Development and Testing Indicators of Restoration Success

Punakaiki Coastal Restoration Project

Edited by

Jason L. Hahner and Mike H. Bowie

Lincoln University Wildlife Management Report No. 52

Department of Ecology
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Chapter 1.

Executive Summary

Introduction

- The Punakaiki Coastal Restoration Project (PCRP) was established to restore sand plain forest to a landsape that had been previously mined and farmed. Over 100,000 trees have been planted to date. The site is adjacent to the Nikau Scenic Reserve which is highly ecologically significant, and it is in the flight path of a unique Westland black petrel colony. Research investigating the potential indicators of ecological restoration success at the PCRP was undertaken over two years. This 12-month research report adds to a baseline survey of the site completed in 2012.

Aims

- To develop and test indicators of restoration success at PCRP.

Methods

- Floral and faunal inventory and monitoring was used to determine characteristics of forest and disturbed environments at the species and community level, with a focus on the transition of these characteristics during restoration.
- Pedology and soil chemical analysis was completed to describe the site template and to identify variables that may influence the restoration of floral and faunal communities at the site.
- A literature review was prepared comprising the Nikau Scenic Reserve, New Zealand coastal sand plain forest ecology and geomorphology, the utilization of indicators in monitoring ecological restoration and the potential for the research to support biodiversity offsetting.

Results

- Pitfall trap catches strongly showed that dung beetles and weta were good mature forest indicator species. Indicator species associated with unplanted and young restored sites were the spider *Anopteropsis adumbrata* and Diapriidae wasps.
- Moth communities differed from between mature and restoration plots. Exotic grassland and young restored areas were characterised by pasture species in the *Orocrambus* and *Wiseana* genera as well as the gorse pod moth. *Aciptilia monospilalis, Anisoplaca achyrota, Chalastra perlargata, Cnephasia jactatana* and *Feredayi graminosa* were found to be useful indicators of mature sites.
- Several leaf litter invertebrates stood out as distinctive indicator species of mature sites: a small, spotted earthworm (yet to be formally identified); a mite-like harvestman (*Aoraki denticulata*); seven mite species and weevil communities.
- Relative proportions of endemic and exotic earthworms (identified using DNA barcoding) were valuable indicators of restoration – endemics were dominant in mature sites, while exotics dominated unplanted and restoration sites.
- Habitat preferences between native and exotic bird species were observed, with natives clearly favouring mature forest and exotics preferring open grassland.
- Aquatic invertebrate indices indicated degraded stream conditions within the restoration area.

- Four species of native fish were identified.
- Tracking tunnels revealed that mice were widespread throughout mature, restored and unplanted habitats, but the presence of rats was exclusive to mature vegetation.
- Blue Penguins were observed and photographed within the PCRP area for the first time.
- It is considered that the future trajectory of restoration success will be determined by canopy closure and subsequent colonisation and recruitment of additional species. Studies showed that epiphytes and plant associations are particularly critical.
- In the oldest restoration planting canopy closure, leaf litter accumulation and plant surfaces available for colonisation are precursors to enhanced diversity.
- Mature stands of invasive gorse provided a valuable nursery resource for 23 native plant species.
- Thirty species of plants were recorded growing epiphytically on lower most 2m of three host species. The tree fern *Dicksonia squarrosa* supported a high number of species including both epiphytes and terrestrial plants growing epiphytically.
- Four different soil series were described across the site: Karoro, Kamaka, Kamaka (shallow variant) and Waiwero.
- A soil chemical response is apparent after the first five years of restoration. Multivariate analysis of soil physic-chemical data allowed separation of the three treatments (Mature, Restored and Unplanted sites).
- Interpretation of soil data at the site is complex and somewhat confounded by the overlay of the four soil series with historic usage of the site. Key chemical variables include C/N ratios, P, Zn, K, S, Mn and Mg.

Conclusions

- This monitoring and research has informed the restoration process on its trajectory from farmed pasture to mature forest, beyond the initial establishment of 100,000 trees over 5 years. This multi-dimensional approach linking changing soil, vegetation and faunal communities, beyond a baseline survey and onward monitoring, potentially provides an example of best practice in restoration ecology.
- The legacy of this work is the development, protection and management of a unique biodiversity asset through a collaborative partnership of Rio Tinto, CVNZ, DOC and Lincoln University. Future management of this site presents an opportunity to further this legacy by developing ecological, educational, and recreational values and potentially benefit the local community through tourism.
- This research may signal a paradigm shift in creative conservation through integrative restoration ecology that includes the floristic, faunal and geological components. This approach is readily transferable and could constitute a new standard for the next generation of restoration projects.

Chapter 2.

Contract deliverables

1. Development, testing and refinement of the 11 restoration indicators short-listed from the Baseline Survey (Lincoln University Wildlife Management Report No.50).
2. Completion of a full literature and information review of the (i) Nikau Scenic Reserve, (ii) coastal sand plain ecology and (iii) biodiversity offset literature.
3. Construction of a full inventory of plant and animal species recorded by previous studies at the Nikau Scenic Reserve, and of plant species established at the PCRP. This will include sorting and more complete identification of invertebrates collected in the Baseline Survey, using Entomology Museum facilities at Lincoln.
4. Accurate mapping of soils at PCRP through ground survey and using GIS. This will include more detailed evaluation of critical physic-chemical variables identified in the Baseline Survey.
5. Establishment of up to three additional monitoring transects to complement the original four transects in the Baseline Survey. More transects will make data from onward monitoring more statistically robust.
6. Increased focus on the significance and identification of native earthworm population through additional sampling and DNA barcoding.
7. Investigation of the role and significance of successional and nurse species of plants (gorse).
8. Exploring and clarifying the role and activities of Conservation Volunteers, DOC and local community in onward recording, monitoring and research at the site.
9. Contributing towards future plans for development of the educational resources/advocacy at PCRP.

Objectives and restoration indicators:

1. Colonisation of native birds
2. Colonisation of soil surface beetles and ants
3. Colonisation of leaf litter invertebrates
4. Establishment of native earthworms
5. Colonisation of restoration plantings by herbivorous insects
6. Establishment of optimal soil nutrients
7. Aquatic invertebrates as a measure of water quality
8. Fish diversity in Hibernia Creek tributary
9. Restoration plantings
10. Mammalian pests
11. Other possible taxa worthy of research – giant collembola, mites, spiders, lizards, petrels, bats, flatworms.

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Introduction

The Punakaiki Coastal Restoration Project

The Punakaiki Coastal Restoration Project (PCRP), located in Punakaiki, New Zealand aims to restore lands that were once utilized for mining and agriculture to a more natural state. Current management of the restoration project involves a partnership between Rio Tinto, Conservation Volunteers New Zealand (CVNZ) and the Department of Conservation (DOC). CVNZ is a non-government environmental organisation operating in Australia and New Zealand utilising volunteer input from overseas visitors and local communities. CVNZ is responsible for project management and implementation. DOC acquired ownership of the land in 2010 and a Memorandum of Understanding between CVNZ and DOC was signed in December 2012.

The vision of the PCRP is to make a positive and lasting impact on the social, economic and environmental values of the unique location. The initial goal of the project was to plant at least 100,000 native trees within the first five years to support the biodiversity of the Punakaiki area and restore the ecological corridor between the mountains and sea. This will support the wellbeing of the only nesting ground of the vulnerable Westland Black Petrel, the natural habitat of the Blue Penguin and expand a rare example of sand plain forest (Nikau Scenic Reserve) bearing nikau palms and rata trees many hundreds of years old. By the end of March, 2013 CVNZ volunteers had established the 100,000th plant. In addition to restoring the land, the partnership aims to develop the site into an eco-tourism attraction.

The project area

Approximately 30% of New Zealand's land is in conservation reserves, mostly within humid, natural upland, or montane regions, compared to fertile lowlands where 88% of land has been extensively modified and fragmented (Craig et al., 2000). The PCRP site, within the Punakaiki Ecological District, encompasses the most northern part of the Barrytown flats, a strip of coastal sand-plain between the foothills of the Paparoa Range and the Tasman Sea (Figure 1). The Barrytown flats are comprised of a complex sequence of old dune ridges and alluvial deposits, which originally would have been entirely covered in forest and wetland (Miskell, 2007b). Nearly all of the Barrytown flats have been modified by forest clearance and drainage for timber harvesting, mining and agriculture. Most of this area has at some time been under licence for prospecting ilmenite and gold (Wilms, 1985a). Based on data collected from 1981 - 2010, the climate within this region of the West Coast is classified as warm and wet with a mean annual rainfall between 2,200 and 2,600 mm; a mean annual temperature ranging from 12 - 13°C; average wind speeds between 4 - 5 m/s and between 1,700 and 1,750 mean annual hours of sunshine (NIWA, n.d.).

Figure 1. Satellite imagery of the Barrytown flats and PCRP project area. Adapted from Google Earth version 6.2.1.6014 (beta), 2012.

The Punakaiki Coastal Restoration Project area is approximately 4km south of Punakaiki on SH 6, the main West Coast road. The greater part of the 80.5 hectare property is on the western, seaward side of the road and adjoins the northern boundary of the Nikau Scenic Reserve. The lesser portion is on the inland side of the road, across from the northern end of the NSR (Figure 2). An extensive amount of the land was logged, mined and then converted into a farm for cattle and sheep. Livestock was still present within restricted areas of the PCRP until about the middle of 2011 (James Washer pers. comm., 2013). The understory vegetation of the few forest remnants scattered throughout the western parcel still reflect disturbance from livestock. The hillsides on the eastern side of the road had been logged, mined, and cleared for livestock and was farmed until about 1970. These slopes are now covered with regenerating native bush. Further up the valley, mature forest exists in a block owned by the Royal Forest and Bird Protection Society, and the Paparoa National Park lies beyond that. It is within this area that the nesting ground of the Westland Petrel (*Procellaria westlandica*, Tāiko) is located. The petrels have been listed as vulnerable on the IUCN Red List of Threatened Species, which means that it is at high risk of endangerment in the wild. This area is the

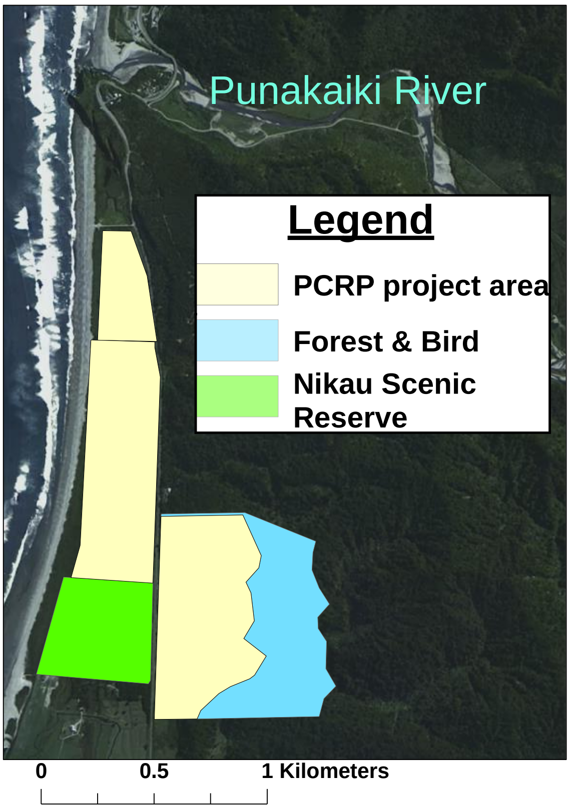

Figure 2. Diagram of the PCRP project land and nearby places of interest.

only Westland Petrel breeding site in the world. The land of the PCRP is situated directly in the flight path of these birds as they migrate between the ocean where they feed and their nesting sites in the hills.

The Nikau Scenic Reserve

Established in 1961 (Don, 1986), the adjoining Nikau Scenic Reserve (NSR) is a virtually square block, 20.2 hectares in extent, of mature coastal sand-plain forest. The plant communities established within the NSR are representative of the surrounding areas. However, the assembly of shingle ridge low forest through to kahikatea-northern rata forest is what makes this reserve's vegetation assembly exceptional. The NSR is considered to be a unique landscape feature because it represents a nearly complete cross section of coastal plain vegetation including a sequence of shingle ridges (Lands and Survey Reserve Series No.7, 1981 as cited in Don, 1986). The reserve extends from State Highway 6 westerly to a strip of Crown Land that runs parallel with the coastline. The eastern length of the reserve encompasses the edge of a low sandy terrace known as Grampian Terrace. At c.10 meters altitude, this terrace extends back to the post glacial cliffs (Don, 1986) and northerly into the restoration area. A second stony terrace has formed parallel and adjacent to the coastline and extends from Lydia Creek in the south to the northern end of the PCRP project site. The central grounds of the NSR have been described as being composed of low sandy ridges cut by meandering stream channels and broad swampy flats (Don, 1986). This contrasts with the hydrological structure of the PCRP lands where the natural streams have been straightened, channelized and re-routed from their original courses, to drain the land for economical purposes and flood control (Jackson, 1994). The majority of the water from the PCRP lands is channelled south, then west past the northern end of the NSR and into a linear wetland. The hydrology within the NSR has also been affected by the artificial diversion of Hibernia Creek from flowing in through the southern end of the reserve (Don, 1986; Jackson, 1994). Scotsman's Creek, which descends from the mature forest of the Paparoa National Park down through the eastern portion of the PCRP lands and into the NSR seems to be the only reasonably unmodified waterway on site. With the exception of State Highway 6 bisecting the project site, the completion of the PCRP will provide the missing link to complete the cross section of sand-plain vegetation from the mountains to the sea.

In an appraisal by Lands & Survey (1981), eight reserves of the Buller area were reviewed for their qualitative features. A 0-10 scale was used to assess their qualities and was based on three select themes: scientific, scenic and recreational. The Nikau Scenic Reserve placed 3rd with respective scores of 6, 3 and 1 (Don, 1986). Although not legitimately part of the NSR, the completed PCRP will enhance scientific, scenic and recreational qualities that should bring greater attention to the NSR.

Cultural and biological significance

Several Maori artefacts have been found within the PCRP and Nikau Reserve areas by CVNZ members. A map by the New Zealand Archaeological Association (NZAA) (Figure 3) indicated the presence and locations of 10 known archaeological sites located within PCRP lands and eight more within the Nikau Scenic Reserve. Descriptions of the sites obtained from the NZAA reveal that at least 10 if not all are of Maori origin. Reported artefacts include eight middens (stone and/or shell ovens); two areas with evidence of stone-working including jade pebbles and adze, sandstone grinders, a granite hammer-stone and greywacke flakes and an area with charcoal becoming exposed within an embankment. Other features include five water races, which do not relate to the apparent modern farm drains; walking tracks within the NSR; additional campfire/fireplace relics and the remains of a hut within the NSR. Many of the stone-working locations were quite extensive and the middens were found throughout the NSR and south-western area of the PCRP.

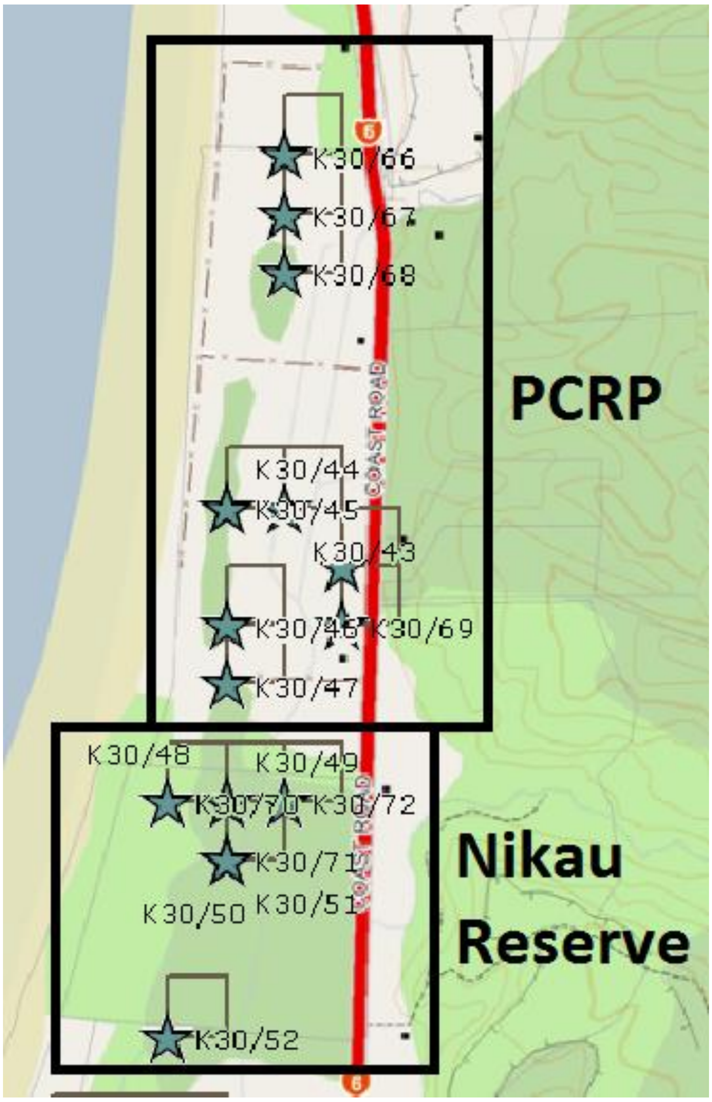

Figure 3. Locations of archaeological sites. Map supplied by the New Zealand Archaeological Association.

The hills inland from the PCRP are the only known nesting ground for the Westland Black Petrel (*Procellaria westlandica*). The petrels spend much of their lives at sea, but return to this specific location each year to nest. Nesting begins in late march and early April. Between late May and early June, a single egg is laid within a burrow. Each egg is incubated by both parents and hatches two months later between August and September. Juvenile Westland Black Petrels generally learn to fly during the month of December (Jackson, 1958 as cited in Best & Owen, 1974). Burrows are generally located on ridge-lines, above cliffs or slips and in areas where trees have suffered from windfall. These features provide the birds opportunities for take-off.

Figure 4. View of the PCRP and NSR from in front of the petrel colony. Photo by James Washer.

During nesting season, the birds spend the daylight hours at sea, returning to shore at dusk. Most of the petrels fly inland each evening at altitudes between 60 and 120m above the ground, and follow direct flight paths up the valleys towards specific burrows (Figures 4 and 5). Some seem to meander about before continuing onto the colony, and some even return to sea. In the mornings however, the birds consistently fly directly to sea at heights between 15 and 70m above the ground (Best & Owen, 1974).

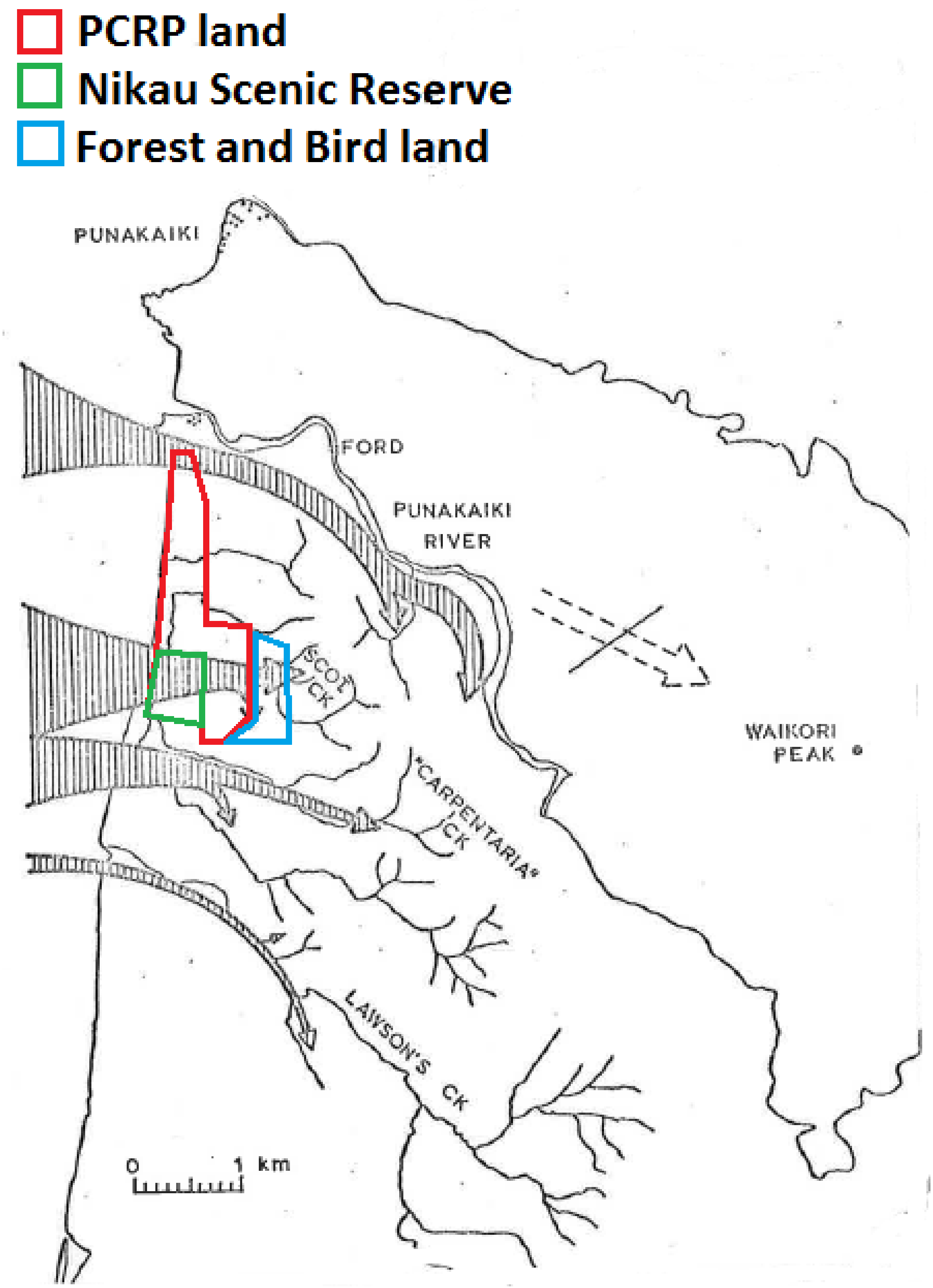

Figure 5. Flight paths of Westland Black Petrels into the colony (Best & Owen, 1974).

Previous and on-going research

Previous ecological studies have been carried out in the region – most significantly the Barrytown Flat Baseline Biological Survey 1985-1986 (Don, 1986) which included the Nikau Scenic Reserve. This study included water quality, aquatic flora and invertebrates, fish, terrestrial vegetation, birds, reptiles and mammals, but not terrestrial invertebrates. Grey District Council has commissioned significant natural area assessments for a number of sites close to this study site (Boffa Miskell, 2006, 2007a, 2007b). These studies focused on vegetation, birds, fish, reptiles and mammals. In a reconnaissance survey for Westland Illmenite Ltd. (Murray-North, 1990) the coastal vegetation strip including the Nikau Scenic Reserve was considered to be of biologically significance.

Lincoln University has been specifically involved in conducting research at the Punakaiki Coastal Restoration Project since 2011. This includes practical work from ecologists, postgraduate students, summer scholars and international interns comprising various aspects of ecological and geological research. A baseline survey focusing on biodiversity and soil characteristics was conducted over the 2011 – 2012 summer (Bowie, Mountier, Boyer & Dickinson, 2012) with results published in a report to Rio Tinto. The present document includes some of the main findings from that report. In June of 2012, Lincoln University signed a one-year research agreement with Rio Tinto to investigate and identify early indicators of restoration success. Research for this project has included ten months of in-field data collection, literature reviews and interviews. The present report contains the findings of the 2012-2013 research study and outlines the potential for further research and development.

Chapter 4.

New Zealand's sand plain ecosystems and geomorphology of the PCRP area.

The coastal sand plain has formed as a prograding coastal system, comprising marine and wind driven sand deposits which have accumulated in a coastal embayment. The eastern length of the PCRP area extends back to post-glacial cliffs and fills in the valley mouth of Scotsman's Creek (G. L. Don, 1986). These calcareous cliffs were most likely shaped during the mid-Holocene period, within the past 6000 years when the sea was at or close to its present level (Bird, 2008). Calcareous cliffs in New Zealand are primarily composed of limestone and marble and provide habitat for rare and threatened fauna (DiBona, Williams, Wiser, & Weidner). Historically, the cliff faces would have been subject to physical, chemical and biological erosion processes from marine and sub-aerial exposure. As rock debris accumulated at the cliff base as talus creating a barrier from the sea, marine erosion was gradually obstructed. A low sandy terrace (referred to as "Grampian Terrace") runs parallel to State Highway 6 at c.10 meters altitude and extends east back to the cliff base (G. L. Don, 1986). A series of marine terraces are preserved in the Miocene deposits, due to continuing tectonic uplift (Braithwaite & Pirajno, 1993; Suggate, 1989).

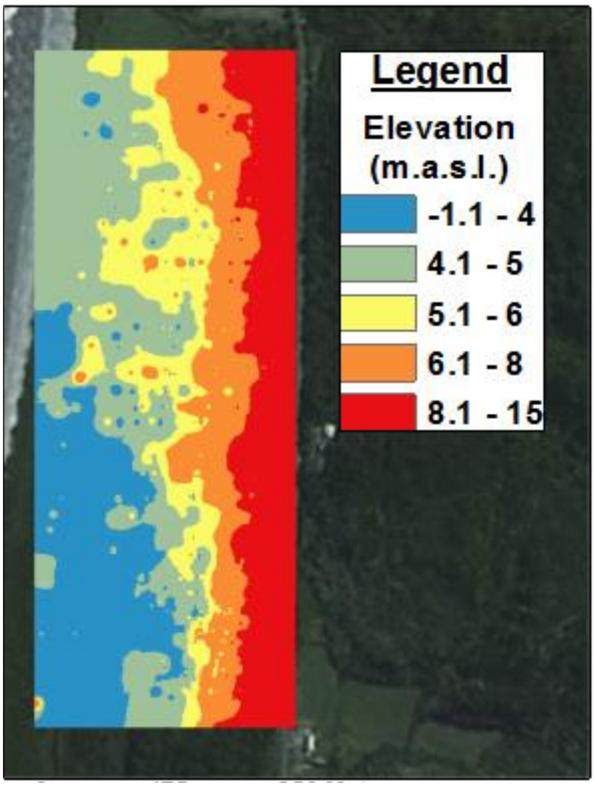

Figure 6. Digital elevation map of the PCRP study area illustrating the terraces, ridges and flats formed through coastal progradation.

The topography of the study area within the PCRP was mapped using a Trimble ProXT differential GPS. The data was transferred into an ArcGIS database to produce a digital elevation model (Figure 6). Much of the central ground between Grampian Terrace and the shore is composed of sets of low sandy ridges and broad swampy flats. The successive formation of beach ridges of sand or shingle above the high tide level are an indication of progradation, a seaward advancement of the coastline. Sources of sediment may include fluvial sources, cliff and rocky foreshore yields, the sea floor or dunes blown from the surrounding area, removal of sand by wind to build landward dunes as well as the washing of sediment into estuaries and tidal inlets. Ilmenite is found associated with the low-lying parts of the landscape (sand plain) while the wind-deposited sand dunes comprise quartz sand. A successional vegetation profile with declining canopy height extending shoreward is an indication that plant succession has been accompanying the deposition of new terrain during progradation at the PCRP (Bird, 2008).

Progradation often takes place on coasts where emergence is in progress, stimulating shoreward drifting of near-shore sediment (Bird, 2008). This is evident on site where an emergent stone shingle seaward terrace, which is obscured by bush extends north through the PCRP site as a visible straight-fronted low scarp (Don, 1986). Several large streams including McMillians Creek, Scotchman's Creek, Lydia Creek and Hibernia Creek as well as numerous smaller unnamed creeks would have historically flowed through the PCRP land and/or Nikau Scenic Reserve from the Paparoa Ranges to the Tasman Sea. Accretion of shingle sediment from the streams coupled with the deflection of the unprotected outflow channels by long-shore drift on the beach eventually sealed off some of these stream mouths, redirecting stream flow. The emergence of the shingle terrace eventually forced Hibernia Creek into a south-directed hairpin bend (Don, 1986). The structural beach ridges and trough formation east of the coastal shingle terrace confined the dispersion of water and eventually formed an intertidal wetland. The initial stage of this wetland would have been a saltmarsh with high salinity. The narrowing of the stream mouths from coastal emergence would have resulted in reduced wave action and current flow, lower levels of salinity and accretion of finer sediments, particularly silt and clay (Bird, 2008). These actions led to the formation of a micro-tidal freshwater swamp which would have been dominated by reeds, rushes and sedges. In such an environment, organic matter from the seasonal decay of freshwater vegetation is deposited over time above the trapped sediment, forming a peat layer. This layer of peat eventually rises above the water's surface and becomes new terrain for scrub and forest vegetation. The outcome of this process is progradation of the coastline by swamp-land encroachment (Bird, 2008).

The prograding coastal sand plain has evolved over approximately the last 5-6 Ka. Different aged surfaces exist, with the youngest surfaces closer to the present day shoreline. Alluvial fan deposits have been deposited throughout the evolution of the sand plain, and are consequently of different ages. It follows that we will see soils of different ages, a relationship known as a chronosequence. This chronosequence is a common feature of prograding coastal systems. Similar systems have been extensively studied in New Zealand; the most relevant one being at Haast (Eger, Almond, & Condron, 2011, 2012; Eger, Almond, Wells, & Condron, 2013). These processes have led to the geological formation of the PCRP and Nikau Scenic Reserve. Despite the influence that land development has had here, the impression of these natural forces can still be observed and continue to affect the area's ecological processes. Comprehension of how these features affect the areas successional processes is essential to understanding the future vegetation assemblages achieved through the restoration project.

Chapter 5.

Climatic variables

Localized micro-climates

The structure of a plant community may have distinct effects on the microclimate. Likewise, microclimatic variables can also influence the composition and structure of a plant community. Previous studies have shown positive correlation between climate variables (light, air temperature, humidity) and plant communities along edge to centre gradients within forested habitats (Gehlhausen, Schwartz, & Augspurger, 2000). Air temperature and leaf litter temperature was measured for a period of 8 and 7 months, respectively. Sensors were placed within the Nikau Scenic Reserve, restored and unplanted monitoring plots along Grampian terrace (Inland; transect 1). This was repeated near the western coastal ridge (Coastal; transect 3) with air temperature sensors only.

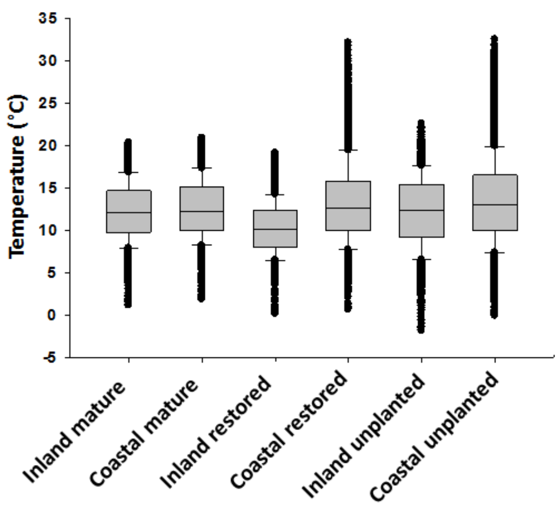

Figure 7. Air temperature within three vegetation types of coastal and inland plant communities over an 8 month period at the PCRP. The bold bar represents the median of the values. The boxes represent the middle 50% of the data values. The whiskers represent where the remaining 50% of values are found above and below the box. Dots represent outlying values.

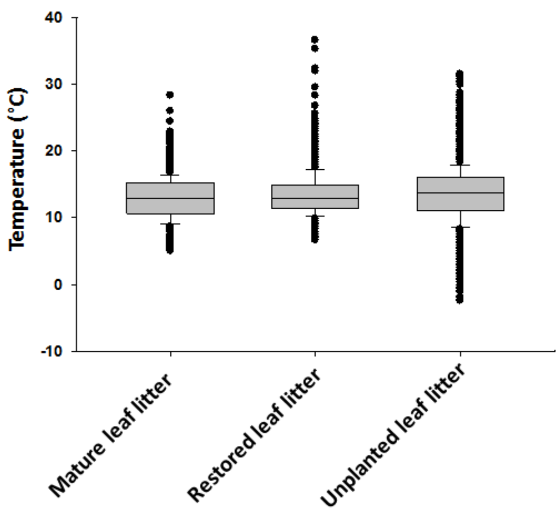

Figure 8. Temperature within the leaf litter of three vegetation types over a 7 month period at the PCRP. The bold bar represents the median of the values. The boxes represent the middle 50% of the data values. The whiskers represent where the remaining 50% of values are found above and below the box. Dots represent outlying values.

Air temperature (Figure 7) and leaf litter temperature (Figure 8) results indicate that both inland and coastal mature forest have a stabilizing or insulating effect on temperature with less variability in temperatures recorded. Inland restored air temperatures reflect those that have been recorded within the mature forested areas. The plantings within this area are also the oldest and largest of the restoration plants and may have reached a stage of maturity to begin influencing air temperatures. Coastal restored, inland unplanted and coastal unplanted areas have greater variability in air temperatures, with coastal restored and unplanted having the greatest averages and variability. This fluctuation can be attributed to greater levels of direct exposure to climatic elements. Restored leaf litter temperature values create a gradient between mature and unplanted leaf litter temperatures, indicating a gradual change in microclimate.

General climatic conditions

On November 6th, 2012 a weather station (manufactured by Onset HOBO® Data Loggers) was erected at the PCRP site. The station was comprised of a data logger, photosynthetic active radiation (PAR) sensor (available light); temperature sensor; rainfall sensor as well as wind speed and direction sensors. Data was collected at ten minute intervals until the 26th of April, 2013.

PAR readings were relatively consistent for the late spring and summer months of November through to February (Figure 9). Light levels began to decrease in March and this trend continued into April. These findings were expected and are reflective of seasonal changes. Fluctuations in PAR affect plants growth by limiting light available for photosynthesis. Temperature variations are also consistent with seasonal changes (Figure 10). Temperature affects metabolic rates and patterns of behaviour for many organisms such as reptiles, fish and invertebrates.

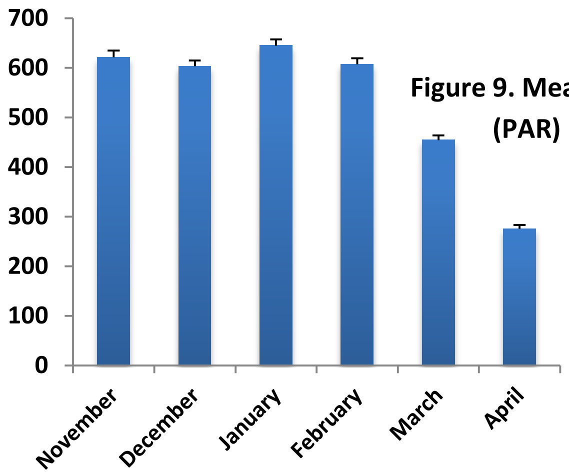

Figure 9. Mean photosynthetically active radiation (PAR) by month during a 6 month

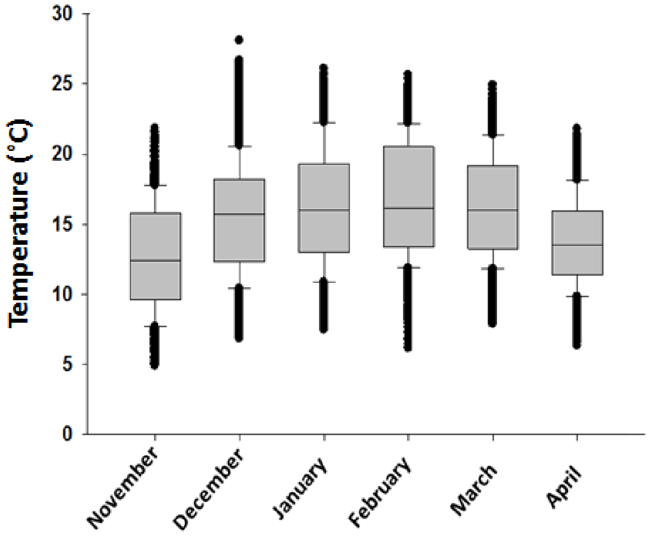

Figure 10. Ambient temperature at the PCRP by month over a 6 month period. The bold bar represents the median of the values. The boxes represent the middle 50% of the data values. The whiskers represent where the remaining 50% of values are found above and below the box. Dots represent outlying values.period at the PCRP (±s.e.).

Wind direction was highly variable for the months of December and March (Figure 11). Wind direction during late spring and summer was most often from the south-east, but began to shift to the north-east in autumn. Wind speed was mostly consistent for sustained winds during the six month period. However, January experienced higher wind gusts, and March was the mildest during this time (Figure 12).

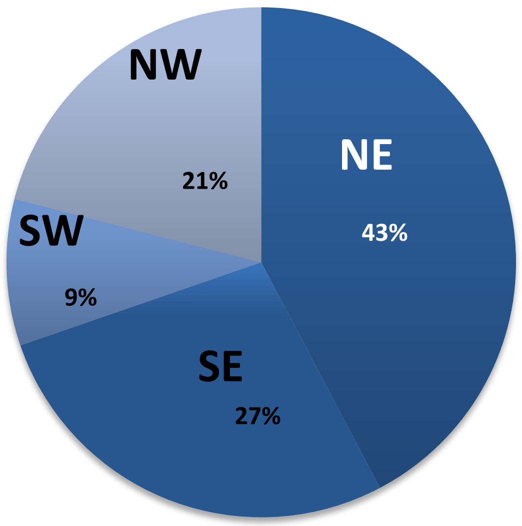

Figure 11. Wind direction at the PCRP from November, 2012 to April, 2013.

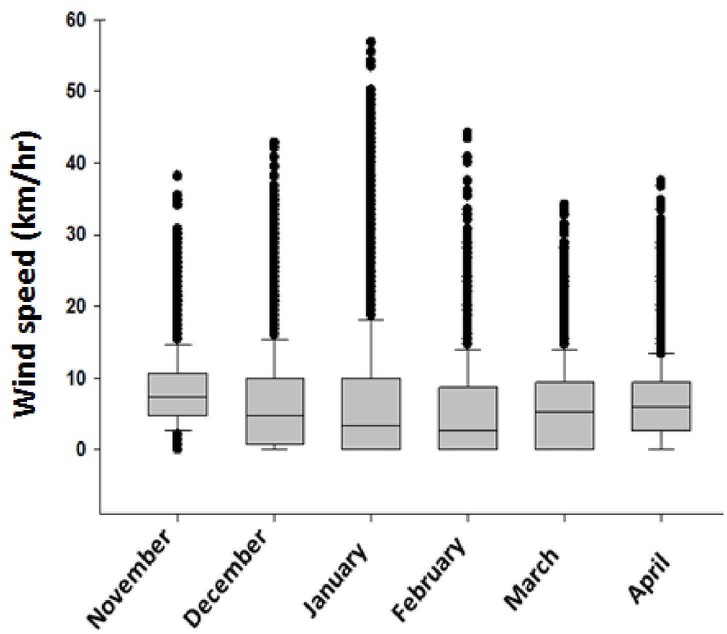

Figure 12. Wind speed at the PCRP by month over a 6 month period. The bold bar represents the median of the values. The boxes represent the middle 50% of the data values. The whiskers represent where the remaining 50% of values are found above and below the box. Dots represent outlying values.

The average monthly rainfall (Figure 13) data was supplemented by rain gauge data recorded by CVNZ's James Washer, who keeps a daily record for onsite rainfall. This data was used to complete data sets for the months of November and April. The Punakaiki area experienced drought conditions for the month of February, 2013, and low rainfall levels for both November 2012 and March 2013. With a mean annual rainfall between 2,200 and 2,600 mm (about 200mm/month) for this region of the West Coast (NIWA, n.d.), a two month period from February through March, 2013 with rainfall levels of 30 and 84mm respectively would have the potential to significantly impact local biota. February was the hottest month of the six months that were monitored.

These conditions could potentially result in greater mortality of restoration plantings. Observations made during this period of time included high stress levels for both restoration plants as well as naturally occurring plants within the Nikau Reserve, northern remnant forest and especially along the band of coastal vegetation. Dry and hot conditions may also influence the areas fauna to disperse in search of cooler and moister areas.

