676189
LCL Mean:   2.7567908
UCL Mean:   3.8914445
Skewness:   0.1235085
Kurtosis:  -0.6704158
```

```
Site:Pp
                Olsen.P

     Min:  0.500000
 1st Qu.:  3.000000
    Mean:  5.361111
  Median:  4.000000
 3rd Qu.:  4.750000
     Max: 29.000000
 Total N: 18.000000
   NA's :  0.000000
Std Dev.:  6.225672
 SE Mean:  1.467405
LCL Mean:  2.265157
UCL Mean:  8.457065
Skewness:  3.569958
Kurtosis: 13.876734
```

Appendix 5.3c: Summary Statistic

All data

	Min.N	Total.N	Total.C
Min:	46.000000	0.11000000	1.18000000
1st Qu.:	155.750000	0.29750000	3.84000000
Mean:	197.972222	0.38194444	4.47083333
Median:	192.500000	0.38500000	4.22500000
3rd Qu.:	245.250000	0.45250000	5.12000000
Max:	504.000000	0.67000000	7.06000000
Total N:	36.000000	36.00000000	36.00000000
NA's :	0.000000	0.00000000	0.00000000
Std Dev.:	86.957949	0.12195595	1.21930279
SE Mean:	14.492992	0.02032599	0.20321713
LCL Mean:	168.549885	0.34068049	4.05828062
UCL Mean:	227.394559	0.42320840	4.88338604
Skewness:	1.062319	0.14029805	-0.07765358
Kurtosis:	3.203908	0.26749961	0.68324823

Site:Wh

	Min.N	Total.N	Total.C
Min:	107.000000	0.28000000	3.0400000
1st Qu.:	149.250000	0.39250000	4.0200000
Mean:	197.833333	0.44666667	4.8222222
Median:	177.500000	0.43000000	4.5150000
3rd Qu.:	206.000000	0.49750000	5.7575000
Max:	504.000000	0.67000000	7.0600000
Total N:	18.000000	18.00000000	18.0000000
NA's :	0.000000	0.00000000	0.0000000
Std Dev.:	92.325033	0.10324158	1.1548239
SE Mean:	21.761219	0.02433427	0.2721946
LCL Mean:	151.921174	0.39532584	4.2479418
UCL Mean:	243.745492	0.49800750	5.3965027
Skewness:	2.336108	0.53369329	0.5561219
Kurtosis:	6.891090	0.12136459	-0.7431635

Site:Pp

	Min.N	Total.N	Total.C
Min:	46.000000	0.11000000	1.1800000
1st Qu.:	162.500000	0.26500000	3.6600000
Mean:	198.111111	0.31722222	4.1194444
Median:	210.500000	0.30500000	4.0750000
3rd Qu.:	250.000000	0.37750000	4.7300000
Max:	329.000000	0.54000000	6.2000000
Total N:	18.000000	18.00000000	18.0000000
NA's :	0.000000	0.00000000	0.0000000
Std Dev.:	83.929864	0.10531776	1.2106851
SE Mean:	19.782458	0.02482363	0.2853612
LCL Mean:	156.373771	0.26484893	3.5173849
UCL Mean:	239.848451	0.36959551	4.7215040
Skewness:	-0.523878	0.05476502	-0.5678522
Kurtosis:	-0.510744	0.52520951	1.1348961

Appendix 5.3d: Summary Statistic

```
All data

            C.N.ratio

     Min:   9.0000000
 1st Qu.: 11.0000000
    Mean: 12.0277778
  Median: 12.0000000
 3rd Qu.: 13.0000000
     Max: 16.0000000
 Total N: 36.0000000
   NA's :  0.0000000
Std Dev.:  1.7318217
 SE Mean:  0.2886369
LCL Mean: 11.4418136
UCL Mean: 12.6137419
Skewness:  0.8285200
Kurtosis:  0.1812996
--------------------

Site:Wh
            C.N.ratio

     Min:   9.0000000
 1st Qu.: 10.2500000
    Mean: 10.9444444
  Median: 11.0000000
 3rd Qu.: 11.0000000
     Max: 13.0000000
 Total N: 18.0000000
   NA's :  0.0000000
Std Dev.:  0.9375953
 SE Mean:  0.2209933
LCL Mean: 10.4781893
UCL Mean: 11.4106996
Skewness:  0.1199382
Kurtosis:  0.6237476
--------------------

Site:Pp
             C.N.ratio

     Min:   11.0000000
 1st Qu.:   12.0000000
    Mean:   13.1111111
  Median:   13.0000000
 3rd Qu.:   14.7500000
     Max:   16.0000000
 Total N:   18.0000000
   NA's :    0.0000000
Std Dev.:    1.6764419
 SE Mean:    0.3951412
LCL Mean:   12.2774362
UCL Mean:   13.9447861
Skewness:    0.4782416
Kurtosis:   -1.0090222
```

Appendix 5.3e: Hillslope summary statistics for Paraparaumu

```
Hill.Loc:CZ

Site.sub.set:PpN

BulkDens

     Min:  0.96000000
 1st Qu.:  0.98500000
    Mean:  1.04000000
  Median:  1.01000000
 3rd Qu.:  1.08000000
     Max:  1.15000000
 Total N:  3.00000000
   NA's :  0.00000000
Std Dev.:  0.09848858
 SE Mean:  0.05686241
LCL Mean:  0.79534081
UCL Mean:  1.28465919
Skewness:  1.24353737
Kurtosis:          NA
-----------------------
```

```
Hill.Loc:CZ

Site.sub.set:PpS

BulkDens

     Min: 1.01000000
 1st Qu.: 1.04000000
    Mean: 1.09333333
  Median: 1.07000000
 3rd Qu.: 1.13500000
     Max: 1.20000000
 Total N: 3.00000000
   NA's : 0.00000000
Std Dev.: 0.09712535
 SE Mean: 0.05607535
LCL Mean: 0.85206059
UCL Mean: 1.33460607
Skewness: 1.01868288
Kurtosis:         NA
-----------------------
```

```
Hill.Loc:MS

Site.sub.set:PpN

BulkDens

     Min:  1.07000000
 1st Qu.:  1.11500000
    Mean:  1.14666667
  Median:  1.16000000
 3rd Qu.:  1.18500000
     Max:  1.21000000
 Total N:  3.00000000
   NA's :  0.00000000
Std Dev.:  0.07094599
 SE Mean:  0.04096069
LCL Mean:  0.97042706
UCL Mean:  1.32290627
Skewness: -0.81584309
Kurtosis:          NA
-----------------------
```

```
Hill.Loc:MS

Site.sub.set:PpS

BulkDens

     Min:  1.01000000
 1st Qu.:  1.07500000
    Mean:  1.12000000
  Median:  1.14000000
 3rd Qu.:  1.17500000
     Max:  1.21000000
 Total N:  3.00000000
   NA's :  0.00000000
Std Dev.:  0.10148892
 SE Mean:  0.05859465
LCL Mean:  0.86788756
UCL Mean:  1.37211244
Skewness: -0.85235766
Kurtosis:          NA
-----------------------
```

```
Hill.Loc:TS

Site.sub.set:PpN

BulkDens

     Min:  1.09000000
 1st Qu.:  1.09500000
    Mean:  1.17666667
  Median:  1.10000000
 3rd Qu.:  1.22000000
     Max:  1.34000000
 Total N:  3.00000000
   NA's :  0.00000000
Std Dev.:  0.14153916
 SE Mean:  0.08171767
LCL Mean:  0.82506391
UCL Mean:  1.52826943
Skewness:  1.72232929
Kurtosis:          NA
-----------------------
```

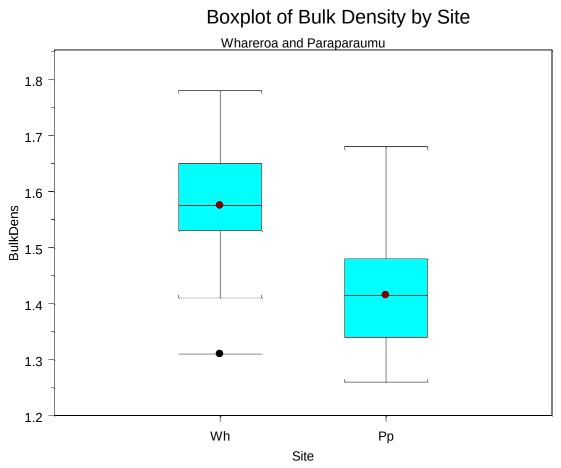
```
Hill.Loc:TS

Site.sub.set:PpS

BulkDens

     Min:  1.0400000
 1st Qu.:  1.2450000
    Mean:  1.3200000
  Median:  1.4500000
 3rd Qu.:  1.4600000
     Max:  1.4700000
 Total N:  3.0000000
   NA's :  0.0000000
Std Dev.:  0.2426932
 SE Mean:  0.1401190
LCL Mean:  0.7171166
UCL Mean:  1.9228834
Skewness: -1.7188272
Kurtosis:         NA
-----------------------
```

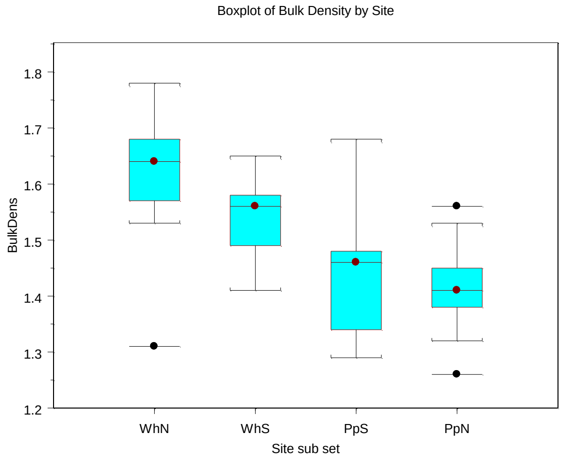
Appendix 5.3f: Hillslope summary statistics for Whareroa.

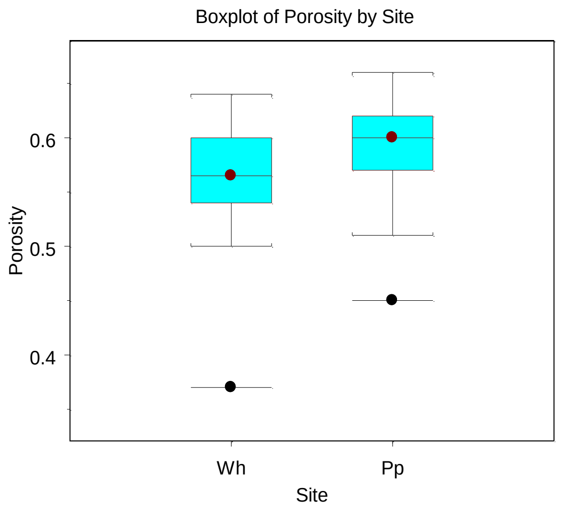
```
Hill.Loc:CZ

Site.sub.set:WhN

BulkDens

     Min:  1.150000
 1st Qu.:  1.265000
    Mean:  1.380000
  Median:  1.380000
 3rd Qu.:  1.495000
     Max:  1.610000
 Total N:  3.000000
   NA's :  0.000000
Std Dev.:  2.300000
 SE Mean:  1.327906
LCL Mean:  8.086483
UCL Mean:  1.951352
Skewness: -4.277283
Kurtosis:  NA
-----------------------
Hill.Loc:MS

Site.sub.set:WhN

BulkDens

     Min:  0.9100000
 1st Qu.:  1.1350000
    Mean:  1.2100000
  Median:  1.3600000
 3rd Qu.:  1.3600000
     Max:  1.3600000
 Total N:  3.0000000
   NA's :  0.0000000
Std Dev.:  0.2598076
 SE Mean:  0.1500000
LCL Mean:  0.5646021
UCL Mean:  1.8553979
Skewness: -1.7320508
Kurtosis:          NA
-----------------------
Hill.Loc:TS