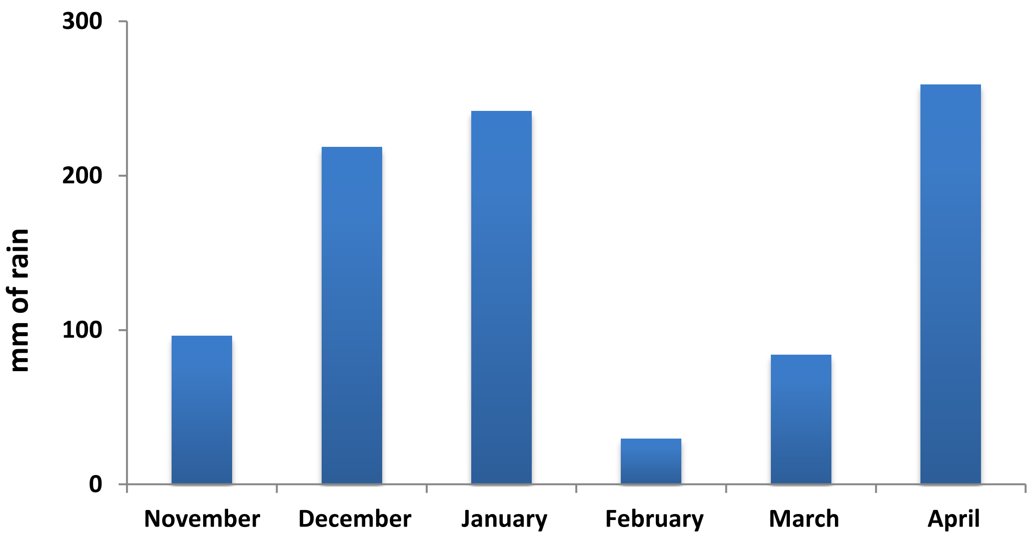

Figure 13. Total rainfall by month at the PCRP over a 6 month period.

Chapter 6.

The role of indicators in restoration monitoring: ecological theory

The importance of monitoring a restoration project

As restoring any environment to its ‘original’ pristine state is an unattainable goal, restoration practitioners must take a biocentric approach whereby restoration is about re-permitting ecological integrity, natural successional processes and evolutionary opportunities (Samways, 1999). As we cannot measure and comprehend all of the various natural processes and linkages, restoration is as much art as it is science and is therefore bounded by our cultural perceptions as well as technical ideals (Samways, 1999). Reestablishment of fundamental ecological functions is crucial for the creation of self-sustaining ecosystems (Majer & Brown, 1997). The successful recovery of the appropriate habitat will provide the necessary conditions for the continued survival of animal (Fox, 1997) and plant species.

It is essential to establish clear objectives for any restoration endeavour (Koch, 2007; Samways, 1999) as it cannot be validly claimed that the restoration has been successful until these objectives have been met (Nichols, 1997). The objectives should be set according to the level of ecological recovery that is desired (is it simply re-greening, rehabilitating, ecological landscaping or complete restoration). Some restoration undertakings have been deemed successful based on obvious visual accomplishments such as establishment of plants and the return of vertebrates without monitoring for the restoration of all features of biodiversity and ecological integrity (Samways, 1999).

In order to qualify the successful completion of the objectives set for a restoration project, a monitoring program must be established with performance indicators and measureable end point milestones (Majer & Brown, 1997; Nichols, 1997; Nichols & Gardner, 1997; Ruiz-Jaen & Aide, 2005a). A well-designed monitoring program with measurable targets provides various other benefits including a feedback for improving rehabilitation techniques (Koch, 2007; Nichols, 1997; Nichols & Gardner, 1997; Ruiz-Jaen & Aide, 2005b) and provide accurate quantification of the return of flora and fauna which can highlight unforeseen problems and enhance continuous improvement of restoration prescriptions (Mattiske & Youngson, 1997).

Some aspects of the return of ecosystem functions, processes and components may be directly measured and monitored, but in order to identify appropriate targets for restoration it is necessary to have reliable knowledge of the requirements of each species that one seeks to recover (Fox, 1997; Majer, Brennan, & Moir, 2007). Achieving this understanding has necessitated extensive research into the processes of ecosystem establishment and ecological traits of various species (Nichols & Grant, 2007). Supplementary benefits of a well-designed monitoring program may include demonstrating restoration development to stakeholders, providing information to interested audience groups and enabling the development of internal improvement targets and milestones (Nichols & Gardner, 1997).

Utilization of indicators in monitoring

Monitoring to obtain all of the information necessary to reconstruct an ideal habitat for all species, or even the most important faunal groups would be impossible. Therefore, it is essential to rationalize the list of what to monitor and obtain quality data on key species or groups that may act as a surrogate to represent the majority of the fauna in order to meet restoration objectives (Fox, 1997; Nichols, 1997; Nichols & Gardner, 1997). Bioindicators reflect organisms or communities of organisms that contain information on the quality of the habitat and its environment (Markert, Bruer, & Zechmeister, 2003).

Because specific indicators are reflective of certain environmental stressors, an expansive range of indicators may allow for a more comprehensive understanding of inflicting environmental conditions. A diverse range of indicators, representing different trophic levels and taxonomic relationships may also facilitate in the understanding of the habitat requirements for the various species studied. Restoring ecosystems requires recovering ecological services, so it is important to determine which species are required for these services and which species, if any, are not (Majer et al., 2007). For example, it is apparent that abundance and diversity of insect pollinators have the potential to significantly influence the process of pollination and seed set, both at the individual plant and community level. Because the processes of pollination and seed set are related to various biological and physical factors of an ecosystem, they are recommended as easily measurable and direct bioindicators (Majer & Brown, 1997).

Although pre-disturbance levels of diversity may be attained, this may not indicate restoration because differences in species composition may persist. Likewise, species richness of one taxonomic group may not act as a surrogate for richness of other groups or of ecosystem functioning. Within the early stages of development, restoration programs are usually characterized by a high abundance of a generalist species as some species with low powers of dispersal are slow to recolonize (Majer et al., 2007). This does not mean that a particular function will not operate or will be enhanced if a particular group is absent or abundant (Majer & Brown, 1997). Therefore it is important to monitor a spread of taxonomic groups from a range of vegetation strata (Majer et al., 2007). Acquiring knowledge of the patterns in which fauna is developing can provide measurable and quantitative information on the efficacy of restoration programs (Majer & Brown, 1997). All vegetation is in a continuous state of change and there is no stable endpoint of a succession (Burrows, 1990). An assemblage of species representing the most mature vegetation of a site actually consists of a temporal mosaic of different successional or seral stages.

Selection of indicators for monitoring

Targeting indicators when monitoring for the progression of a restoration program provides information necessary to fulfil the objectives and purposes at a reasonable cost (Nichols & Gardner, 1997). Utilization of indicators condenses the quantity of organisms and environmental parameters necessary to monitor to gain insight into the progress of the restoration program. Majer et al. (2007) estimated that during the course of their various projects, nearly one-third of the time available had been spent trying to correctly identify animals to putative species. It was also found that little information was available for such a range of species to assist with the interpretation of their data. This was attributed to a lack of basic taxonomic and ecological knowledge of invertebrates. It is now generally accepted that properly selected indicators can influence the outcome, possibly even the success or failure of a restoration program (Majer & Brown, 1997). The use of indicators is now a fundamental component of quantitative and accountable ecological assessments which are required by, and useful for modern industry (Peterson et al. 1992, Lemont et al. 1993 as cited in Read, 1997). The processes of determining suitable indicators may be implemented amongst global restoration programs; however trends need to be confirmed in other climatic zones, habitat types and for distinct environmental disturbances as the function of fauna groups in ecological processes varies between different ecosystems (Nichols, 1997). Ruiz-Jaen & Aide (2005b) reviewed *Restoration Ecology* journal articles and found that diversity, vegetation structure and ecological processes were the most common ecosystem attributes used in t studies to determine restoration success.

Preliminary extensive monitoring is required to identify potential indicators and establish optimum techniques, habitat requirements and sampling times to determine the responses of taxonomic groups to environmental stressors. This allows for the refinement of the monitoring program, which in conjunction with ecological, behavioural and toxicological research, should facilitate in determining which species to monitor (Read, 1997). It is also necessary to determine if meeting the habitat requirements for these select species is likely to provide for the pursuance for many other species on the site (Fox, 1997). Other factors that should be considered when determining which fauna groups to monitor includes their role in ecological function and development, abundance or rarity and practicality of surveying (Nichols, 1997). In some cases, the difficulty and inefficiency of monitoring for some species outweighs the benefits of the data that they might provide (Nichols, 1997). It is beneficial to monitor fauna groups with abundance large enough to enable quantitative statistical analysis of the results (Majer et al., 2007; Nichols, 1997). Important ecological functions that should be considered for monitoring includes but are not limited to the roles of invertebrates in pollination and nutrient cycling. If a selected group is particularly rare, it may be necessary to develop specific habitats for these species. In addition to establishing which fauna groups to monitor as bioindicators, it is also important to consider what are the most appropriate habitats, techniques and sampling times for these taxa (Read, 1997). The ability that some faunal groups have in capturing the public's attention such as spiders, scorpions (Majer et al., 2007) and birds (Markert et al., 2003) has also been considered in the indicator selection process. The ability to gain public interest into a restoration program could lead to community involvement, sources of funding as well as provide political influence.

The performance indicators for these selected groups should be defined by the development of end-point milestones as the milestones define the indicators that should be measured (Nichols, 1997). It is usually not necessary nor possible to be able to identify every organism to the species level. However, for quantitative statistical analysis it is essential to know whether two specimens are the same or different species (Nichols, 1997; Nichols & Gardner, 1997).

A hover fly observed within the restoration area. These can be efficient pollinators

Chapter 7.

Invertebrates from pitfall traps and artificial habitats

Methodology

The 2012 baseline survey (Bowie et al., 2012) established four monitoring transects were established within the PCRP study area. These transects were aligned with dune ridges which are oriented parallel with the coast. These ridges were formed during the progradation (formation) of the land as the ocean receded, consequently soil along the length of each ridge should be approximately of the same age. Each transect consisted of three plots with each plot located on the same dune ridge in order to minimise confounding variables such as soil age, structure and elemental composition. For each transect, one plot was located within mature forest; one within a restoration plot; and one within abandoned farmland. In July 2012, three more transects were established in the same manner to complement the original four transects in order to make data from monitoring more statistically robust (Figure 15). Each of the transect plots contained a series of monitoring devices including 7 pitfall traps; 4 wooden discs to imitate woody debris (Bowie & Frampton, 2004); 3 artificial weta refuges (Bowie, Hodge, Banks, & Vinc, 2005); 2 corrugated lizard monitoring devices (Lettink & Cree, 2007) and 4 synthetic-bark tree wraps (Bell, 2009) (within mature plots only).

Artificial habitats

For the 2012 – 2013 research year, observational monitoring of the artificial habitats was completed on the 19-20 of July, 2012 and 20-22 of February, 2013 and included:

- wooden discs
- weta refuges
- corrugated lizard monitoring devices
- synthetic-bark tree wraps

As synthetic-bark wraps are only used in mature plots, figures do not include data gathered from these unless specifically stated as such.

Pitfall traps

Pitfall trap holes were dug using an 80mm diameter soil corer. The pitfall traps were arranged linearly with three meter spacing between each trap in each plot. Each pitfall trap hole received a plastic collar to retain the shape of the hole between collection events and support the collection cup during sampling. A galvanized steel roof (180 x 180mm) was positioned above the hole to deflect rain and prevent undesirable debris from falling into the hole. Setting of the pitfall traps involved placing a 350ml plastic ‘honey pot’ containing 100ml of Monopropylene Glycol (antifreeze) as a preservative. On 18th July, 2012 a total of

84 pitfall traps were set within transects 1 - 4. The sample collection period lasted for 33 days and concluded on August 20th, 2012.

A second pitfall trap collection event involved three additional transects for a total of 147 pitfall traps (7 transects x 3 plots x 7 replicates). The second sampling event began on December 17th, 2012 and concluded on January 9th, 2013 after 23 days of sample collection. The sampling period was reduced due to predicted high rainfall and the possibility of flooding occurring within the pitfall traps.

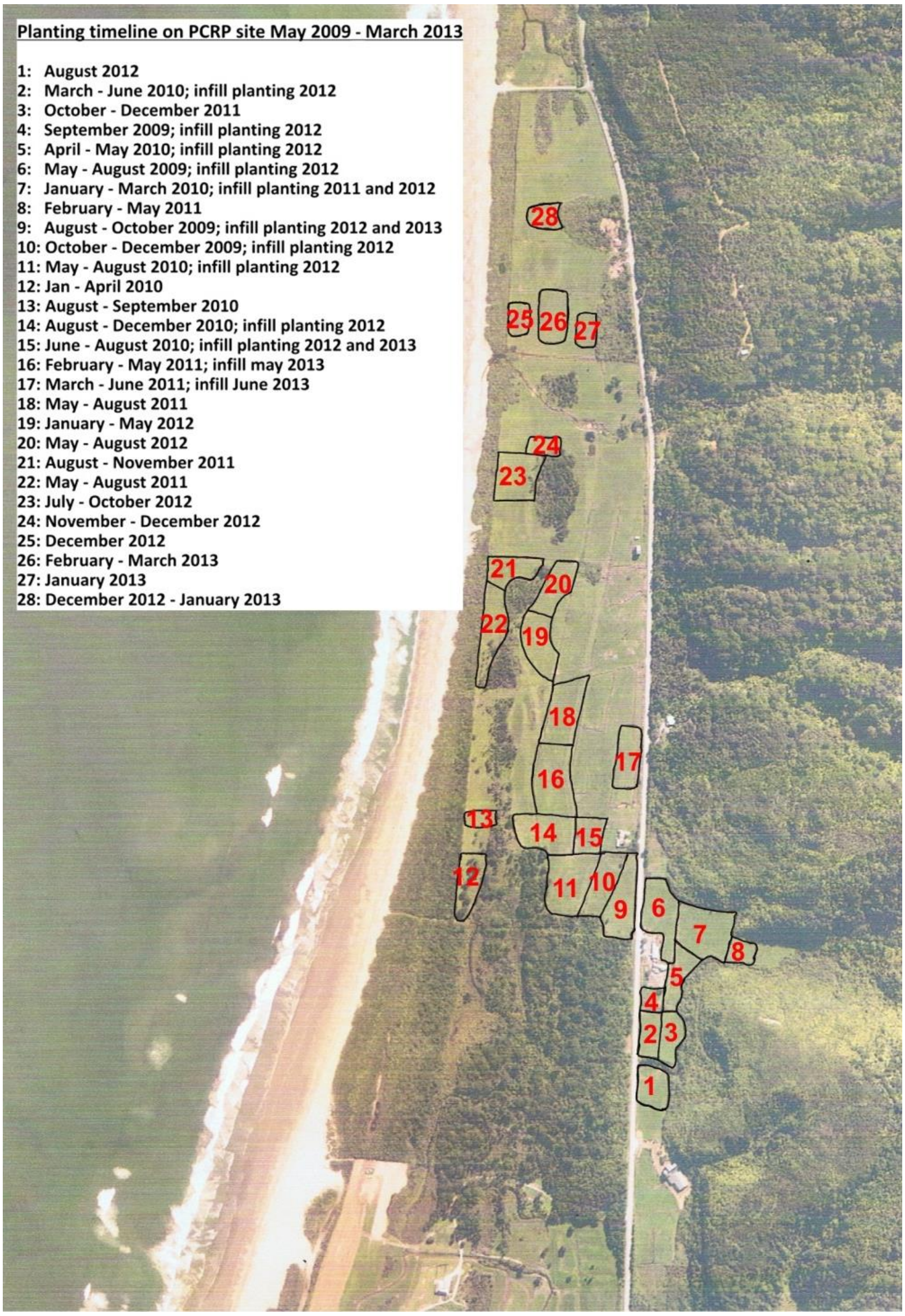

Figure 14. Planting sites and dates (including infill planting) at PCRP

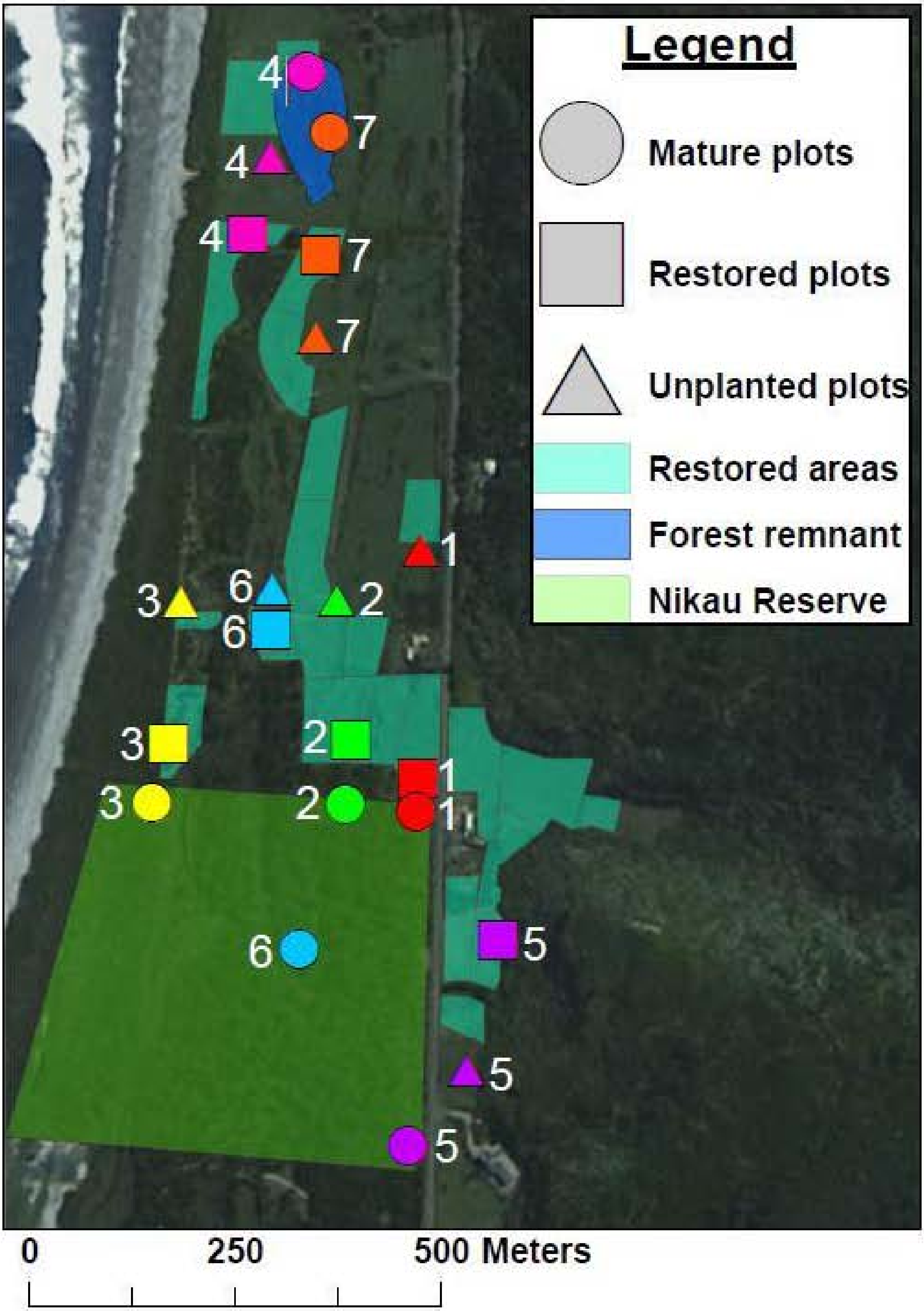

Figure 15. Monitoring transects constructed for monitoring restoration success. Individual transects are denoted by colour, plot treatments are indicated by shapes.

Results and discussion

Table 1. Mean number of invertebrates observed during artificial habitat monitoring. Likely indicator species are highlighted.

Observations	July 2012			February 2013		
	Mature	Restored	Unplanted	Mature	Restored	Unplanted
Chilopoda						
Centipedes	1.25	24.5	4.75	0.43	14.57	4.86
Millipedes	2.75	8.25	2.75	4.71	9.57	13.00
Carabids	1.00	0.75	0.00	2.57	0.57	0.43
Weevils	0.25	0.25	0.00	0.00	0.00	0.00
Tenebrionids	0.00	0.00	0.00	0.14	0.00	0.00
Unidentified beetles	0.00	6.25	0.00	0.14	3.43	1.14
Wasps	0.00	0.00	0.00	0.00	0.00	0.14
Ants	0.00	0.00	0.00	11.57	0.00	2.86
Snails	0.00	29.00	40.25	0.29	16.71	18.43
Immature earthworms	0.00	0.00	0.00	3.71	8.57	17.29
Native earthworms	0.00	0.00	0.00	7.00	0.57	0.00
Exotic earthworms	0.00	0.00	0.00	0.00	3.29	6.29
Unidentified earthworms	3.50	17.25	19.00	0.14	2.00	1.57
Wireworm	0.00	1.00	1.00	0.14	1.29	1.00
Harvestmen	0.00	0.00	0.25	0.29	3.29	3.14
Dolomedes minor	0.00	0.00	0.75	0.00	0.57	0.14
Anopteropsis adumbrate mature	0.00	0.00	0.50	0.00	4.14	1.71
Anopteropsis adumbrata immature	0.00	0.00	0.00	0.00	0.14	0.43
Orb-web spider	0.00	0.00	0.25	0.00	0.00	0.14
Therid Spider	0.00	0.25	0.25	0.14	0.29	0.29
Cambridgea Spider	0.50	0.25	0.00	0.00	0.00	0.29
Unidentified Spiders	6.00	12.25	5.75	2.57	0.86	1.57
Egg case (arachnid)	0.25	0.00	0.00	0.00	0.00	0.00
Spider web	0.25	0.50	0.25	0.00	0.00	0.00

Observations	July 2012			February 2013		
	Mature	Restored	Unplanted	Mature	Restored	Unplanted
Moth larvae	0.00	0.00	0.25	0.00	1.29	0.71
Cockroaches	1.25	5.00	0.00	2.00	0.71	0.00
Leaf-vein slugs	0.00	0.00	0.25	0.14	0.14	0.14
Unidentified slugs	0.00	6.00	0.25	0.00	1.43	17.29
Flatworms	0.25	2.50	1.25	4.00	12.00	5.57
Flatworm egg	0.50	0.50	1.00	0.00	0.00	0.00
Tipulidae (Cranefly)	0.00	0.00	0.00	0.29	0.00	1.00
Weta						
Cave weta	0.00	0.00	0.00	0.86	0.14	0.00
Tree weta	2.50	0.75	0.00	2.29	0.86	0.43
Cicada	0.25	0.00	0.00	0.00	0.00	0.00
Pupa	0.00	0.00	0.50	0.00	0.00	0.00
Click beetle	0.00	0.00	0.00	0.00	0.29	0.14
Mealy bugs	0.00	0.00	0.00	2.86	0.00	0.00
Mouse holes	0.00	1.25	1.00	0.00	0.00	0.00

Artificial habitats

Invertebrate indicators were identified based on their habitat preferences. Some organisms such as the tree weta (*Hemideina crassidens*) (Figure 16) and carabid beetles (Figure 17) clearly preferred mature forested habitats. Fewer were observed within the restoration monitoring plots. This is likely resulting from the transformation of habitat within the restoration plots as the plants continue to grow. We would expect the abundance of these species to continue to increase with development of the restoration plantings.

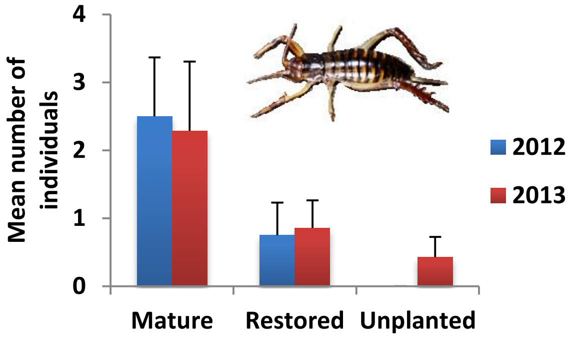

Figure 16. Mean tree weta (*Hemideina crassidens*) abundance (± s.e.).

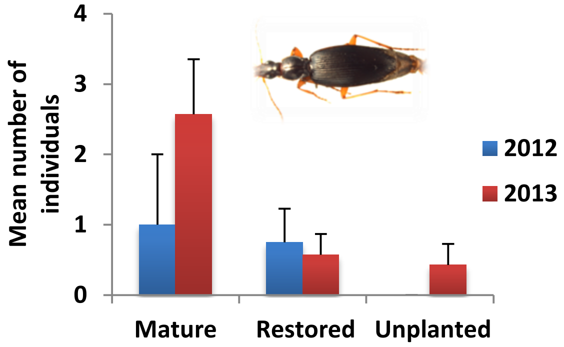

Figure 17. Mean carabid beetle abundance (± s.e.).

During the 2013 collection event, a total of 3 tree weta and 3 carabid beetles were observed within the unplanted monitoring plots. The weta were found in transect plots *Unplanted 3* and *Unplanted 5* and were likely a result of their close proximity to mature forest with distances of approximately 10 and 15m respectively. These plots are also positioned parallel with the forest edge, which would increase the likeliness of a weta finding refuge within them. The carabid beetles were observed in plots *Unplanted 1* and *Unplanted 4* and their presence may also be attributed to the proximity of dissimilar, vegetated habitat. Plot *Unplanted 1* is parallel to and within approximately 8m of a naturally regenerating strip of riparian vegetation, which could potentially act as a habitat corridor for these species. Plot *Unplanted 4* is also parallel to and approximately 10m away from the forest remnant.

Figure 18. Tree weta within a weta 'motel' refuge (photo by Jon Sullivan).

Other organisms including snails (Figure 21), centipedes (Figure 22) and two species of spiders (Figures 19 and 20) prefer open grass or shrub type habitats over mature forested habitats. As the restoration plantings continue to mature, we expect to observe a decline of these species within the restoration monitoring plots.

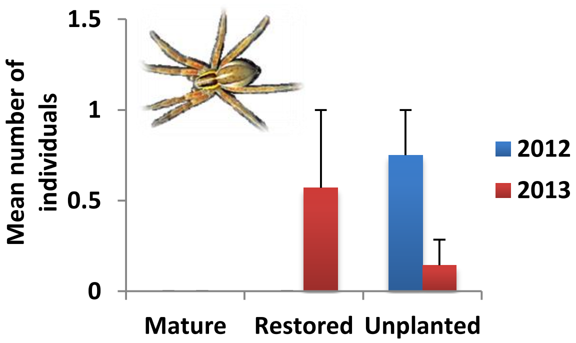

Figure 19. Abundance of *Dolomedes minor* spiders (± s.e.).

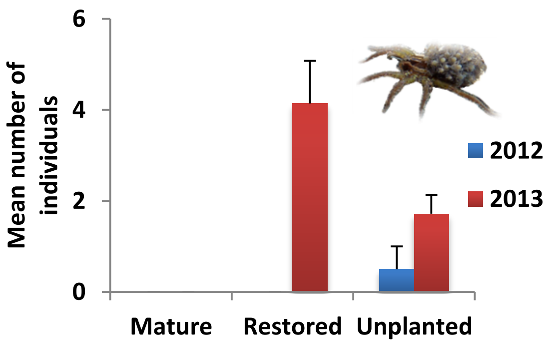

Figure 20. Abundance of *Anopteropsis adumbrata* spiders (± s.e.).

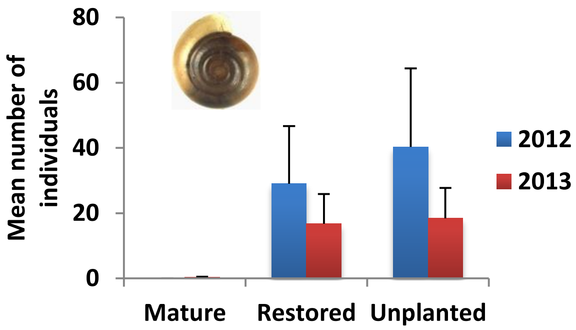

Figure 21. Abundance of snail sp. (± s.e.).

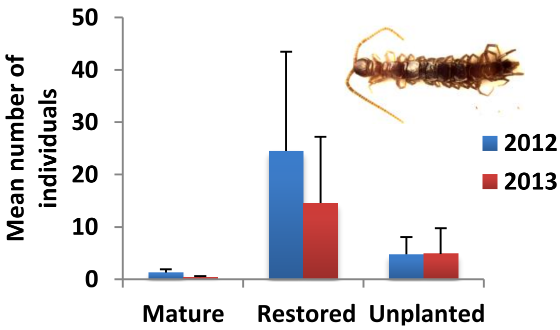

Figure 22. Abundance of centipedes (± s.e.).

As the restoration plants mature, it will be possible to begin monitoring for restoration bio-indicators at various layers of the vegetation strata, as within the mature forest with synthetic tree wraps. Monitoring within different layers of the vegetation is important because many species such as cockroaches inhabit several zones within the forest. Cockroaches for example have been observed in similar abundances within the artificial habitats on the soil surface within both the restoration and mature monitoring plots (Figure 23). However, the abundance of cockroaches observed within the mature plots would more than double if the quantity observed behind synthetic tree-wraps (Figure 24) were appended to this data.

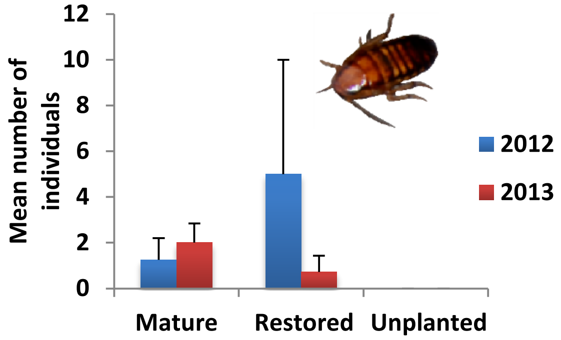

Figure 23. Abundance of soil surface cockroaches (*Celatoblatta vulgaris*) (± s.e.).

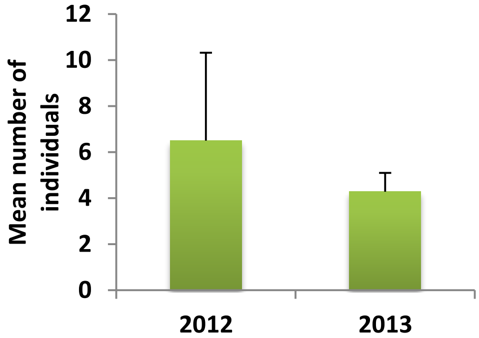

Figure 24. Abundance of cockroaches (*Celatoblatta vulgaris*) behind synthetic tree wraps (± s.e.).

Although the restoration plantings are not yet developed enough for synthetic tree wraps, various other monitoring methods can be implemented for the observation of organisms at various levels of the vegetation. This may include shaking of the plant or branches (known as beating) with a collection apparatus beneath. Other possible bio-indicators may include orb-web building spiders and recognisable foraging of host plants by monophagous species e.g. flax scraper moth (*Orthoclydon prafactata*), *Pseudopanax* leaf miner (*Acrocercops panacitorsens*) and Karamu leaf miner (*Acrocerops zorionella*).

Figure 25. Mike Bowie monitoring artificial habitats with fellow Lincoln University staff & students.

Pitfall trap results

Dung beetles

The dung beetles *Saphobius edwardsi* and *S. lesnei* were the most common beetle species trapped at the site over two years with 1042 individuals caught in total. Of these, 98.7% were caught in the mature sites, with only 10 and four trapped in restored and unplanted sites respectively. All three sampling dates showed significantly higher number in the mature sites although the winter sample caught less than a tenth the numbers (Figure 26). The mature remnant containing M4 and M7 caught 79.7% of the total beetles and this imbalance is shown by the large standard errors (Figure 26). It is very likely that the higher abundance of beetles in this remnant is a result of manure from cows using the trees for shelter. It will be interesting to see if dung beetle numbers diminish over time as the manure is broken down.

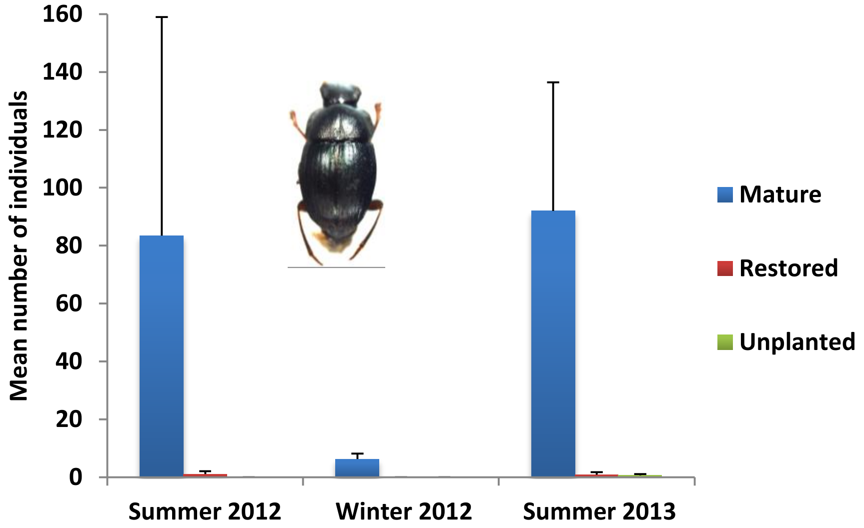

Figure 26. Mean dung beetle abundance from pitfall traps in transects sampled on three occasions (± s.e.).

Figure 27. Dung beetle (*Saphobious* sp.) from pitfall traps.

Weta

Weta caught in pitfall traps consisted of one cave weta species (*Talitropsis sediloti*) and two ground weta species (*Hemiandrus* n. sp. and *Pleioplectron* n. sp. "black face"; Peter Johns, pers. comm.). All weta apart from a single specimen were caught in mature sites and therefore show significantly higher weta abundance over three sampling periods (Figure 28).

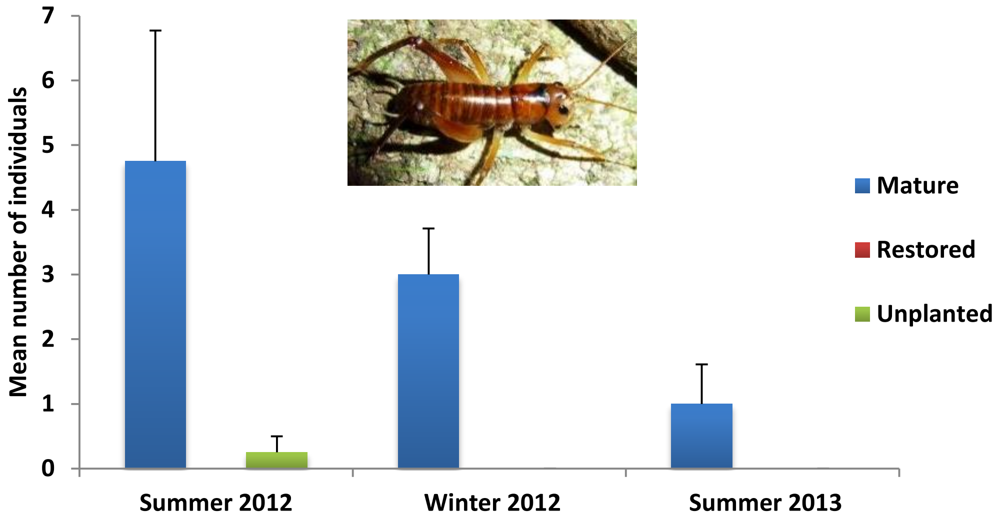

Figure 28. Mean weta abundance from pitfall traps sampled on three occasions (± s.e.).

Figure 29. Male tree weta in NSR at night.

Figure 30. Female cave weta in NSR at night.

Small beetles

Small beetles including Zopheridae, Hydrophilidae, Leiodidae, Erotylidae and Dryopidae, but excluding Staphylinidae, Curculionidae, Scarabaeidae (e.g. grass grub and dung beetles) and Carabidae were significantly more abundant in mature sites (Figure 31).

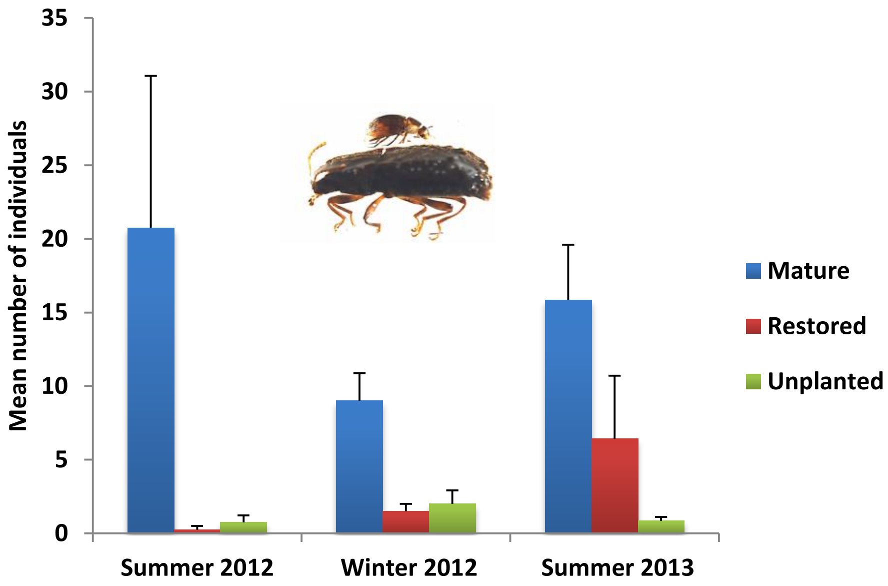

Figure 31. Small beetles (excluding weevils & staphylinidae) sampled on three occasions (± s.e.).

Figure 32. Stag beetle *Geodorcus helmsi* found in soil in NSR

Grassland spiders (*Anopteropsis adumbrata*)

The most common spider collected in the unplanted grassland and restored sites was *Anopteropsis adumbrata* (Figure 35). This species was significantly less abundant in the mature sites (Figure 33). Another grassland spider species trapped in lower numbers was the nursery web spider *Dolomedes minor* (Figure 34).

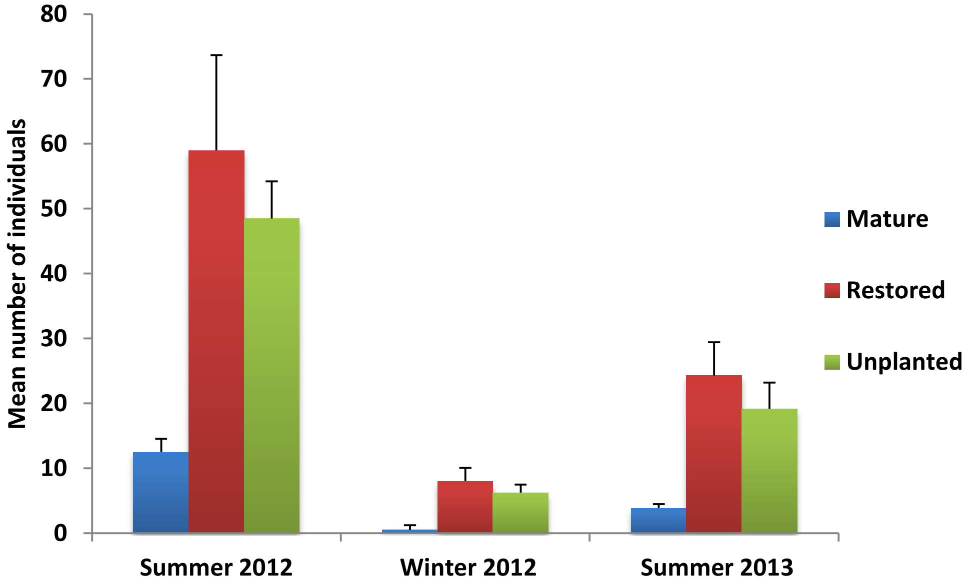

Figure 33. Mean abundance of *Anopteropsis adumbrata* from pitfall traps sampled on three occasions (± s.e.).

Figure 34. Nursery web spider (*Dolomedes minor*).

Figure 35. *Anopteropsis adumbrata* spider carrying juveniles.

Wasps

Wasps (mainly from the Diapriidae family) (Figure 36) were found in large numbers particularly in the summer pitfall trapping dates where they were found to be significantly more in the unplanted and restored sites than in the mature sites (Figure 37). Pitfall traps are not usually a chosen method of capture for wasps, but with mean abundance values exceeding 100 in the first summer of monitoring, these wasps must be closely associated with the soil surface ecology in the more open grassland sites.

Figure 36. Diapriid wasps were commonly collected from pitfall traps in exotic grassland sites.