Site.sub.set:WhN

BulkDens

     Min: 1.19000000
 1st Qu.: 1.21000000
    Mean: 1.24000000
  Median: 1.23000000
 3rd Qu.: 1.26500000
     Max: 1.30000000
 Total N: 3.00000000
   NA's : 0.00000000
Std Dev.: 0.05567764
 SE Mean: 0.03214550
LCL Mean: 1.10168907
UCL Mean: 1.37831093
Skewness: 0.78215212
Kurtosis:         NA
-----------------------
```

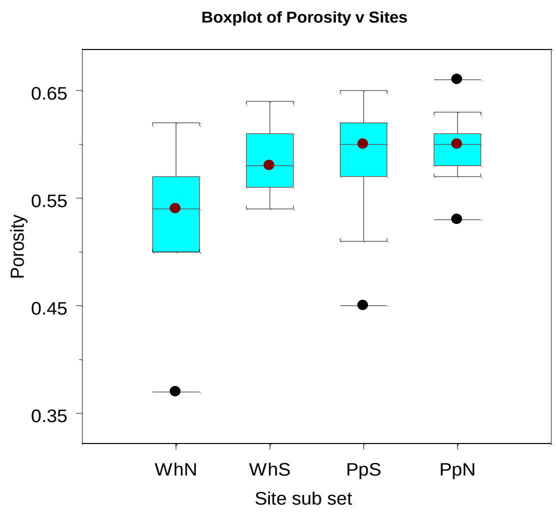
```
Hill.Loc:CZ

Site.sub.set:WhS

BulkDens

     Min:  0.98000000
 1st Qu.:  1.07500000
    Mean:  1.12666667
  Median:  1.17000000
 3rd Qu.:  1.20000000
     Max:  1.23000000
 Total N:  3.00000000
   NA's :  0.00000000
Std Dev.:  0.13051181
 SE Mean:  0.07535103
LCL Mean:  0.80245735
UCL Mean:  1.45087598
Skewness: -1.32940407
Kurtosis:           NA
-----------------------
Hill.Loc:MS

Site.sub.set:WhS

BulkDens

     Min: 1.080000e+000
 1st Qu.: 1.110000e+000
    Mean: 1.140000e+000
  Median: 1.140000e+000
 3rd Qu.: 1.170000e+000
     Max: 1.200000e+000
 Total N: 3.000000e+000
   NA's : 0.000000e+000
Std Dev.: 6.000000e-002
 SE Mean: 3.464102e-002
LCL Mean: 9.909517e-001
UCL Mean: 1.289048e+000
Skewness: 1.656420e-014
Kurtosis:            NA
-----------------------
Hill.Loc:TS

Site.sub.set:WhS

BulkDens

     Min: 1.03000000
 1st Qu.: 1.05500000
    Mean: 1.11333333
  Median: 1.08000000
 3rd Qu.: 1.15500000
     Max: 1.23000000
 Total N: 3.00000000
   NA's : 0.00000000
Std Dev.: 0.10408330
 SE Mean: 0.06009252
LCL Mean: 0.85477608
UCL Mean: 1.37189058
Skewness: 1.29334278
Kurtosis:         NA
----------------------
```

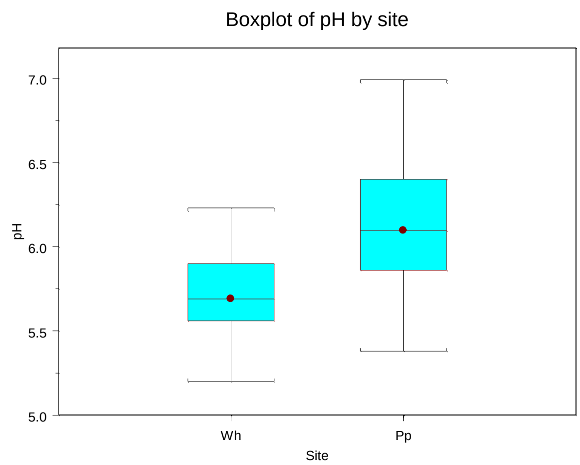
Appendix 5.4a: Boxplots for dependent variables

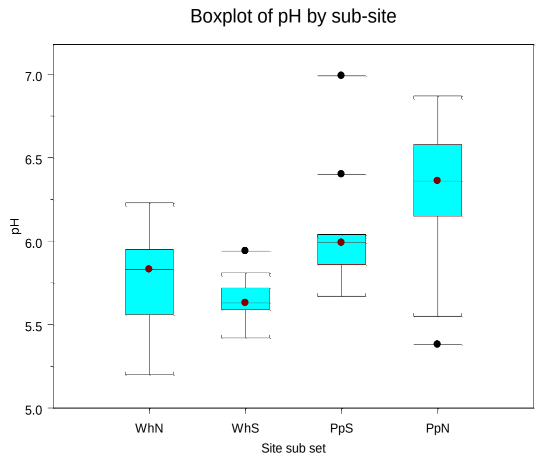




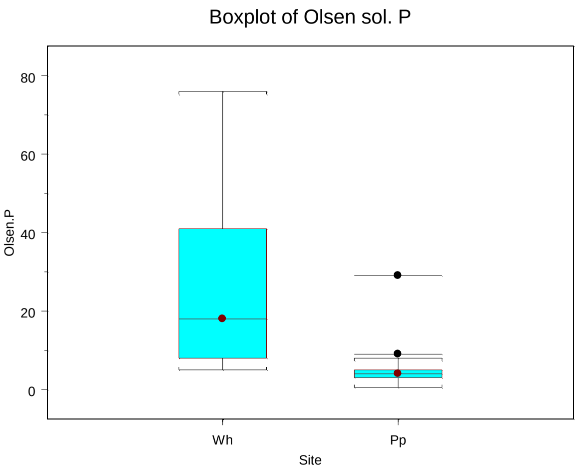


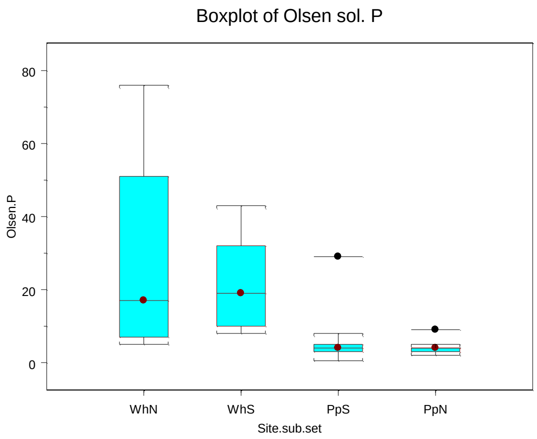


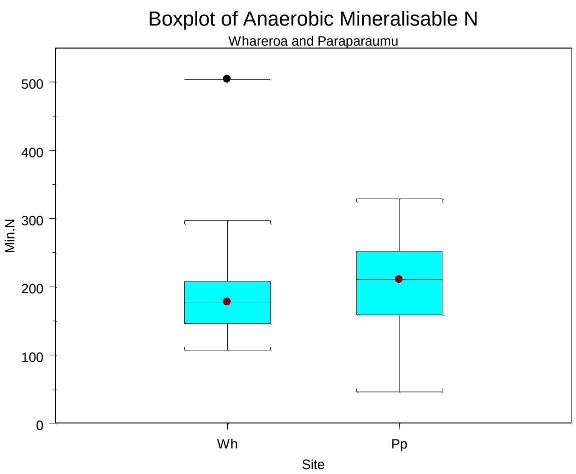


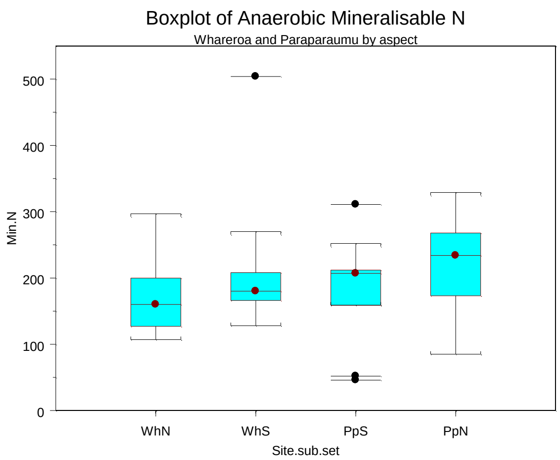


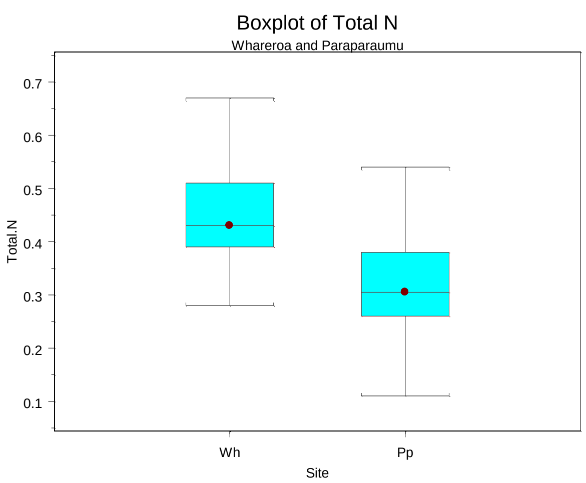
Appendix 5.4b: Boxplots for dependent variables

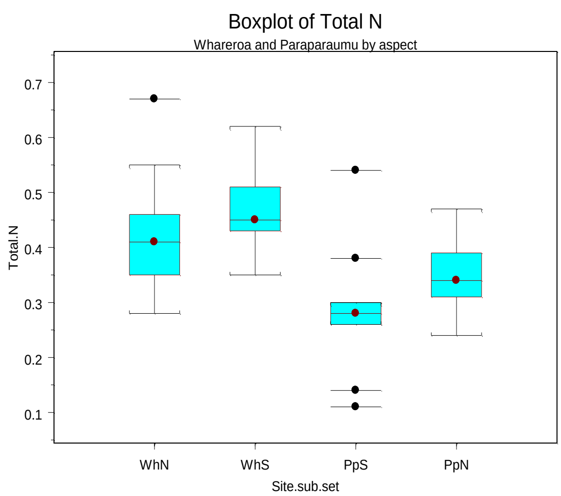




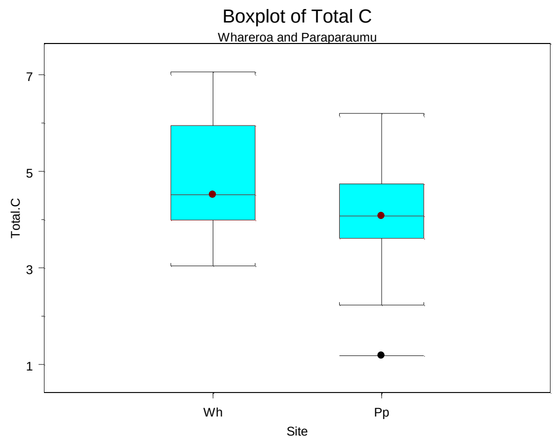


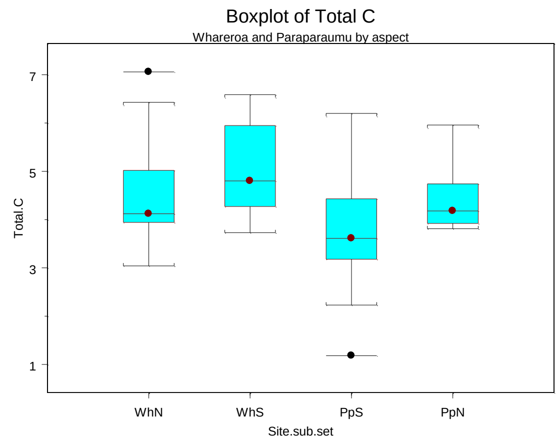


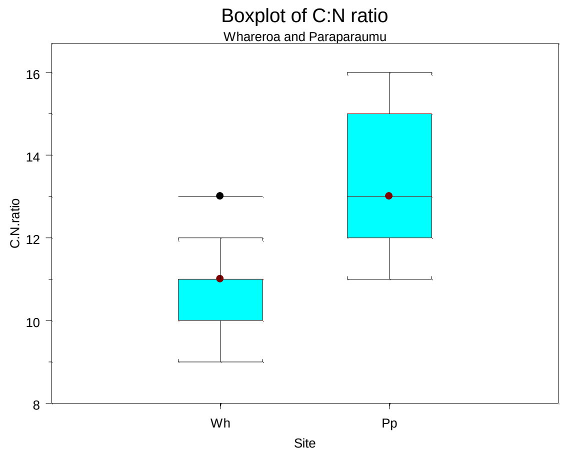


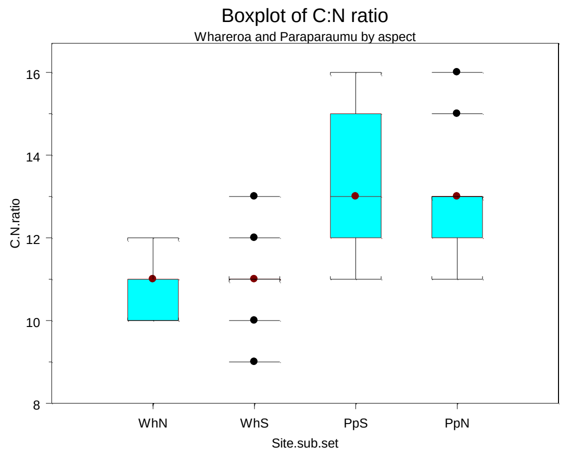


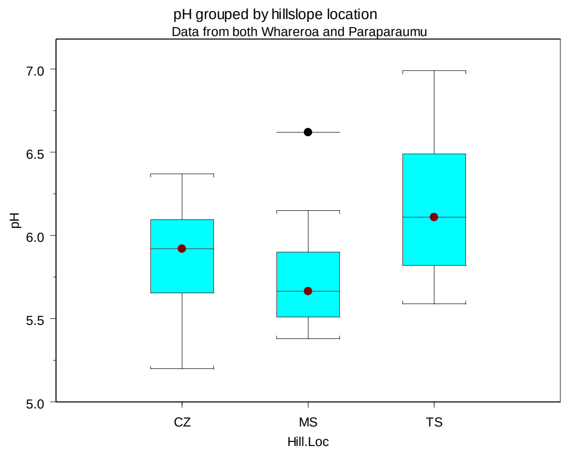
Appendix 5.4c: Boxplots for dependent variables

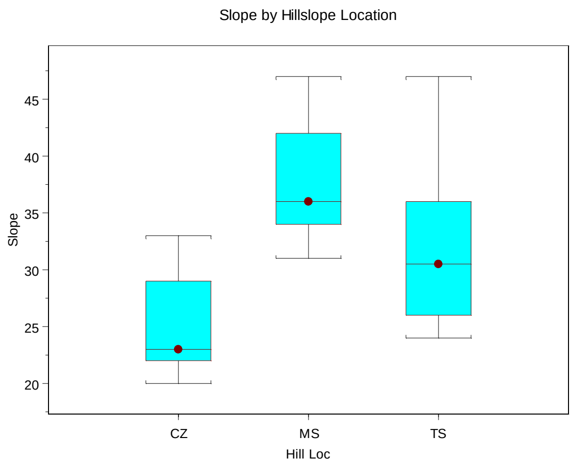




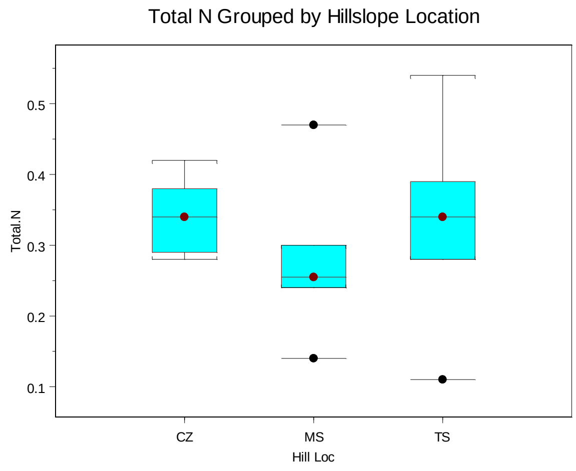


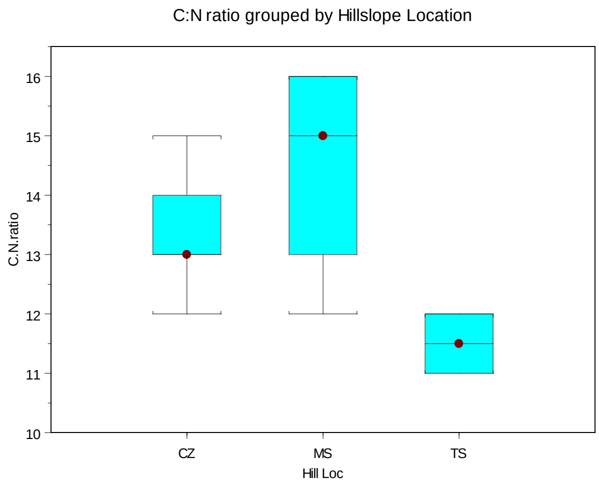






Appendix 5.4d: Boxplots for dependent variables





Appendix 5.5: Correlation matrix.

*** Correlations for data in: WhPp.SiteData.V5 ***

	BulkDens	Porosity	pH	Olsen.P	Min.N	Total.N	Total.C	C.N.ratio	SandVol	SiltVol	ClayVol
BulkDens	1.00000000	-0.84781439	-0.17858902	0.39137159	-0.04132595	0.20708047	-0.01250225	-0.5421281	-0.13408508	0.16309277	-0.29332807
Porosity	-0.84781439	1.00000000	0.12220493	-0.07381624	0.08236216	-0.08861446	0.05765063	0.3367908	-0.03945694	0.01757746	0.30059314