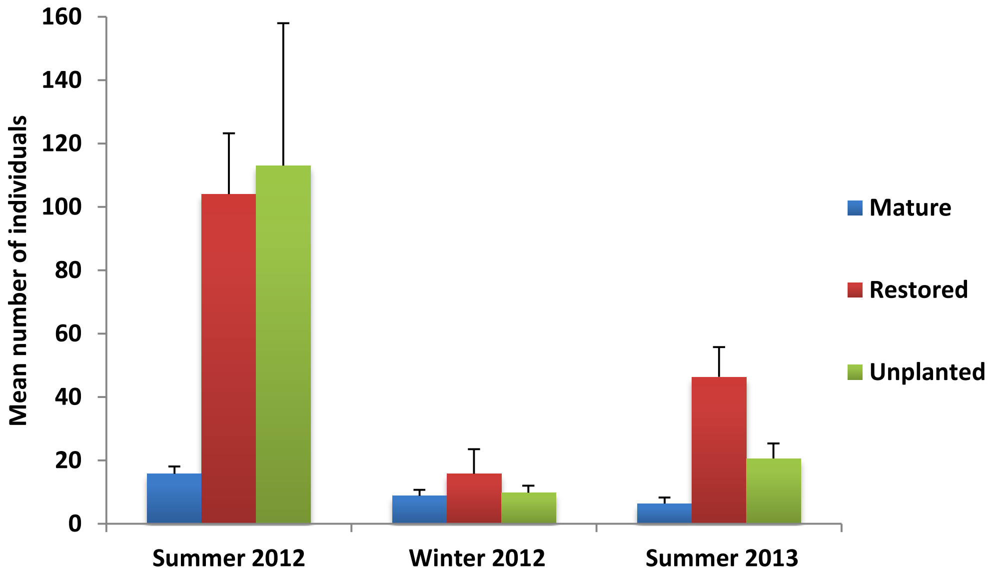

Figure 37. Mean abundance of wasps from pitfall traps sampled on three occasions (± s.e.).

Chapter 8.

Leaf litter invertebrates

Leaf litter has been utilized as an index for forest productivity as the nutrient content may determine how quickly the nutrients will be available for uptake by vegetation following decomposition (Grant, Ward, & Morley, 2007). Environmental factors regulating the rate of decomposition and release of nutrients include the levels of available nutrients, litter quantity and quality, abundance and richness of decomposer organisms and the various interactions between these factors (Swift et al. 1979; Hingston 1980)(Grant et al., 2007). Population densities of both collembolan and mite species have been found to be correlated with litter and canopy cover (Majer et al., 2007). Fifty percent or more of the terrestrial biodiversity is linked to the soil litter system and given mites tie together many components of the soil food web, they are excellent indicators of disturbance (Walter & Proctor, 1999).

Methodology

Leaf litter was sampled from each of the 21 transect plots once during the months of August and September 2012 and once again in January 2013. Results also include data from the baseline survey (Bowie et al., 2012). Litter was collected from within a 21x30cm steel frame (the size of an A4 piece of paper), which was placed randomly within the transect plot area. Only dead litter not attached to plants was collected. Litter that extended beyond the edges of the frame was torn or broken so that only the parts within the frame were collected. Litter was collected to the soil/mineral layer and placed into pre-weighed plastic bags. The bags were weighed again with the leaf litter to determine the mass of the wet litter. The leaf litter was then transferred into Tullgren funnels (Figure 38). Empty containers were placed beneath the funnels prior to the litter being placed within the funnels. These containers caught any small litter or organisms that fell through the funnels during the litter transfer. The empty containers were then

Figure 38. Tullgren extraction funnel used for leaf litter invertebrates.

replaced with collection cups containing propylene glycol (anti-freeze) and the funnels were placed into the buckets, above the collection cups. Any litter or organisms caught within the empty containers during the transfer of the litter into the funnels was placed back within the funnels on top of the litter. Lids fitted with 15 Watt light bulbs were set above the funnels and left on for a period of one week. The effects of constant light and loss of moisture within the litter stimulates invertebrate to burrow downwards where they consequently fall through a wire mesh screen and into the collection cup. Following extraction, the litter was weighed once again for dry litter mass. A total of six extraction funnels were used for leaf litter allowing two complete transects to be sampled each week for a total sampling period of four weeks per sampling event.

Results and Discussion

Spotted earthworms

Small spotted earthworms were found only in leaf litter from mature sites (Figure 39). A mean of nine worms per site were found in the summer of 2012, however a year later abundance was significantly less (<1) probably due to the unseasonal dryness at the PCRP.

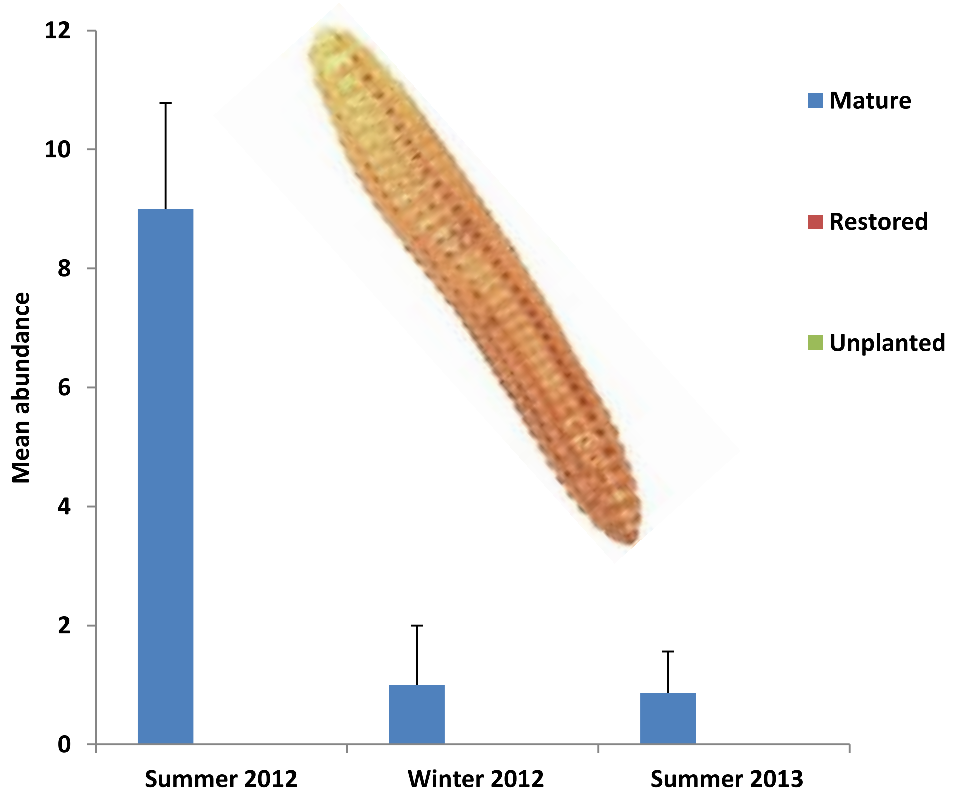

Figure 39. Mean abundance of 'spotted' earthworms (± s.e.).

Harvestmen

The mite-like harvestman *Aoraki denticulata* were only found in leaf litter from mature sites (Figure 40). These harvestman, although small, are very distinctive, making them a good indicator species.

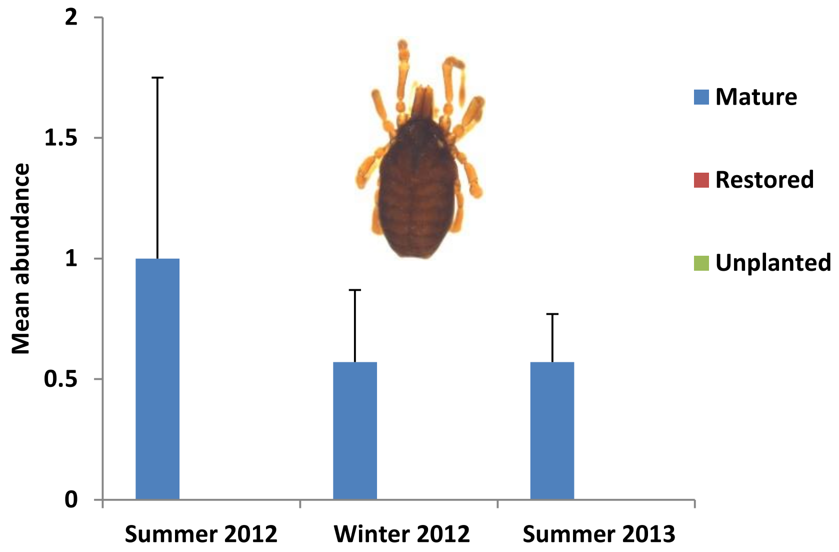

Figure 40. Mean abundance of the harvestman (*Aoraki denticulata*) (± s.e.).

Weevils

Up to 32 species of weevil were identified (see Appendix 1) but over 50% of those found in leaf litter samples were a small species called *Geochus tibialis*. Weevils were only found in mature leaf litter with large numbers found in the summer of 2012 (Figure 41). Drier conditions probably contributed to the lower abundance in the summer of 2013.

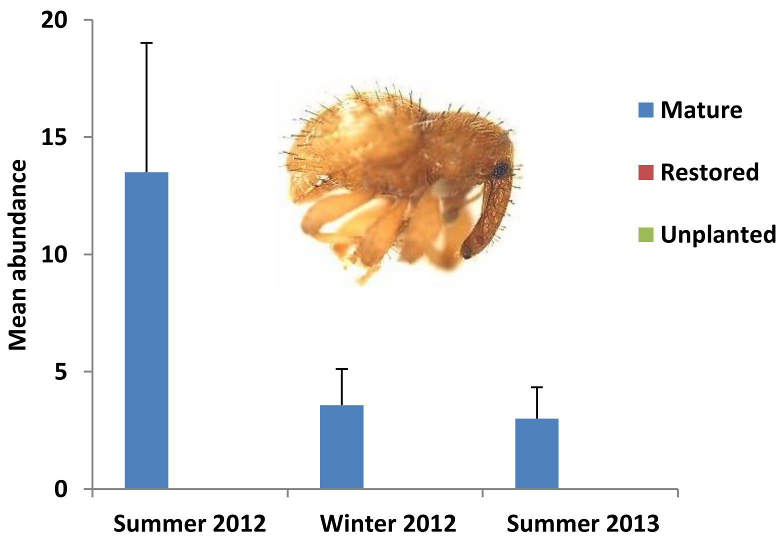

Figure 41. Mean abundance of weevils in leaf litter sampled on three occasions (± s.e.).

Mites

Approximately 35 species (Recognisable Taxonomic Units) of mites were found in leaf litter, with a large proportion of them being from the family Oribatidae. Seven species were found to be largely in the mature forest leaf litter (Figure 42) and potentially very useful as indicator species. Two Oribatidae (RTU 4 & 6) and two Uropodina (RTU 7 & 16) look to be the most reliable indicators being present in mature sites more than 60% of the time on average (Figure 42).

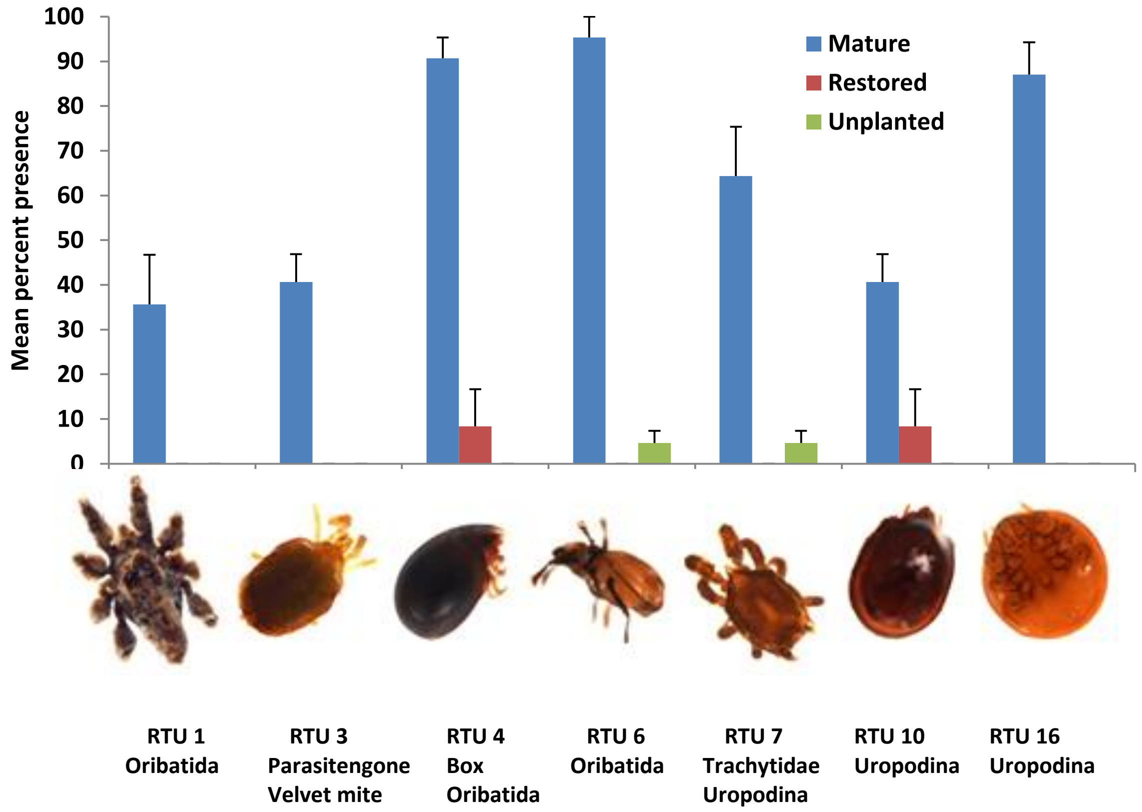

Figure 42. Mean presence of mites identified as indicator species over three litter samples across mature, restored and unplanted transects (± s.e.). Mites shown within the figure are identified according to the Recognisable Taxonomic Unit (RTU) shown below each mite.

Beetles

Beetles (excluding Staphylinidae) were found to be very abundant in mature sites apart from the winter sampling (Figure 43). The diversity of beetles found in the leaf litter has important roles in decomposition and in turn provide prey for larger invertebrates and insectivorous birds.

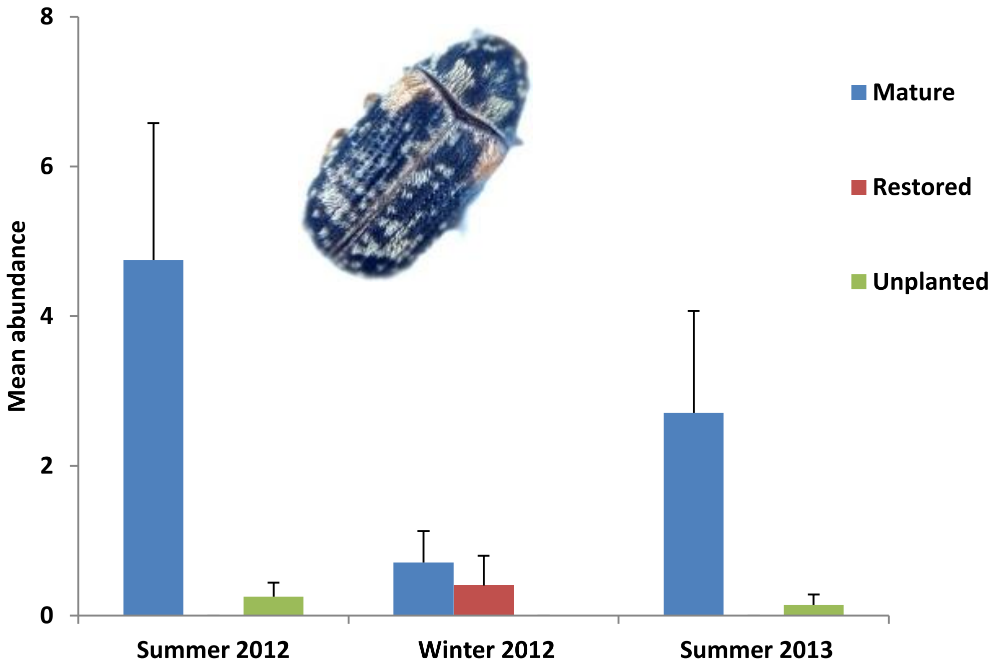

Figure 43. Mean abundance of beetles in leaf litter sampled on three occasions (± s.e.).

Chapter 9.

Re-establishment of Native Earthworms

Introduction

New Zealand has more than 200 endemic earthworm species described to date (Blakemore, 2011; Boyer, Blakemore, & Wratten, 2011; Lee, 1959), and many putative new species yet to be described (Boyer, 2012; Buckley et al., 2011). In addition to those, European earthworms have been introduced to pastures and other agricultural land to increase primary production in the 1960s (Stockdill, 1966). At least 23 exotic species are currently present in New Zealand and half a dozen of these have significant distribution in agricultural land and pastures, namely *Aporrectodea caliginosa*, *Aporrectodea rosea*, *Aporectoda longa Lumbricus terrestris*, *Lumbricus rubellus* and *Octolasium cyaneum* (Lee, 1961; Schon, MacKay, Minor, Yeates, & Hedley, 2008; Stockdill, 1966).

It has been reported that endemic earthworm communities disappeared quickly after the introduction of exotic grassland and crops mainly because of environmental changes (Lee, 1961). Therefore, the introduction of European species is believed to have had no direct influence on endemic earthworm communities. However interspecific competition is difficult to demonstrate and it has never been tested in New Zealand, partly because accurate sampling and identification of endemic earthworms is very challenging.

If habitat modification is the major factor leading to endemic earthworm disappearance, then restoration of native habitat may be sufficient to restore endemic earthworm communities. Sequential planting programs offer the perfect opportunity to investigate this hypothesis by studying native earthworm re-colonisation at different ages after replanting.

The aim of this study was to estimate the impact of habitat modification, namely plant species composition, on endemic earthworm communities and determine whether the restoration of native habitat helps the restoration of endemic earthworm communities.

Methods

Sampling

Earthworms were sampled by digging and careful hand-sorting soil samples, each 200 mm x 200 mm x 200 mm. Three soil samples were collected from each treatment in each transect (i.e. 0.024 m^3 of soil). Data from these three soil samples were pooled together for statistical analysis. Holes were dug in line with the pitfall traps. Earthworms were sampled in August and October 2012 as well as January 2013. The exact location of the holes varied from one sampling session to another.

Earthworms were hand sorted on site, weighed and identified to Recognizable Taxonomic Units (RTUs) or named species where possible. Tissue samples were collected and used in DNA analyses to confirm identification.

Molecular identification

Earthworm tissue samples were placed in ethanol 95% prior to molecular analyses. Molecular analyses were used to assess earthworm diversity (number of species) in the study site. A subsample of 35 specimens representative of all sampled morphotypes was used for DNA analyses. Standard DNA barcoding methods (Hebert, Ratnasingham, & deWaard, 2003) were applied to extract, amplify and sequence earthworm DNA for the standard barcoding region cytochrome oxidase subunit 1 (COI) (Boyer & Wratten, 2010). The R package SPIDER (Species Identity and Evolution in R) was used to build the phylogenetic tree, determine species boundaries and estimate the number of species present (Brown et al., 2012).

Statistical analyses

Earthworm sampling data (abundance and biomass) was pooled for each transect and analysed using ANOVA and TUKEY tests with R software.

Results

Based on DNA analyses, a total of 10 native and four exotic species were collected from the study area (Figure 44). Exotic species were *Dendrobaena octaedra*, *Lumbricus rubellus, Amynthas corticis* and *Octolasion cyaneum*. Native earthworms were mostly undescribed species.

These numbers are conservative estimates based on the collection of 2,550 earthworm specimens. It is likely that further work will unveil additional species.

Phylogenetic tree of earthworm species from the PCRP

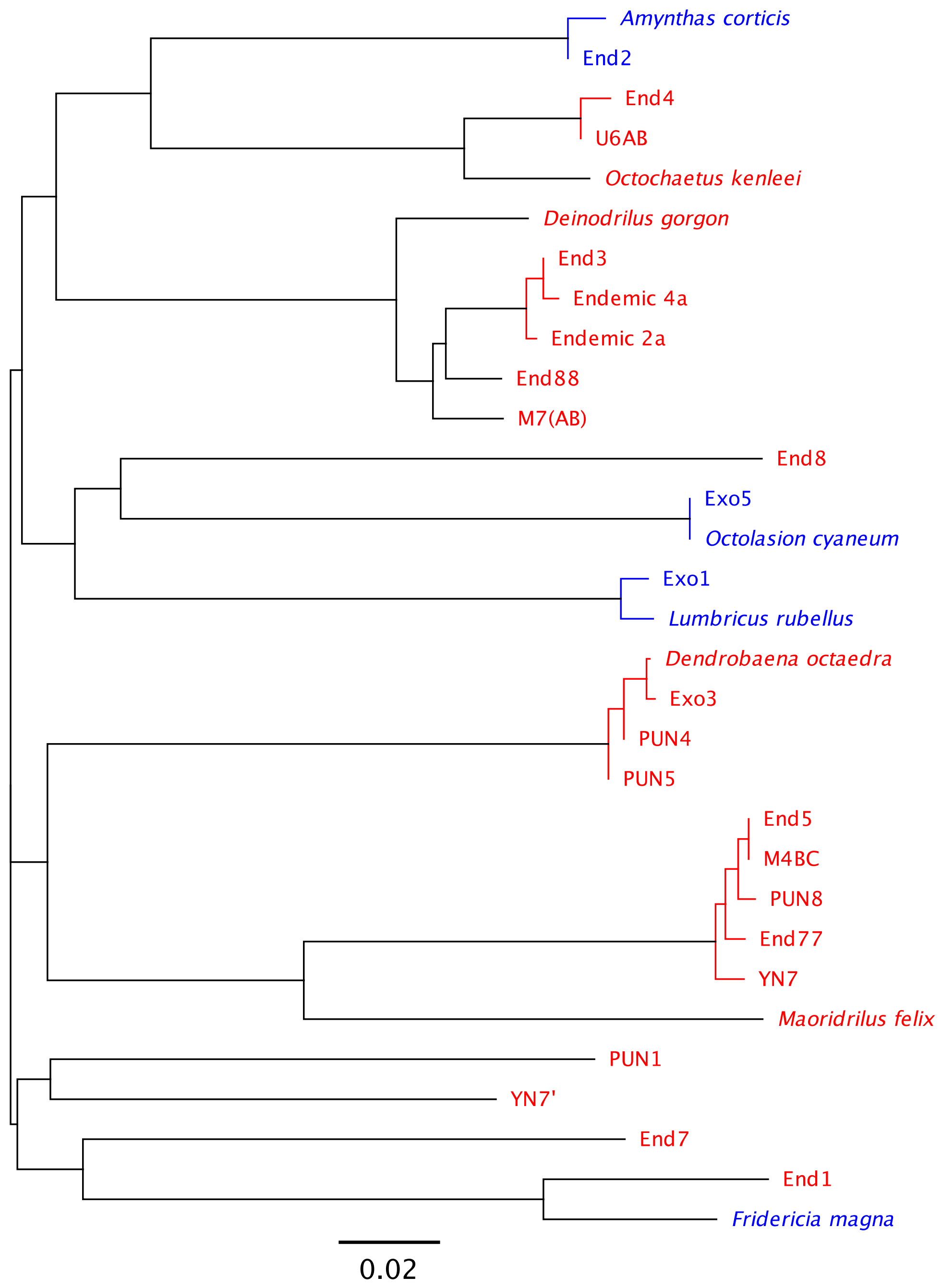

Figure 44. Neighbour-Joining tree based on a 696 base pair fragment of the COI gene for 22 earthworm individuals collected from the PCRP (code names) as well as sequences from eight described species (latin names), which correspond to the closest relative species for which DNA sequences were available on Genbank. Each code corresponds to the DNA of one individual earthworm, red coloured codes are native species, blue coloured codes are exotic species. Codes linked by a coloured line correspond to individuals of the same species. The tree is drawn to scale, with horizontal branch lengths corresponding to percentage difference (see scale for 2% of difference). The evolutionary distances were computed using the Kimura 2-parameter substitution model

There was significantly less earthworms (mean total abundance) in the mature sites than in both restored ($P<0.001$) and unplanted sites ($P<0.001$) (Figures 45).

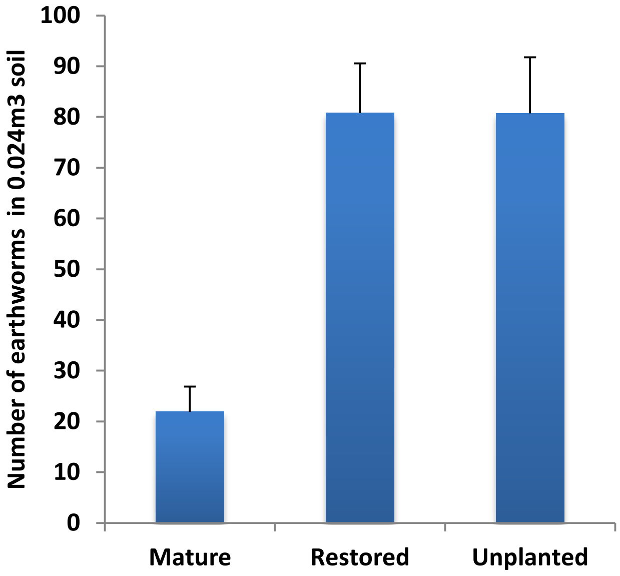

Figure 45. Mean number of earthworms collected per transect (three soil samples) in Mature, Restored and Unplanted areas (+s.e.).

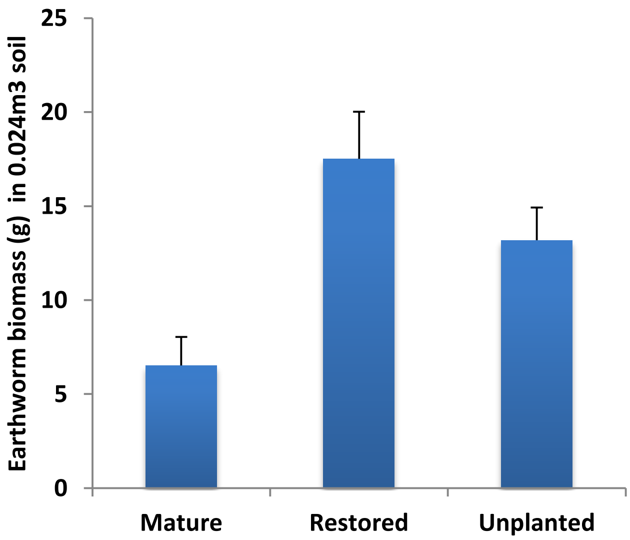

Figure 46. Mean biomass of earthworms collected per transect (three soil samples) in Mature, Restored and Unplanted areas (+s.e.).

These differences are mainly due to exotic earthworms, which were more abundant in unplanted and restored sites compared to mature sites ($P<0.001$). Differences between earthworm abundance in restored and unplanted sites were not significant ($P>0.05$). Similar trends were observed for earthworms biomass except that Restored areas had higher biomass than Unplanted areas with marginally significant difference (P=0.09)(Figure 46). Higher earthworm biomass is likely to lead to higher ecosystem services provided by the earthworm community. These services include organic matter decomposition, topsoil formation, soil mixing, increase of soil fertility and provision of food source for predators (Boyer & Wratten, 2010).

The proportion of native versus exotic earthworms varied with the treatment both for abundance and biomass (P<0.001). There was significantly higher proportions of natives in mature sites than in restored and unplanted sites (both for abundance and biomass, P<0.001) (Figures 47 and 48). Although initial results indicated an intermediate level of natives in restored sites (Bowie et al. 2012), here we find no differences in the proportion of natives in restored and unplanted sites (Abundance: P=0.75, Biomass: P=0.88). However, when taking into account the age since restoration, there is an increase of the proportion of native earthworms with time (Figure 49).

This re-colonisation by native species after restoration is confirmed by the pitfall trap data where the proportion of native is higher in restored sites than in unplanted sites (Figure 50).

It seems earthworm communities and particularly the proportion of endemic earthworms, could be a valuable indicator of restoration success, however, the increase in native earthworms is only visible after 3-4 years of restoration.

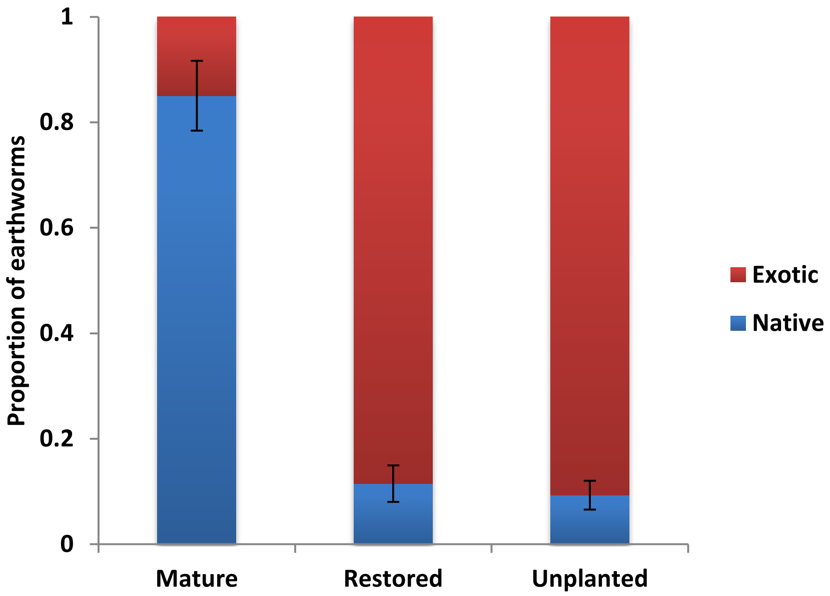

Figure 47. Proportion of exotic or native earthworms in Mature, Restored and Unplanted areas (Mean ±s.e.). Data were pooled per transect i.e. three soil samples.

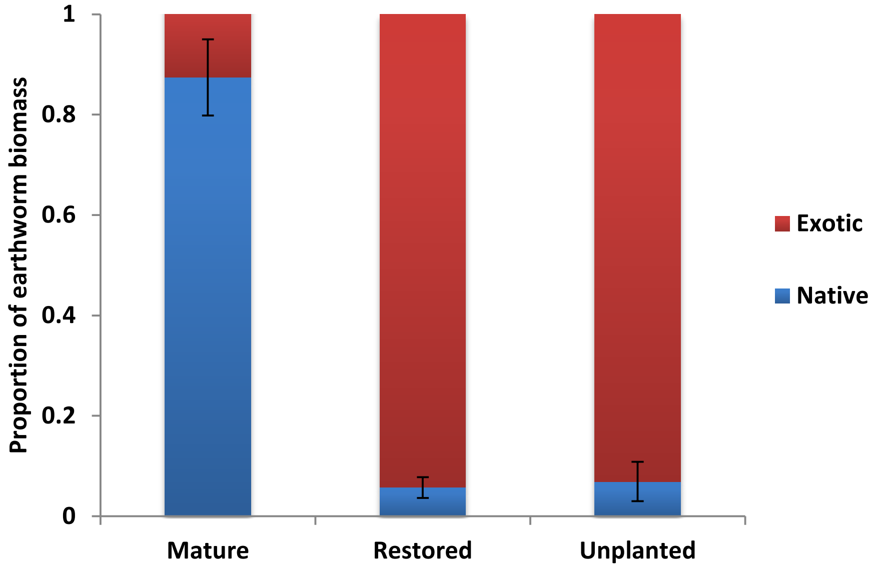

Figure 48. Proportion of exotic or native earthworm biomass in Mature, Restored and Unplanted areas (Mean ±s.e.). Data were pooled per transect i.e. three soil samples.

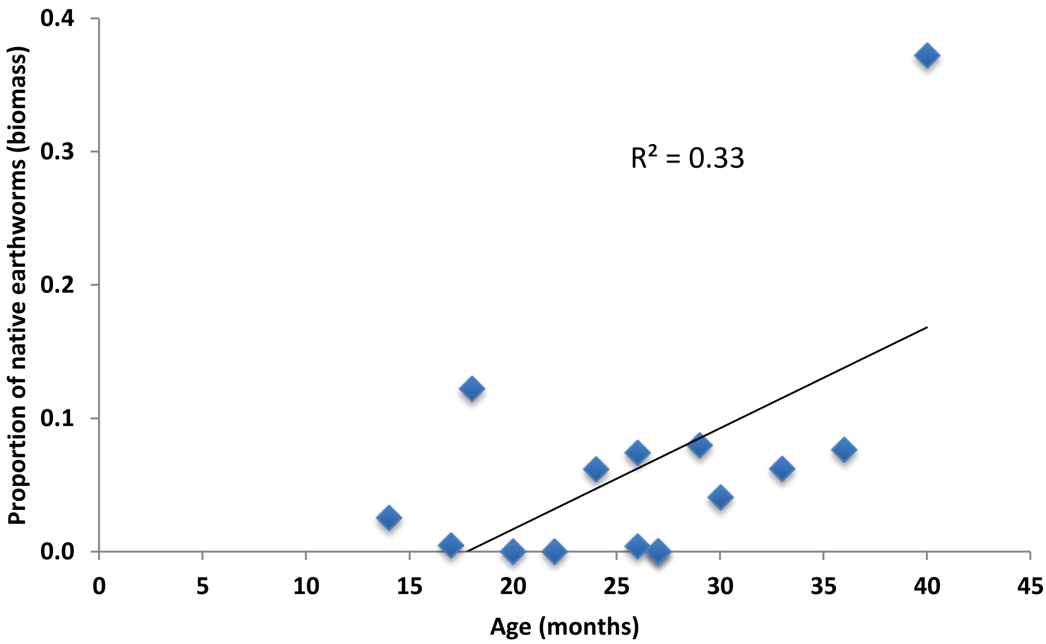

Figure 49. Proportion of biomass represented by native earthworms in Restored areas in relation to age (in months) since restoration. Data were pooled per transect (i.e three soil samples).

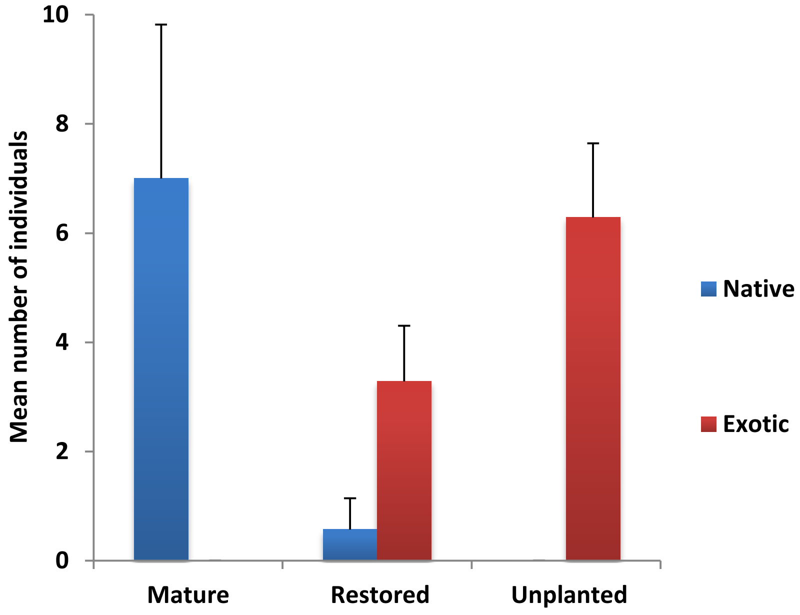

Figure 50. Mean abundance of native and exotic earthworms in artificial habitats placed in Mature, Restores and Unplanted areas during February 2013 sampling event (±s.e.).

Figure 51. From the left: CVNZ team leader Bruce Eade and Lincoln University staff member Jason Hahner lead CVNZ volunteers through an earthworm sampling event.

Chapter 10.

Re-colonisation of herbivorous insects

Methodology

Investigating the presence of herbivorous insects within the vicinity of each of the mature and restored transect plots was completed with the use of light traps to catch moths (the adults of herbivorous larvae). Trapping was completed between February 12th and March 10th, 2013. The light traps used were fitted with 60 watt incandescent light bulbs. The traps themselves are constructed from a wooden box fitted with a removable lid made from a metal funnel. Within the funnel is a cross-fitted plexiglass deflector which both houses the light bulb and acts to intercept flying invertebrates which fall into the funnel and collection box below.

During each night of trapping, one light-trap was set within a mature transect plot, and another within the restored plot of the same transect. Each light-trap is powered by separate generators of the same size and same fuel capacity. Approximately half an hour after last light, both generators are started and allowed to operate until they have run out of fuel, approximately two and a half to three hours duration. Samples are collected on the following morning. Any invertebrates that are found on the traps, but not within the box are collected with soft-tipped forceps and carefully placed into a plastic bag. The lid to the collection box is removed and the plastic bag is quickly fitted across the top of the box. The box is inverted and gently agitated to influence the collected invertebrates to enter the bag. The bag is then removed from the box, and any invertebrates remaining within the box are collected with forceps. The plastic bags are immediately placed into a freezer for several hours. Samples are then removed from the bags and placed into sturdier containers lined with tissue and returned to the freezer for preservation until curation and identification.

Results and Discussion

Moths caught from light traps were used as the measure of herbivorous insects present in mature and restored sites. A total of 42 moth species were identified. Although greater numbers and species richness were collected in the restored areas (Figure 52) this probably reflects the openness of these sites compared to the denser mature sites which would not let the light spread too far. In any case it is the species composition rather than the total number of moths caught that is more relevant.

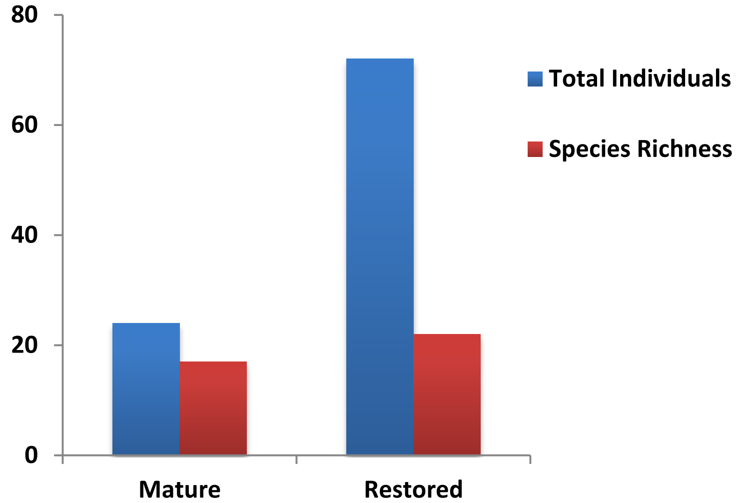

Figure 52. Light trap results from 14 locations.

Moth species that would be good indicators of the more open grassland based on their hosts (species with askerisk in Table 2) include: *Cydia succedana* (gorse pod moth), grass larval moth species *Orocrambus flexuosellus* and *O. ramosellus*, and pasture pests known as Porina (*Wiseana copularis* and *W. umbraculata*). From the five species above 55 moths were recorded from the restored sites compared with only a single moth in the mature sites. Species considered to be good indicators of mature sites would include moth species which larvae feed specifically on natives found in bush (indicated by hash in Table 2) and would include: *Aciptilia monospilalis*, *Anisoplaca achyrota*, *Chalastra perlargata*, *Cnephasia jactatana*, *Feredayi graminosa* – all of which were found in the mature sites.