pH	-0.17858902	0.12220493	1.00000000	-0.10079206	0.24467473	-0.13052047	-0.08379063	-0.0487632	0.22888249	-0.24019773	0.01400143
Olsen.P	0.39137159	-0.07381624	-0.10079206	1.00000000	0.16888486	0.41954209	0.26320719	-0.4407555	-0.19909728	0.22100204	-0.16773753
Min.N	-0.04132595	0.08236216	0.24467473	0.16888486	1.00000000	0.60473122	0.55103220	-0.3663494	-0.06512579	0.07447575	-0.08336869
Total.N	0.20708047	-0.08861446	-0.13052047	0.41954209	0.60473122	1.00000000	0.91559270	-0.4967317	-0.33099542	0.36448774	-0.23850834
Total.C	-0.01250225	0.05765063	-0.08379063	0.26320719	0.55103220	0.91559270	1.00000000	-0.1373469	-0.24214560	0.26704149	-0.17839057
C.N.ratio	-0.54212812	0.33679082	-0.04876320	-0.44075550	-0.36634943	-0.49673171	-0.13734692	1.0000000	0.30791766	-0.34034240	0.24056334
SandVol	-0.13408508	-0.03945694	0.22888249	-0.19909728	-0.06512579	-0.33099542	-0.24214560	0.3079177	1.00000000	-0.99797299	-0.58850385
SiltVol	0.16309277	0.01757746	-0.24019773	0.22100204	0.07447575	0.36448774	0.26704149	-0.3403424	-0.99797299	1.00000000	0.53586064
ClayVol	-0.29332807	0.30059314	0.01400143	-0.16773753	-0.08336869	-0.23850834	-0.17839057	0.2405633	-0.58850385	0.53586064	1.00000000

Appendix 5.6a: Pairwise *a posteriori* comparisons for those variables found to be significant

Pairwise *a posteriori* comparisons: Texture and the interaction between Aspect and Site --- Both Whareroa and Paraparaumu.

Tests among levels of factor Aspect: (Group 1 – north facing, Group 2 – south facing).

within	Groups	t	P_perm	Bonferroni adj.P
Level 1 of HillLoc	(1,2)	2.0020	0.0688	0.1376
Level 2 of HillLoc	(1,2)	1.6392	0.1240	0.1240
Level 3 of HillLoc	(1,2)	5.1808	0.0008	**0.0024**