Table 2. Moths caught in light traps at paired restored and mature transect sites

Moth species / taxon	**Origin / Status**	**Host species / larval food**	**Restored sites**							**Mature sites**						
			1	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Aciptilia monospilalis[#]	*E*	*Schefflera & Pseudopanax*								1						
Anisoplaca achyrota[#]	*E*	*Hoheria* fruit								2					1	
Apoctena orthropis	*E*	?								1						
Austrocidaria callichlora	*E*	*Coprosma* species	1													
Bactra noteraula	*E*	*Cyperus* (sedge) & *Desmoschoenus*			**2**											

		(Pingao) species														
Barea exarcha	*A*	Dead wood			**1**											
Chalastra perlargata#	*E*	Ferns								1	1					
Chloroclystis inductata	*E*	Flowers			**1**											
Cnephasia jactatana#	*E*	*Carmichaelia*, ferns, *Fuchsia, Griselinia*, Flax, etc								1						
Ctenopseustis obliquana	*E*	Polyphagous								1						
*Cydia succedana**	*BC*	Gorse			**1** **2**		1					1				
Epyaxa lucidata	*E*	Herbs											1			
Epyaxa rosearia	*E*	Herbs	2													
Epiphyas postvittana	*A*	Polyphagous			**1**											
Eudonia leptalaea	*E*	Sod webworm			**1**			1				1				
Eudonia melanaegis	*E*	Mosses			**1**											
Eudonia minualis	*E*	Mosses	**1**													
Eudonia submarginalis	*E*	Sod webworm	**1**		**5**											
Feredayi graminosa#	*E*	*Melicytus ramiflorus*								1						
Gellonia dejectaria	*E*	Polyphagous on trees and liianes										**1**				
Graphania insignis	*E*	Herbs	1			1				1						
Graphania mutans	*E*	Herbs	1			5	1	1								
Graphania ustristriga	*E*	Aboreal larvae on shrubs and lianes	1			1										

Hydriomena rixata	*E*	*Gunnera* sp. (endemic or extotic)						1								
Hygraula nitens	*A*	Aquatic larvae in ponds						3				5				
Leptocroca sp.	*E?*	Dying stems, roots & leaves on ground										**2**				
Merophyas leucaniana	*E*	Grasses					1	1								1
Oecophorid sp.	?	??										**1**				
Opogona omoscopa	*A*	Decaying vegetation				1	1			**1**					1	
*Orocrambus flexuosellus**	*E*	Grass bases	**1**				4	1								
*Orocrambus ramosellus**	*E*	Grass bases						1								
Patagoniodes farinaria	*E?*	*Senecio*					1									
Platyptilia repletalis	*E*	*Plantago* flowers	**1**		**2**	1	1	1								
Rhapsa scotosialis	*E*	Dead leaves on ground								1						
Schrankia costaestrigalis	*I*	wetland						1				**1**			1	
Stericta carbonalis	*?*	*Eucalyptus* seeds										1				
Tingena sp.	*E*	Leaf litter										**1**				
Udea flavidalis	*E*	Polyphagous on herbs and lianes	1 + **1**													
Uresiphita maorialis	*E*	Kowhai						1								
*Wiseana copularis**	*E*	Subterranean larvae in		1	1 1	2										

		grassland on grasses		0	+ 1											
*Wiseana umbraculata**	*E*	Subterranean larvae in grassland on grasses			1											
Xanthorhoe occulta	*E*	Leaves										**1**				
Unknown Noctuidae	*?*	Unknown		9												
Unknown Crambidae	*?*	Unknown		1												

Key:
E= Endemic
A= Adventive
I= Indigenous
BC= Introduced Biological Control
?= Unsure of species origin
Red numbers indicate 2012 data (Bowie et al. 2012) otherwise 2013 data
* = Moth species which larvae feed on exotic grasses or gorse
# = Moth species which could potentially be used as indicators species for mature bush

Chapter 11.

Bird Surveys

Birds play an important role as bio-indicators as they are conspicuous, easy to observe, one of the best studied organisms, and in the focus of public interest and care (Markert et al., 2003). Birds are also sensitive to environmental change and have a history of being successfully used as bio-indicators. In addition to using birds as bio-indicators, bird surveys may provide information on the opportunities for seed dispersal and plant colonization within the study area from granivorous (seed eating) birds (Traveset & Rodriguez-Perez, 2008). The dynamics of seed dispersal influences the colonization of new habitats and maintenance of diversity, with implications for succession and regeneration (Wang & Smith, 2002).

Methodology

Five-minute bird counts were completed in three forested areas and three sites within the restoration area, duplicating the sites and methods utilized during the 2012 baseline survey (Bowie et al., 2012)(Figure 53). These methods follow a modified version of Dawson and Bull (1975). The sites utilized during the bird survey are not correlated with the vegetation/invertebrate transects due to a 250m spacing requirement. After arriving within the sampling location, surveyors sit or stand quietly for a period of one minute to compensate for the disturbance of their arrival. During the 5-minute bird count, birds were recorded according to whether they were seen or heard including the number of each species detected. Birds seen flying through a habitat, but without showing evidence of actually utilizing the habitat area for feeding, nesting or perching were not counted. Likewise, birds heard from a sampling location that are clearly within a different adjacent habitat were also excluded. Following the 5-minute survey

Figure 53. Locations of the bird monitoring sites.

period, an additional 20 minute observational period was included to supplement the species list. This additional data was not utilized in the data analysis.

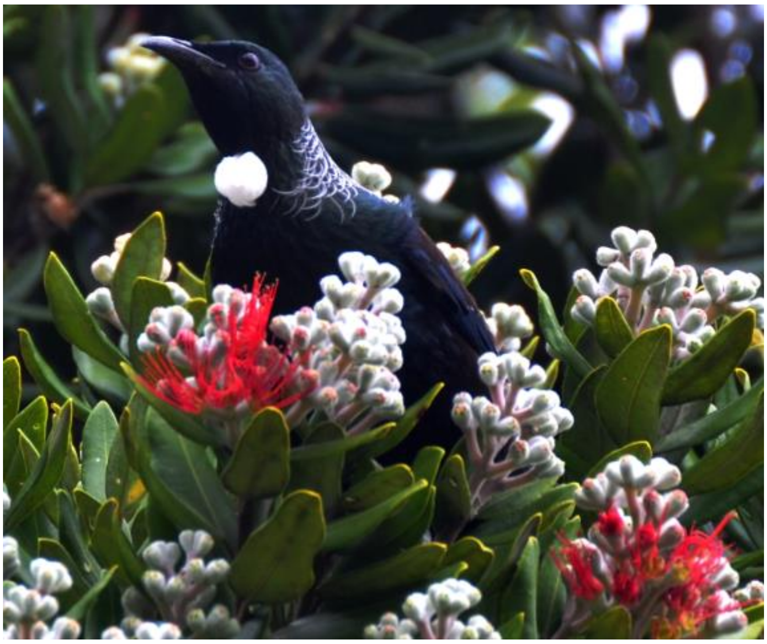

Figure 54. Tui (*Prosthemadera novaeseelandiae*) are often observed in the NSR.

Results and Discussion

Six and seven native species were recorded in the restoration plantings and mature sites respectively (Table 3). The weka and the shining cuckoo were the two species found in the mature sites but not in the restoration sites during the counts, but the weka are often seen in all parts of PCRP sites. In a similar vein, kereru were recorded in five minute bird counts in restoration plantings but not in mature sites, even though they are regularly seen and heard in most aeras. What this indicates is a lack of monitoring sessions to pick up the more common species. Seasonal bird surveys reveal that native bird species prefer mature forest plant communities, while exotic bird species prefer the restored habitats (Figure 55). One possible explanation for this is the contrast of floral communities between open and non-mature planting areas compared to mature native New Zealand forests. Many of the exotic bird species are from Europe and have evolved with the European plant species where they feed on seeds found in the abandoned pastures. Likewise, native New Zealand bird species would have evolved with native New Zealand plant species found within mature New Zealand forests. Specific dietary and habitat requirements define each species preferred habitat type. However, this does not mean that birds will not frequent a different habitat type. Also, as the restoration plantings continue to mature, these areas begin to develop more of the attributes of a native mature forested habitat and have already begun to attract native bird species (Table 3). A full list of bird species observed can be found in Appendix I.

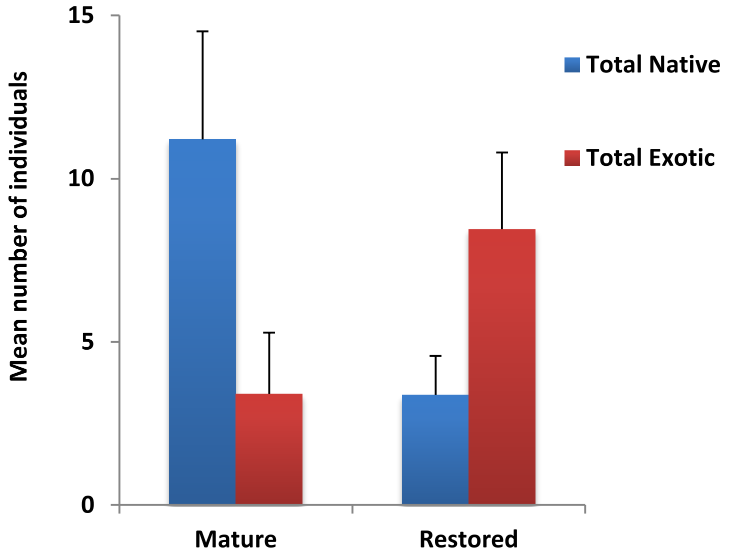

Figure 55. Means of eight bird observation sampling events at six sites over 3 seasons (± s.e.)

Table 3. Bird species observed within forested and restored habitats during five minute bird counts. Although the abundance of native and exotic bird species is similar in each habitat, the numbers of individuals observed is not.

Forested Plots		Restored Plots	
Native species	**Exotic species**	**Native species**	**Exotic species**
Bell Bird	Black bird	Bell Bird	Black Bird
Fantail	Chaffinch	Fantail	Chaffinch
Grey Warbler	Goldfinch	Grey Warbler	Goldfinch
Shining Cuckoo	Hedge Sparrow	Kereru	Greenfinch
Spurwinged Plover	Redpoll	Red-billed Gull	Hedge Sparrow
Tui	Skylark	Tui	Redpoll
Waxeye	Thrush	Waxeye	Skylark
Weka			Thrush

There are also possible drawbacks of using birds in monitoring programs. The life cycle of birds make them difficult to establish short term perturbations. Bird populations in seasonal migration or staging may conceal environmental stresses and their demographic parameters are affected by a multitude of factors (Markert et al., 2003). Bird species which nest in a variety of habitats have been found to breed successfully in restored areas (Curry & Nichols, 1985 as cited in Nichols & Grant, 2007). However, birds with specific nesting requirements such as hollow trees will not find suitable nesting sites in newly restored areas, but may still be found foraging within them (Nichols & Grant, 2007). Therefore, the mobility of birds can impede on the site specific abilities to use birds as indicators (Markert et al., 2003). Monitoring of bird populations within the PCRP should continue as birds are widely accepted as indicators of restoration success. However, interpretation of data collected should be carefully considered before any conclusions are made.

Figure 56. Pukeko (*Porphyrio porphyrio melanotus*) are often seen in open grassland and wetland areas at the PCRP.

Figure 57. Kereru (Hemiphaga novaeseelandiae) are often seen perched within the coastal strip of vegetation at the PCRP.

Chapter 12.

Aquatic invertebrates as a measure of water quality

Methodology

Aquatic invertebrates were sampled on the 11th January, 2012; the 28th September, 2012 and the 11th March, 2013. Samples were collected with a D-shaped aquatic kick-net over a period of 30 seconds. Downstream sites were sampled before upstream sites in order to minimise disturbance. The contents of the net were emptied into a tray containing clean water. Aquatic invertebrate fauna were collected from within the tray with soft tipped forceps and preserved in ethanol.

The *Scotsmans Creek* sampling sites are located 50m east of State Highway 6, about two and four meters downstream from a track crossing which links two restoration areas (Figure 58). There is a structure which supports an abandoned sluicing pipe overhead. This section of stream flows out of naturally regenerating forest is mostly covered by canopy and has a stony substrate with some woody debris. The *Nikau Reserve* sampling sites are located approximately 29 and 30m downstream (west) from where Scotsmans Creek passes beneath State Highway 6 (Figure 58). This section of waterway is within the Nikau Scenic Reserve, is completely covered by canopy and has a stony substrate with more woody debris than the east side of the road. To sample these two sites, the kick-net was placed on the bottom of the stream and the collector proceeds to shuffle and kick their feet, agitating the stony substrate upstream of the net for a period of 30 seconds.

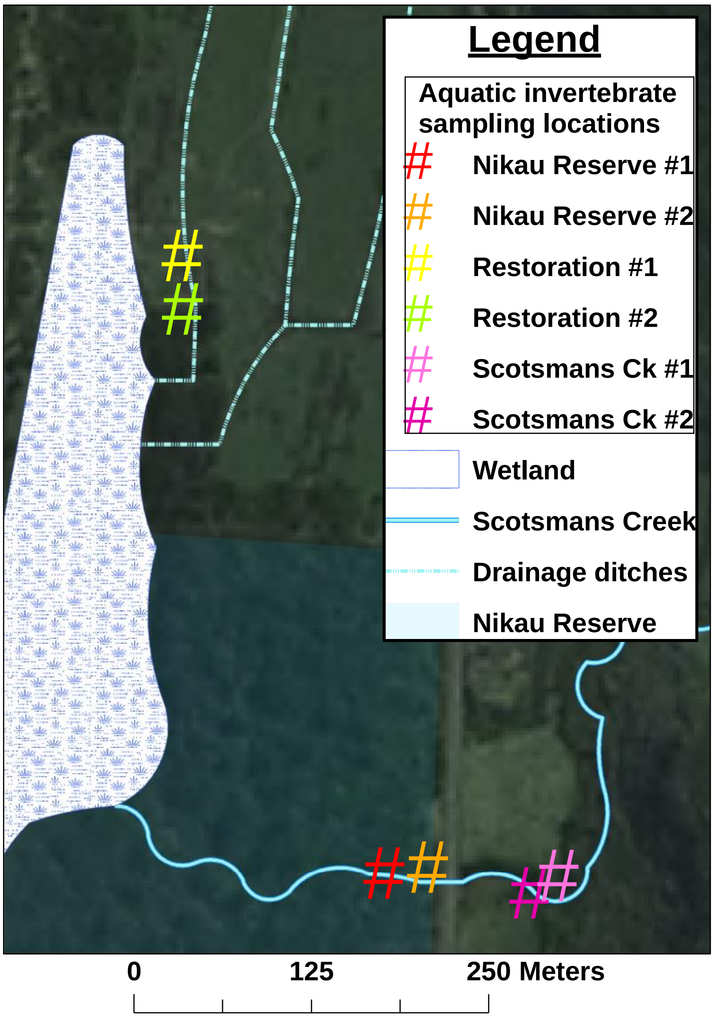

Figure 58. Sampling locations for aquatic invertebrates.

The *Restoration Planting* sampling sites were located within a drainage ditch which runs south through most of the PCRP land. The sampling locations are 0.5 and 10m downstream (south) of the second track bridge west of State Highway 6 (Figure 58). This section of the waterway has no canopy cover, but is largely obstructed with exotic grass and other aquatic vegetation. The substrate within this drain is sandy in some locations, but contains a silty sludge within the sampling area. Presence of woody debris is uncertain due to low to no visibility through the vegetation, but it is thought to be absent from this area. Sampling in this location was completed by shuffling the kick-net through the grass and aquatic vegetation in sharp upward and upstream motions for a period of 30 seconds.

Results

Samples taken from the *Restoration Planting* sampling sites produced a greater number of individuals (Figure 59), yet a lower species richness was found (Figure 60). This can be mostly attributed to large numbers of molluscs such as snails as well as dragonfly and damsel fly larvae sampled within the *Restoration Planting* sites. A full list of aquatic invertebrate taxa and individuals sampled at the PCRP is included in Appendix 1.

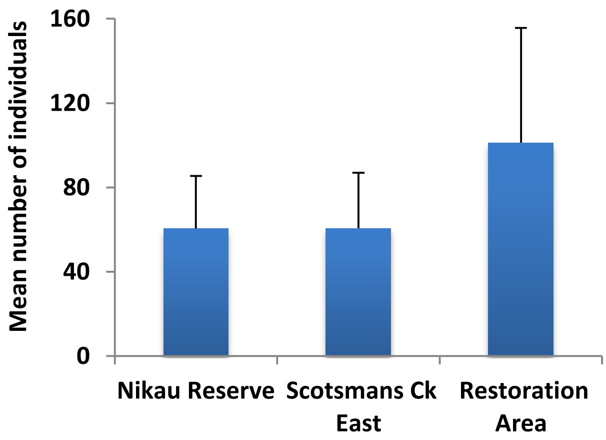

Figure 59. Average number of aquatic invertebrates collected (± s.e.).

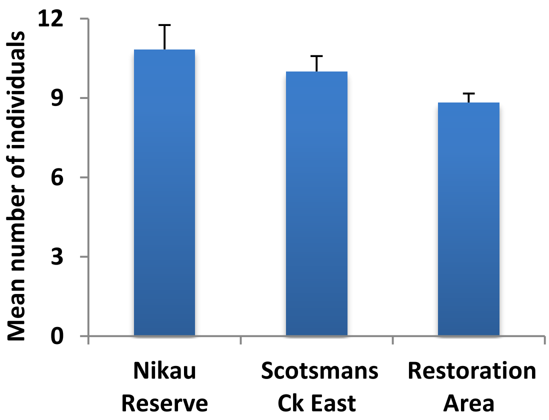

Figure 60. Species richness of aquatic invertebrates (± s.e.).

The Macro-invertebrate Community Index (QMCI) (Stark, 1985) was developed to assess the health of New Zealand's streams through the use of a quantified system of aquatic invertebrate indicators based on tolerance to water and habitat quality. The most sensitive taxa are given an index score of 10 and taxa that can survive in the poorest quality water are given a score of 1. The *Restoration Planting* sampling site scored a lower QMCI rating than the other two sampling sites (Figure 61). This was due to the larger number of snails (scored 3-4) sampled in this location. An aquatic health index based on the percent of mayflies, stoneflies and caddisflies in sample (%EPT) also reveal differences in water quality between the altered and natural streams (Figure 62). These species are sensitive to water quality and a high abundance of individuals indicates a healthy system.

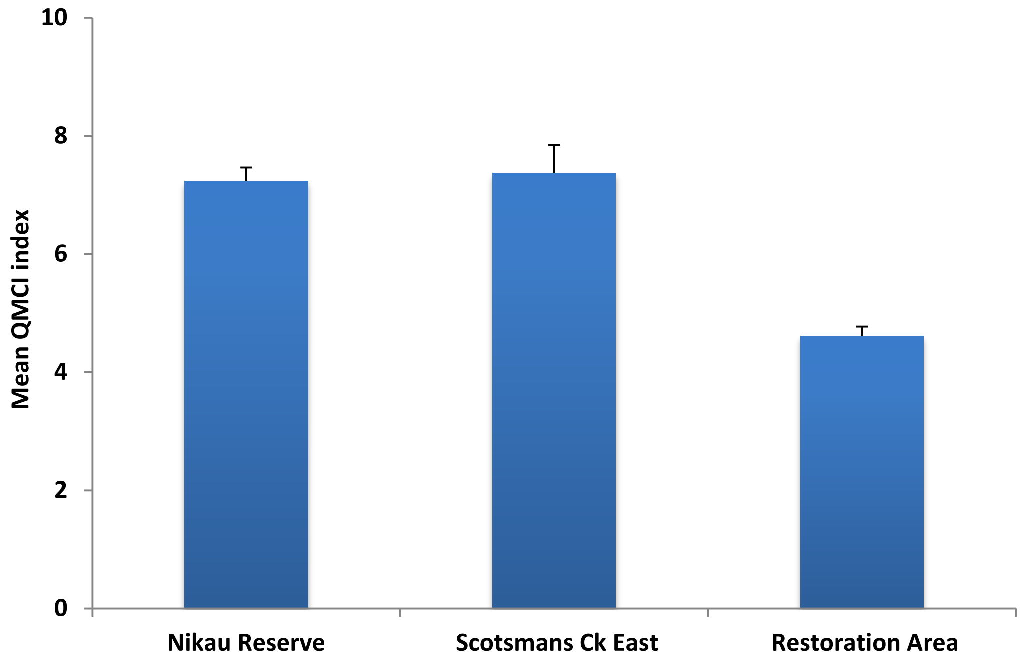

Figure 61. QMCI index for aquatic invertebrates (± s.e.).

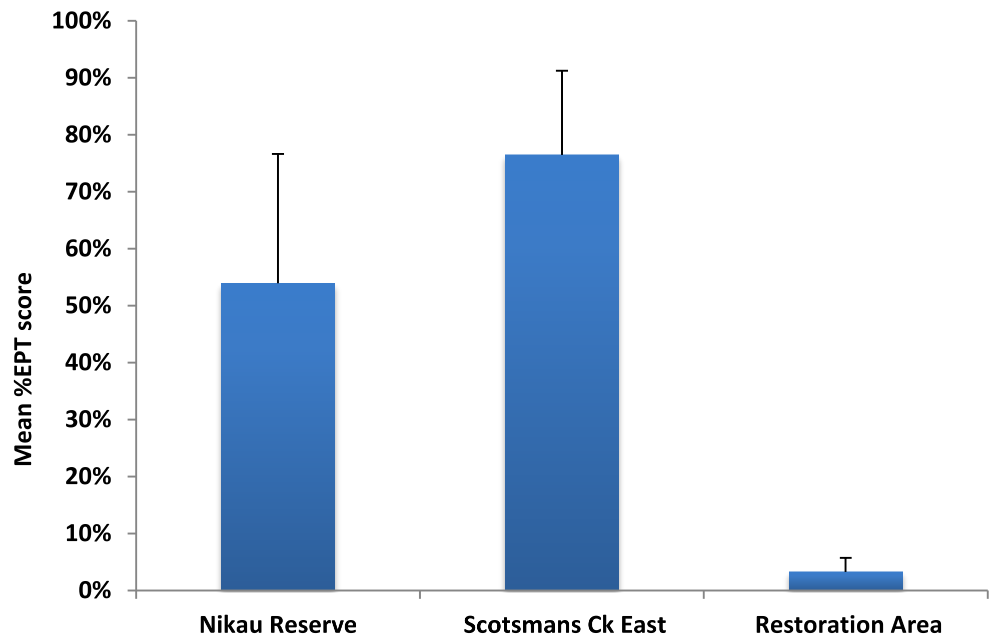

Figure 62. %EPT taxa for aquatic invertebrates (± s.e.).

Chapter 13.

Fish diversity

Methodology

Fish trapping was completed to identify species trends within a waterway flowing through mature, restored and unplanted areas. A total of 15 '*G-Minnow*' style live traps were acquired from Landcare Research, NIWA and DOC (Figure 63).

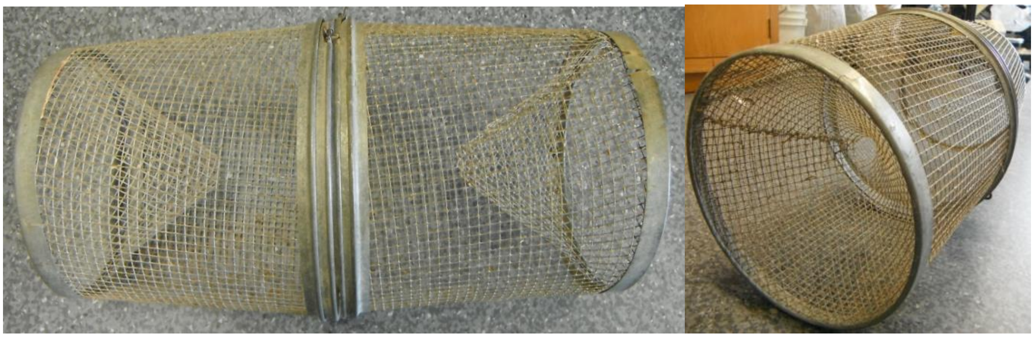

Figure 63. G-Minnow traps used for trapping fish.

Trapping for fish was completed from the 11th to the 12th of December, 2012. Traps were baited with *Vegemite* inside of perforated plastic containers. The traps were spaced out at approximately 10m intervals within each sampling area (Figure 64) and left for a period of 24 hours. Fish that were caught within the traps were counted, photographed, measured for length and then released.

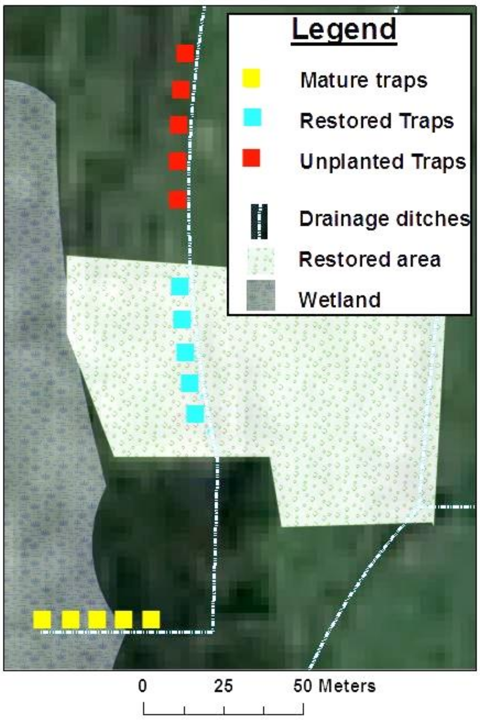

Figure 64. Fish trapping locations.

Results and Discussion

Similarities in fish species abundance and richness were seen within the restored and unplanted trapping locations (Table 4). The majority of the fish caught here were Inanga (*Galaxias maculatus*) (Figure 65) with one Shortfinned eel (*Anguilla australis*)(Figure 66) caught within the unplanted area.

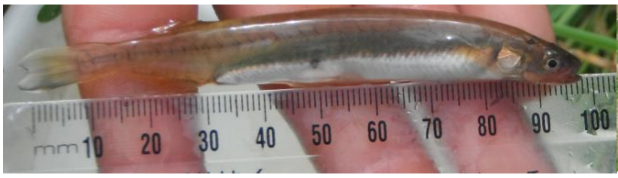

Figure 65. Inanga (*Galaxias maculatus*).

Figure 66. Shortfinned eel (*Anguilla australis*).

Fish trapping within the mature forested area revealed a change in individual abundance and species composition (Table 4). Although some Inanga were still caught, there was a greater abundance of Banded kokopu (*Galaxias fasciatus*) (Figure 68) as well as a Giant kokopo *(Galaxias argenteus*) (Figure 67).

Figure 67. Giant kokopo (*Galaxias argenteus*).

Figure 68. Banded kokopu (*Galaxias fasciatus*).

Table 4. Mean number of individuals captured within five traps from three habitat types of the same waterway.

Species	**Mature**	**Restored**	**Unplanted**
Banded kokopu (*Galaxias fasciatus*)	2.4	0	0
Giant kokopo (*Galaxias argenteus*)	0.2	0	0
Inanga (*Galaxias maculatus*)	2.2	24.4	16.8
Shortfinned eel (*Anguilla australis*)	0	0	0.2

There are several habitat characteristics that may have contributed to the differences in species caught. One distinct difference is the lack of canopy cover within the restored and unplanted trapping areas when compared to the mature area. Although canopy cover was not directly measured within the trapping areas, a noticeable difference exists. Along some of the mature section of stream, cover is provided by either tree canopy or by sedges. These sedges grow in tufts within the water's edge, creating unique habitat types. Within much of the restored and unplanted areas, the riparian and littoral zones are still dominated by exotic grass and dense aquatic vegetation. Although it is apparent that these habitat conditions are suitable for some species of fish such as Inanga, they will not likely support the full range of fish species found within the mature forest habitats.

Chapter 14.

Mammalian pests

Pest mammal herbivore browsing has a detrimental impact on forest structure and floral and faunal composition (Craig et al., 2000; Didion, Kupferschmid, & Bugmann, 2009; McArthur & Goodwin, 2000). New Zealand's endemic avifauna evolved in the absence of mammalian predators. With little inherent natural defence mechanisms, native bird species are now frequently predated upon by rodents, mustelids and possums (Moors, 1983) and is of particular scientific and public interest (Elliot, Wilson, Taylor, & Beggs, 2010).

Brushtail Possums (*Trichosurus vulpecula*)

Possums are generalist folivores that consume a broad range of plant species (McArthur & Goodwin, 2000) but can be preferential to some plant species and consumption is non-random, with some species being highly favoured, particularly short-lived seral tree species (Owen & Norton, 1995). This selective feeding behaviour leads towards reduction in vegetative species diversity, resulting in an accretion of unpalatable biomass (Didion et al., 2009; Owen & Norton, 1995). Possums, like other herbivores impact the structure of trees by showing preferential consumption of the apical bud of seedlings. Grazing of the fresh stems causes the formation of multiple leaders and irregular branching (McArthur & Goodwin, 2000). The impact of possums on an ecosystem impedes upon forest birds as there is a considerable overlap between possum and bird diet (Owen & Norton, 1995). Possums also predate on the nests of threatened birds (Craig et al., 2000). Currently New Zealand spends approximately NZ$50 million on possum control. However, for full possum eradication of the highest priority sites costs have been estimated at NZ$1 billion (DOC, 2001).

Mice

Mice have been found to be indicators of ecological disturbance and successional development. Abundance of mice populations have been found to rapidly increase following disturbance and then decline as the vegetation structure matures. The rapid colonization has been attributed to the species ability to rapidly reproduce, their generalist habitat and food requirements and mobility. The declines in population following the successional development of a forested area is thought to generally be the result of reduced shelter as the gradual change in lower vegetation structure becomes more open (Nichols & Grant, 2007).

Rats

In a study to determine human settlement chronology in New Zealand, rat bones were carbon dated and populations were determined to have been wide-spread by approximately 1280AD (Wilmshurst, Anderson, Higham, & Worthy, 2008). Rats have been video recorded predating and scavenging on eggs and juvenile native bird species (K. P. Brown, Moller, Innes, & Jansen, 2008). Rat invasion to remote islands of New Zealand's archipelago have subsequently resulted in the annihilation of native floral and faunal populations including bird, bat and invertebrate species. With increased development in methods of control, rat eradication programs have been successful on remote islands with more than 90 islands now predator free (Towns & Broome, 2003).

Stoats

Stoats were introduced to New Zealand by Europeans in the 1880's in an attempt to control the populations of introduced rabbits as well as for fur and hunting sport (DOC, 2001). In a study by King and Moody (1982), the digested contents from 1599 stoats collected from 14 national parks over a period of 8 years were described. The relevance of the order of prey species was not specified, but included brushtail possums, rabbits, hares, hedgehogs, rats, mice, birds, freshwater crayfish, skinks, ground weta, cave weta, tree weta, as well as carrion and offal of possums and deer.

Methodology

Some tracking tunnel surveys have been previously carried out by CVNZ, having established five tracking tunnel transects within the mature forest areas of the Nikau Scenic Reserve, the band of coastal vegetation and the hills east of State Highway 6. To enhance our knowledge about the presence of pests within the PCRP area, three additional tracking tunnel transects were established within the planted and unplanted areas as well. Each transect consists of 10 tracking tunnels spaced out at 50m intervals. Some of the tunnel material and some tracking cards were supplied by DOC. The rest of the material was

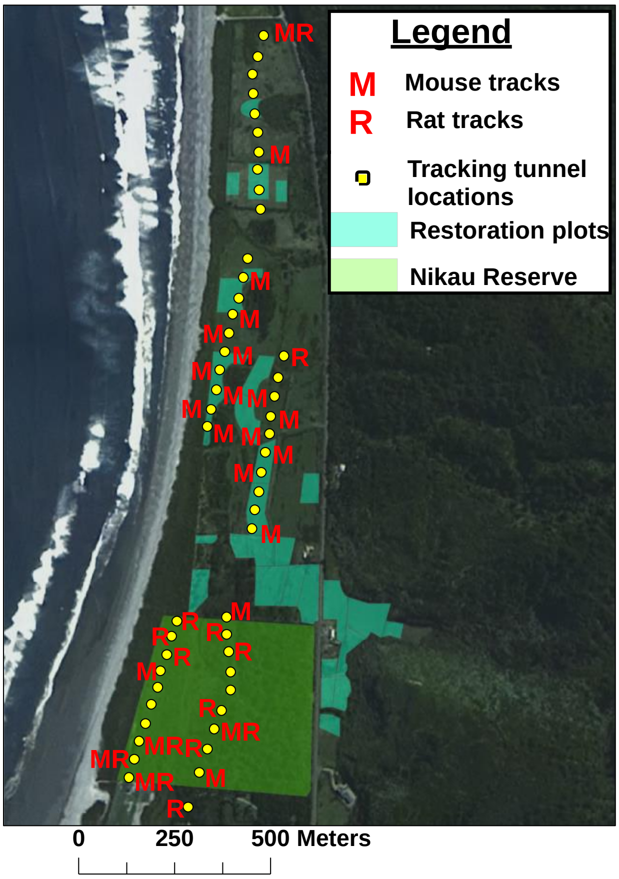

Figure 69. Tracking tunnel locations and findings.

supplied by CVNZ and Lincoln University. Monitoring was completed in November, 2012 by Lincoln University on the five transects shown in Figure 69 with peanut butter used as bait. Another sampling event was completed by CVNZ team leader Bruce and volunteers on the 2nd April, 2013 with peanut butter and on the 3rd April, 2013 with beef as baits. Sampling methods were based on standard operating procedures developed by DOC.

Results and discussion

Results shown in Figure 69 include those from previous CVNZ tracking tunnel monitoring events (July and August, 2010) from within the NSR and southern band of coastal vegetation.

Mice were found to be widely distributed throughout the restoration and abandoned farmland areas (Figures 70 and 71). Some mice were also found within the NSR as well as the band of coastal vegetation. Rats were found to be widely distributed throughout the mature forest transects. Only two tracking tunnels within the restoration/unplanted areas recorded the presence of rats and both of these were located within the edges of vegetation remnants. It is quite likely that rat numbers may increase as restoration plantings mature.

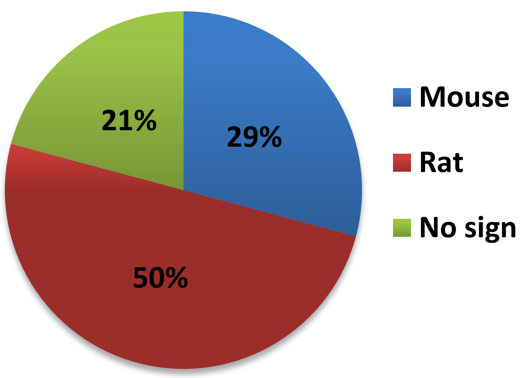

Figure 70. Proportion of tracking tunnels with evidence of a mouse or rat within the NSR and southern strip of coastal vegetation.

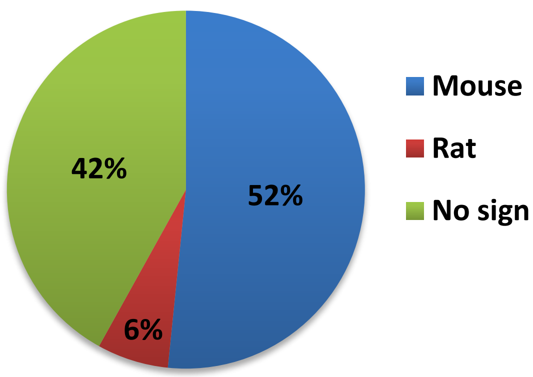

Figure 71. Proportion of tracking tunnels with evidence of a mouse or rat within the restored and unplanted transects.

CVNZ maintain 5 pest-trap lines within the NSR, coastal vegetation band, and within the hillsides east of State Highway 6. The traps are baited with meat and surveyed by volunteers under the supervision of a CVNZ team leader. Due to unpredictable weather patterns and an eventful schedule, trapping regimes have not been administered under an established schedule. No records had previously been kept of trapping success. However

CVNZ has begun to keep a detailed record of locations for species and numbers trapped. Records now include 1 stoat that was recorded trapped on February 7th and another 3 on February 14th, all within the coastal band of vegetation. CVNZ has also begun to work on establishing a trapping routine and has made this a priority for the next five years. No stoats were recorded during tracking tunnel monitoring.

The Animal Health Board, whose mission is to eradicate bovine tuberculosis from New Zealand hires pest control contractors to complete annual control measures within and surrounding the PCRP and Nikau Scenic Reserve. Contractors have established transects along which they deploy kill-traps and hand-lay cyanide and 1080 (sodium monofluoroacetate) poison. Poison baits apparently do not have a significant effect on New Zealand's West Coast invertebrate populations, although some types of lures attract more invertebrates than others (Spurr & Drew, 1999). Contractors claim that possum numbers have decreased in the area and rat populations substantially decline following poison deployment. To our knowledge, this information is based on observation and is not supported by any comprehensive monitoring program. We have requested information regarding monitoring and trapping results from the Animal Health Board, but have not yet received information to date.

On several occasions, possums have been observed within the PCRP area and dead possums have been seen on the road adjacent to the PCRP area. A stoat has also been observed during the middle of the day on the 21st of February 2013 within the restoration area. Wild goats are common throughout the Paparoa Ranges east of the PCRP area and commonly frequent the restoration area east of the road. On one occasion, goats have been spotted on the western side of the road. Goats are culled within the Paparoa Ranges by DOC contractors and recreational hunters and several individuals help to control goat populations onsite.

Chapter 15.

Other taxa potentially worthy of research

Little blue penguins (*Eudyptula minor*)

In early February, 2013 a blue penguin was discovered in a soil profile pit by a Department of Conservation staff member. This was the first documented sighting of a blue penguin within the immediate PCRP area. The following day, another penguin was found in the same hole and was thought to be different than the first based on its size. The soil profile holes were subsequently covered to keep the penguins out, as they would not be able to escape without assistance. Neither penguin was injured.

Two weeks later, four surveillance trail-cameras fitted with infrared sensors and light were deployed along the beach access trail at the south-western corner of the PCRP area near the pit where the penguins had previously been found. On the second night, three of the four cameras captured photographs of a blue penguin (Figure 72).

Figure 72. Blue penguin photographed during two nights of photo trapping.

Blue penguins are found in many places around New Zealand and Australia. However their populations are declining throughout New Zealand and are now considered a protected native species. It is estimated that West Coast populations only number in the high hundreds to low thousands (Penguin Trust, 2013). Continued monitoring of blue penguins on the PCRP land may reveal nesting sites. Conservation opportunities to facilitate the penguins' use of the land could include supplying nesting boxes and increasing pest control within these areas.

Arboreal geckos

In late February, 2013 a gecko trapping event was completed over a period of several days. Four northern-rata trees on a north-south oriented transect at the western end of the Nikau Scenic Reserve were selected for trapping (Figure 74). It was thought that the canopies of these trees may potentially provide suitable habitat for arboreal (canopy dwelling) gecko species as their long lateral branches host many epiphytes that would offer sources of refuge. The extensive canopies would also create access to sunlight for warmth and means of dispersal to adjacent tree canopies. Trapping methods were based on DOC standard operating procedures which involved baiting G-minnow traps (the same used for fish trapping) with slices of peach. We used both fresh peach slices from a jar as well as slightly fermented peach slices in each trap. A wet sponge was placed in each trap as a source of moisture for any potentially trapped geckos as well as plenty of leaf litter for cover.

Figure 73. Jason Hahner setting gecko traps amongst epiphytes in a northern-rata trees

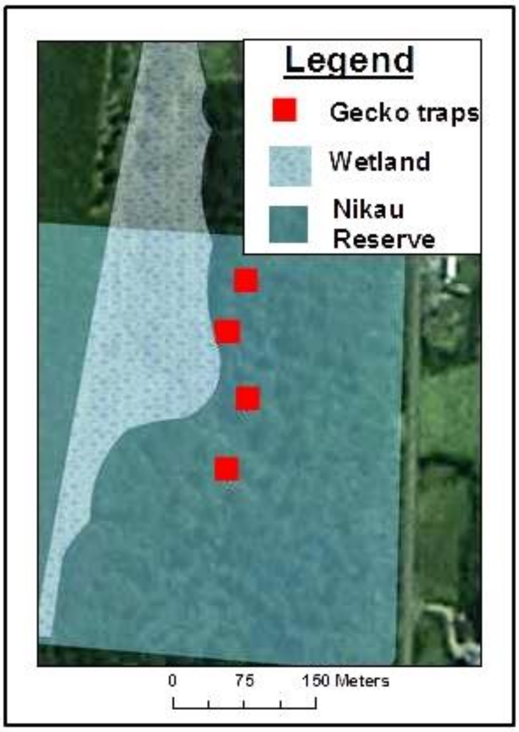

Figure 74. Locations of the gecko traps.

The tree canopies were accessed with the use of ropes and harnesses and the traps were secured to the trees with bungee-cords (Figure 73). The traps were left for a period of three days. Although these efforts were unsuccessful at finding arboreal geckos, the traps did successfully collect two large tree weta. These results do not necessarily mean that arboreal geckos do not occupy the Nikau Scenic Reserve. More extensive monitoring in the future may reveal their presence.

Skinks

In late October, 2012 a skink trapping was attempted over a period of three days. Traps were set in an identical manner as they were for gecko trapping. However, instead of being placed within the canopy, the six traps were placed within the vegetation along the western edge of the coastal band of vegetation. These efforts were also unsuccessful, and future monitoring of skinks should be more extensive. No lizards have been observed by workers at PCRP over the five year period.

Fungi

Fungi are an integral part of any terrestrial ecosystem and are essential for the growth of some plant species. Although fungi were not part of our aims, we did keep a photographic record of any species observed. Species that were identified included: *Cortinarius peraurantiacus*, *Favolaschia calocera*, *Ganoderma* sp., *Leratiomyces erythrocephalus*, *Trichia verrucusa*, and *Pycnoporus coccineus*. An ongoing inventory of fungi should be kept and a small study should investigate the presence of Mycorrhyza on native species in the mature sites as they may be important in the restoration trajectory.

Chapter 16.

Soils at the PCRP

Methodology

Soil observation pits measuring approximately 1m^2 and 1-2m deep were excavated at each of the 21 transect plots in mid-January, 2013. The pits were dug by hand to eliminate the potential of soil compaction from heavy equipment. The profiles of the soil pits were described according to the methods provided by Milne, Clayden, Singleton & Wilson (1995). Soils were sampled (using bulked sub-sampling) from the two surface horizons for laboratory analysis. Oven-dried (110^o C) samples were microwave digested in 5M +H_20_2 then analysed using standard ICP-OES methodology (Varian 720-ES Inductively Coupled Plasma Optical Emission Spectrophotometer fitted with an SPS-3 auto-sampler and ultrasonic nebulizer).