Tests among levels of the factor Hill Loc: (Group 1 – Convex Creep Zone, Group 2 – Midslope, Group 3 – Footslope).

Within	Groups	t	P_perm	Bonferroni P
Level 1 of Aspect	(1,2)	2.6545	0.0330	**0.0330**
	(1,3)	2.8136	0.0184	**0.0368**
	(2,3)	3.7889	0.0082	**0.0246**
Level 2 of Aspect	(1,2)	0.1487	0.8944	0.8944
	(1,3)	2.6993	0.0298	0.0596
	(2,3)	2.8116	0.0230	0.0690

Pairwise *a posteriori* comparisons: Anaerobic Mineralisable N and the interaction between Site and Hill Location ---Both Whareroa and Paraparaumu.

--- Results ---
Pairwise *a posteriori* comparisons
Tests among levels of the factor **site:** (Whareroa – Group 1, Paraparaumu – Group 2)

within	Groups	t	P_perm	Bonferroni adj.P
Level 1 of HillLoc	(1,2)	1.1057	0.3140	0.3140
Level 2 of HillLoc	(1,2)	2.5320	0.0298	0.0596
Level 3 of HillLoc	(1,2)	3.1772	0.0116	**0.0348**

Tests among levels of the factor **Hill location:** (Group 1 – Convex Creep Zone, Group 2 – Midslope, Group 3 – Footslope).

Within	Groups	t	P perm	Bonferroni adj.P
Level 1 of Site	(1,2)	2.3007	0.0150	**0.0450**
	(1,3)	1.4164	0.1802	0.3604
	(2,3)	0.6964	0.4896	0.4896
Level 2 of Site	(1,2)	0.5595	0.5948	>0.9999
	(1,3)	2.0820	0.0740	0.2220
	(2,3)	0.2671	0.7842	0.7842

Appendix 5.6b: Pairwise *a posteriori* comparisons for those variables found to be significant.

Pairwise *a posteriori* comparisons: All variables tested simultaneously.

Paraparaumu Scenic Reserve data only.

Tests among levels of the factor Hill.loc

Groups	t	P_perm	Bonferroni adj.P
1,2	0.6216	0.8876	0.8876
1,3	1.3204	0.1132	0.2264
2,3	1.6384	0.0492	0.1476

Pairwise *a posteriori* comparisons: Carbon/Nitrogen ratio.

Paraparaumu Scenic Reserve data only.

Groups	t	P_perm	Bonferroni adj. P
1,2	0.1831	0.8578	0.8578
1,3	3.3028	0.0052	**0.0156**