Geomorphic evolution of the prograding coastal sand plain at Punakaiki

The coastal sand plain has formed as a prograding coastal system, comprising marine and aeolian sand deposits which have accumulated in a coastal embayment. This sand plain consists of a series of relict shorelines (sand dunes or gravel ridges) with an intervening low lying sand plain and lagoon-swamp deposits. Illmenite is found associated with the low-lying parts of the landscape (sand plain) while the aeolian-deposited sand dunes comprise quartz sand. The oldest shorelines abut against the postglacial marine cliff, cut into Miocene marine sediments (silts, mudstones) of the Blue Bottom Group. The marine cliff represents the mid-Holocene high sea stand. A series of marine terraces are preserved in the Miocene deposits, due to continuing tectonic uplift (Braithwaite & Pirajno, 1993; Suggate, 1989).

Soil development in a prograding coastal system

The prograding coastal sand plain has evolved over approximately the last 5-6 Ka. Different aged surfaces exist, with the youngest surfaces closer to the present day shoreline. Consequently, we see soils of different ages, a relationship known as a chronosequence. This chronosequence is a common feature of prograding coastal systems. Similar systems have been extensively studied in New Zealand; the most relevant one being at Haast (Hewitt, 1998; Wilms, 1985a). In addition, alluvial fan deposits derived from the Miocene aged sediments of the marine terraces have been deposited throughout the evolution of the sand plain, and are also of different ages. These fans are more prevalent both closer to the marine cliff, and also in the northern part of the site. Here, they often bury existing land surfaces, so buried soils are common. At Punakaiki, soils are developed on a range of surfaces (Table 5).

Table 5. Soil development on different aged surfaces, Punakaiki.

Land surface	Soil series (Wilms, 1985)	NZ soil classification (Hewitt, 1998)	Soil profile characteristics (Wilms, 1985)	PCRP Transect Number
Well drained sand and gravel shorelines/ridges/plains	Young soils **Okari** (less developed than Karoro)	Raw or recent	Recent soil with a weakly developed A horizon over C horizon	
Well drained sand and gravel shorelines ridges /plains	**Karoro**	Sandy or orthic Brown	Weakly structured A horizon, slight B horizon development	1*, 3, U4
Well drained sand and gravel shorelines/ridges /plains	**Mahinapua** (more developed than Karoro soils)	Sandy or orthic Brown	Weakly structured A horizon; reasonably thick, strongly developed B horizon	
Well drained sand and gravel shorelines/ridges /plains	**Utopia** (more developed than Mahinapua)		Thin iron pan just below A horizon, overlying a strongly developed B horizon. Further iron deposition at the water table.	
Alluvial fans (poorly drained, strongly gleyed. Parent material is heavy textured colluvium from Miocene silts and mudstones.	**Kamaka**		Friable A horizon overlying massive, slightly mottled B horizon. Buried soils and illminite sands at depth.	M2, M5, M7, R4, R5, U5
Alluvial fans over sand	**Kamaka**	Shallow variant	Thin friable A horizon overlying sand or buried soils at depth	6**, R7,U7,
Poorly – very poorly drained swales (organic matter with significant additions of alluvium)	**Waiwero**		Successive additions of peat and alluvium, thicker than 70 cm. Occasional wood and stones in profile.	U2
Poorly / very poorly drained swales or back swamp/lagoon features (peat, with slight additions of alluvium)	**Rotokohu**	Organic soils	Saturated weakly / strongly decomposed organic matter over sand	

Pits R2 and M4 were not described.
*No evidence of tree roots from former forest in R1.
**Dredging disturbance evident in U6.

The following sections briefly describe four different components of the soil landscape at Punakaiki. An understanding of how these landscapes and soils have formed, as well as their chemical and morphological properties, will inform our further understanding and interpretation of the ecological dynamics of the site, as described in this report.

Chronosequence developed on well drained sand and gravel shorelines: Karoro soil series. (Transects 1 and 3)

These well drained soils, developed on sand, show an Ah, Bw, C profile development. R1 and M1 are both developed on the same dune shoreline land surface with M1 showing a deeper Bw horizon to 55 cm, compared to the R1 at 38cm depth. Localised iron pan formation below 1m in M1 is most likely associated with the greater volume of water flux in the soil profile, aided by macro-rooting patterns of trees and shrubs. Organic matter is likely to be higher in this profile too. U1 is located on an adjacent sand plain of a similar age surface. Iron pans occur at depth and evidence of a buried soil at 46cm is evident (Figure 75).

R1 U1 M1

Figure 75. Transect 1: Oldest sand dune shoreline soil profiles

In contrast, transect 3 is closer to the present shoreline (M3 is approximately 150 m from the present high water mark). The soils from U, R and M profiles are all developed in a gravel – sand matrix and can be classified as Karoro soil series. Closer to the present day shoreline, Okari soils can be found, at approximately 25-50 m from the present high water mark. Thus, Transect 3 represents a gravel ridge (berm) shoreline. Both the presence of imbricated clasts within the soil profile at depth (R3, U3) and large, discoid clasts on the surface at M3 confirm the origin as a gravel berm. R3 and M3 both have deeper Ah and Bw horizons. The profiles by way of colour, texture and depth indicate an increase in organic matter from U3, to R3 and to M3. AS with M1, the deepest B horizon exists in the M sites (Figure 76).

R3 U3 M3

Figure 76. Transect 3: Youngest shoreline (gravel) soil profiles

Table 6. Comparison of soil chemical variables (mean values) between Transects 1 and 3 in Mature Vegetation (M1,M3), Restored Vegetation (R1, R3) and Unplanted (U1 , U3) plots in the two surface soil horizons (Ah and Bw).

	Ah Horizon						Bw Horizon					
	Mature		Restored		Unplanted		Mature		Restored		Unplanted	
	M1	M3	R1	R3	U1	U3	M1	M3	R1	R3	U1	U3
pH	4.7	5.1	4.8	5.0	4.7	4.4	4.8	5.6	5.3	5.6	4.9	4.7
N (%)	0.26	0.11	0.27	0.30	0.35	0.62	0.08	0.11	0.15	0.06	0.10	0.17
C (%)	3.58	1.71	2.80	2.95	4.31	6.81	1.63	1.71	1.67	0.63	1.86	1.59
C/N ratio	15.9	15.7	10.2	9.8	12.4	11.1	20.7	15.7	11.5	9.9	18.8	9.5
P (mg kg $^{-1}$)	374	1264	571	496	640	1269	280	381	429	241	305	324
K (mg kg $^{-1}$)	2406	2668	1144	2487	2424	3353	2811	4529	1302	2027	2456	3050
S (mg kg $^{-1}$)	350	2489	434	327	591	1247	161	151	217	87	230	188
Fe (%)	2.39	1.83	3.82	2.08	4.18	2.14	2.95	2.02	4.22	1.91	4.57	1.56
Ca (%)	1.37	0.79	1.37	0.74	1.82	0.73	1.80	0.83	1.49	0.70	1.70	0.55
Mg (mg kg $^{-1}$)	1586	3637	2197	4445	2599	3114	1905	4540	2406	3972	2354	3282

The sandy matrix and lack of clays in Transect 1 may reduce the CEC, while expected increased amounts of OM in profiles would act as exchange sites and contribute to CEC. Considering Transect 1 is older than Transect 3, it would be expected that Transect 1 would have greater OM and N, and possibly a greater amount of secondary minerals such as iron, calcium, magnesium and potassium to be released during weathering of the parent material. Chemical analysis (Table 6) did show that C/N ratio, Fe and Ca were consistently higher in both horizons in Transect 1 soils. However, in the older soils, OM and N were not higher, and K and

Mg were consistently lower. Reasons for these discrepancies become clearer when more of the transects are included in the matrix (*see* Pages 84-94).

Soils developed on alluvial fans: Kamaka soil series (Transect 5)

Transect 5 is close to the foot of the Miocene marine cliff. All three profiles show silty alluvial material overlying ilmenite sand, suggesting alluvial fan deposition over a sand plain (Figure 77). With increasing distance from the marine cliff, the thickness of fan material decreases. R5 which occupies a proximal position to the cliff, has fan material to 90cm depth, overlying sand; while the distal M5 profile has 20 cm fan material over loamy sand to sand. U5 and M5 were both poorly drained, and exhibited mottling at depth.

R5 U5 M5

Figure 77. Transect 5: Alluvial fan over illmenite sand plain

Alluvial fans over sand: Kamaka soil series with buried soils at depth (Transects 4 and 7)

Transect 4 is located on the sand plain, in a region of alluvial fan deposition. The surface of active alluvial fans will have a network of small stream channels meandering across their surfaces. The nature of alluvial fan deposition means that periodically, stream channels avulse and change flow direction, causing local scouring of a shallow channel surface. Profile R4 contained several buried soils and different horizons which can be interpreted to explain the depositional history of such events in this part of the landscape (Figure 78). Interpreting the soil from the base, we have:

Table 7. Interpretation of depositional environment for Profile R4.

Depth in cm	Soil horizon	Depositional event and interpretation
120-70	4C, 4bBg	Fine textured fan deposit with soil development (4bBg) in situ
70	Sharp wavy boundary	Stream avulsion and channel erosion surface formed. This would represent one "storm" event.
70-44	3bBw(f)	Channel in-filled with alternating layers of sand and organic matter, suggesting a swamp / lagoon environment
40-45	Sharp wavy boundary, Bfm	Another erosion surface (indicated by iron pan)
40/52-30	2Bg	subsequently infilled with clays back filling the erosion channel - a low energy depositional environment
30-0	Bw(g), Ah	Overtopped by aeolian sands with current soil developed within this aeolian dune deposit.

Figure 78. R4: Alluvial fan deposits over sand plain

Some low-lying parts of the landscape in the sand plain contain drainage channels and creeks. These are prone to regular flooding events and the water table is high. Consequently, the soils are poorly-drained and often waterlogged. They show grey colours and rust-coloured mottles at depth (Figure 79). The soil profile is characterised by layers of partly decomposed organic matter (like large, woody flood debris) and sandy-silty alluvial material, sometimes including large clasts or cobbles.

Regular flooding events from the creeks depositing alluvium will also bury existing land surfaces. Buried soils are evident at 25, 58 and 83 cm depth in profile U2. These soils are acid due to the organic acids present, resulting from the partly decomposed organic matter.

Soils developed in poorly drained swales: Waiwero series (Transect 2)

Figure 79. U2: Soils adjacent to creeks in low-lying parts of sand plain

Soil Chemical Analysis

Two earlier studies of soil chemistry were based on very limited soil sampling and replication. The first baseline survey (Bowie et al., 2012) found:

- Conversion of the original forest to pasture had led to
    - significantly higher soil pH
    - halving of soil carbon concentrations
    - doubling of soil phosphorus concentrations.
- Soil nitrogen concentrations were much lower in the Nikau Scenic Reserve, compared to all modified stands of vegetation (including the mature remnants).
- Lower Fe, K, Mg, Ni and S in the Nikau Reserve soils were identified

- Soil Zn and B were variable between stands and may also be significant.
- It was suggested that concentrations of some of these elements may be critical features of a successful restoration.

A subsequent report that forms part of the present study ((Zhong, 2012) Appendix V) focussed on soil descriptions and chronosequences at PCRP. Zhong distinguished the characteristics of different-aged soils at the site, separating young, medium- aged and older mature soils. Three different-aged soils were represented through three different distances from the western side of the highway towards the coast.

In agreement with the baseline study (above), Zhong (2012) found:

- Mature forest soils had lower pH.
- Young soils were rich in organic matter, containing higher (total) concentrations of C, N and P.
- Mature forest soils contained lower P [He pointed out that soil P depletion may relate to ecosystem retrogression].
- K, S, Li and Mg concentrations were highest in the young soils
- Older soils were low in Ni and Zn.

Zhong (2012) also found that:

- Younger soils contained higher B
- Plots with more mature vegetation contained higher soil K concentrations.

Summary data from the present study are shown in Table 8. The observed trends of trace element differences between mature, restored and unplanted plots, as described above, appear to breakdown when data from the 7 transects in the present study are combined. However:

- Carbon and nitrogen concentrations and C/N ratios were all higher in mature stands, with concentration ranges similar to those measured in mature stands during the baseline survey.
- Soil pH was similar in the three categories of plots.

Trends in other elements (Table 8), with some exceptions:

- An increasing gradient of soil Zn and Na from unplanted to Mature plots.
- A decreasing gradient of soil Mn from unplanted to Mature plots.
- More K, S and Mg in Mature plot soils

Table 8. Summary of pH, carbon and nitrogen data from restored, mature and unplanted plots, across the range of 7 transects.

			pH	C (%)	N (%)	C/N Ratio
Mature	**Ah**	**Mean**	**4.7**	**10.69**	**0.63**	**16.9**
		s.e.	0.16	3.348	0.190	0.88
	Bw	**Mean**	**5.0**	**2.44**	**0.16**	**15.8**
		s.e.	0.17	0.497	0.038	1.40
Restored	**Ah**	**Mean**	**4.9**	**3.38**	**0.31**	**11.3**
		s.e.	0.12	0.371	0.037	0.68
	Bw	**Mean**	**5.2**	**1.42**	**0.12**	**12.4**
		s.e.	0.13	0.393	0.032	0.70
Unplanted	**Ah**	**Mean**	**4.7**	**4.04**	**0.35**	**11.4**
		s.e.	0.11	0.680	0.057	0.393
	Bw	**Mean**	**4.9**	**1.37**	**0.09**	**15.5**
		s.e.	0.07	0.214	0.017	1.32

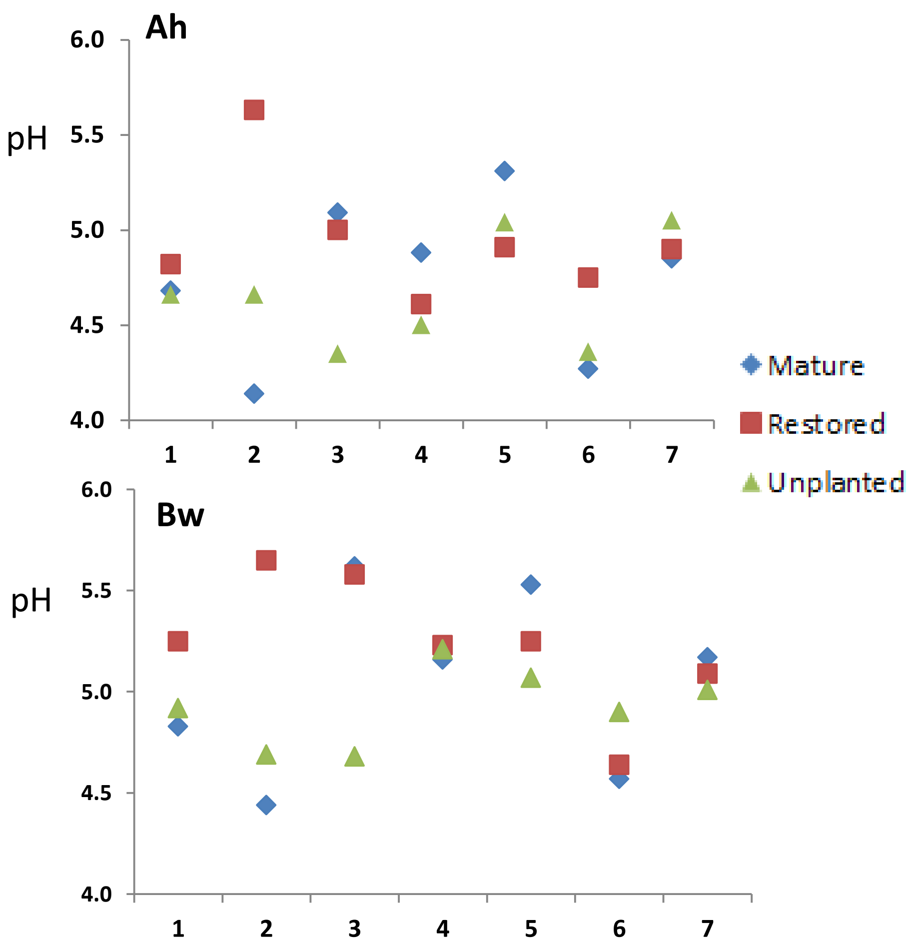

Figure 80. Soil pH in upper (Ah) and lower (Bw) horizons, across the 7 transects in Mature, Restored and Unplanted plots.

The apparent discrepancies with the earlier studies are likely to be at least partly related to soil variability across the site outweighing the three selected variables (Mature, Restored and Unplanted) within each of the 7 transects (Figure 80); any differences between Mature, Restored and Unplanted plots are simply masked when the data are grouped in this manner.

In terms of soil pH (Figure 80) it is easier to visualise this masking effect. In both soil horizons, unplanted plots tend to have lower pH than restored plots. The mature plot soils tend to be less distinctive, with significantly higher soil pH only in Transects 4 and 5, located respectively at the extreme north-east and south-west corners of the site (Figure 15).

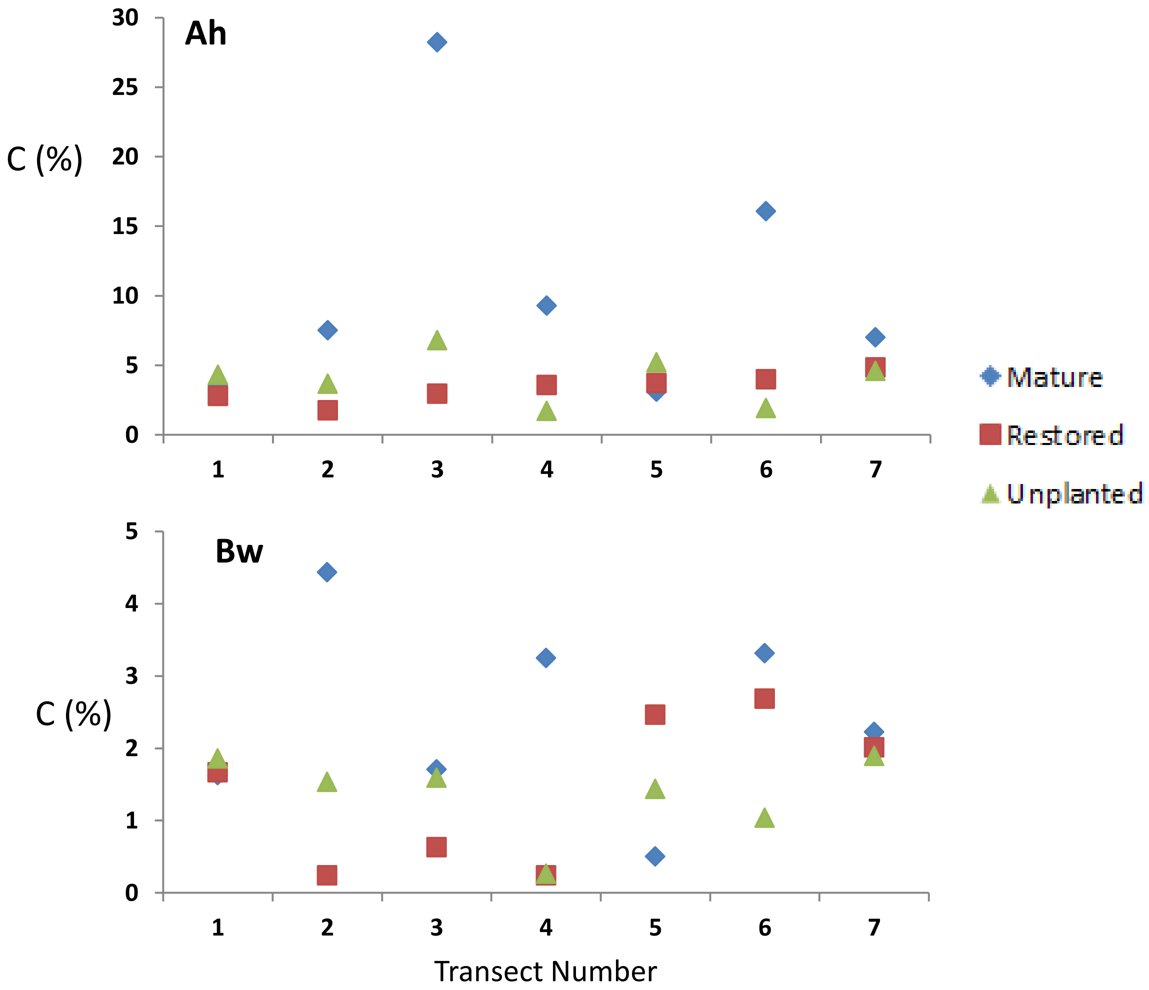

Figure 81. Total carbon concentrations in upper (Ah) and lower (Bw) soil horizons, across the 7 transects in Mature, Restored and Unplanted plots.

Table 9. Total concentration (mg kg -1) of a range of chemical elements in restored, mature and unplanted plots, across the range of 7 transects.

			P	K	S	Fe	Mg	Li	Ni	Zn
Mature	**Ah**	**MEAN**	**835.6**	**4287.6**	**984.3**	**28745.9**	**4082.7**	**35.1**	**20.0**	**43.5**
		± se	165.53	979.79	271.62	2623.68	821.37	9.75	5.51	8.60
	Bw	**MEAN**	**520.8**	**4995.7**	**313.1**	**34774.4**	**4751.4**	**48.8**	**26.1**	**40.5**
		± se	72.02	1204.43	59.03	2944.37	1014.69	14.30	7.42	10.78
Restored	**Ah**	**MEAN**	**669.6**	**2300.0**	**434.3**	**32079.6**	**3880.6**	**30.4**	**19.6**	**33.3**
		± se	68.16	409.84	56.73	3285.88	562.40	5.78	3.12	5.19
	Bw	**MEAN**	**486.4**	**2463.8**	**204.8**	**32321.3**	**3900.2**	**31.4**	**17.9**	**31.4**
		± se	53.57	538.67	51.03	4254.38	513.63	6.74	3.36	4.57
Unplanted	**Ah**	**MEAN**	**730.4**	**2637.7**	**634.9**	**31297.9**	**2897.9**	**21.9**	**13.8**	**24.5**
		± se	96.20	291.37	134.13	2609.61	246.67	2.35	1.49	2.07
	Bw	**MEAN**	**443.0**	**2480.4**	**190.5**	**33078.4**	**2813.4**	**21.5**	**13.7**	**21.8**
		± se	61.31	192.77	24.51	4124.43	186.99	1.41	3.05	1.01

			As	Ca	Cd	Cr	Cu	Mn	Na	Pb
Mature	**Ah**	**MEAN**	**4.7**	**11272.5**	**0.1**	**44.2**	**7.1**	**2553.2**	**485.9**	**20.5**
		± se	0.53	1320.31	0.02	5.92	1.42	672.92	108.91	2.78
	Bw	**MEAN**	**6.0**	**13553.0**	**0.1**	**52.9**	**5.5**	**3071.4**	**309.1**	**21.4**
		± se	0.75	2239.83	0.02	4.34	1.48	981.70	89.17	1.35
Restored	**Ah**	**MEAN**	**5.4**	**11001.3**	**0.1**	**49.1**	**5.3**	**2807.1**	**132.7**	**17.4**
		± se	0.98	1357.46	0.02	7.94	0.61	712.94	19.94	1.39
	Bw	**MEAN**	**5.0**	**11168.5**	**0.1**	**48.5**	**5.0**	**2791.9**	**113.5**	**16.6**
		± se	0.93	1669.10	0.03	9.83	0.60	793.11	21.13	1.68
Unplanted	**Ah**	**MEAN**	**5.4**	**15684.2**	**0.1**	**50.4**	**3.8**	**3813.0**	**181.8**	**16.7**
		± se	0.61	1761.62	0.02	8.85	0.34	578.46	16.43	0.98
	Bw	**MEAN**	**5.5**	**15206.6**	**0.1**	**50.1**	**2.9**	**3566.1**	**114.6**	**17.2**
		± se	0.66	1711.23	0.02	8.33	0.31	595.12	6.53	1.63

Soil carbon concentrations (Figure 81) in Mature plots were lower than other plots in only in the Bw horizon in Transect 5, which was located on the east side of the highways and in the NSR. There was inconsistent variation between soil N concentrations in Mature, Restored and Unplanted plots (Figure 82). Higher N in Mature plots in Transects 2 and 4 may reflect places where stock have sheltered in recent years: both are at the northern side of stands of trees. Variables of this nature, relating to the more recent history of different locations at the site, are likely to be responsible for inconsistent trends of soil N between Mature, Restored and

Unplanted plots. Although measures of soil N do not reflect well on our choice of transects, consistently higher C/N ratios were evident in the mature plot soils (Figure 82). Lower concentrations of P in mature plots, as discussed by Zhong (Appendix 4), were only evident in plots on eastern side of the NSR, on the upper terrace (Figure XII). Two other plots in NSR (M3 and M6) had higher P, possibly due to differing soil types in those areas. Higher concentrations of K, Zn and Mg are evident in some Mature plot soils were contrary to findings in the earlier reports, although higher values of these elements all occurred towards the north of the site. This suggests that the influence of historical site modification is as significant as the maturity of the vegetation at any particular location. In these cases, once again, it is possible that areas used by stock for shelter have influenced soil chemistry.

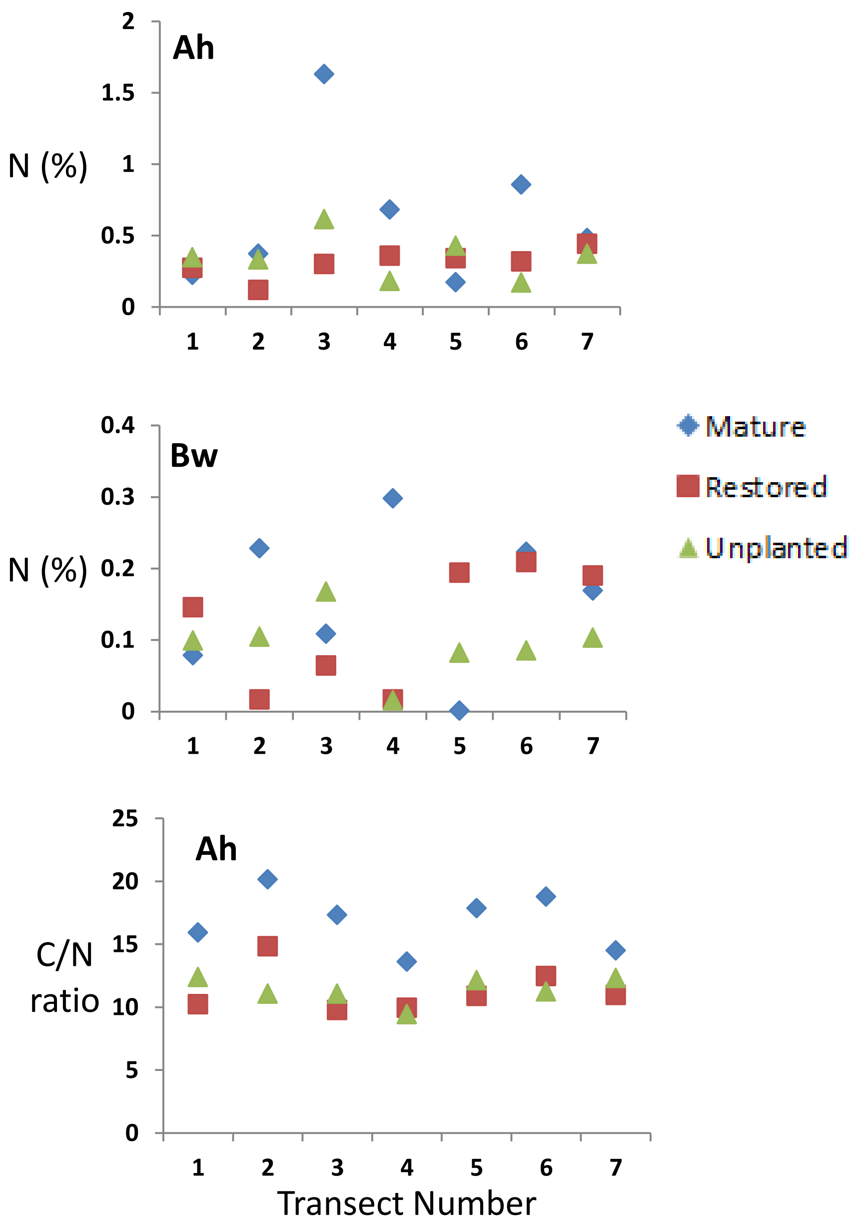

Figure 82. Total nitrogen concentrations in upper (Ah) and lower (Bw) soil horizons, and soil C/N ratios (Ah only) across the 7 transects in Mature, Restored and Unplanted plots.

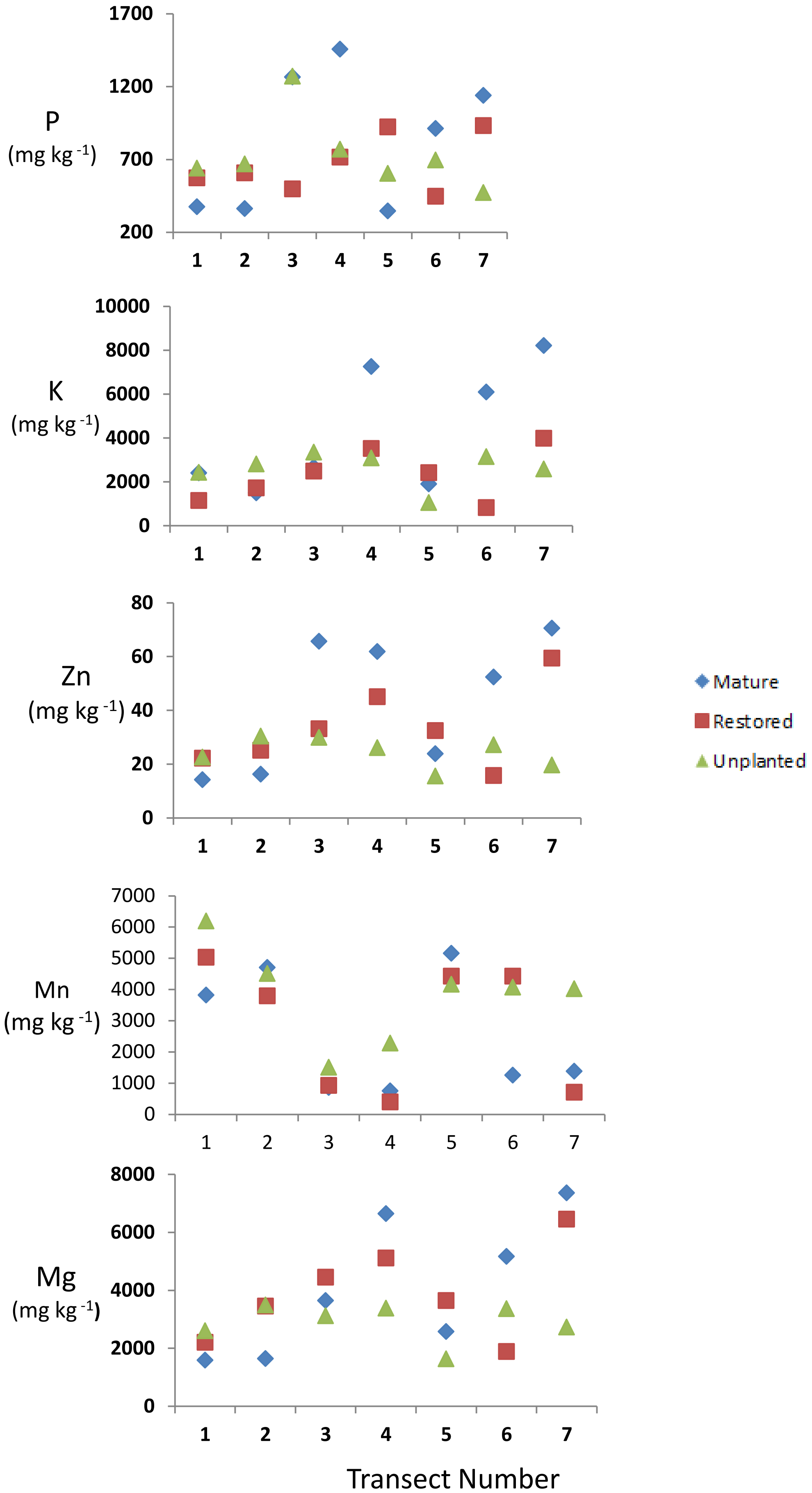

Figure 83. Total P, K, Zn, Mn and Mg concentrations in upper (Ah) soil horizon, across the 7 transects in Mature, Restored and Unplanted plots.

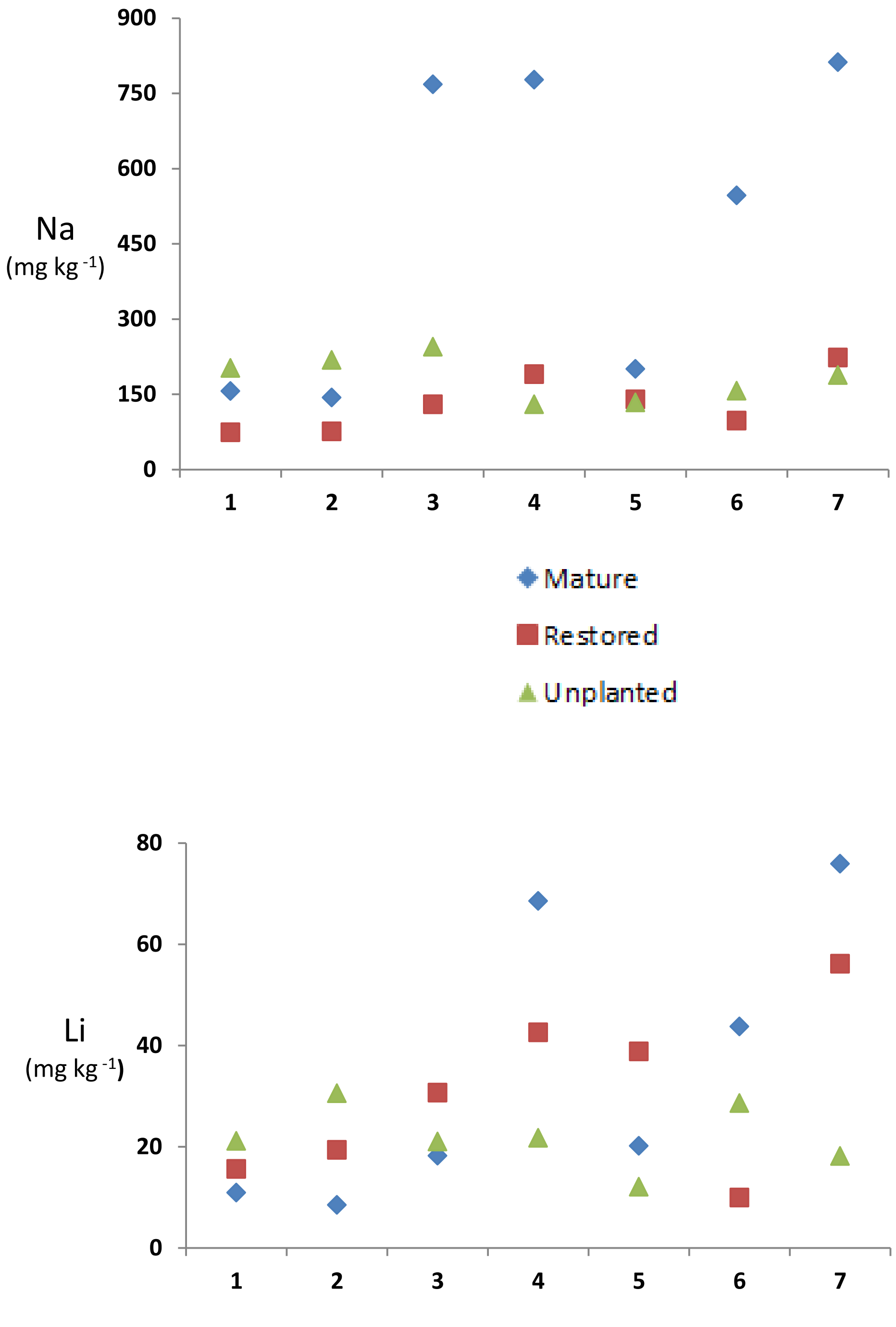

Figure 84. Total Na and Li concentrations in upper (Ah) soil horizon, across the 7 transects in Mature, Restored and Unplanted plots.

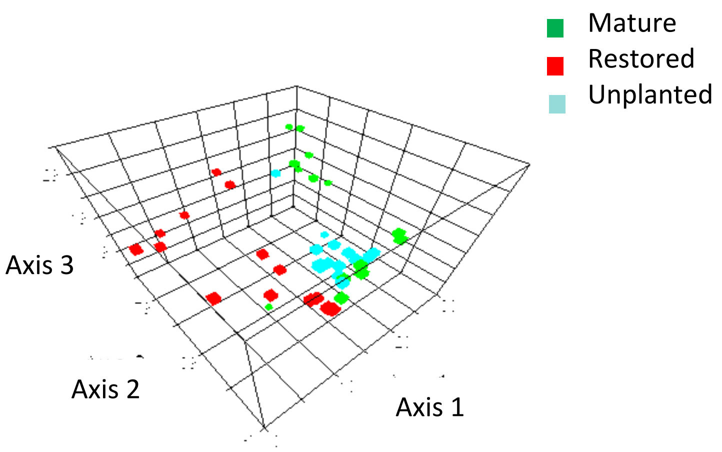

Figure 85. Nonmetric Multidimensional Scaling (NSM) ordination analysis of the soil chemistry data set. This nonparametric technique uses rank order information to identify similarity in a data set. Similar objects are near each other and dissimilar objects are farther from each other.

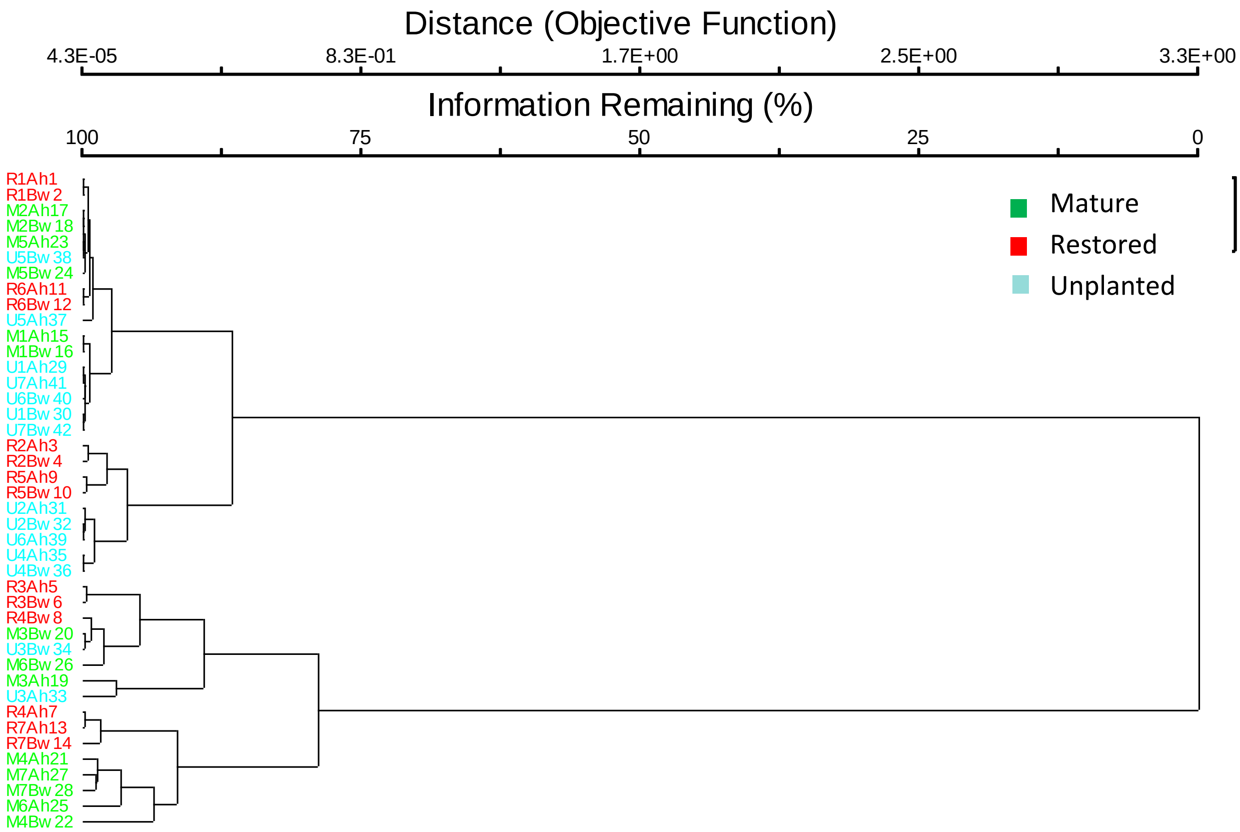

Figure 86. Dendrogram using hierarchical clustering of the soil chemistry data set. Algorithms are used to connect objects to form clusters based on their distance; the y-axis marks the distance at which the clusters merge.

Multivariate techniques, using ordination, for exploratory analysis of the soil chemistry data (Figure 85) show that the three transect treatments do not differ consistently, and neither do the two soil horizons. However, with more iterations and lower stress, there is definite clustering by treatment. Using hierarchical clustering (Figure 86), there are clear similarities between groups of Mature and Unplanted plots, but distance between the groupings of Mature plots are possibly largest of all. This requires further study.

Conclusions

The seven transects selected for study in the present project did not provide consistent differences in soil chemistry between the three targeted treatments (Mature, Restored and Unplanted plots). Assumptions of differences between treatments, based on two preliminary studies were largely unfounded. Instead, a more complex but potentially more interesting picture emerges from the more detailed soil analysis. Two variables that could not be factored into the analysis were detailed historic usage of the plots and the underlying variability of the soil types across the plots (studied simultaneously in the present work). Both appear to play a large part in determining the chemical characteristics of the soil.

Nonetheless, soil chemistry data do allow separation of the three treatments using multivariate analysis. Soil chemical factors that allow this distinction appear to include:

- Carbon and nitrogen concentrations and C/N ratios were all higher in mature stands.
- Soil P concentrations were substantially lower in some mature vegetation plots, particularly on the upper eastern terraces. Variablity of P across the site varied by a factor of 4-5, without an obvious chronological explanation.
- An increasing gradient of soil Zn and Na from unplanted to Mature plots.
- A decreasing gradient of soil Mg from unplanted to Mature plots.
- More K, S and Mg in Mature plot soils.

The most significant finding of the soil chemistry analysis is that after the first five years of restoration, a soil chemistry response is apparent. This means that either restoration practices modify soil chemistry in a very short timeframe, or else that restoration work has been carried out parts of the site that are chemically distinct. Further research is already underway to identify the descriptors responsible for this apparent distinctive soil physico-chemistry, and to explore this further.

Figure 87. Jason Hahner digging (top & middle) and Carol Smith analysing soil pits (bottom).

Chapter 17.

Vegetation surveys

A fundamental component of assessment of the progress of a restoration effort is comparison with a benchmark community. The Nikau Scenic Reserve (NSR), adjacent to the PCRP site, provides this point of reference for soils, and floral and faunal communities. Remnant patches of vegetation within the PCRP site provide the opportunity for further useful comparisons. Whilst these remnants have been accessible to livestock in recent years, much of the native canopy is intact and understory vegetation clearly is recovering rapidly. The NSR and remnant forest stands also provide useful insights into temporal and spatial processes of vegetation change, in the context of the restoration effort. This chapter (and Appendix IV) describe two studies of the vegetation carried out during the assessment period.

The aims of the two studies reported in this Chapter were:

- To establish a benchmark community with the NSR and forest remnants
- To evaluate the trajectory of the restoration plantings
- To investigate the role of gorse as a nurse species
- To evaluate differences in species assemblages between the reference sites and the restoration site
- To evaluate the effectiveness of canopy closure and shading within existing restoration plantings
- To investigate opportunities for establishment of epiphytic native plant species, identifying key host species (e.g. tree fern spp., rata stumps) in the NSR
- To focus on the requirements of ferns and nikau palms to establish in the area.

A glossary of plant species abbreviations used in this chapter can be found in Appendix II.

Methodology

Establishing a mature benchmark plant community with the Nikau Scenic Reserve and a forest remnant

Within the NSR and remnant forest, seven 10 x 10m quadrats were established (Figure 88). Plots labelled M1, M2, M3, M5 and M6 are located within the NSR and plots M4 and M7 within the remnant forest. These plots are positioned within the mature transect plots established for invertebrate monitoring and are labelled correspondingly. Vegetation was categorized based on height, trunk diameter and stratified layers. Assessments consisted of both direct measurement and ocular estimation. Stratification was divided into seven categories:

1. Ground cover vegetation (grass and herbs between 0 and 1.3 m in height, seedlings excluded)
2. Shrubs and saplings (woody species between 0 and 1.3m in height)
3. Subordinate trees (woody species between 1.3 and 6m in height)
4. Tall trees (woody species between 6 and 12m in height)
5. Emergent trees (woody species greater than 12m and taller than the canopy)
6. Epiphytes
7. Vines

Trees were defined as having trunks taller than 1.3m and a diameter greater than 5cm DBH (diameter at breast height measured at 1.3m from the ground). Tree heights were measured to the base of the crown using a Suunto clinometer. The base of the crown was chosen due to the difficulty of seeing each tree crowns apex through the canopy. Each tree was tagged for reference in future monitoring events. A modified Braun-Blanquet method (Braun-Blanquet, 1932) (Table 10) was used to determine species abundance and contributing cover. Canopy cover was assessed by digital analysis of photographs taken with a fisheye lens at each corner and centre of each quadrat. Leaf litter depth was also recorded.

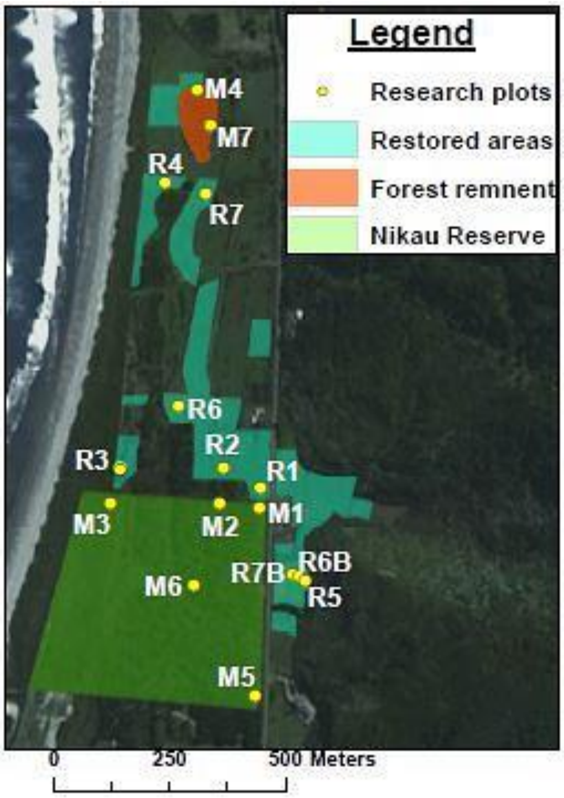

Figure 88. Locations of the vegetation research plots. Mature plots are labelled with an 'M' and restored plots with an 'R'.

Table 10. Modified Braun-Blanquet scale for floral assessments

Braun-Blanquet scale	Range of cover (%)	Midpoint of cover range (%)
5	75-100	87.5
4	50-75	62.5
3	25-50	37.5
2b	15-25	20
2a	5-15	10
1	<5; numerous individuals	2.5
+	<5; few individuals	0.1

Epiphytes were surveyed within the circumferential area between 1.3 and 1.8 meters from the soil on each tree (trees defined as greater than 1.3m in height and 5cm DBH) within the research plots. Only epiphytes with at least one root and one leaf within the delineated area were recorded. These methods were repeated for each stem on multi-stemmed trees. Vines were recorded for each plot. Individual stems sprouting from the soil were counted as independent vines.

Trajectory of the restoration plantings

Restoration plantings in nine research plots located throughout the PCRP area were surveyed. Plots were labelled R1-R7 plus R6B and R7B. Plots R1-R7 are positioned within the restored transect plots established for invertebrate monitoring and have been labelled correspondingly. Every planted native plant within the nine 10 X 10m plots each received labelled aluminium tags fixed to a long wire staple which was inserted into the ground at the base of each plant. Measurements included height, basal diameter, canopy area, and canopy density. Canopy area of each plant was calculated using the equation for the area of an ellipse (Canopy area = $\pi * \frac{maximun\ width}{2} * \frac{minimun\ width}{2}$). Canopy density was determined from both canopy area calculations as well as digital analysis of photographs taken with a fisheye lens at each corner and centre of each quadrat.

Results include data from a previous survey in December, 2011 (Bowie et al., 2012) for all plots except R6 and R7 as they did not exist at that time. Data from 2011 was compared to data collected in 2013 to determine average height and canopy area growth rates for the restoration plantings. Mortality of the plantings was also determined from 2011 data as well as direct observation of deceased or missing plants. Data from restoration research plots was grouped by year planted to assess average heights and canopy areas.

The role of gorse as a nurse species and its significance in successional processes

Controlling the presence, dispersal and reoccurrence of gorse within the restoration area has been a complex and costly obstacle for PCRP management. Generally gorse is considered to be invasive pest species that must be managed. To understand the successional role of gorse and its potential as a nursery species, five 100m^2 research plots were established beneath mature gorse stands. Four of these plots were located adjacent to each other within the same stand, and the fifth was approximately 15m to the north. Survey data includes abundance and heights of all native plant species greater than 5cm in height, ground cover and canopy cover of the research plots. Canopy cover was analysed with the same digital photography equipment used in the reference and restoration plots. For more detailed information see report by Carter-Brown (2013).

Results and discussion

Despite recent and long-term disturbance from livestock within the remnant forest (plots M4 and M7), mean plant species richness was identical for both benchmark plant communities (Figure 89). Results from the gorse study reveal that there are nearly as many native plant species naturally regenerating beneath the gorse as there are planted native species within the restoration plots (Figure 89).

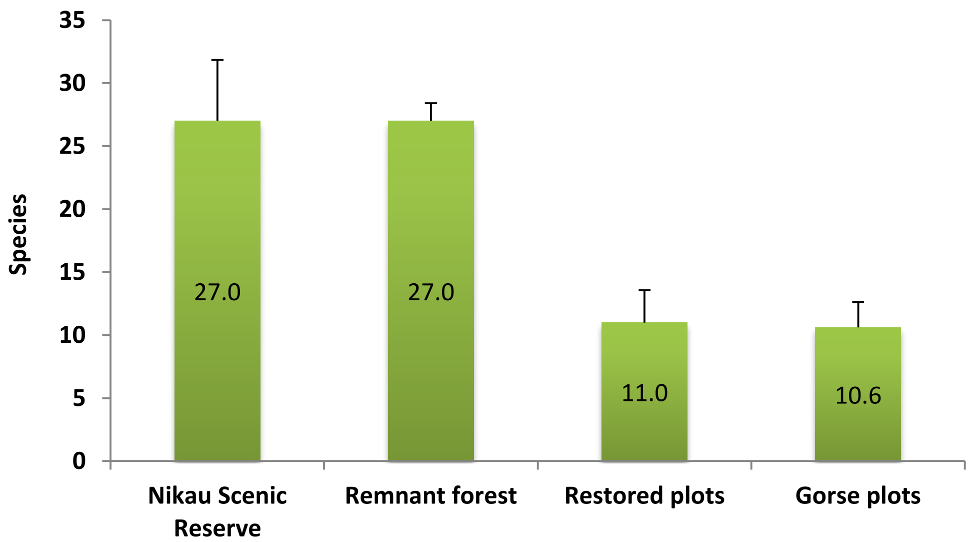

Figure 89. Mean plant species richness within research plots (± s.e.).

Analysis of the plant communities within the Nikau Scenic Reserve and forest remnant

Nearly all seven stratification categories are present within each of the seven mature research plots (Figure 90 and 91). The exceptions are shrubs within plots 1, 2 and 6 as well as tall trees in plot 7. Although the species richness for each category varied by plot, the epiphyte community consistently contributed greatest to species diversity than any other category.

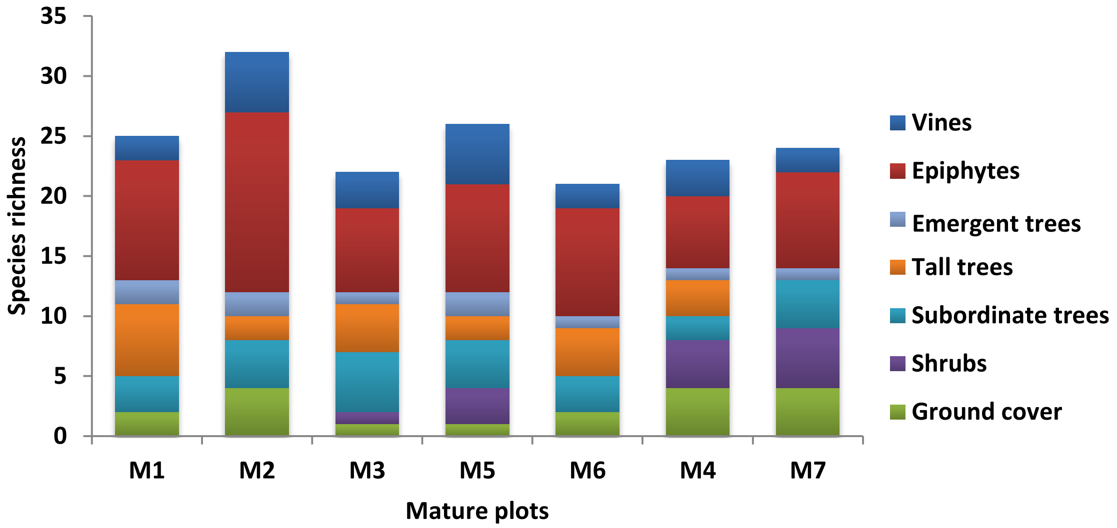

Figure 90. Species richness of the seven stratification categories within the mature research plots.

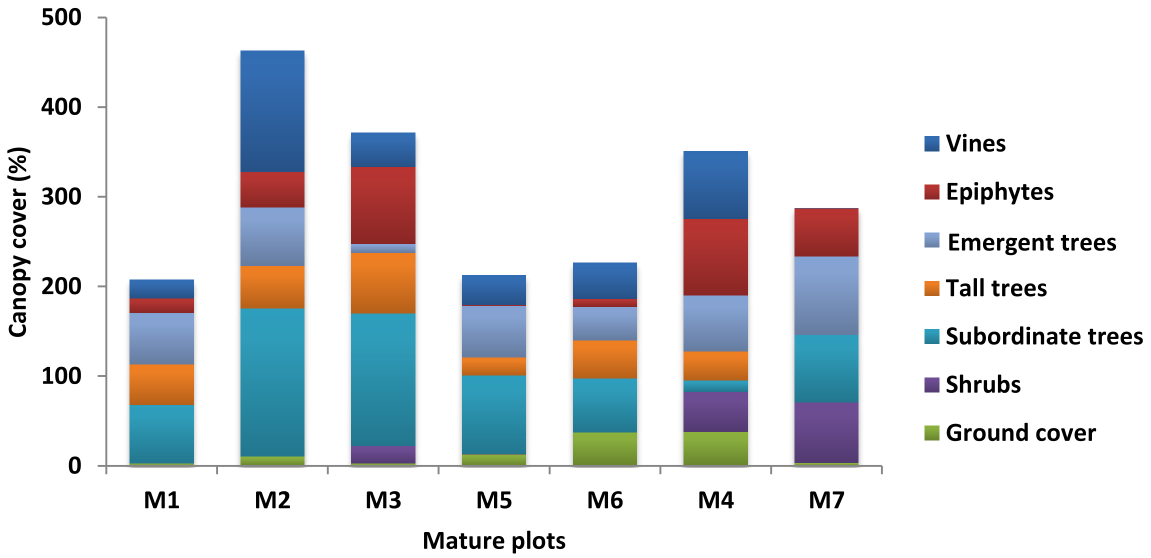

Figure 91. Contribution to canopy cover (%) by each of the seven stratification categories within the mature research plots.

Species richness of each of the seven stratification categories share a relatively similar distribution when comparing the NSR to the remnant forest (Figure 92). The apparent exception is the greater quantity of species within the shrubs layer in the remnant forest. This could be attributed to previous disturbance from land development and continued suppression of the lower layers from grazing by livestock. The increase of the shrub layer is likely a result of the removal of livestock and the allowance for successional processes to transpire. There are no apparent similarities in canopy cover (%) contribution by the different strata layers when comparing between the NSR and remnant forest (Figure 91). This may be due to the variation of physical, chemical and chronological properties between the five NSR research plots.

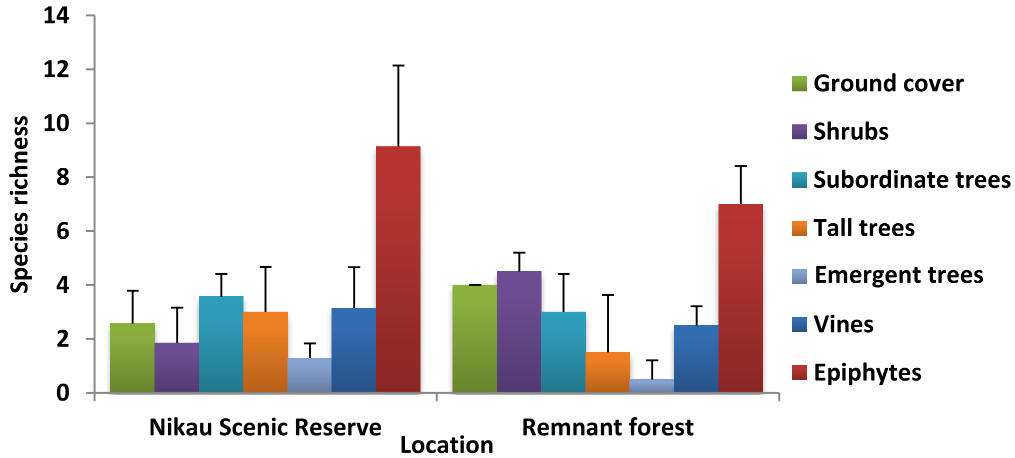

Figure 92. Species richness of the seven stratification categories within the NSR and remnant forest plots (± s.e.).

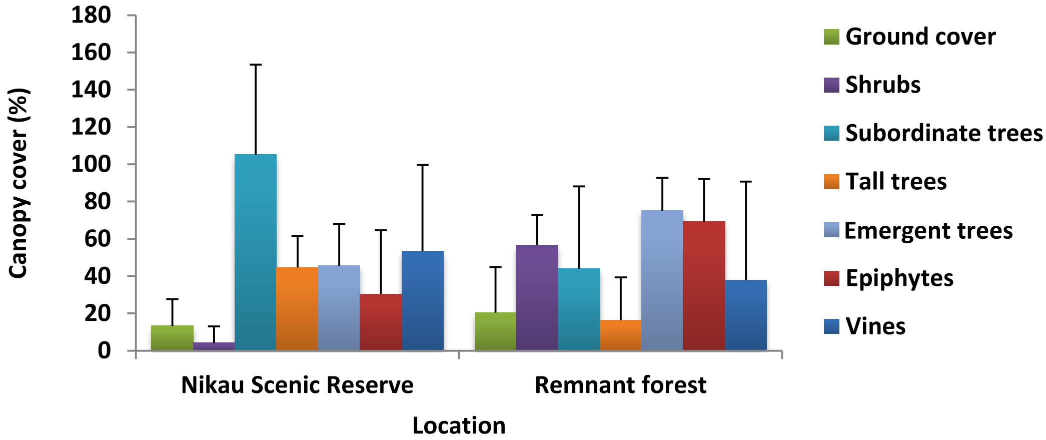

Figure 93. Contribution to canopy cover (%) by each of the seven stratification categories within the NSR and remnant forest plots (± s.e.).

Significant differences were also found for the distribution of height and trunk diameter of trees within the mature research plots (Figure 94). Trees within the forest remnant plots are both taller (plot M4) and have a larger DBH (plot M7) than trees within the NSR plots.

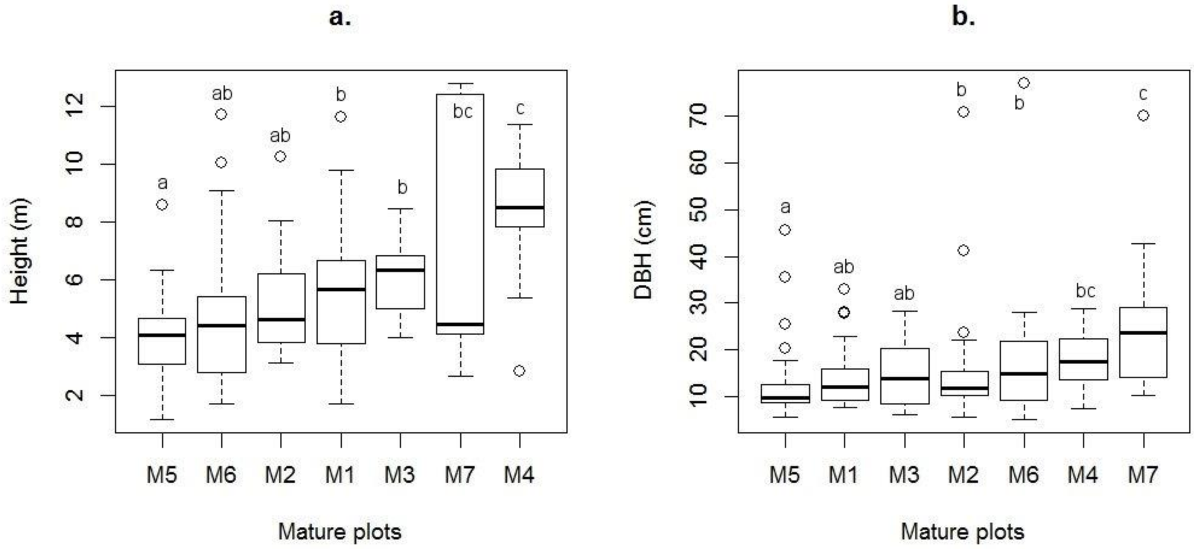

Figure 94. Comparison of height (a.) and DBH (b.) distributions between the mature research plots. The bold bar represents the median of the values. The boxes represent the middle 50% of the data values. The upper whiskers represent where the 25% of values greater than those within the box are found and lower whiskers represent where the remaining 25% of values are found. Dots represent outlying values. Box plots that do not share a letter are significantly different.

In both the Nikau Scenic Reserve and the remnant forest, the ground cover is mostly composed of leaf litter (62% on average), with the exception of plot M3 (70% rocks). Fine woody debris (<10cm diameter) can also be found in all of the mature plots with a mean coverage of 21%. Coarse woody debris (>10cm diameter) can be found in all mature plots with an average of 6% cover, with the exception of plot M1. To a lesser extent, some of the ground cover within the mature plots is also composed of roots (plots M6 and M7) and bare soil (plot M3).

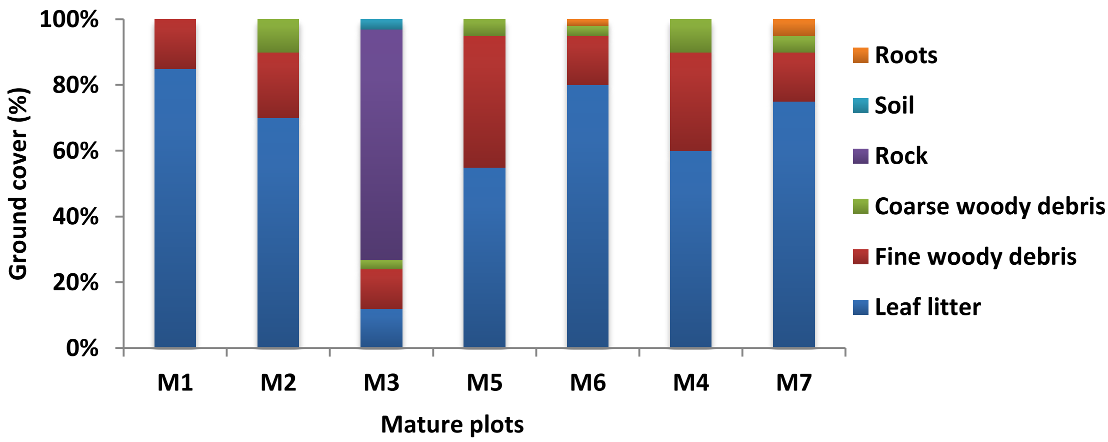

Figure 95. Results of ground cover survey (%).

Leaf litter depth also plays a crucial role in determining seed germination and groundcover composition. Studies have shown that greater levels of leaf litter reduced seedling recruitment in areas of canopy gaps yet enhanced recruitment under intact canopy. Leaf litter inhibits seedling emergence and establishment of small-seeded, shade-intolerant species, but enhances emergence and establishment of large-seeded, shade-tolerant species, possibly through increased humidity and reduced detection by predators (Dupuy & Chazdon, 2008). The leaf litter depth is greatest in plot M5 (10.3 cm) and is least in plot M3 (1.1 cm) (Figure 96). The average leaf litter depth is 5.6 cm in the Nikau Scenic Reserve and 3.8 cm in the remnant forest.

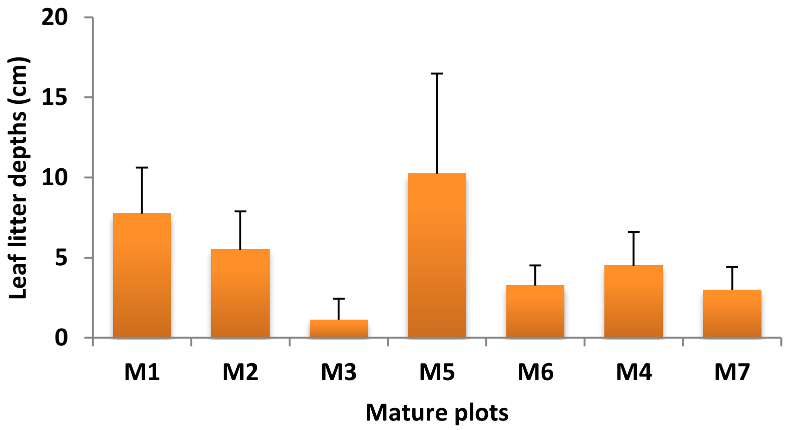

Figure 96. Average leaf litter depths per mature plot (± s.e.).

Leaf litter sampled and dried from each transect plot reveals that mature plots have a substantially greater mass of leaf litter than the restored and unplanted plots (Figure 97). However, leaf litter is beginning to accumulate within plot R1, the oldest restored plot which is three to four years old (Figure 98).

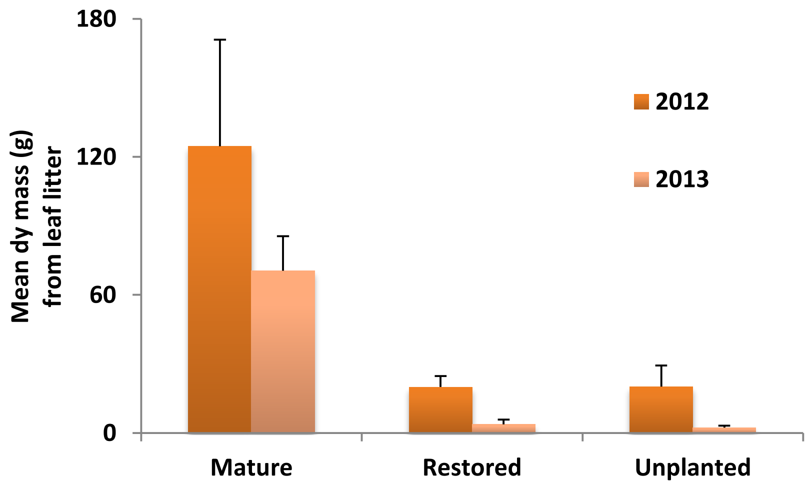

Figure 97. Mean dry mass of leaf litter collected from a 21x30cm area within each vegetation area.

Figure 98. Leaf litter accumulating within the oldest restoration plot, R1 (19 February 2013).

The number of epiphyte species located on tagged trees was counted in each plot (Figure 99) with a mean of 11.2 epiphyte species per plot in the NSR and 4.5 in the remnant forest. The species richness of epiphytes is greatest in plot M2 (16 species) and is lowest in the remnant forest plots M4 and M7 (3 and 6 species respectively). The remaining plots within the Nikau Scenic Reserve have approximately the same number of epiphyte species (between 9 and 11 species).

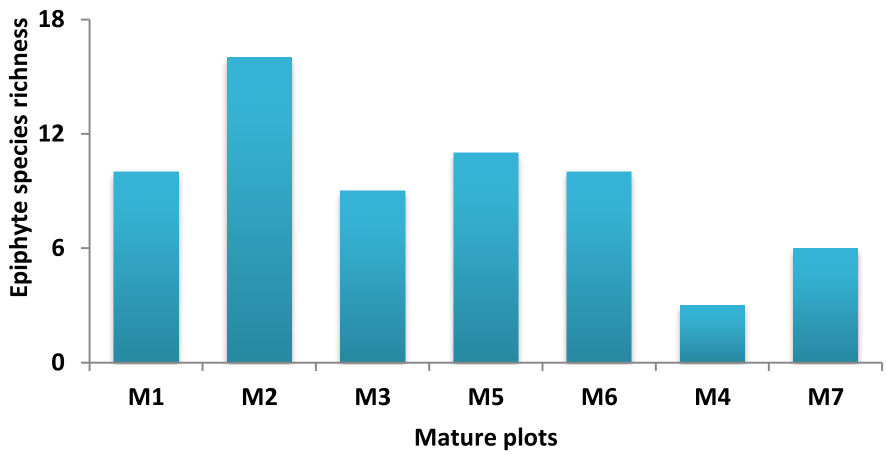

Figure 99. Epiphyte species richness within mature plots.

The number of epiphyte species was counted for each tagged host tree species (Figure 100). Certain host species facilitate the symbiotic relationship of a greater quantity of epiphyte species than other host species (e.g., 12 epiphyte species found on *D. squarrosa*, 8 on *H. arborea*, and 7 on *W. racemosa*), whereas other tree species host only one specific epiphyte species (e.g., *C. grandifolia*, *D. cupressinum*, and *S. microphylla*).

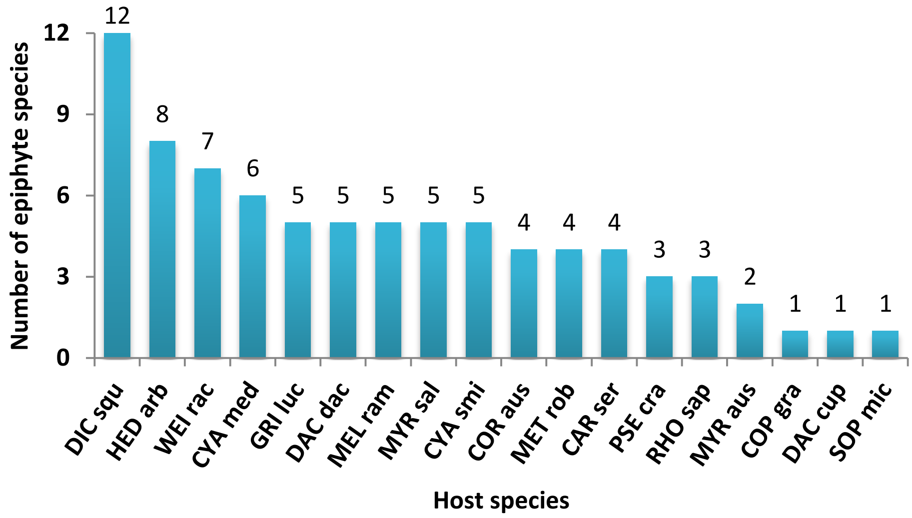

Figure 100. Quantity of epiphyte species per host tree species.

In order to understand the specificity of each epiphyte species, the number of host species was counted for each epiphyte species (Figure 101). Some epiphyte species are not highly selective (e.g., *M. perforata*, *M. diffusa*, *A. flaccidum* and *M. pustulatum*), whereas others seem to be specific to one host species only (e.g., *H. revolutum*, *L. billardieri* and *T. venosum*). The preferred host species for *H. revolutum* is *W. racemosa*, and *L. billiardieri* and *T. venosum* are specific to tree-fern *D. squarrosa*.

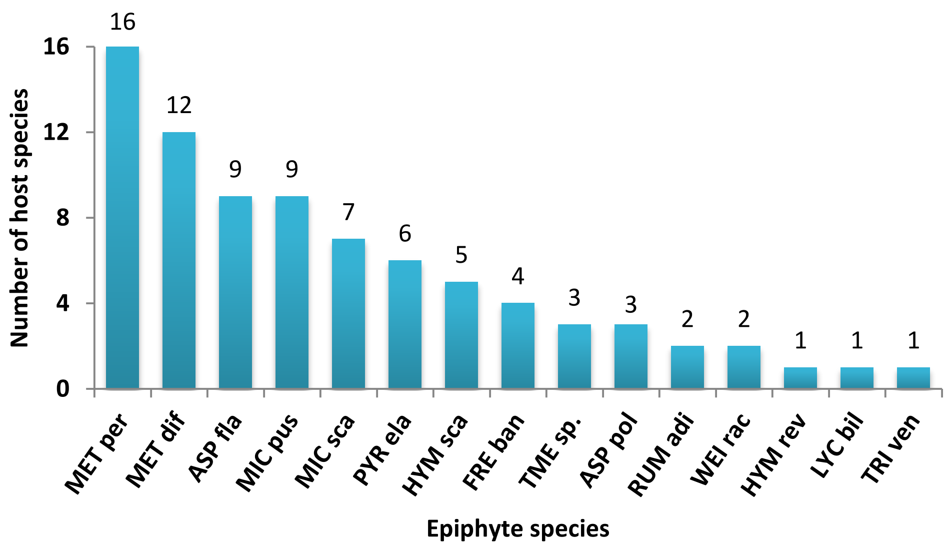

Figure 101. Quantity of host tree species per epiphyte species.

Figure 102. Nikau Palm (*Rhopalostylis sapida*) hosting an assemblage of epiphytes at the PCRP.

Trajectory of the restoration plantings

To compare relative growth between restoration plots, plots were grouped based on the year of which they were planted. The relative growth of four plant species was compared between restoration plots 4, 5, 6 and 7 (Figures 103 and 104) and the relative growth of one species (*Coprosma lucida*) was compared between restoration plots 2 and 3.

For restoration plots 4, 5, 6 and 7, only two species had more than five individuals in each plot (*Coprosma propinqua* and *Coprosma robusta*) which allowed for statistical analysis (Figures 103 and 104). The relative growth of height does not show any difference between the plots but the relative growth of canopy area shows that these two species grow slowest in plot 5. *Aristotelia serrata* and *Pittosporum tenuifolium* show similar results but insufficient data inhibits statistical analysis that may show significant differences. *Aristotelia serrata* has a negative relative growth of canopy area in plot 5 because the average canopy area of these individuals had reduced from December 2011 to January 2013. Because plot 5 shows significant differences with the other plots, it will not be included in the species comparisons.

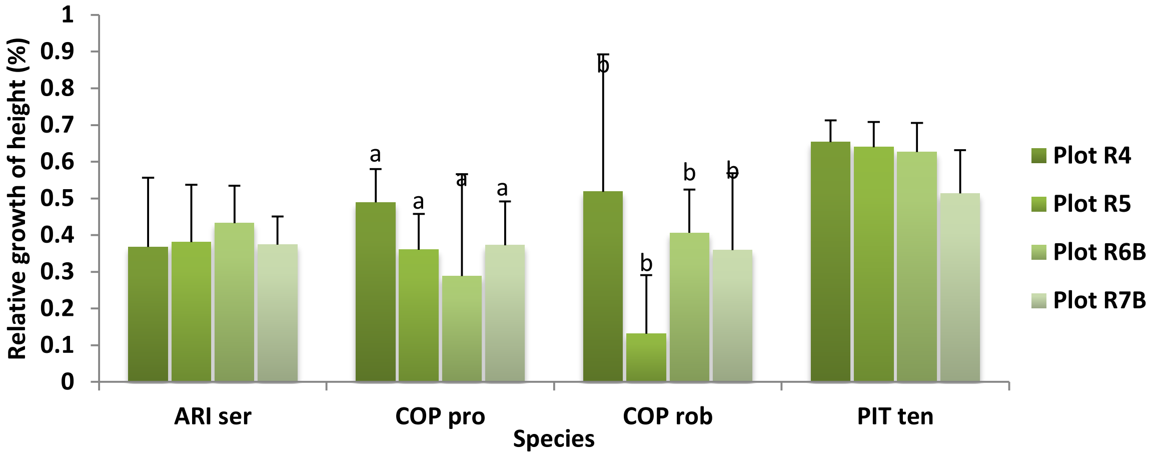

Figure 103. Relative growth in height for four species in restoration plots 4, 5, 6B and 7B (± s.e.). Means that do not share a letter are significantly different.

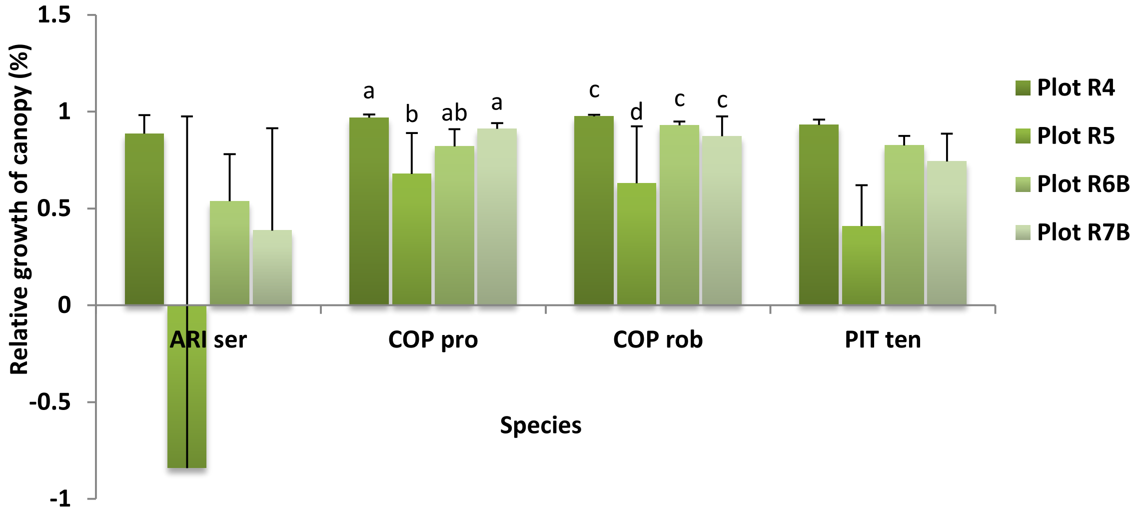

Figure 104. Relative growth of canopy area for four species in restoration plots 4, 5, 6B and 7B (± s.e.). Means that do not share a letter are significantly different.

Plant species were also compared to identify which species had the quickest rate of relative growth and therefor would be the most suitable for rapidly achieving a closed canopy. Only the relative growths of individuals of the same age which are located in like plots were compared. Individuals located in restoration plots 4, 6 and 7 were grouped according to their species as these plots are 1-2 years old and do not show significant differences between them (Figures 105 and 106). Plant species were also compared in plots 2 and 3 which are 2-3 years old (Figures 107 and 108).

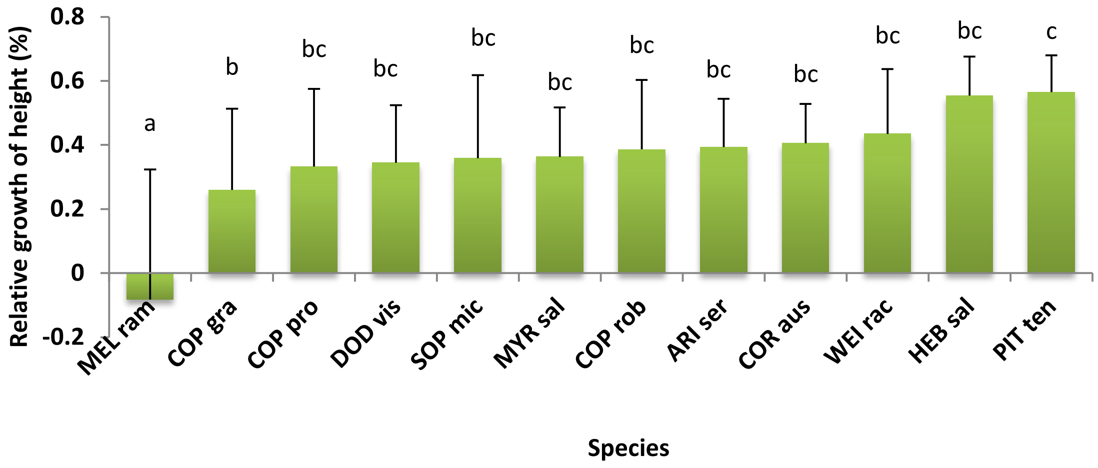

Figure 105. Relative growth of height per species in restoration plots 4, 6 and 7 (± s.e.). Means that do not share a letter are significantly different.