2,3	3.5720	0.0094	**0.0188**

Pairwise *a posteriori* comparisons: Soil Texture

Whareroa Farm data only.

Groups	t	P_perm	Bonferroni adj. P
1,2	2.0699	0.0784	n/a
1,3	0.9914	0.3440	n/a
2,3	0.3969	0.6822	n/a

Appendix 5.6c: *a posteriori* pairwise comparisons for those variables found to be significant

Pairwise *a posteriori* comparisons: Texture and the interaction between Aspect and Hill Location.

Paraparaumu Only.
Tests among levels of the factor Aspect

within	Groups	t	P_Monte Carlo	Bonferroni adj.P
Level 1 of HillLoc	1,2	0.9402	0.4002	n/a
Level 2 of HillLoc	1,2	0.7916	0.4918	n/a
Level 3 of HillLoc	1,2	0.1825	0.1544	n/a

Tests among levels of the factor Hill location:

Within	Groups	t	P_Monte Carlo	Bonferroni adj.P
Level 1 of Aspect	(1,2)	8.3108	0.0046	**0.0138**
(north)	(1,3)	5.1632	0.0144	**0.0288**
	(2,3)	2.0007	0.1278	0.1278
Level 2 of Aspect	(1,2)	1.2240	0.3056	n/a
(south)	(1,3)	0.7178	0.5286	n/a
	(2,3)	0.9901	0.3918	n/a

Pairwise tests for Olsen P and the interaction between Aspect and Hill Location.

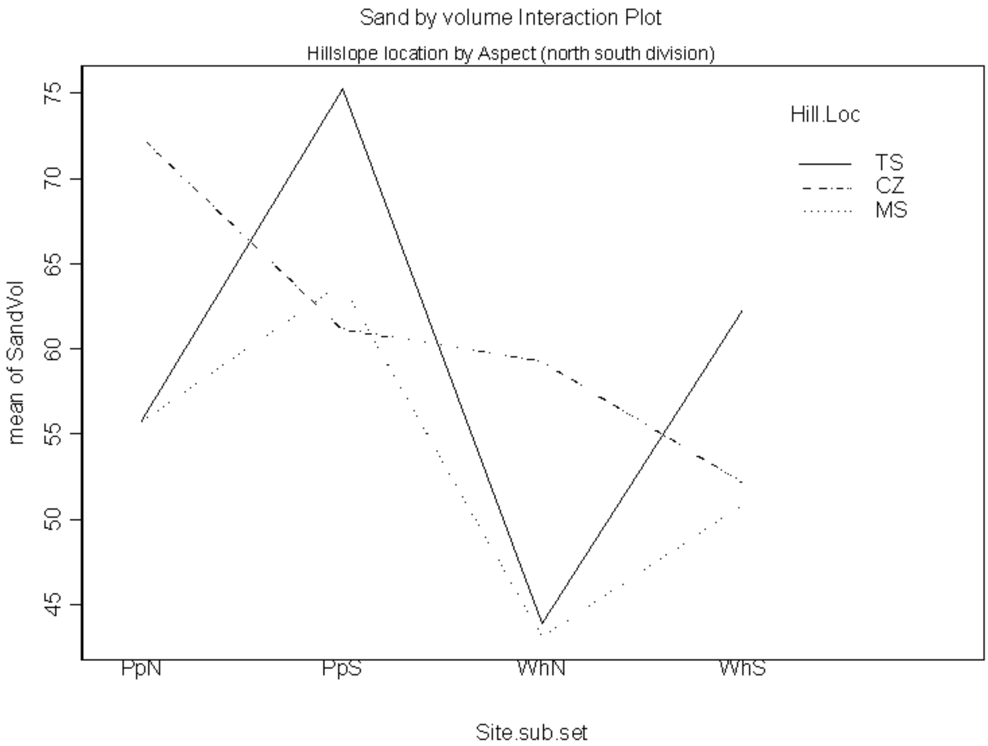
Paraparaumu Only
Tests among levels of the factor Aspect:

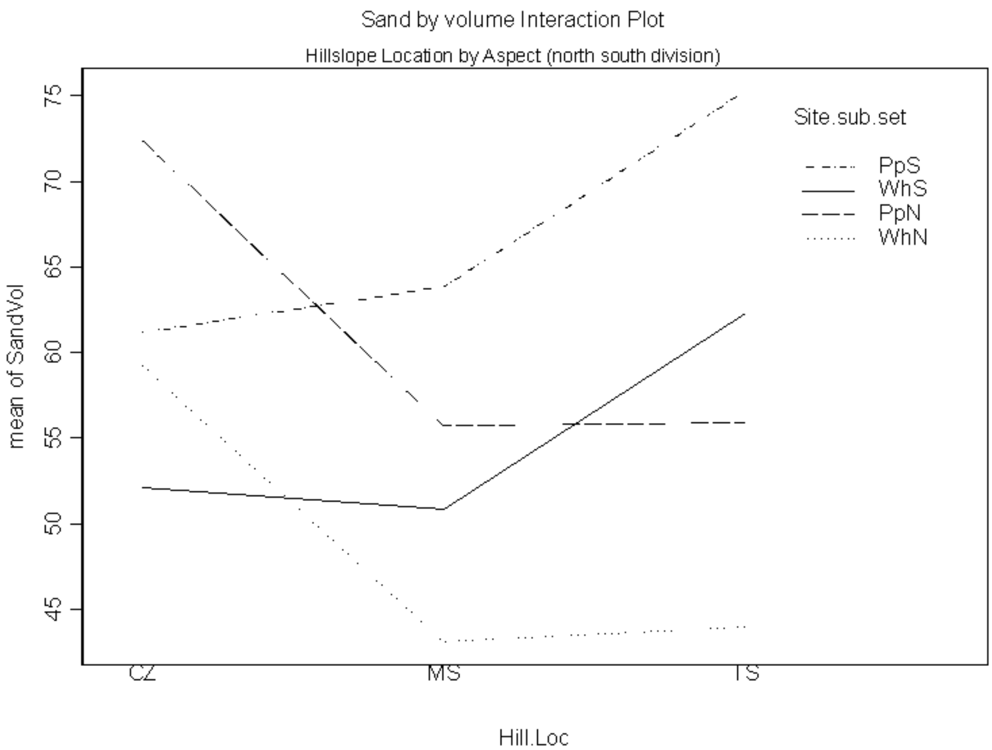
within	Groups	t	P_Monte Carlo	Bonferroni adj.P
Level 1 of HillLoc	(1,2)	2.9789	0.0312	0.0936
Level 2 of HillLoc	(1,2)	1.0510	0.3644	0.3644
Level 3 of HillLoc	(1,2)	2.2594	0.0980	0.1960

Tests among levels of the factor Hill location:

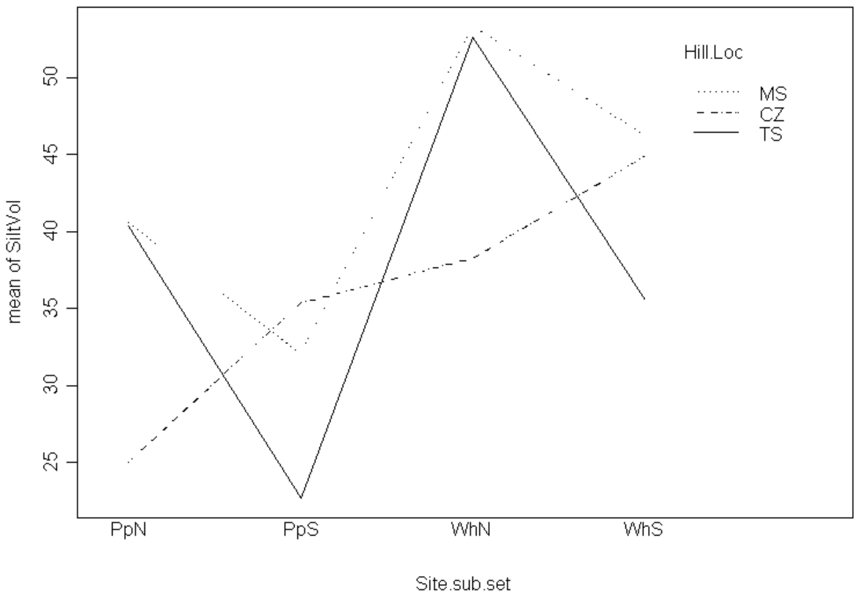
Within	Groups	t	P_Monte Carlo	Bonferroni adj.P
Level 1 of Aspect	(1,2)	1.1032	0.3476	n/a
	(1,3)	1.1327	0.3340	n/a
	(2,3)	0.6311	0.5714	n/a
Level 2 of Aspect	(1,2)	0.3247	0.7638	n/a
	(1,3)	2.2267	0.1096	n/a
	(2,3)	1.6158	0.2078	n/a