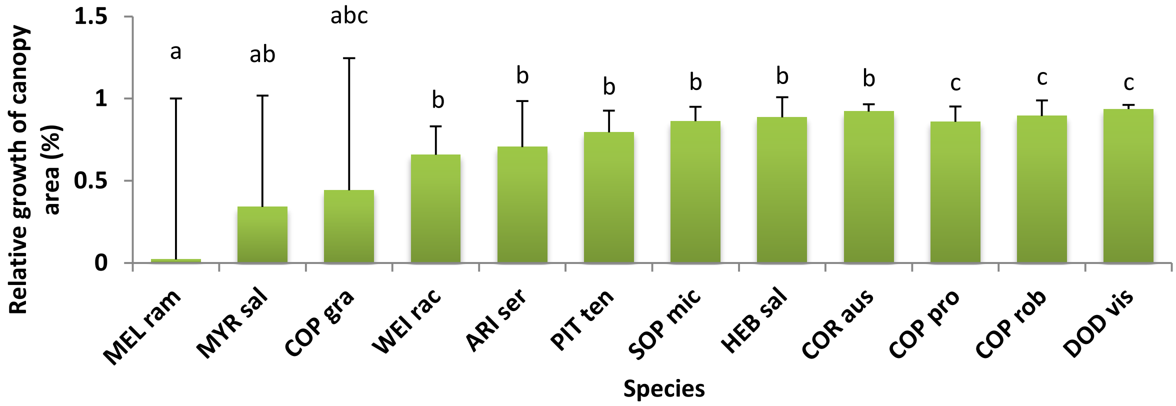

Figure 106. Relative growth of canopy area per species in restoration plots 4, 6 and 7 (± s.e.). Means that do not share a letter are significantly different.

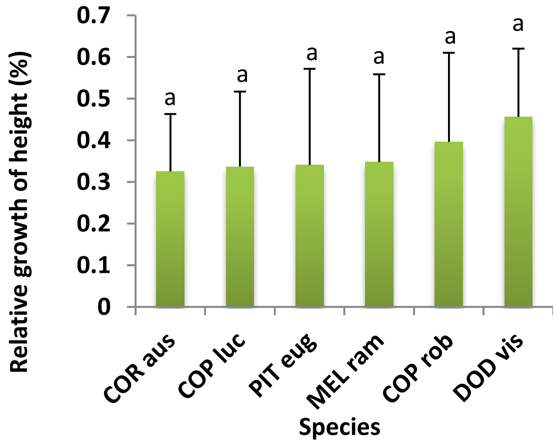

Figure 107. Relative growth of height per species in restoration plots 2 and 3 (± s.e.). Means that do not share a letter are significantly different.

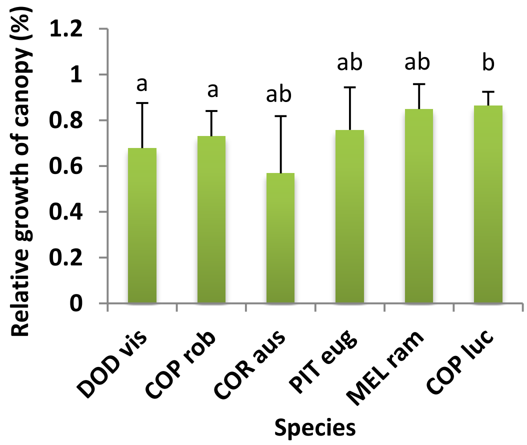

Figure 108. Relative growth of canopy area per species in restoration plots 2 and 3 (± s.e.). Means that do not share a letter are significantly different.

Melicytus ramiflorus attained the least amount of growth in terms of both height and canopy area during the second year following planting (Figures 105 and 106). *Coprosma robusta*, *Coprosma propinqua* and *Dodonea viscosa* had significantly greater relative growth of canopy area during the second year following planting (Figure 106). Although no difference in height between species was found within these plots (Figure 107), *C. lucida* produced a significantly larger canopy area than *D. viscosa* and *C. robusta* (Figure 108). In the third year following planting, there are no longer significant differences in the height and canopy relative growth between *Melicytus ramiflorus*, *Copromsa robusta* and *Dodonea viscosa* (Figure 107). However, *Coprosma lucida* had a great canopy relative growth than *Copromsa robusta* or *Dodonea viscosa* (Figure 108).

The mean height, mean basal diameter and the mean canopy area were calculated for the restoration plants from measurements recorded in December 2011 and in January 2013. The data from the restoration plots was grouped into four classes according to the plants age. The average height (Figure 109) and average basal diameter (Figure 111) of the restoration plants tends to increase with plant age. The rate of growth for restoration plants (for both height and basal diameter) also increases with age. The annual growth (%) between 2-3 year old plants and 3-4 year old plants is 1.5 times greater than between 0-1 year old plants and 1-2 year old plants.

Variations of the average height and the average basal diameter were compared to the average height and the average DBH of trees measured in the Nikau Scenic Reserve. Data from the forest remnant was omitted from this analysis as there were significant differences amongst the data. The mean height for 3-4 years old restoration plants is about 33% of the average tree height in the NSR and the 3-4 year old restoration plants basal diameter is about 27% of the average DBH of trees in the NSR (Figures 109-112). The average canopy area also increases with the plant age and each year's growth attributes to 70% of the total canopy area (Figure 113). The average canopy area in NSR was 80% (Figure 14).

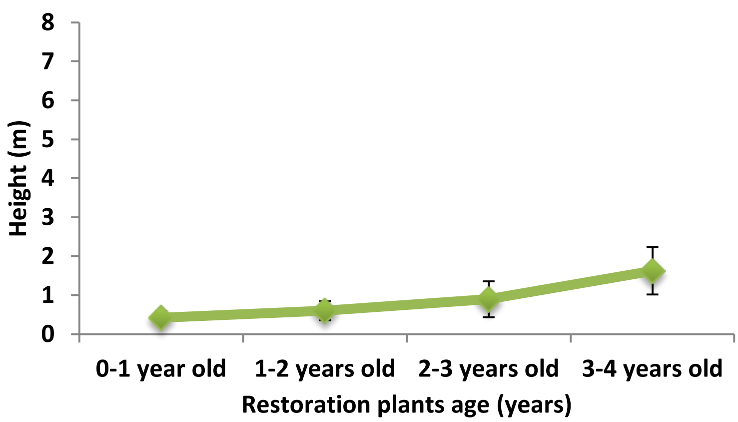

Figure 109. Average plant height by plant age in restored plots (± s.e.).

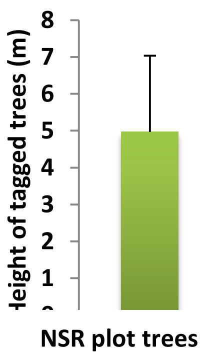

Figure 110. Average tree height in the Nikau Scenic Reserve (± s.e.).

Figure 111. Average plant basal diameter by plant age in restored plots (± s.e.).

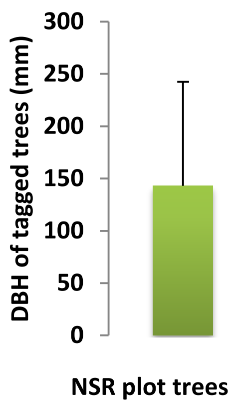

Figure 112. Average tree DBH in the Nikau Scenic Reserve (± s.e.).

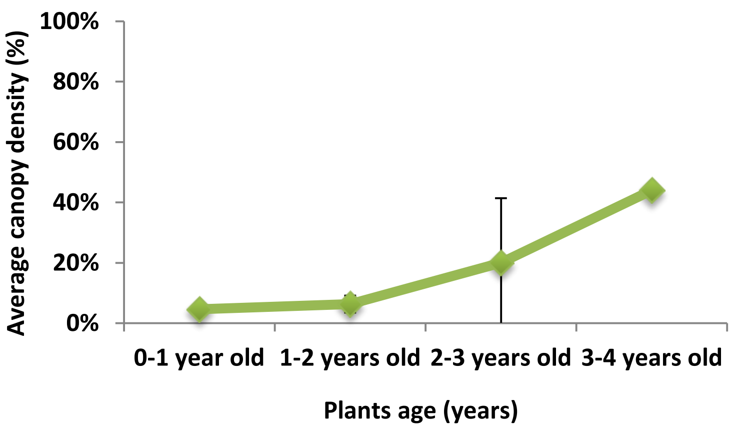

Figure 113. Average canopy density in restored plots by age (± s.e.).

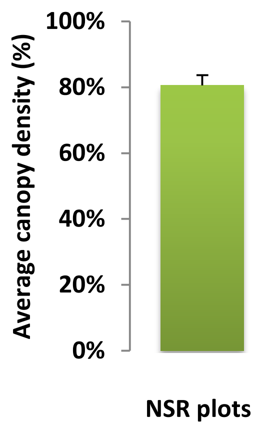

Figure 114. Average canopy density in the Nikau Scenic Reserve (± s.e.).

Mortality amongst plants in the first year following planting averages at about 37% (Figure 115). This decreases drastically within the second year to approximately 7.5% and 2% by the fourth year. There are several possible explanations for this trend including adverse weather conditions while plants are young and susceptible; shock from the planting process; browsing by hares and disturbance by birds such as wekas and pukekos is also common in newly planted areas.

Figure 115. Mortality (%) amongst restoration plantings by year following planting (± s.e.).

The Shannon-Wiener Index (Spellerberg & Fedor, 2003) is a commonly used measure of diversity which is often applied to assess ecosystem health. The index takes both the number of species and the relative number of individual into account (Krebs, 1989).The Shannon Index expresses the degree of variation of species within a given ecosystem and is calculated in equity and evenness of the species in a given population. With the exception of restored plot 4, the mature plots have greater diversity values. There is also less variation in the Shannon index values within the mature plots than the restored plots with standard deviation values of 0.12 and 0.33 respectively (Figures 116 and 117).

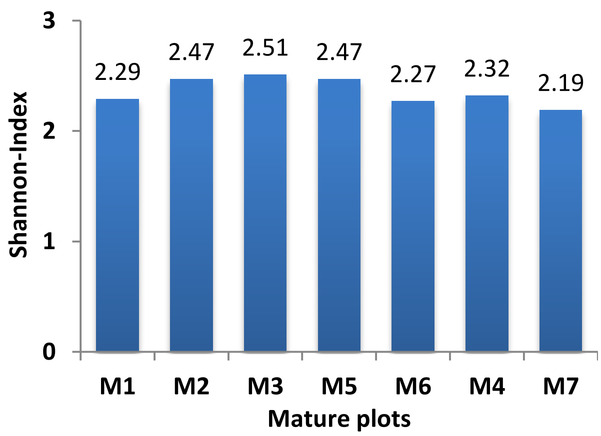

Figure 116. Shannon diversity index for mature plots.

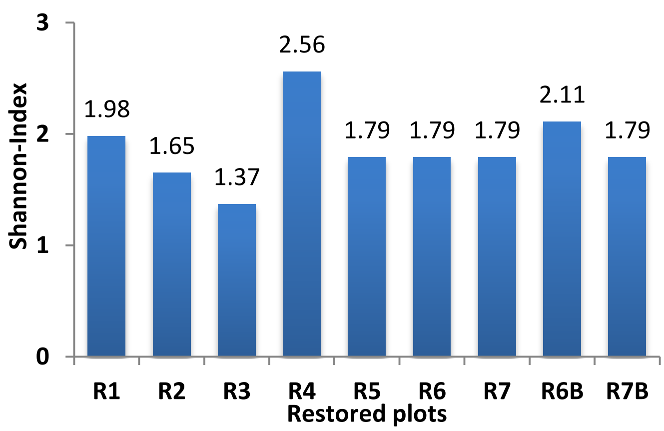

Figure 117. Shannon diversity index for restored plots.

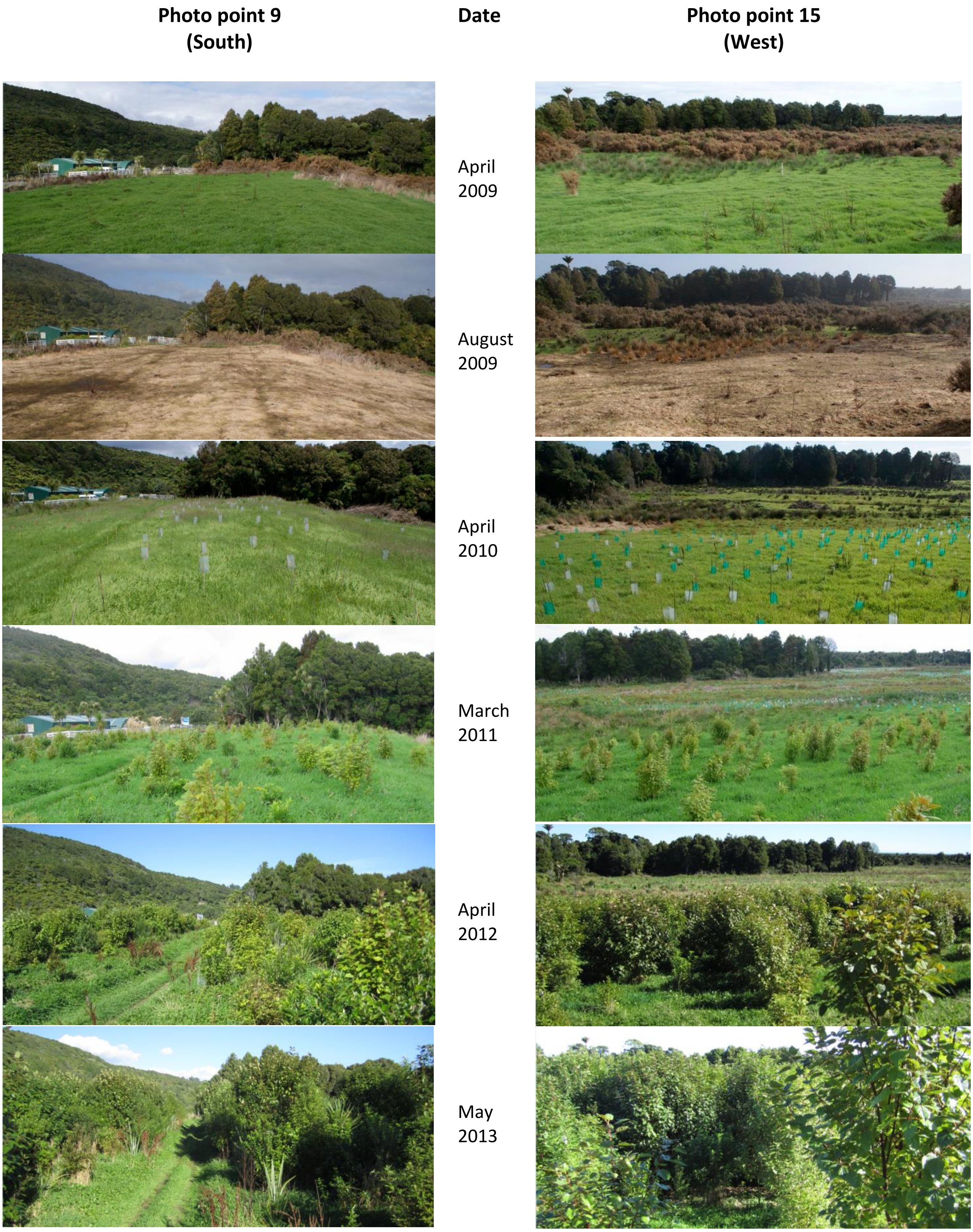

Figure 118. Southern and western views from a photo-point stations 9 and 15 respectively taken between April 2009 and May 2013 (Photos by James Washer).

The role of gorse as a nurse species and its significance in successional processes

Five 100m^2 gorse research plots were established within the PCRP close to the main road (Figure 119). The plots were 25m from seed sources directly east across the road, 120m from forest remnant containing M4 and M7, and 705m from M1 in Nikau Scenic Reserve. A total of 23 native plant species were observed and identified within the plots including 14 native woody species (>50mm in height) (Figure 120). These data provide an insight into which plant species might replace gorse during the next successional phase and the potential composition of that plant community.

Figure 119. Locations of gorse (circled in yellow) and distances from native seed sources

The presence of native woody species within the gorse research plots can be attributed to the relative absence of exotic grass species when compared to unplanted abandoned paddock. Shade resulting from a developed canopy (native or exotic) inhibits the growth of exotic pasture grass, allowing for the germination of seed from woody plant species. Canopies also provide places for birds to perch, enhancing the probability of plant colonization through seed dispersal by birds. Canopy closure (%) within the gorse research plots is similar to that within the mature forest research plots (Figure 121). At three to four years old, the most mature of the restoration research plots has a canopy that is approximately half as closed as the mature and gorse research plots. As the restoration plants canopies continue to develop, we expect to observe native plants beginning to colonize beneath them as well.

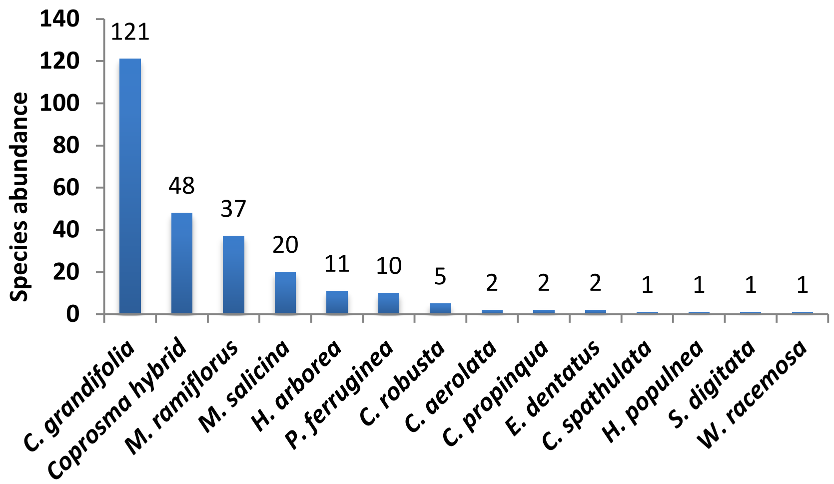

Figure 120. Abundance of native woody species (>50mm in height) recorded within gorse plots

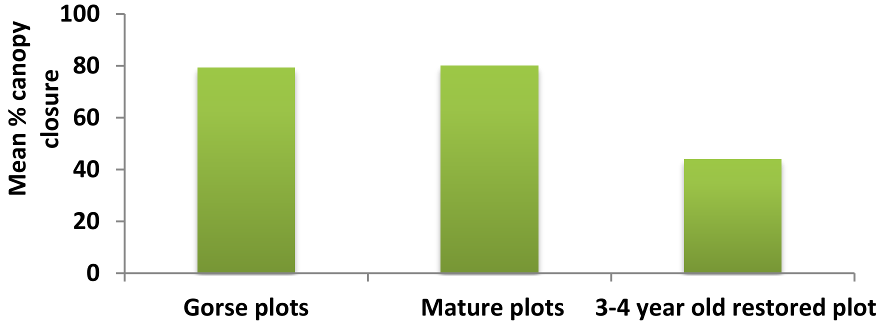

Figure 121. Mean per cent canopy closure of the gorse, mature and 3-4 year old restoration plots.

Although through natural successional processes a transition from abandoned pasture to gorse stands followed by native forest may eventuate, this approach will take longer to achieve a plant community comparable to the reference sites than an active restoration approach (Norton, 2009). This is demonstrated by the Shannon-Index score from each vegetation treatment (Figure 122). The exact age of the gorse stand surveyed is unknown.

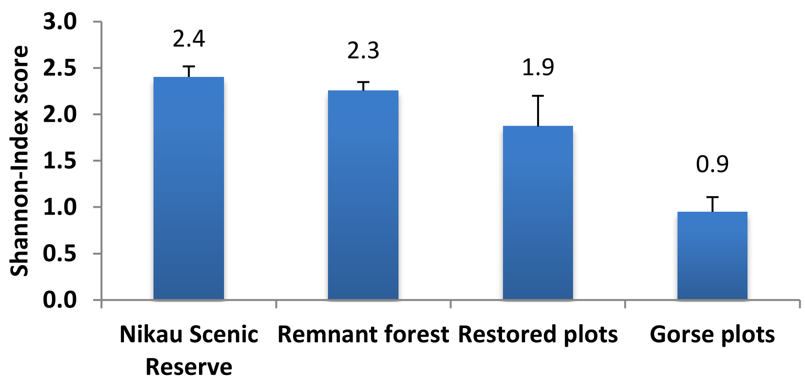

Figure 122. Shannon diversity index for each of the vegetation research plot categories (± s.d.). Values have been derived from tagged trees for the NSR and remnant forest, planted plants for the restored plots, and native woody species greater than 50mm in height.

Epiphyte study

Three epiphyte host species of importance were identified in NSR: *Rhopalostylis sapida* (nikau palm), *Dicksonia squarrosa* (wheki, rough tree fern), and *Metrosideros* spp. (Rata, specifically *M. diffusa, M. fulgens* and *M. perforata*). Due to difficulty identifying the Ratas to species *post hoc*, with photos, all three were grouped together as one RTU (Recognisable Taxonomic Unit). A variable number of each species were selected from two sites within the NSR with one just west of the State Highway 6 and the second site east of the wetland. The entire circumference of the lowermost two meters of each individual host tree was sampled for presence/absence of species growing epiphytically. The DBH of the host tree was also recorded.

The results were collated in Excel 2010 and a species list was compiled. In addition to this each species was classed as either a 'true epiphyte' or a 'terrestrial plant growing epiphytically'. Rstudio was used to run a GLM with host species as explained by host DBH, RTU richness, and their interactions. A (Pearson's) Chi-squared test was also run with host species, true epiphyte, and not-true epiphyte species as factors.

A total of 30 species of plants were found growing epiphytically on the lowermost 2m of three host species sampled. Of these 30 species, 20 were true epiphytes (their normal growth habit) while the remaining 10 species are classed as terrestrial plants growing epiphytically (Figure 124). The key findings are that *Rhopalostylis sapida* only supported true epiphytes on the individuals that were sampled, and that *Dicksonia squarrosa* supported a (relatively) high number of terrestrial species. *D. squarrosa* and *Metrosideros* spp. had higher RTU richness than *R. sapida* (Figure 123).

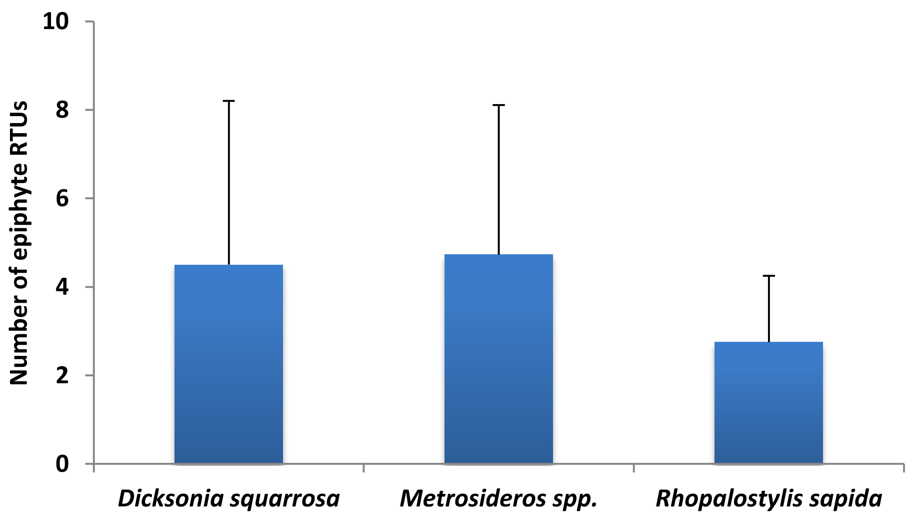

Figure 123. Epiphyte RTU richness of three host species. D. squarrosa SD = 3.70, Metrosideros spp. SD = 3.38, R. sapida SD = 1.50. The GLM of host species as explained by host DBH, RTU richness, and their interactions was not significant (host DBH, P = 0.901, T value = 0.127; RTU richness, P = 0.256, T value = 0.1.181; host DBH: RTU richness, P = 0.439, T value = -0.794; D.F. = 18).

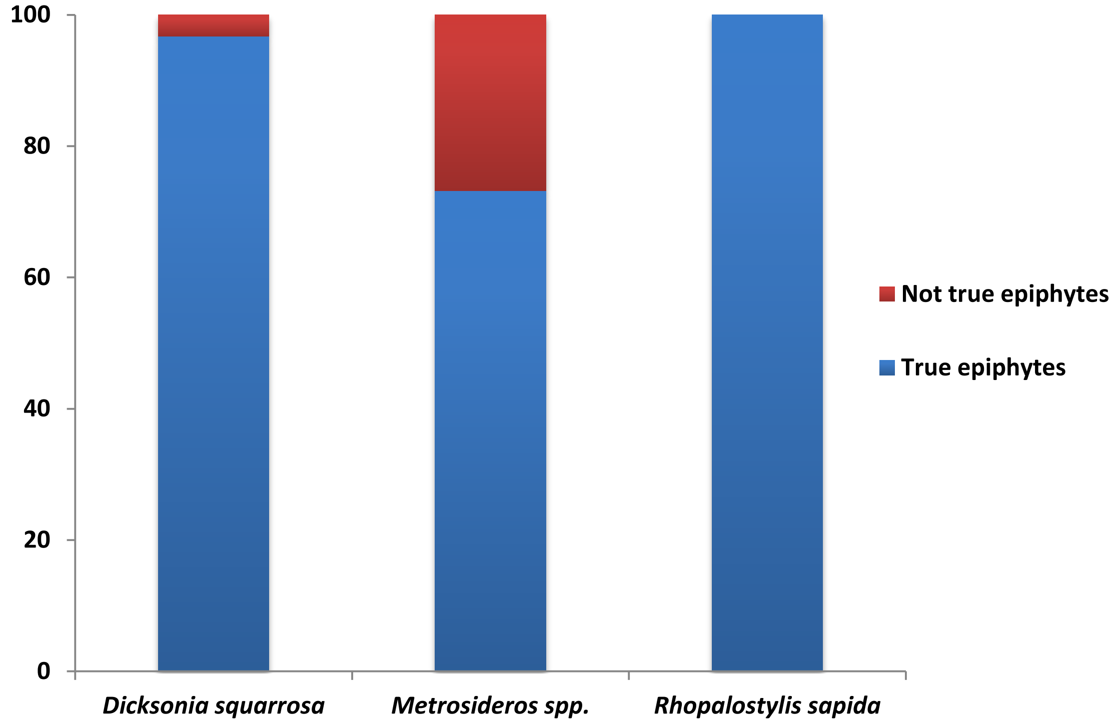

Figure 124. The percentage of true epiphytes or terrestrial species growing epiphytically on three host trees. The Chi-squared test showed that there was a significant difference (P = <0.001, X^2= 15.81, D.F. = 2) between the number of true epiphytes and terrestrial species in relation to host species.

Discussion

In total 122 plant species that have not been planted in the restoration plantings were identified as present within the reference sites, remnant vegetation patches within the restoration site and self-seeded within patches of gorse. A total of 34 native plant species have been planted, but most plants consist of about 12 different species. The reason for this difference is that the initial selection of restoration plantings aimed for primary successional species. These were selected for their resilience to exposed conditions and for the purpose of closing the canopy as rapidly as possible to shade out the grass, allowing for natural colonisation by other native plant species. Ferns have yet to be planted in the restoration plots, largely due to the lack of sufficient canopy cover.

The reference sites shared an identical plant species richness value, but differences in the plant community structure were observed. Information gained from surveying these sites has provided a benchmark to compare the restoration plantings against and can be used as a guide for future planting.

Restoration planting monitoring plots have elucidated plant species that are optimal for primary plantings and achieving canopy cover as well as which plant species are best for secondary plantings beneath an established canopy. Understanding when the highest levels of plant mortality occur informs management of how to distribute care and maintenance for the plantings over time.

Epiphytes were found to contribute a large portion to the species richness within the reference sites. Certain host species facilitate the symbiotic relationship of a greater quantity of epiphytes species than other host species, and some relationships appear to be exclusive. The epiphyte community should be further studied as data was collected only from below 2m on the trunks of the host trees.

Mature gorse stands provided an effective nursery for the self-establishment of native plants. In total, 23 native plant species self-established within five x 100m^2 plots. Although the species richness is comparable to that within the restoration plots, the gorse plots have a lower Shannon-diversity index score. Data collected during the gorse study also provided an indication of which species are likely to self-colonise within the restoration area once sufficient canopy closure is achieved.

Suggestions for site management include:

- Primary plantings should consist exclusively of pioneer species and planted at spacing that minimizes the amount of time required to achieve canopy closure.

- Secondary plantings should be guided by the composition and structure of the reference plant community.

- Propagation of species that have been shown to establish themselves may be unnecessary, unless they have been found to be fundamental for achieving canopy closure. Examples include: *Coprosma grandifolia, Hedycarya arborea, Melicytus ramiflorus,* and *Myrsine salicina*.

- Natural or artificial bird perches could be established to increase seed rain in the restoration area. International studies have shown that bird perches used in association with control (shading) of pasture grasses can significantly increase seed rain and improve rates of plant recruitment. This method has not been systematically tested in New Zealand before. An experiment could be set-up at PCRP to test this method as part of a wider study at a number of restoration sites in New Zealand.

- Control of gorse in areas intended for future restoration plantings should continue, but mature gorse in areas that will not be planted should be not be treated. Gorse supresses grass growth and provide shelter for native seedlings.

- Tree fern logs sourced from nearby forestry sites and distributed around the restoration site may encourage the establishment of epiphytes and terrestrial plants, and provide a habitat for invertebrates.

- Ferns could be propagated and planted in areas with sufficient canopy cover and dieback of pastures grasses. Plot R1 is likely to be suitable for planting ferns in the near future.

Chapter 18.

Biodiversity offsets and collaboration between stakeholders

Biodiversity offsets are measurable conservation actions which compensate for significant residual adverse biodiversity impacts arising from project development after appropriate prevention and mitigation measures have been taken. The goal of biodiversity offsets is to achieve no net loss and preferably a net gain of biodiversity with respect to species composition, habitat structure and ecosystem function and people's use and cultural values associated with biodiversity (BBOP, 2012b).

There are many reasons why governments, conservation organisations and private businesses have encouraged the development and implementation of biodiversity offsets worldwide. Biodiversity offsets integrate environmental issues into planning and development and aim to address the concerns of all stakeholders involved. Through this mechanism, the adverse impacts of development on biodiversity are measured and can potentially be successfully compensated to achieve beneficial outcomes.

Biodiversity enhancement strategies similar to offsets have been in development within the US for more than two decades and have offered guidance for legislation in other countries such as Australia, Brazil, Canada, the European Union and Switzerland. These countries already have legislation which mandates compensation for biodiversity loss. Other countries that are currently seeking to adopt biodiversity compensation strategies include France, South Africa, Madagascar, Mexico and Uganda (ten Kate & Inbar, 2008).

New Zealand's biodiversity has suffered numerous extinctions stemming from fire, land clearance, hunting, overexploitation of resources and the introduction of plants and animals, resulting in the loss of 32% of endemic land and freshwater birds, 3 of 64 reptile species and possibly 11 of the 2300 known vascular plants (BIO, 2013). As an extreme example of the extent of land clearance which has affected parts of New Zealand, the western and southern North Island lowlands and eastern South Island plains have lost 95.8% and 92% of their respective original native land cover (MfE, 2013).

DOC and NZ

When compared to offset programmes within Australia and the United States of America, biodiversity offset policy and design in New Zealand is currently in a rudimentary phase. Some progress towards the development of a standardised national system for offsetting has been compiled by the Department of Conservation (DOC) which was released in a report in 2010. DOC has since developed a document titled *Guidance on Best Practice Biodiversity Offsetting in New Zealand*, which is currently under review. The DOC Biodiversity Offsetting Programme has been formed in alignment with the international Business and Biodiversity Offsets Program (BBOP). Sharing the same definition for biodiversity offsets as the Business and Biodiversity Offsets Program (BBOP), the document focuses on 'no net loss' offsets, appropriate limits to offsetting, and overcoming systemic barriers to successful offsets (DOC, 2012).

Rio Tinto

In 2004, Rio Tinto launched their biodiversity strategy at the IUCN World Congress in Bangkok. This strategy includes their goal of achieving a net positive impact (NPI) on biodiversity within the regions of which they operate (Temple et al., 2012). Through a combination of innovation, adoption, global pilot projects and professional consultation, Rio Tinto's biodiversity strategy has evolved to incorporate widely acceptable methods of biodiversity management and conservation that are acknowledged within both the private and government sectors. For example, the mitigation hierarchy (Rio Tinto, 2008)(Figure 125) is a conceptual framework for thinking about biodiversity risks and opportunities and developing appropriate responses (Temple et al., 2012), which has also been adopted by BBOP and Western Australia EPA (BBOP, 2012a).

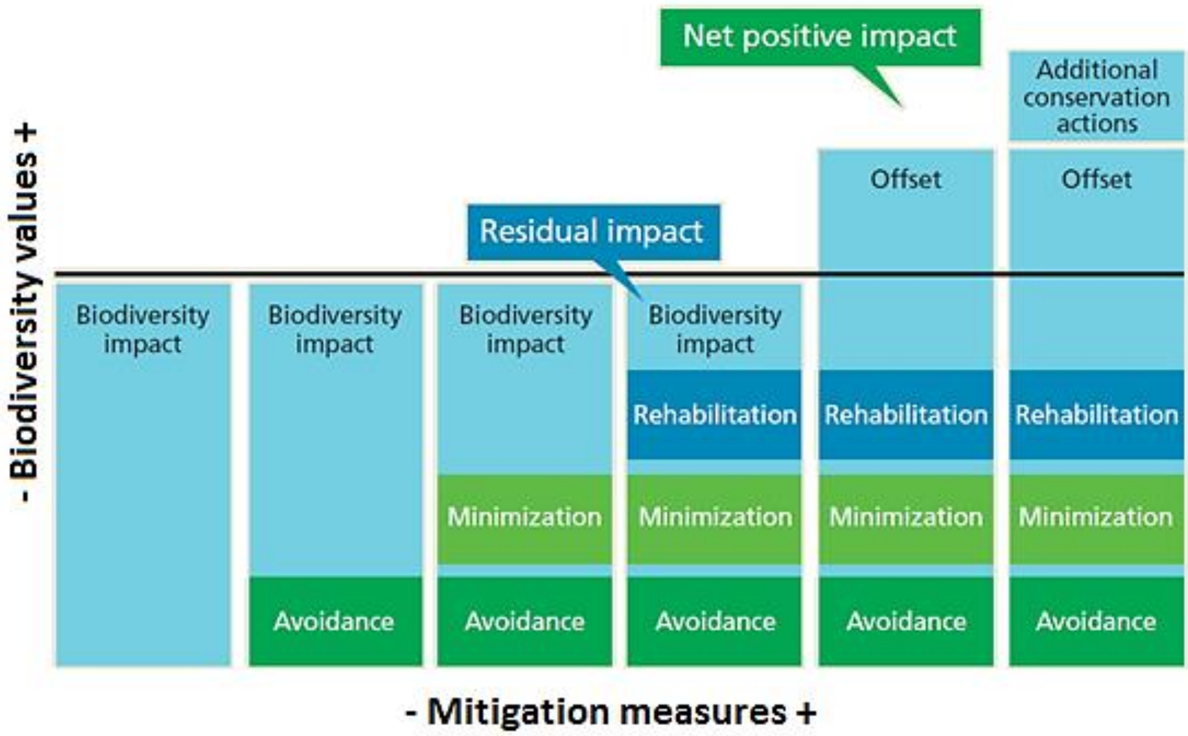

Figure 125. The mitigation hierarchy demonstrates the stepwise process of mitigating impacts on biodiversity and achieving a net positive impact with the use of biodiversity offsets and other additional conservation actions. (Rio Tinto, 2008).

Rio Tinto engages a nine-stage Biodiversity Action Plan (BAP) to achieve their corporate goals with respect to biodiversity (Rio Tinto, 2012). Stage four of the BAP requires a Risk and Impact Assessment involving the measurement of impacts to natural habitats using 'Quality-Hectares'. Essentially a mathematical product, Quality Hectares quantifies the quality of an environment by multiplying the area (in hectares) by its determined quality relative to a pristine state, on a scale of 0-1 (Rio Tinto, 2012). This metric is also used to measure net gains to biodiversity for habitats during the mitigation stage (stage 5) of the BAP.

Habitat Hectares

Rio Tinto's Quality Hectares strategy has partially evolved from Habitat Hectares, a metric developed in Victoria, Australia to assess 'vegetation quality' which has been defined as the degree to which the current vegetation differs from a 'benchmark' representing the average characteristics of a mature and apparently long-undisturbed stand of the same vegetation community (Parkes, Newell, & Cheal, 2003). There are two sources of benchmark data to compare from including direct field measurements and Ecological Vegetation Classes (EVC). An EVC represents a level of detail higher than the floristic community and its constituent taxa and may contain inaccuracies due to modelled distributions and coarse scale (Parkes et al., 2003). Therefor it is recommended to employ both sources of benchmark information.

Habitat Hectares was developed by the Victorian Department of Natural Resources and Environment (NRE) on the basis that it must:

- Provide an objective assessment of quality that is both reliable and repeatable.
- Measure the degree of 'naturalness' as a contribution to broader conservation value assessments.
- Indicate the direction and amount of potential improvement for lower quality sites.
- Allow comparison between different vegetation types.
- Combine quality and quantity assessments.
- Enable calculation of net outcomes, either for trade-off/offset scenarios or for measuring overall performance of policies and program.
- Be undertaken rapidly by a range of natural resource managers (i.e. not just botanical ecologists).
- Present a simple and robust message to land managers about the important components of native vegetation and its management (Parkes et al., 2003).

The site condition components incorporated into Habitat Hectares have been scaled broadly (i.e. often ± 50%) to allow for the natural variations within each component. Broad ranges allow assessors to make clear choices between categories and also limits the degree of variability resulting from the range of skill levels between users of the metric (Parkes et al., 2003). Although not intended to measure the conservation significance or habitat suitability for individual species, Habitat Hectares is continuously being trialled by NRE in combination with conservation significance measures to produce outcomes such as a 'Biodiversity Benefits Index' for purchasing land management services or developing bioregional-scale overviews for indicator or performance measure frameworks (Parkes et al., 2003).

Rio Tinto's international pilot projects have resulted in an understanding that although the basic design and implementation steps of an offset may remain constant, the nature of an offset is dependent on the specific situation (Rio Tinto, n.d.). According to Mr. Dutson from The Biodiversity Consultancy who has contributed to Rio Tinto's offset program, in the absence of a prescriptive metric such as 'habitat hectares', quality may be quantified using any pre-existing locally-applicable methods, creating a metric by drawing on ideas from other analogous metrics and customising to ensure locally-important features are captured. The metric should work on a linear score of quality with a scale from 0-1 where a score of 0.1 would be worth 10% of a mature, long-undisturbed benchmark environment (Guy Dutson, pers. comm. 6 February 2013). An example of such a scale has been recommended by Rio Tinto where a score of '0' represents a completely dysfunctional habitat with no representation of its pristine condition, and a score of '1' represents a fully pristine habitat (Rio Tinto, 2012)(Figure 126).

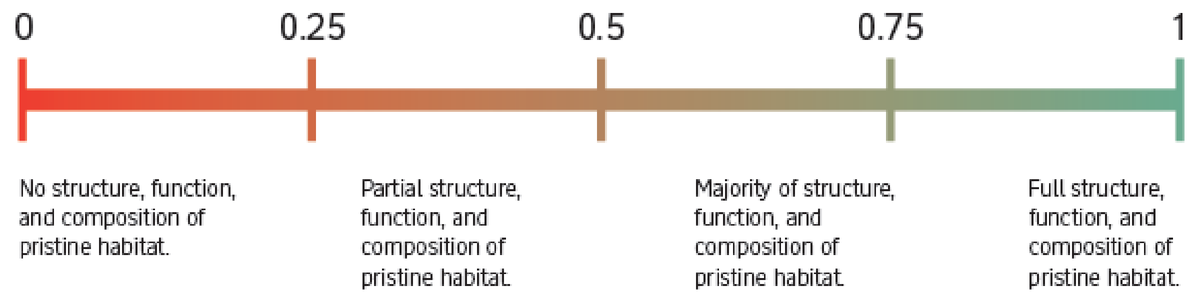

Figure 126. Quality multipliers used in the Quality Hectares offset program (Rio Tinto, 2012).

New Zealand's silent offsets

New Zealand's environmental consent policies are not exclusive of offsetting. In fact, offsets have become a common requirement for companies to receive consent for development and are mandated by the environmental court. In some cases, the defendant utilizes a professional consultancy to review and support the terms of the offset required such as with Meridian Energy Limited and the Mokihinui Hydro Project (MHP) (*Memorandum of counsel for Meridian Energy Limited*, 2011).