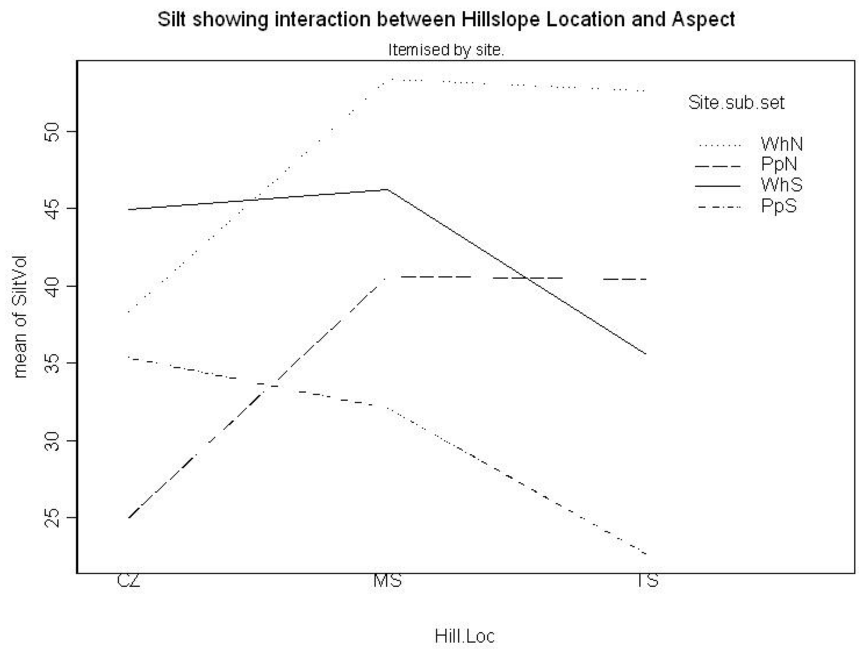
Appendix 5.7a: Interaction plots where significant values have been returned.



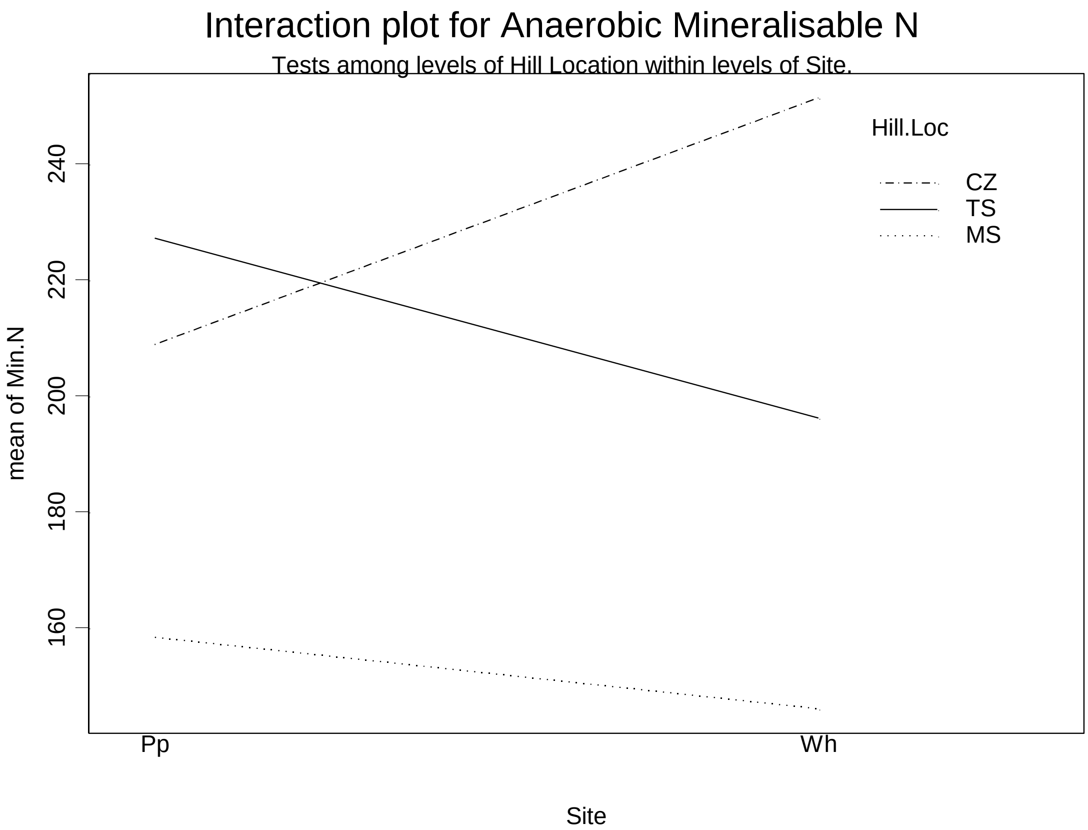


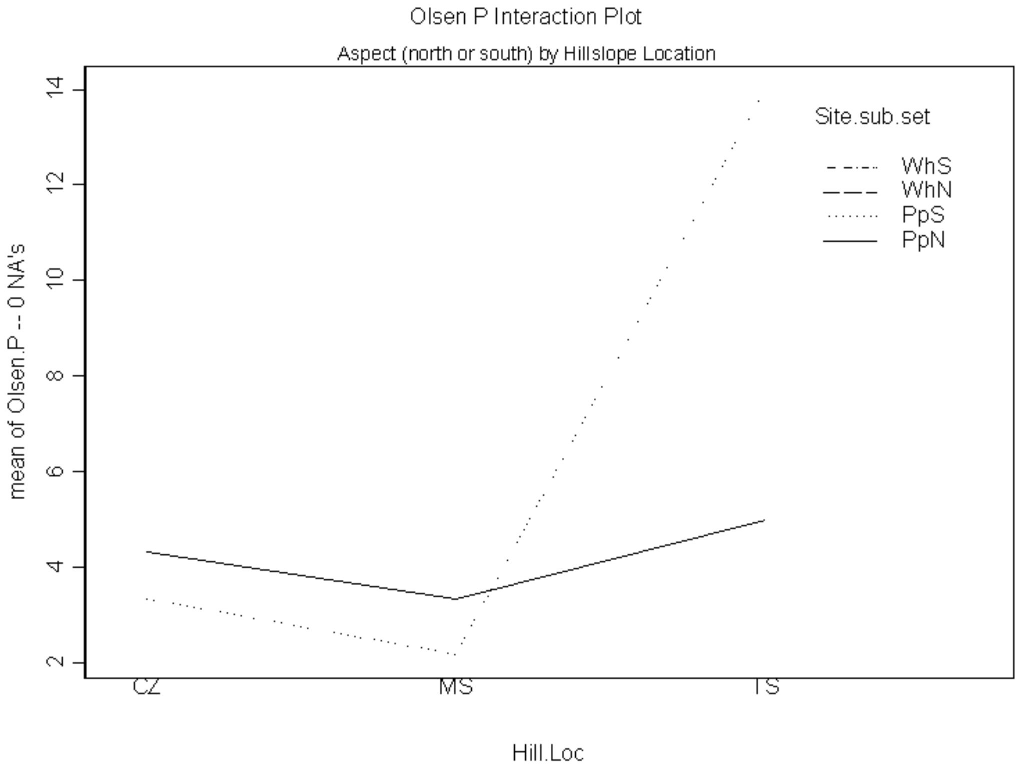
Appendix 5.7b: Interaction plots where significant values have been returned.





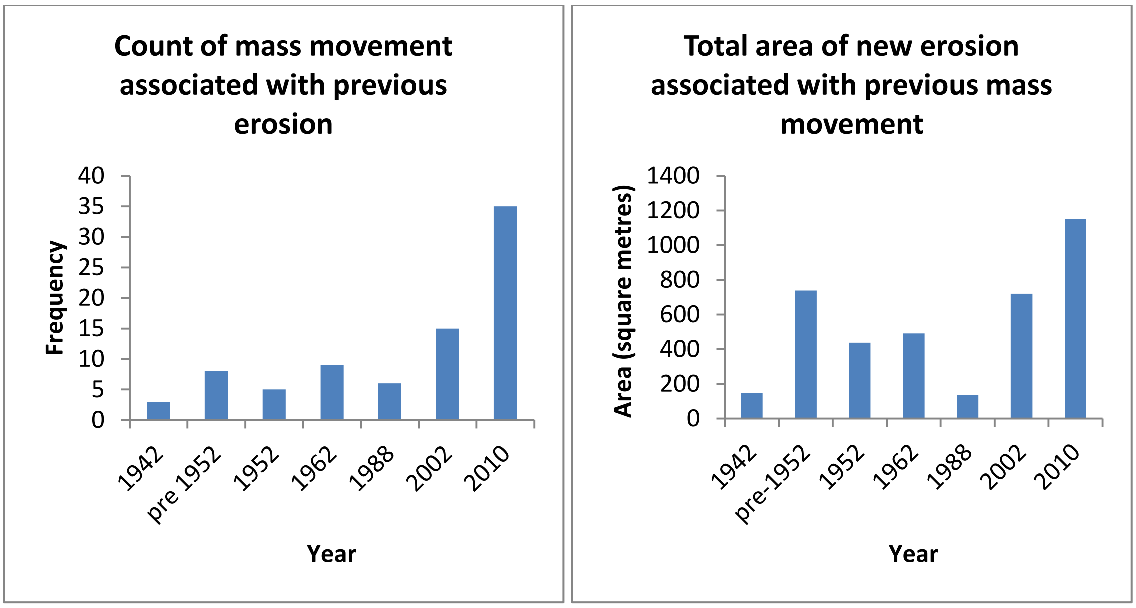
Appendix 5.7c: Interaction plots where significant values have been returned.



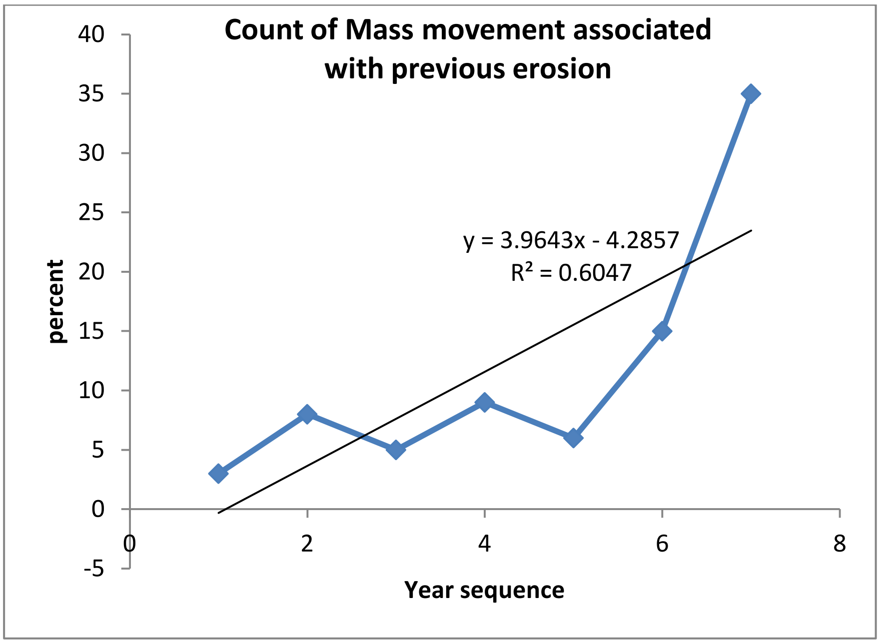


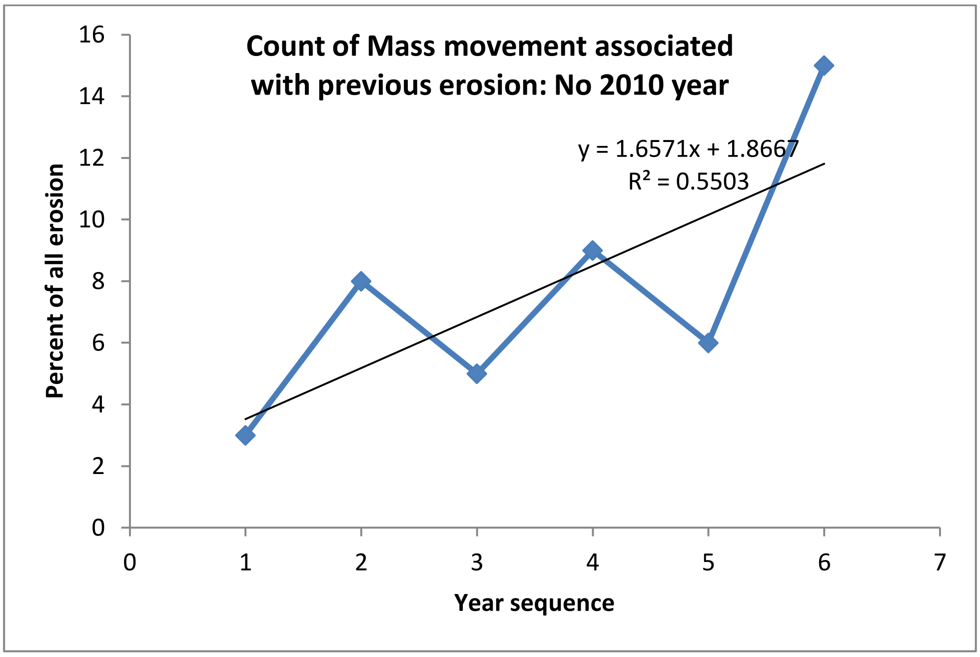
Appendix 6.0. GPS datapoints recorded at Whareroa with Trimble GPS handheld device.

Appendix 6.1: Histogram of new mass movement association with previous sites of mass movement (raw data).



Appendix 6.2: Correlation of old mass movement and new mass movement as a temporal trend.





Appendix 6.3: Mass movement data

Table 1: Data for mass movement adjacent or intersecting previous sites of mass movement

Period	Slope failure related to previous failure scarp	Total no of slope failure	Percent new slope failure occurrences associated with previous erosion sites	Area of new slope failure associated with previous mass movement	Total area of slope failure (m^2)	Percent of failure associated with previous failure
1942	3	65	4.62	147.66	6102.44	2.42
pre1952	8	46	17.39	739.28	3795.43	19.48
1952	5	144	3.47	438.56	6972.53	6.29
1962	9	52	17.31	490.58	1964.96	24.97
1988	6	63	9.52	134.1	3035.1	4.42
2002	15	94	15.96	719.52	3138.52	22.93
2010	35	72	48.61	1150.56	2861.57	40.21
Total	81	536	16.70	3820.26	27870.55	17.24

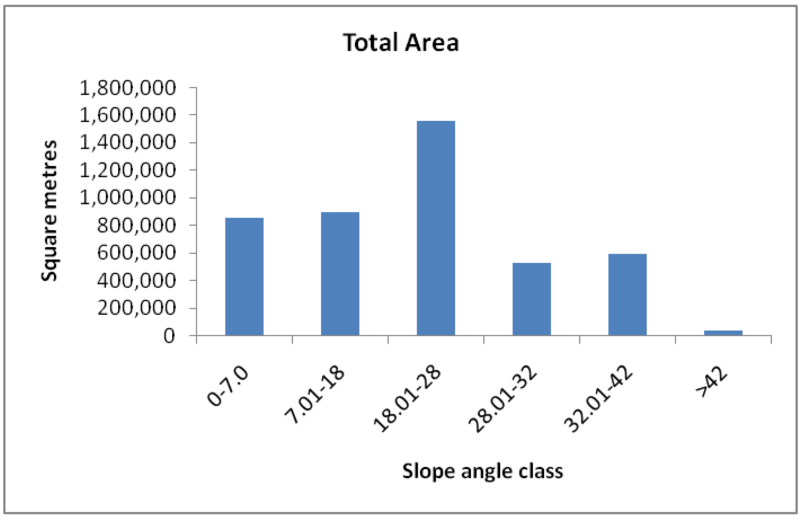
Table 2: Data for mass movement grouped by slope aspect

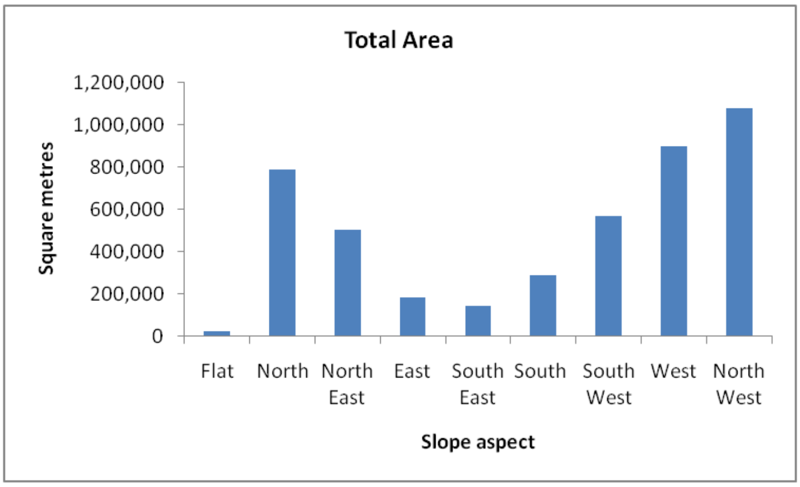
Aspect	Total Area (m^2)	Erosion Count	Relative Erosion Count (per ha.)	Erosion Area (m^2)	Relative Erosion Area (percent)
Flat	23,750	0	0.00	0	0.00
North	787,500	163	2.07	10,825	1.37
North East	505,000	101	2.00	4,533	0.90
East	182,500	20	1.10	1,083	0.59
South East	141,875	3	0.21	271	0.19
South	286,875	15	0.52	459	0.16
South West	566,875	33	0.58	2,154	0.38
West	896,250	169	1.89	10,810	1.21
North West	1,075,625	190	1.77	9,632	0.90
	4,466,250	694	1.55	39,767	0.89

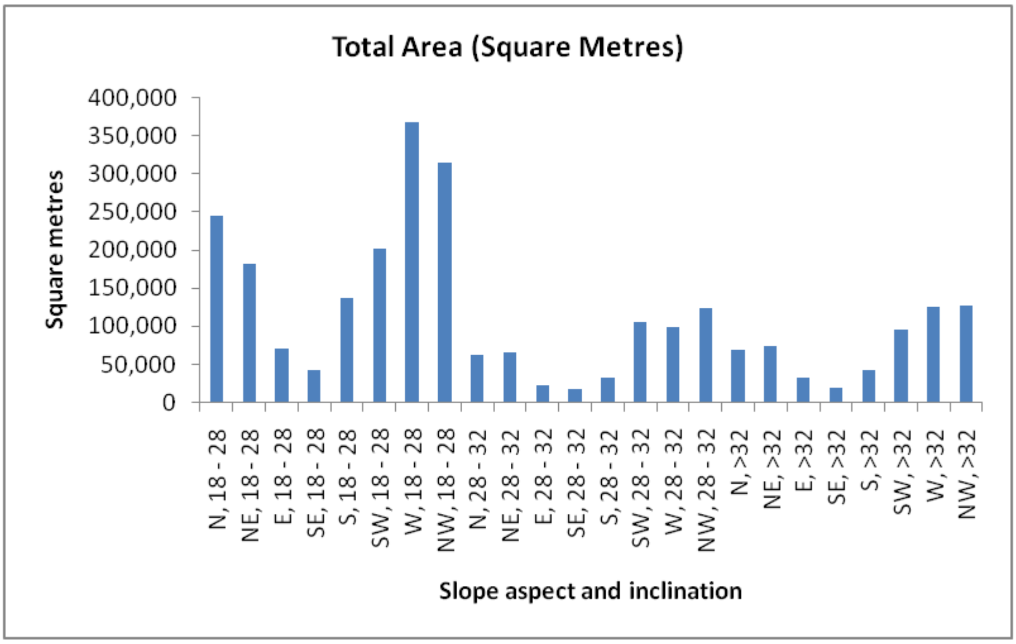
Table 3: Data for mass movement grouped by slope angle

Slope Class	Total Area (m^2)	Erosion Count	Relative Erosion Count (per ha.)	Erosion Area (m^2)	Relative Erosion Area (per ha.)
0-7.0	855,000	22	0.26	1,092	0.13
7.01-18	893,750	102	1.14	6,141	0.69
18.01-28	1,560,625	303	1.94	18,903	1.21
28.01-32	528,125	115	2.18	6,334	1.20
32.01-42	591,250	147	2.49	7,108	1.20
>42	37,500	4	1.07	189	0.50
	4,446,250	693	1.55	39,767	0.89

Appendix 6.4: Histograms of mass movement for slope aspect and angle and slope/aspect classes.

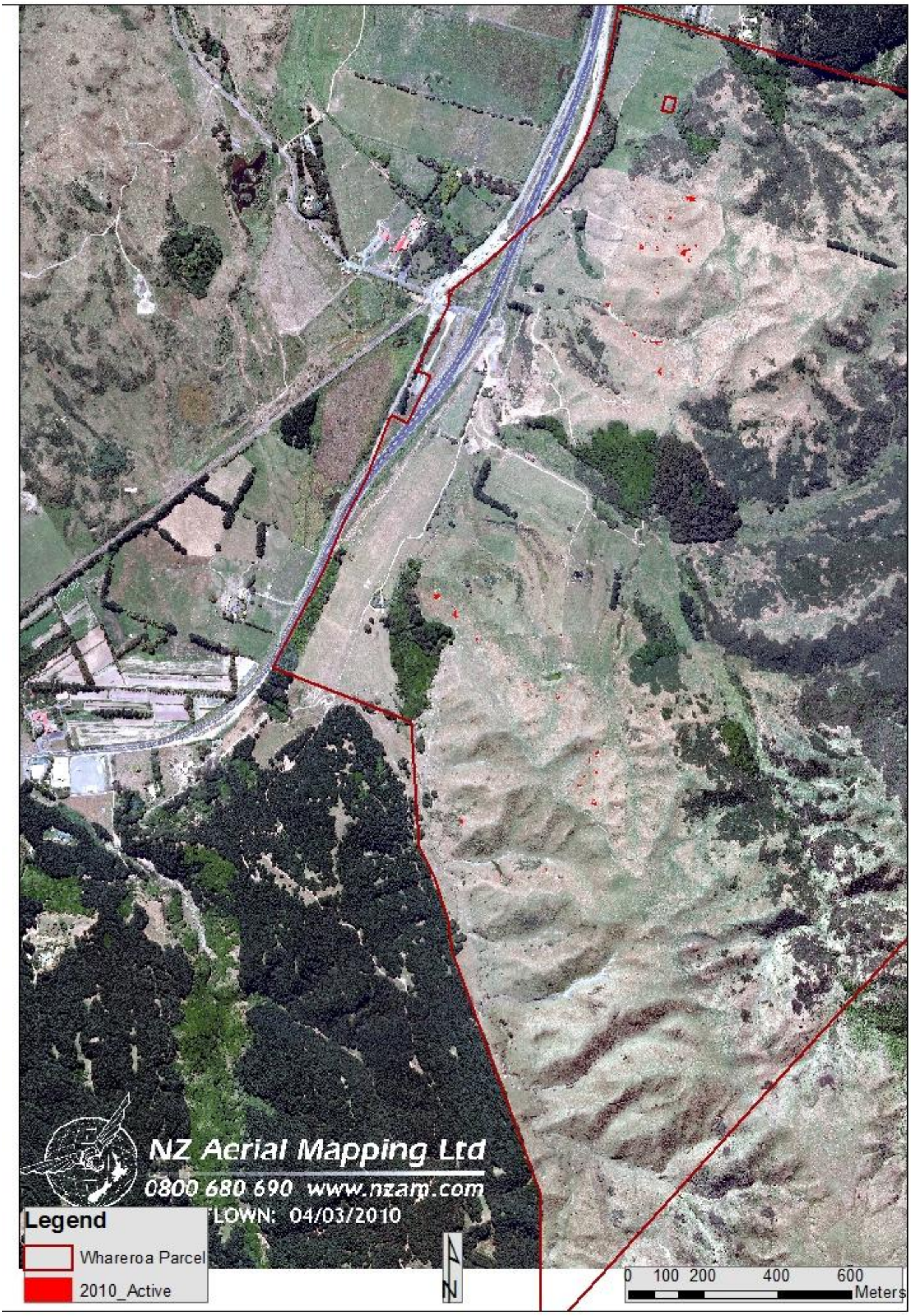






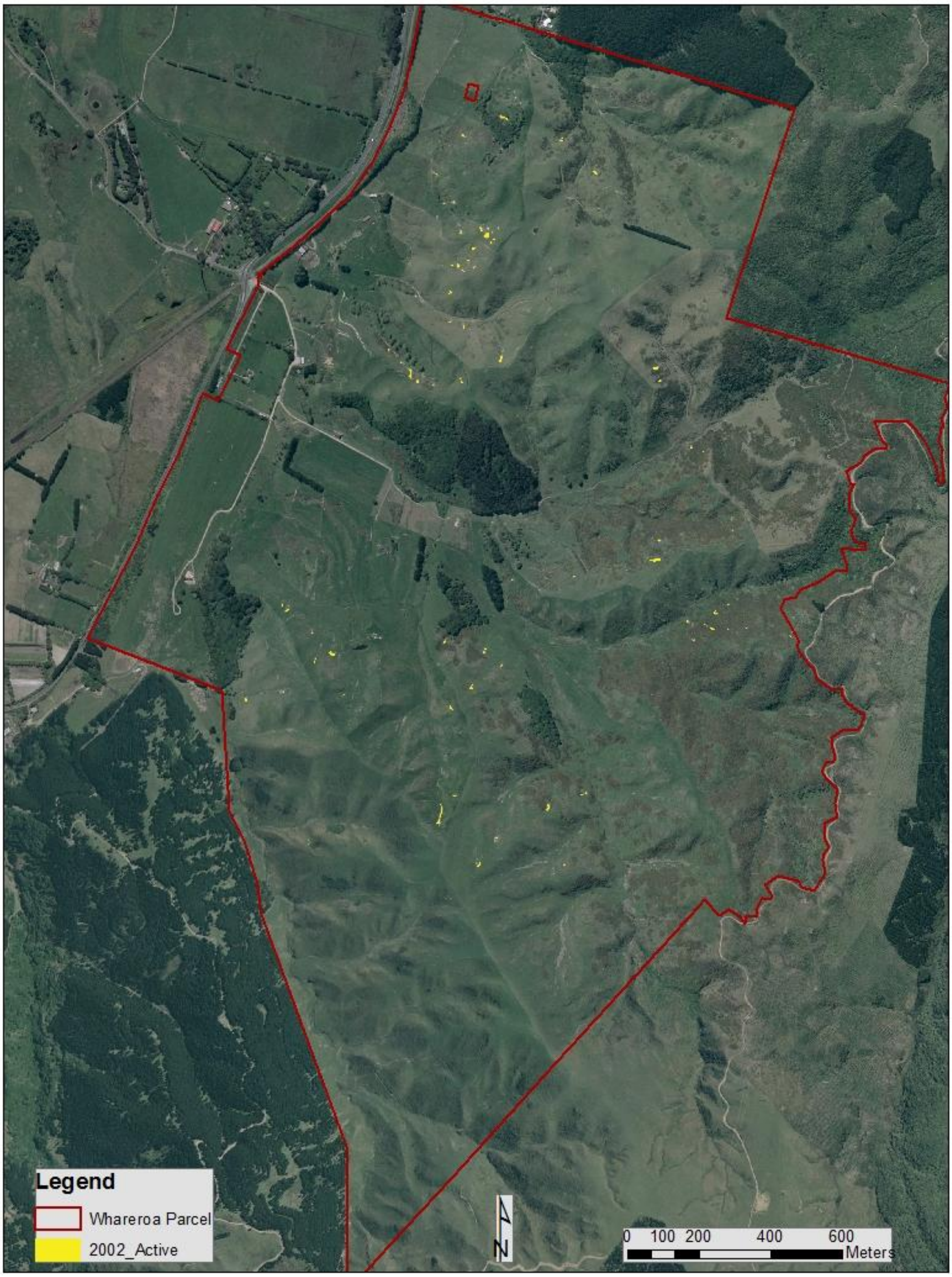
Appendix 6.5a: Maps of mass movement for each year's aerial image.

Whareroa mass movement 2010



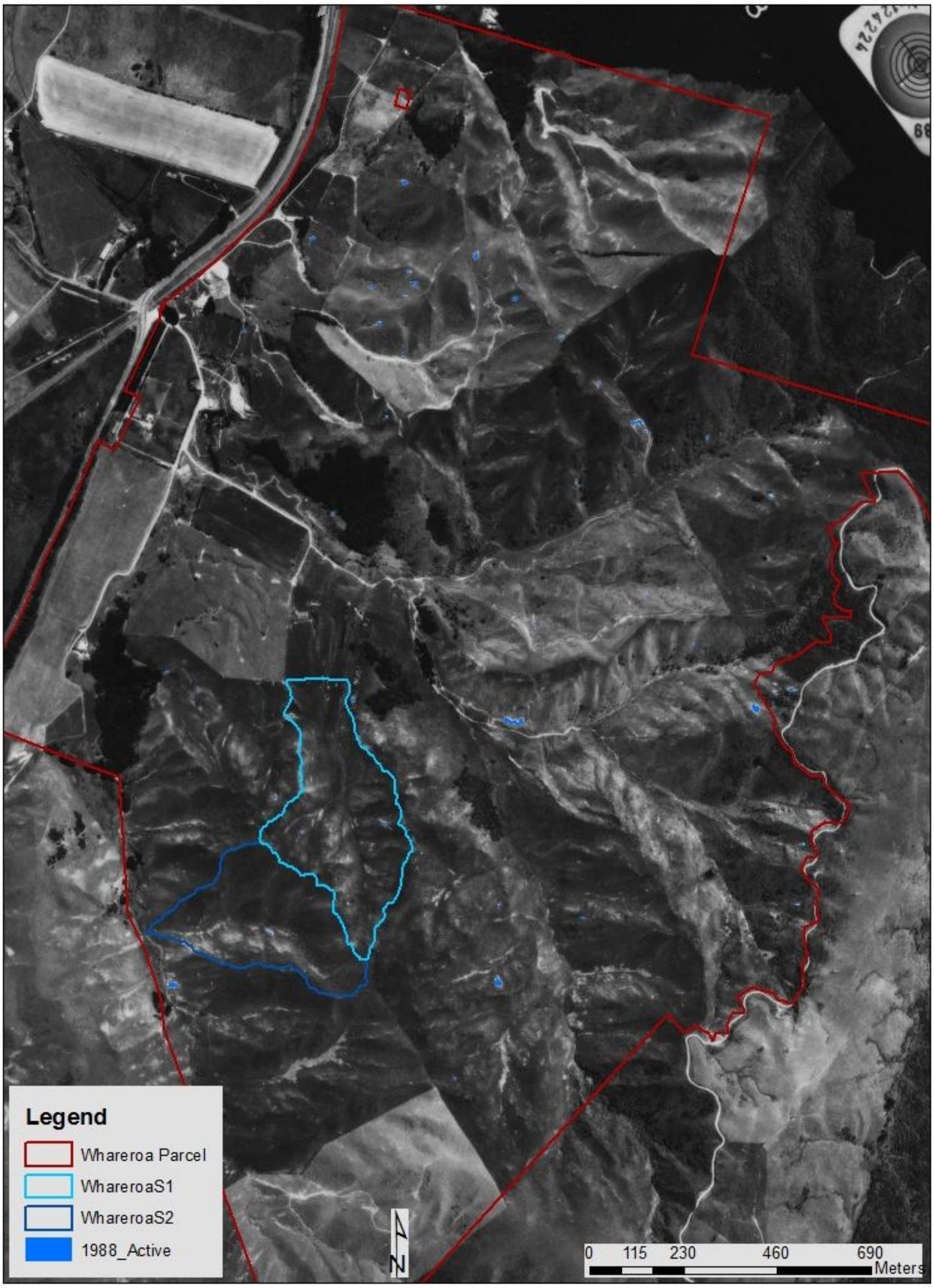
Appendix 6.5b

Whareroa mass movement 2002



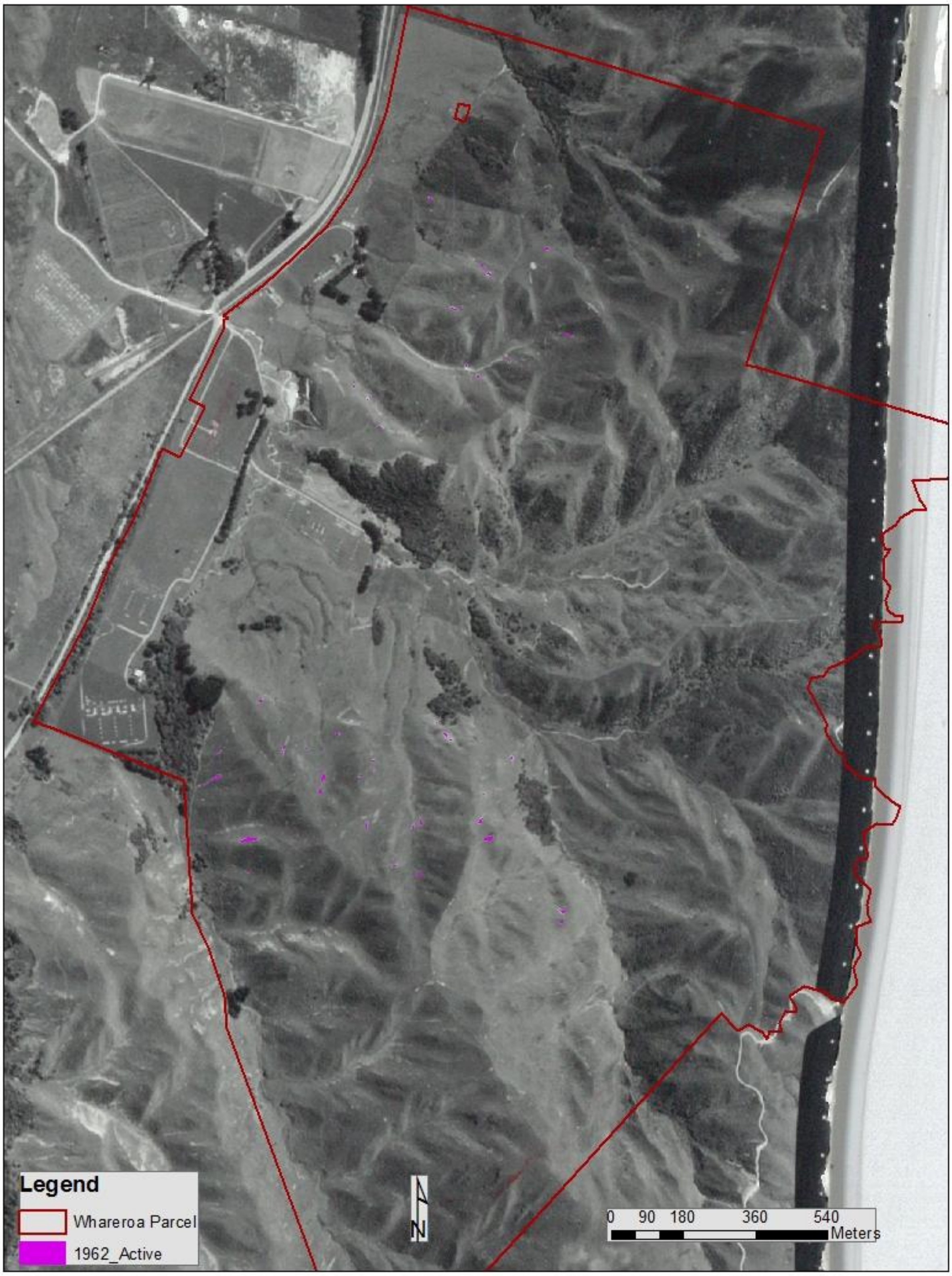
Appendix 6.5c

Whareroa erosion 1988

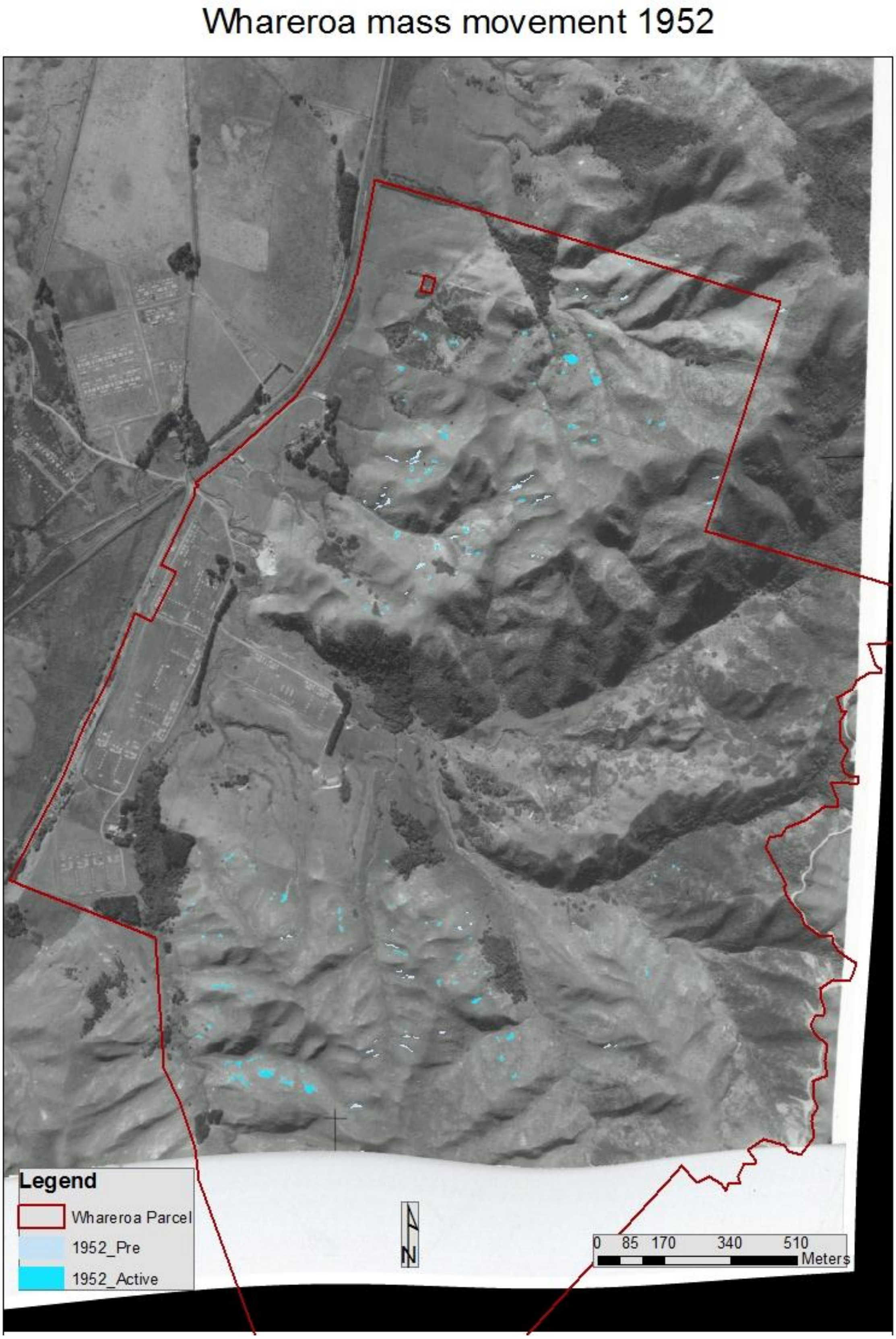


Appendix6.5d

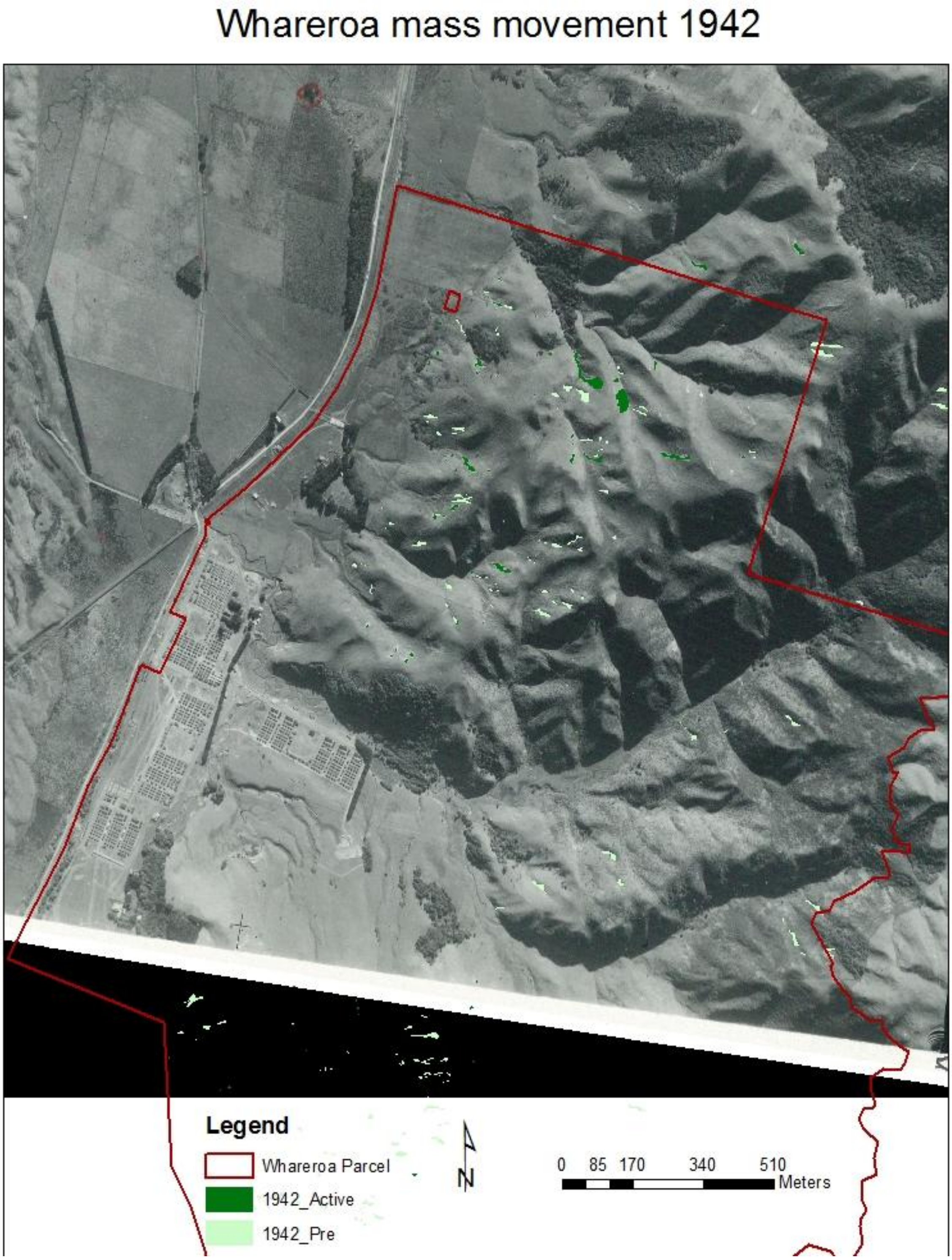
Whareroa mass movement 1962



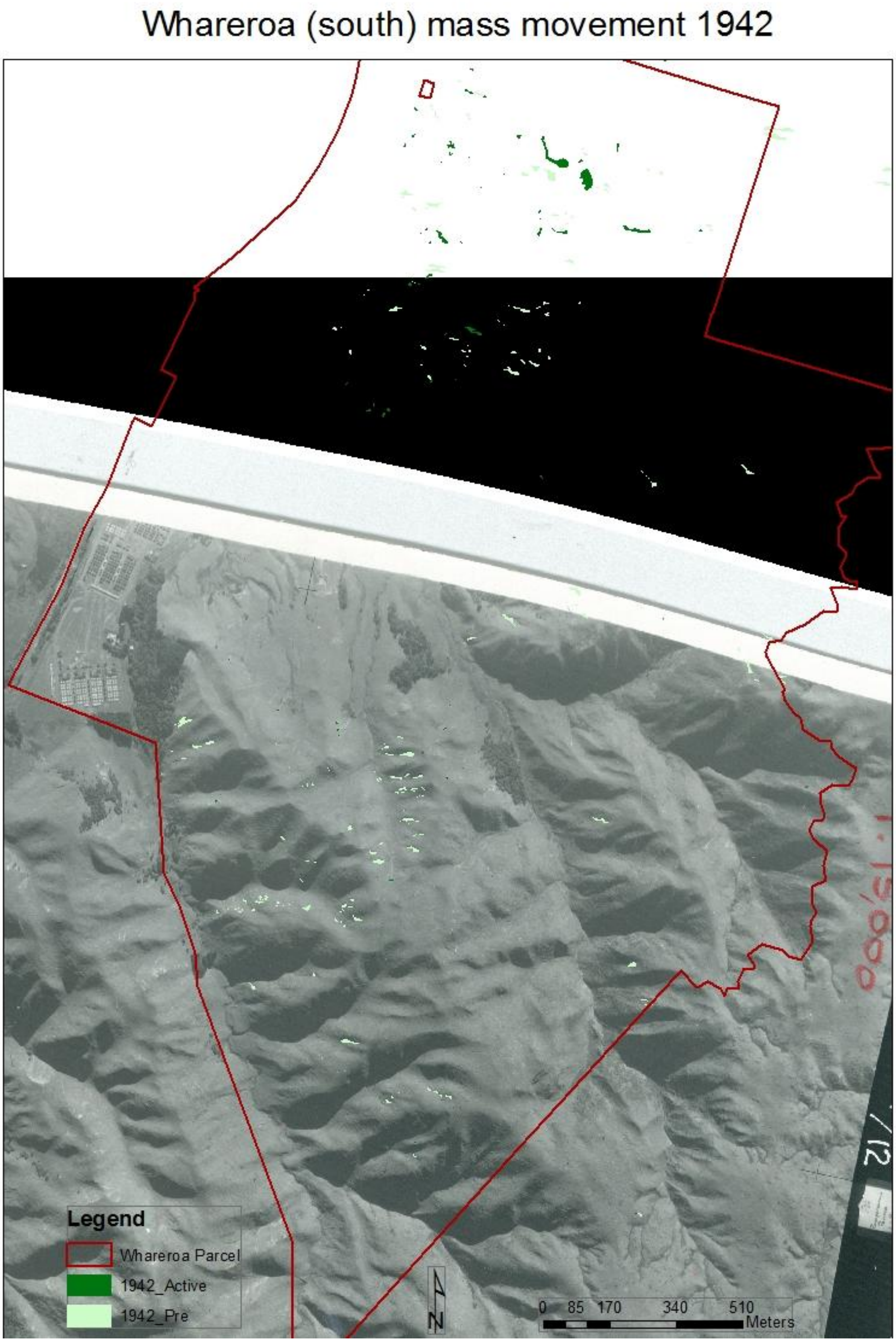
Appendix 6.5e



Appendix 6.5f

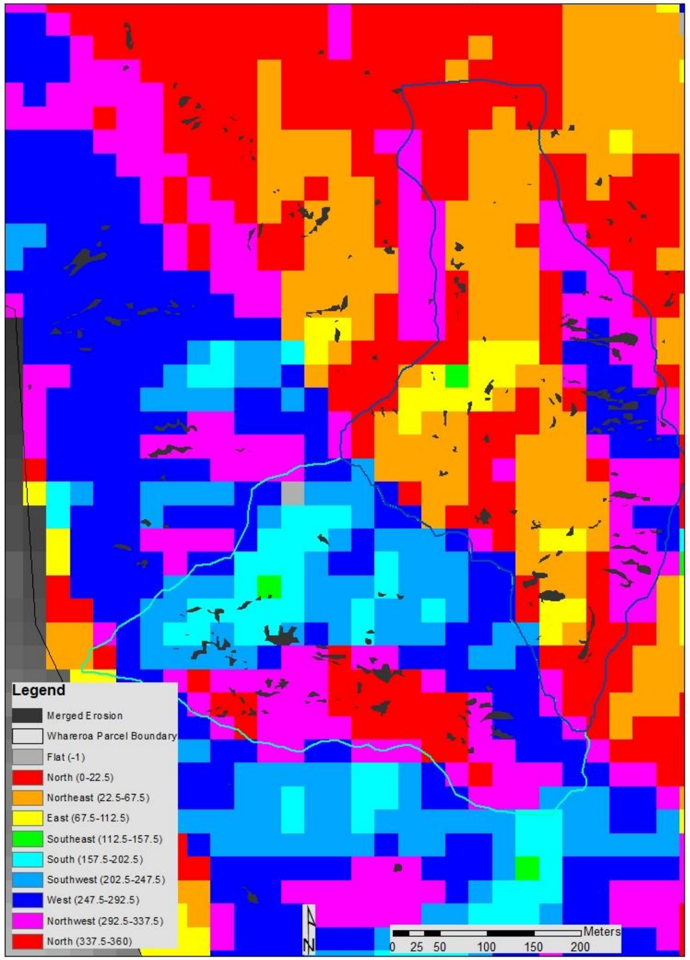


Appendix6.5g



Appendix 6.6: Map of erosion showing slope aspect and angle.

Whareroa Erosion and Aspect



Whareroa: Slope angle and mapped erosion