In order to compensate for the impact of developing the MHP, Meridian agreed to purchase 70 hectares of Waimangaroa Bush, a rare forest type. This forest type however is not found within the area that was to be affected by the MHP, but was deemed to be significant based on its quality, size, location and rarity. Being different than the area impacted by the MHP, the Waimangaroa Bush offset was deemed to be 'out-of-kind', where a different biodiversity type is considered as part of a mitigation or compensation proposal(*Memorandum of counsel for Meridian Energy Limited*, 2011).

Dr Ussher, Restoration Ecologist and Principal at Tonkin & Taylor Limited was the hired consultant to review the offset proposal and confirmed that the model used to develop the offset was based on 'like-for-like' offsetting as there are currently no robust, published models which deal with out-of-kind offsetting (*Memorandum of counsel for Meridian Energy Limited*, 2011). Dr Ussher relied on a modified version of the Habitat Hectares offset model. Although the offset area does not cater to the full range of flora and fauna that were impacted by the MHP, the offset site was regarded as more significant than the impacted site due to its rarity, and therefore could be considered as a 'trading up' offset. This action is in accordance with the guidelines of the Business and Biodiversity Offsets Programme and was also confirmed as acceptable in court by Dr. David Norton, Associate Professor at the School of Forestry, University of Canterbury (*Memorandum of counsel for Meridian Energy Limited*, 2011).

Indeed, offsetting is currently well underway in New Zealand. However, further research and development with focus on ecological measurements and comparison of impact and offset sites; establishment of an appropriate offset currency; and development of effective implementation techniques is required in order to achieve an implementable robust and sustainable system of biodiversity offsetting in New Zealand (DOC, 2010).

PCRP

The present study of the Punakaiki Coastal Restoration Project will contribute towards developing qualitative and quantitative ecological measures for net gains of biodiversity, comprehensive models of impacted ecosystem functionality and an increased understanding of the successional processes leading to ‘restoration success’. These measures can be used to support the development of generic models for business and biodiversity offset programmes in New Zealand. Furthermore, this information may be useful for facilitating a partnership based on the experiences gained by Rio Tinto from developing international methods of business and biodiversity offsetting, Lincoln University’s continued ecological studies and the current offset development endeavours by DOC.

Chapter 19.

Recommendations for restoration improvements

Changes in the soil and landscape during the disturbance period preceding restoration can supersede the subtle soil and landscape differences that control pre-disturbance vegetation types (Havel, 1975). Previous dredging, channelling and rerouting of the original streams on the PCRP site have altered the flow, direction and likely substrate of the original waterways. These activities have also likely altered the topography, soil landscape and hydrology of the land. Consequently there may be inherent and permanent differences in floral and faunal composition between the PCRP restoration area and reference sites.

Hydrology

Provision of increased canopy cover over the streams within the restoration area should limit the presence of the exotic grasses and aquatic flora that are obstructing the flow of water. Managing in-stream vegetation will affect the movement of water during high flow events, which should increase without the resistance of the vegetation. The aquatic vegetation also acts to retain the silt sediment. An increased rate of flow coupled with a lower amount of in-stream vegetation should eventually flush the sediment out of the channelized streams. In some places, this may reveal an underlying layer of stones that has been covered by sediment, and sand in others. However, soft-bottomed streams are not simply a consequence of underlying geology, but also dependant on stream slope, land use and other factors (MfE, 1998). An increase in water flow combined with a lack of stream-bank vegetation could result in stream-bank erosion. Therefore it is important to select riparian plants with root characteristics beneficial to stream bank stabilization. Further information on plant species best suited for bank stabilization can be found within the Landcare Research database (Phillips, Marden, Ekanayake, & Watson, 2008). As the riparian plants mature, lose branches and eventually die, they will contribute to in-stream woody debris and the stream's biotic and abiotic features will begin to resemble those within the Nikau Scenic Reserve.

A report commissioned by the Department of Conservation (Jackson, 1994) focussing on wetland hydrology management including that of the Nikau Scenic Reserve recommended restoring a segment of the original hydrological regime and the associated floodplain communities of this coastal lowland. Completing this would require consent from the private landowners of the Coates' farm to the south of the reserve to allow redirecting the modified flow of Hibernia Creek back into the former natural channels within the reserve (Jackson, 1994).

A segment of coastal wetland and natural drainage patterns could potentially be restored within the PCRP land, where modification through straightening and channelling of the natural waterways has impacted on the historical hydrology of the land within and surrounding the project site. A potential area for reinstating a portion of the lands natural hydrology is shown in Figure 127, where overflow from two ponds (A) is currently directed south via a drainage ditch to an intersection (B) which is presently blocked by an earthen crossing without a culvert pipe. The water currently escapes west and into abandoned paddock which has naturally begun to form a wetland dominated by rushes (C) before being channelled once again west to the coast. The proposed renovation would involve blocking the westward channel at the strip of coastal vegetation leaving the developing wetland (C) and redirecting the overflow into the low-lying central vegetation strip (D), which will conduct the water south through naturally formed channels to the NSR wetland (E). With its lower elevation, the central vegetation strip was likely to have previously been an area subject to occasional standing water prior to land development. This proposal would require further assessment.

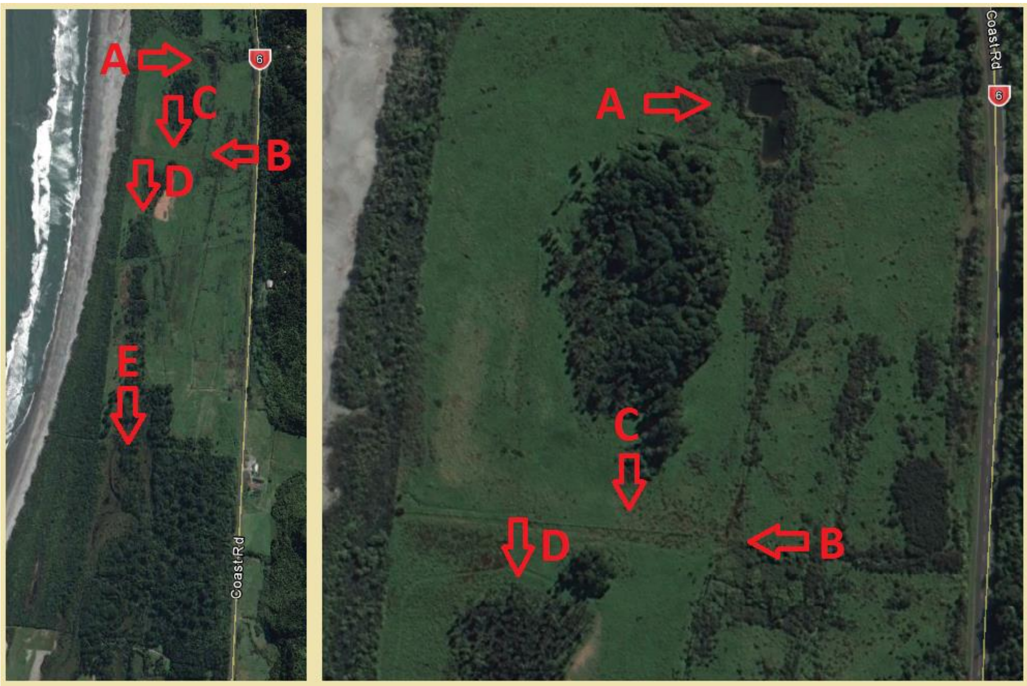

Figure 127. Potential area for hydrological improvements where overflow water from the ponds (A) can be re-directed into the low-lying central strip of remnant vegetation (D).

Increasing biodiversity

Restoring the biodiversity to a restoration area requires the development of a self-sustaining ecosystem. A critical requirement for re-establishing a self-sustaining ecosystem is to ensure that vital ecosystem functions and processes are returned (Grant et al.,

Figure 128. Bumble bee pollinating native plants at the PCRP.

2007; Majer et al., 2007). Some imperative ecosystem functions include litter decomposition, return of pollinators and nutrient cycling. If the dynamics of the desired plant community are to be restored, the insects responsible for pollinating these plants must be restored as well (Majer & Brown, 1997). In order to accomplish the reinstatement of ecosystem functions and processes, it is important that all components of the biota are re-established (Majer et al., 2007). Although it is desirable to encourage the return of a rich invertebrate fauna from a full range of functional groups, ecological equivalence allows functional compensation by other member species to compensate for species loss under different sets of environmental conditions (Majer & Brown, 1997). Increased diversity within a restoration program stabilizes the functioning of the total ecosystem, whereas simplified ecosystems may be less stable and require greater amounts of energy and nutritional inputs (Majer et al., 2007). Therefore, it is necessary for restoration practitioners to give special consideration to recolonizing invertebrates which make up over 95% of terrestrial species that are alive today (Majer & Brown, 1997).

Prompting the return of biodiversity to a restoration area can be monitored with the selection of indicators and measured at the species level as presence/absence; density; breeding success and morphometrics including body weight and length. At a community level, indicators may include diversity (e.g. Shannon-Wiener index), similarity, classification and ordination (Nichols, 1997).

Figure 129. Birds nest observed (20/2/2013) within the oldest restoration plantings (R1).

Invertebrate colonisation

Critical physical differences between mature reference sites and those of newly restored areas include the provision of suitable habitats, inhibiting the potential for the immigration of selective species. Species that are slower to colonize a recently restored habitat include those that are dependent on habitat characteristics such as deep litter depth, logs, hollow trees, exfoliating bark, developed vegetation structure and density, canopy cover, temperature, humidity, soil structure, nutrient availability and food sources that are similarly slow to recolonize (Fox, 1997; Grant et al., 2007; Majer et al., 2007; Mattiske & Youngson, 1997; Nichols, 1997; Nichols & Gardner, 1997; Nichols & Grant, 2007). Alcoa mining restoration has made the inclusion of log habitats standard practice in restoration programs (Nichols & Grant, 2007). In order to accelerate the establishment of ecosystem functions and process, restoration programs should make every effort to increase the rate at which some of these resources become available (Nichols & Gardner, 1997). Ultimately, climatic factors (e.g. rainfall, temperature, evaporation) will also have a large influence on ecosystem function. However, it is important that restoration activities do not impede on ecosystem function as there is a direct link between these and ecosystem sustainability (Grant et al., 2007).

Figure 130. Cicadas were observed within the restoration plantings.

Vegetation

The initial objective for restoring an abandoned farmland should be to suppress the pasture vegetation by planting native species that are most efficient at developing a closed canopy and at densities that maximise effectiveness for cost. These should be pioneer species that would naturally colonize within the surrounding area. Secondary plantings should then represent the dominant species identified within the benchmark plant community, in this case the Nikau Scenic Reserve and forest remnant.

Melicytus ramiflorus obtained the least amount of height and canopy growth during the second year following planting. Thus, this species is probably not well adapted to establishing itself in open canopy environments. This is generally the case for mature forest species, which appear in later successional stages. Although differences in canopy growth are no longer apparent in the third year following planting, this species does not contribute to the suppression of exotic pasture species during the first two years. By replacing *M. ramiflorus* with species adapted to open environments, control of pasture weeds should be more readily accomplished. It is recommended that *M. ramiflorus* be planted as a secondary species once canopy cover has developed.

In order to achieve a floral community representative of the NSR, it is necessary to encourage the colonisation of species from the reference community. The epiphytes contributed more to species richness than any other strata category in the mature plots. This study identified host species *Dicksonia squarrosa*, *Hedycaria arborea* and *Weinmania racemosa* as hosts to a large variety of epiphyte species. *Dicksonia squarrosa* and *Weinmania racemosa* were also found to be essential for the colonisation of epiphytes *Lycopodium billardieri*, *Trichomanes venosum* and *Hymenophyllum revolutum*. Another host species, which has been found to begin its life as an epiphyte, then later host numerous other species of epiphytes is *Metrosideros robusta*, also known as Northern Rata.

By the closing stages of planting at the PCRP, in order to have accomplished creating a plant community similar to that within the NSR, the number of plant species with the potential to become trees (trunks taller than 1.3m and greater than 5cm DBH) should reach 16 individuals per $100m^2$. Also, species richness should reach 34 species and the Shannon-Index should exceed 2.0 within $100m^2$, which has already been accomplished within restoration plots R4 and R6B.

Chapter 20.

Evaluation of the role and activities for CVNZ and DOC in onward monitoring and research at the PCRP

The completion of this research project was facilitated through collaboration with the projects partner organisations, Conservation Volunteers New Zealand and the Department of Conservation. Key persons from these organisations supplied direct assistance, background information and materials. This collaborative participation also resulted in reciprocal benefits for both CVNZ and DOC.

Conservation Volunteers New Zealand

CVNZ played a significant role in enabling Lincoln University staff and students to work on-site by contributing services including housing, office and laboratory facilities. CVNZ qualified Jason Hahner (Lincoln University) as a certified CVNZ Team Leader so that he could involve CVNZ volunteers in various aspects of the research investigation. Volunteers of CVNZ worked directly with Lincoln University staff on numerous occasions which helped to increase work efficiency and meet deadlines. Some of the activities that volunteers participated in include deployment and collection of monitoring devices; establishment and maintenance of transect plots and field collection of invertebrate samples. Under the supervision of CVNZ team-leaders, volunteers continue to contribute to onsite monitoring by recording the results of pest-mammal trapping efforts.

Figure 131. CVNZ volunteers contribute to maintenance of the monitoring transects.

James Washer (CVNZ Project Manager) was a tremendous source of assistance for a range of events including arranging volunteer assistance; supplying essential information and insight into the restoration project; helping to supply and transport material throughout the site and participating in arboreal gecko trapping efforts. Dave Sharp (CVNZ Corporate and Government Partnerships Manager) arranged for Jason to obtain his CVNZ Team Leader certification and also guided him through the risk assessment processes.

The reciprocal result of this collaboration includes an enriched experience for the volunteers who are involved with the study and a scientific evaluation of the restoration effort for CVNZ staff and stakeholders. This past year has elucidated the potential for CVNZ staff and volunteers to continue to participate and contribute to onward monitoring. Under supervision and guidance by knowledgeable professionals, monitoring and research by volunteers can have valuable outcomes. For example, results gained from trapping and tunnel tracking monitoring may inform CVNZ staff or Lincoln researchers of the efficacy of current pest management practices. However, as most CVNZ volunteers are inexperienced with environmental monitoring and unfamiliar with New Zealand flora and fauna, their efforts will be most beneficial at their current level of involvement.

The Department of Conservation

DOC staff member Jane Marshall was very helpful in supplying some of the tracking tunnel material and several of the G-minnow traps. Chippy Wood served as a valuable source of local knowledge and helped researchers to gain insight into local history and biogeography. It is hoped that future research will see an increased interest and level of participation by DOC.

Chapter 21.

Conclusions

The future trajectory of restoration success at PCRP will be determined by subsequent colonisation and recruitment of additional species. In the oldest restoration planting canopy closure, shading of pasture grasses, leaf litter accumulation and woody plant surfaces available for colonisation are precursors to enhanced diversity. Studies showed that epiphytes and plant associations with key host species are particularly critical. Differences in soil chemistry were identified after the first five years of restoration. Advances have been made in developing a good range of restoration indicators including measures of communities of dung beetles, weta, spiders, moths, leaf litter invertebrates, earthworms, mites, birds, aquatic invertebrate and fish. The most significant mammalian pests were mice and rats.

A summary of the outcomes of this 12-month project (Table 11) provides an overview of potential restoration indicators and their trajectory at PCRP in the Unplanted, Restored and Mature plots. This provides guidance to future restoration practice, beyond the initial establishment of 100,000 trees over 5 years. This is a multi-dimensional approach linking changing soil, vegetation and faunal communities.

The legacy of this work is the protection and management of a unique biodiversity asset through a collaborative partnership of Rio Tinto, CVNZ, DOC and Lincoln University. We recommend that future management of this site develops the PCRP as an ecological, educational, tourist and recreational resource.

Table 11. Potential restoration indicators at PCRP in the Unplanted, Restored and Mature plots. The likely restoration trajectory of indicators is for values to move from Restored to Mature over time.

INDICATOR	Method	Unplanted	Restored	Mature
Invertebrates				
Dung beetles	Pitfall traps	*	*	***
Cave & ground weta	Pitfall traps	*		***
Small beetles	Pitfall traps	*	*	***
Anopteropsis adumbrata (spider)	Pitfall traps	***	***	*
Wasps (mainly Diapriidae)	Pitfall traps	***	***	*
Small 'spotted' earthworms	Leaf litter extracts			***
Harvestman *Aoraki denticulata*	Leaf litter extracts			***
Weevils	Leaf litter extracts			***
Beetles (excluding Staphylinidae)	Leaf litter extracts	*	*	***
Wellington tree weta	Weta refuges	*	**	***
Anopteropsis adumbrata (spider)	Artificial refuges	***	***	
Oxychilus sp. (Exotic Snail)	Artificial refuges	***	***	
Moths (grassland species)	Light trapping	N/A	***	*
Moths (mature site species)	Light trapping	N/A		***
Worms (native no's & biomass)	Soil sampling	*	*	***
Worms (no's)	Pitfall traps	***	***	*
Worms	Wooden discs	***	***	*
Birds				
Native species	5-min bird counts	N/A	*	***
Exotic species	5-min bird counts	N/A	***	*
Soils				
C/N ratio	Soil analysis	*	**	***
Zn	Soil analysis	*	**	***
Mn	Soil analysis	*	**	***
K	Soil analysis	*	**	***
Mg	Soil analysis	***	**	*
Vegetation				
Canopy closure	10 x 10m plots		*	***
Leaf litter	10 x 10m plots		*	***
Exotic grass	10 x 10m plots	***	***	
Epiphytes	10 x 10m plots			***

Key:

Blank = not found

* = rare / very low

* = few / low

*** = many / high

N/A = Not Applicable/not tested

Project Recommendations

Research

1. Continue monitoring identified key restoration indicators – some yearly, others every 3 years
2. Advance in our understanding of ecosystem services in mature and restored sites. Which species are the main ecosystem providers and can these be enhanced in restoration plantings:
   - Pollinators – invertebrates and birds
   - Seed dispersers – invertebrates and birds (use artificial and natural roosts in restoration areas)
   - Nutrient cyclers – invertebrates e.g. dung beetles, worms, beetles
   - Biocontrol agents – invertebrates e.g. parasitic wasps, predatory beetles, spiders, birds.
   - Decomposers – identification of key Fungi assemblages (especially mycorrhizae).
3. Setup some new long-term research plots to investigate best planting regimes
4. Incorporate some missing key species (e.g. tree ferns) into restoration plantings with canopy cover
5. Publish research in scientific journals and popular press on the restoration work at the PCRP
6. Reduce rat density in the Nikau Scenic Reserve

Infrastructure

1. Establish a functional ecology laboratory in existing building
2. Establish a "Living Lab" interpretive walkway to showcase ecological aspects of the "Farm to Forest" restoration.
3. Establish a Petrel viewing shelter with state of the art live video feed from petrel colony &/or penguins

Other

1. Establish a formal partnership with CVNZ, Rio Tinto and DOC to reinforce our commitment to the PCRP
2. Seek some external funding for addition research and advocacy projects related to petrels and penguins

Figure 132. Sunset view at the PCRP overlooking a stand of nikau palms

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Appendix I

Species lists

Inventory of invertebrates found in the Nikau Scenic Reserve and PCRP site between 2011 and 2013

Common name	Taxonomic name	Location collected	Date	Rarity/ No. found	Native/ Exotic
MITES	**ACARI**				
RTU 3 (Velvet Mite)	Trombidiidae sp. 1	Leaf litter in Mature sites		common	N
RTU 11 (Velvet Mite)	Trombidiidae sp. 2	Leaf litter in Mature sites			
RTU 7	Uropodina: Trachytidae	Leaf litter in Mature sites			
RTU 8	*Chyzeria* sp.	M1 under log, M5 in soil	Aug 3	2	
RTU 9	Prostigmata sp. 1	Leaf litter			
RTU 20	Prostigmata sp. 2	Leaf litter			
RTU 23	Mesostigmata	Leaf litter			
RTU 13	Bdellidae indet. sp.	Leaf litter			
RTU 1	Oribatida indet sp. 1	Leaf litter in Mature sites			
RTU 2	Oribatida indet sp. 2	Leaf litter			
RTU 4 (Box Oribatid)	Oribatida indet sp. 3	Leaf litter			
RTU 6	Oribatida indet sp. 4	Leaf litter in Mature sites			
RTU 14	Oribatida indet sp. 5	Leaf litter			
RTU 15	Oribatida indet sp. 6	Leaf litter			
RTU 18	Oribatida indet sp. 7	Leaf litter			
RTU 21	Oribatida indet sp. 8	Leaf litter			
RTU 22	Oribatida indet sp. 9	Leaf litter			
RTU 25	Oribatida indet sp. 10	Leaf litter			
RTU 26	Oribatida indet sp. 11	Leaf litter			
RTU 32	Oribatida indet sp. 12	Leaf litter			
RTU 33	Oribatida indet sp. 13	Leaf litter			
RTU 34	Oribatida indet sp. 14	Leaf litter			
RTU 37	Oribatida indet sp. 15	Leaf litter			
RTU 38	Oribatida indet sp. 16	Leaf litter			
RTU 39	Oribatida indet sp. 17	Leaf litter			
RTU 17	Parasitidae: Pergamasinae	Leaf litter			
RTU 36	Ologamasidae	Leaf litter			
RTU 10	Uropodina indet. sp. 1	Leaf litter in Mature sites			
RTU 16	Uropodina indet. sp. 2	Leaf litter in Mature sites			
RTU 29/35	Uropodina indet. sp. 3	Leaf litter			
RTU 40	Uropodina indet. sp. 4	Leaf litter			
SPRINGTAILS	**COLLEMBOLA**				
Giant springtail	*Holacanthella ?brevispinosa*	Pitfall trap in Mature 2B (Nikau Scenic Reserve)	2011/12	4	N
EARTHWORMS	**ANNILIDA**				
	Small, spotty, corn cob-like	Leaf litter in mature sites	2011/12	common	N
	Amynthas corticis	Soil sampling			E
	Dendrobaena octaedra	Soil sampling			E
	Lumbricus rubellus	Soil sampling			E
	Octolasion cyaneum	Soil sampling			E
Dark endemic	Undet . sp. 1	Soil sampling, under discs	common		N
	Undet . sp. 2	Soil sampling			N

	Undet . sp. 3	Soil sampling			N
	Undet . sp. 4	Soil sampling			N
	Undet . sp. 5	Soil sampling			N
BRISTLETAILS	**ARCHAEOGNATHA**				
	Undet sp.	Under logs M3			N
FLATWORMS	**PLATYHELMINTHES**				
Light brown	*Newzealandia* sp. 1	Under iron near U1			N
Dark brown	*Newzealandia* sp. 2	Under iron near U1			N
Orange	Undet. sp 1	Under iron near U1			N
SNAILS	**MOLLUSCA**				
	Allodiscus punakaiki	Litter M1	2/12/11		N
	Cavellia reeftonensi	Pitfall M1A	-11/1/12		N
	Cytora pannosa	Pitfall M1A	-11/1/12		N
	Georissa purchasi	Litter M4	30/12/11		N
Cellar snail	*Oxychilus* sp.	Grassland sites (U's & R's)	12/2011	common	E
	Phrixgnathus celia	Pitfall M2E	-11/1/12		N
	Potamopyrgus	Aquatic sampling	11/1/12	common	N
	Rhytida patula	Under log near M3 /track to beach	3/8/12	1	N
Leaf-vein slug	**Athoracophoridae**				
	Undet. sp	Under foam wrap		2	N
DOBSONFLIES	**MEGALOPTERA**				
	Archichauliodes sp.	Aquatic sampling	11/1/12		N
CADDISFLIES	**TRICOPTERA**				
	Costachorema sp.	Aquatic sampling	11/1/12		N
	Olinga sp.	Aquatic sampling	11/1/12		N
	Rakiura ?venale	On bone in Scotsman's Ck	3/8/12	Common	N
MAYFLIES	**EPHEMEROPTERA**				
	Atalophlebioides cromwelli	Scotsmans Ck	21/3/13	Few	N
	Austroclima sepia	Scotsmans Ck 1	21/3/13	5	N
	Coloburiscus humeralis	Aquatic sampling	11/1/12	common	N
	Deleatidium c.f. lillii	Aquatic sampling	11/1/12	common	N
	Ichthybotus bicolor	Nikau Scenic Reserve	21/3/13	2	N
	Neozephlebia scita	Nikau Scenic Reserve	21/3/13	Common	N
	Zephlebia c.f. versicolor	Nikau Scenic Reserve	21/3/13	1	N
	Zephlebia spectabilis	Nikau Scenic Reserve	21/3/13	1	N
MOTHS/BUTTERFLIES	**LEPIDOPTERA**				
	Aciptilia monospilalis	Light trap M1	5/2/13		
Pseudopan. leaf miner	*Acrocercops panacitorsens*	Leaf damage in Nikau Reserve	14/4/13		N
Karamu leaf miner	*Acrocercops zorionella*	Leaf damage in Nikau Reserve	14/4/13		N
	Anisoplaca archyrota	Light trap M1 & M6	5/2/13+		
	Apoctena orthropis	Light trap M1	5/2/13		
	Austrocidaria callichlora	Light trap R1	5/2/13		
	Bactra noteraula	Light trap R3	12/1/12		N
	Barea exarcha	Light trap R4	18/2/13		
	Chalastra perlargata	Light trap M1 & M2	5/2/13+		
	Chloroclystis inductata	Light trap R3	12/1/12		N
	Cnephasia jactatana	Light trap M1	5/2/13		
	Ctenopseustis obliquana	Light trap M1	5/2/13		
Gorse pod moth	*Cydia succedana*	Light trap R3, R5 & M3	12/1/12+	common	E
	Epyaxa rosearia	Light trap R1	5/2/13		
LB Apple moth	*Epiphyas postvittana*	Light trap R3	12/1/12	common	N
	Eudonia leptalea	Light trap R3, R6 & M3	12/1/12+		N
	Eudonia melanaegis	Light trap R3	12/1/12		N

	Eudonia minualis	Light trap R1	10/1/12		N
	Eudonia submarginalis	Light trap R1 & R3	10&12/1		N
	Feredayi graminosa	Light trap M1	5/2/13		
	Gellonia dejectaria	Light trap M3	12/1/12		N
	Graphania mutans	Light trap R1 & R6	5/2/13+		
	Graphania insignis	Light trap R1 & M1	5/2/13		
	Graphania ustristriga	Light trap R1	5/2/13		
	Hydriomena rixata	Light trap R6	14/3/13		
	Hygraula nitens	Light trap R6 & M3	14/3/13+		
	Leptocroca sp.	Light trap M3	12/1/12		N
Common copper	*Lycaena ?Salustius*	Observed resting on vege	14/12/12	1	N
	Merophyas leucaniana	Light trap R5 & R6	14/3/13+	common	
Magpie moth	*Nyctemera annulata*	Feeding on ragwort	12/1/12	common	N
	Oecophorid sp.	Light trap M3	12/1/12		N
	Opogona omoscopa	Light trap M1 & M6	10/1/12+		E
Flax scraper moth	*Orthoclydon praefactata*	Leaf damage in Nikau Reserve	14/4/13		N
	Orocrambus flexuosellus	Light trap R1, R5 & R6	10/1/12+	common	N
	Orocrambus ramosellus	Light trap R6	14/3/13		
	Patagonoides farinaria	Light trap R5	14/3/13		
	Platyptilia repletalis	Light trap R4 & R6	18/2/13+		
	Rhapsa scotoscialis	Light trap M1	5/2/13		
	Schrankia costaestrigalis	Light trap M3, M6 & R6	12/1/12+		N
	Stericata carbonalis	Light trap M3	14/2/13	1	E
	Tingena sp.	Light trap M3	12/1/12		N
Cinnabar moth	*Tyria jacobaeae*	Observed resting on vege	14/12/12		E
	Platyptilia repletis	Light trap R1 & R3	10&12/1		N
	Udea flavidalis	Light trap R1	10/1/12+		N
Porina	*Wiseana copularis*	Light trap R3+	12/1/12+	common	N
Porina	*Wiseana umbraculata*	Light trap R3	12/1/12		N
	Xanthorhoe occulta	Light trap M3	12/1/12		N
BEETLES	**COLEOPTERA**				
Wood borers	**Anobidae**				
	Ptinus speciosus	Malaise trap R3	Dec-Jan	2+	??
Fungus weevils	**Anthribidae**				
	Cacephatus incertus	Malaise trap in M3	Feb-Mar	1	
	Etnalis spinicollis	Malaise trap in R3 & M3	Oct-Feb	7	
	Liromus pardulis	Malaise trap in R3 & M3	Nov-Mar	10	
Ground beetles	**Carabidae**				
	Amorotypus edwardsii	Malaise Trap in R3 & M3	Nov-Mar	common	N
	Bembidion rotundicolle	R3,U3 pitfalls	-9/1/13	common	N
	Ctenognathus helmsi	Under wet log near M6 track	5/10/12	common	N?
	Ctenognathus sp. 1	M4 pitfalls & under logs	Dec-Jan	common	N
	Euthenarus puncticollis	Pits & soil in U & R sites only	Nov-Jan	12+	N
	Holcaspis oedicnema	M7 wooden disc	22/2/13	1	N
	Mecodema ducale	Lizard Lodge R1	20/7/12	1	N
	Mecodema metallicum	Under log between M2 & M3	3/8/12	1	N
Tiger beetle	*Neocicindela parryi*	Pitfall in R2A	-11/1/12	1	N
	Neoferonia integrata	Under logs, wood discs in Ms	All year	common	N
	Nesamblyops oreobius	M2 Pitfall trap G		1	N
	Notagonum feredayi	Wood discs, soil sampling U&Rs	Dec-Feb	20+	
	Oopterus sp.	M4 wooden disc	20/7/12	1	N
	Platynus macropterus	Wooden Disc C at R3	20/1/12	1	N
	Scopodes fossulatus	Pitfall Trap G in R7	-9/1/13	1	N
Long-horn beetles	**Cerambycidae**				

	Ambeodontis tristis	Ex. Spider web in M1	2/8/2012	1	N
Squeaking longhorn	*Hexatricha pulverulenta*	Malaise trap R3	Dec-Mar	7+	N
Lemon tree borer	*Oemona hirta*	Malaise trap in R3	Dec-Jan	1	??
	Prionoplus reticularis	Light trap in R's	Feb-Mar	6	N
	Somatidia sp.	Malaise trap M3 & R3	Dec-Jan	3	N
	Unident Cerambycidae	Malaise trap M3 & R3	Oct-dec	3	N
Flower longhorn	*Zorion ?minutum*	Malaise trap in Mature 1	-12/1/12		N
Minute fungus beetles	**Corylophidae**				
	Indet. sp. 1	Interception trap 7B	Aug-Sep	4	N
	Indet. sp. 2	Malaise trap M3, M1 & R3	Nov-Feb	3	N
Click beetles	**Elateridae**				
	Lomenus similis	Malaise trap in Mature 3	Dec-Jan	4	N
	Metablax acutipennis	Malaise & Light traps in M3	Jan-Feb	7	N
	Panspoeus guttatus	Malaise trap in M3	Nov-Feb	8	N
	Unidentified sp. 1	Malaise trap in M3	Nov-Dec	4	N
	Unidentified sp. 2	Malaise trap in M3	Nov-Dec	11	
	Unidentified sp. 3	Malaise trap in R3	Jan-Feb	7	
	Unidentified sp. 4	Caught outside PCRP office	25/10/12	1	N
Minute beetles	**Clambidae**				
	undet. sp.	Pitfall M2A	Dec-Jan	1	
Checkered beetles	**Cleridae**				
	Phymatophaea sp.				
Ladybirds	**Coccinellidae**				
	Undet . sp. 1	Malaise traps		1	
	Undet . sp. 2	Malaise traps		2	
	Undet . sp. 3	Malaise traps		1	
	Undet . sp. 4	Malaise traps		1	
	Undet . sp. 5	Malaise traps		2	
	Undet . sp. 6	Malaise traps		2	
	Undet . sp. 7	Malaise traps		17	
	Undet . sp. 8	Malaise traps		1	
11-spot ladybird	*Coccinella undecimpunctata*	Malaise trap in M3	Dec-Jan	1	
Silken fungus beetles	**Cryptophagidae**				
	Undet . sp. 1	Malaise traps in R3	Jul-Dec	8	
	Undet . sp. 2	Malaise traps in R3 & M3	Oct-Dec	3	
	Undet . sp. 3	Malaise trap in M3	Nov-Dec	1	
Weevils	**Curculionidae**				
	Adstantes rudis	Malaise trap in M3, R3, M1	Oct-Mar	5	N
	Agacalles undet. sp.	Leaf litter M7	12/2/13	1	N
	Andracalles undet. sp.	Malaise trap R3	Nov-Mar	2	N
	Bantiades undet. sp.	Leaf litter M4	30/12/12	1	N
	Bradypatae undet. sp.	Pitfall trap in Mature 1	Dec-Jan	4	N
	Catoptes sp. nr. *coronata*	Malaise trap in Mature 1	Dec-Jan	3	N
	Clypeolus undet. sp.	Pitfall M1 & M2	Dec-Jan	2	N
	Crisius undet. sp. 1	Pitfall U4 & M6	Dec-Jan	2	N
	Crisius undet. sp. 2	Pitfall U4	Dec-Jan	1	N
	Cuaeopteris conicus	Feeding on wood M1 & M5	Dec-Feb	3	N
	Dendrotrupes vestitus	Malaise trap in Mature 3	Dec-Jan	1	N
	Didymus undet. sp.	Malaise trap in M3 & R3	Dec-Jan	5	N
	Etralis spinicollis	Malaise trap in M3 & R3	Oct-Dec	7	N
	Geochus tibialis	Leaf litter M3 & Pitfalls in Ms	Dec-Feb	8	N
	Hoplophaphus spinifer	Malaise trap in Mature 3	Dec-Feb	4	N
	Liromus pardulis	Malaise trap in M1 & M3	Dec-Jan	2	N

	Lithocia undet. sp.	Leaf litter in M2	5/2/13	1	N
	Mandolatus undet. sp.	Pitfall in R3	Dec-Jan	7	N
	Mesoreda undet. sp.	Malaise trap R3	Dec-Jan	2	N
	Metacalles undet. sp.	Leaf litter M4	30/12/12	1	N
	Neocylon metrosideros	Malaise trap R3	Dec-Jan	15	N
	Nestrius undet. sp.	Leaf litter M2, M5, M1	Feb	5	N
	Pactola variabilis	Malaise trap in Mature 3	Oct-Jan	4	N
	Psephelax sulcatus	Malaise & Intercep trap in M3	Aug-Feb	13+	N
	Rhicnobelus metallicus	Malaise trap in Mature 3	Oct-Nov	1	N
	Rhinorhynchus rufulus	Malaise M3 & R3	Oct-Feb	4	N
	Scolopterus tetracanthus	Malaise trap in Mature 1	-12/1/12	1	N
	Sharpius brouni	Malaise trap in R3	Oct-Nov	1	N
	Stephanorhynchus atelaboides	Malaise trap in M3 & R3	Dec-Jan	2	N
	Strongylopterus hyloboides	Malaise trap in Mature 3	Dec-Jan	1	N
	Synaculles indet. sp.	Malaise trap in Mature 3	Oct-Nov	1	N
	Zeacalles undet. sp.	Leaf litter M4	30/12/12	1	N
Water beetles	**Dryopidae**				
	Parnida agrestis	Pitfall in M3	Dec-Jan	1	N
Fungus beetles	**Erotylidae**				
	Cryptodacne synthetica	Pitfall in M1 & M4	Dec-Jan	2	N
	Loberus ?depressus	Ex. Flax sheath in M4	3/8/12	3	N
Water beetle	**Hydraenidae**				
	Undet . sp.	Aquatic sampling	11/1/12		N
Water scavenger beetles	**Hydrophilidae**				
	Undet . sp. 1	Pitfall trap M4E	Dec-Jan	2	
	Undet . sp. 2	Pitfall trap M3C	Dec-Jan	1	
Minute brown scavenger beetles	**Latridiidae**				
	Undet . sp. 1	Malaise traps		6	
	Undet . sp. 2	Malaise traps		2	
	Undet . sp. 3	Malaise traps		1	
	Undet . sp. 4	Malaise traps		1	
	Undet . sp. 5	Malaise traps		1	
	Undet . sp. 6	Malaise traps		2	
	Undet . sp. 7	Malaise traps		1	
	Undet . sp. 8	Malaise traps		11	
	Undet . sp. 9	Malaise traps		2	
	Undet . sp. 10	Malaise traps		3	
	Undet . sp. 11	Malaise traps		1	
	Undet . sp. 12	Malaise traps		1	
	Undet . sp. 13	Malaise traps		1	
Round fungus beetles	**Leiodidae**				
	Undet . sp. 1	Malaise traps M3 & R3	Oct-Nov	2	
	Undet . sp. 2	Pitfall traps M5 & M2	Dec-Jan	3	
	Undet . sp. 3	Malaise trap M3	Feb-Mar	1	
	Undet . sp. 4	Malaise traps in M3	Dec-Jan	2	
	Undet . sp. 5	Malaise trap M3	Feb-Mar	1	
	Undet . sp. 6	Malaise & Pitfall traps in M3	Dec-Mar	14	
Stag beetles	**Lucanidae**				
	Geodorcus helmsi	Soil in Mature 2	25/10/12	2	N
False darkling beetles	**Melandryidae**				

	Ctenoplectron vittatum	Malaise trap in Mature 1	Dec-Jan	1	N
	Unidentified sp. 1	Malaise trap M3 & R3	Dec-Jan	2	N
	Unidentified sp. 2	Malaise trap R3	Nov-Dec	2	N
	Unidentified sp. 3	Malaise trap R3	Dec-Jan	2	N
Tumbling flower beetles	**Mordellidae**				
	Mordella promiscua	Malaise trap in Mature 3	Nov-Jan	4	N
Hairy fungus beetles	**Mycetophagidae**				
	Unidentified sp. 1	Malaise trap M3	Dec-Jan	4	N
	Unidentified sp. 2	Malaise trap M3	Nov-Dec	2	N
Sap beetles	**Nitidulidae**				
	Epuraea sp.	Interception trap 7B in M3	Aug-Sep	1	N
	Soronia asperella	Pitfall R5A	Dec-Jan	1	N?
Lax beetles	**Oedemeridae**				
	Thelythassa lineata	Malaise trap in R3	Dec-Feb	3	N
	Thelythassa memoralis	Malaise trap in M3 & R3	Nov-Jan	6+	N
Wedge shape beetles	**Rhipiphoridae**				
	Rhipistena lugubris	Malaise M3	Dec-Jan	1	N
Chafers	**Scarabidaeidae**				
	Odontria australis	Malaise trap in M3	Jul-Aug	many	N
	Odontria indet sp.	M6 Interceptor trap 9A	-23/9/12	1	N
Kanuka beetle	*Pyronota* sp.	Pitfall trap in R3	Dec-Jan	1	N
	Sericospilus sp.	Malaise trap R3 & M3	Jan-Feb	2	
Dung beetles	*Saphobius edwardsi*	R3A & M pitfalls esp. M4	-11/1/12	common	N
	Saphobius lesnei	M site pitfalls			
	Saprosites sp.	Pitfalls in U1 & U2	Dec-Jan	common	N
	Scraptiidae				
	Unidentified sp. 1	Malaise traps in M3 & R3	Oct-Dec	4	N
Marsh beetles	**Scirtidae**				
	Undet . sp. 1	Pitfall & Malaise		6	
	Undet . sp. 2	Malaise traps		4	
	Undet . sp. 3	Malaise traps		2	
	Undet . sp. 4	Malaise traps		1	
	Undet . sp. 5	Malaise traps		2	
	Undet . sp. 6	Malaise traps		3	
	Undet . sp. 7	Malaise traps		9	
	Undet . sp. 8	Malaise traps		10	
	Undet . sp. 9	Malaise traps		5	
Flat bark beetles	**Silvanidae**				
	Cryptomorpha brevicornis	Wooden disc U3C	12/1/12	1	
Rove Beetles	**Staphylinidae**				
	Undet . sp. 1	Pitfall traps at most sites	Jan&Aug	9	
	Undet . sp. 2	Malaise traps in M3	Dec-Feb	2	
	Undet . sp. 3	Malaise traps in M3	Feb-Mar	2	
	Undet . sp. 4	Leaf litter in M1	2/12/12	2	
	Undet . sp. 5	Pitfall in M1B	Dec-Jan	2	
	Undet . sp. 6	Leaf litter in M1	2/12/12	1	
	Undet . sp. 7	Pitfalls in U3 & M7	Dec-Jan	2	
	Undet . sp. 8	Pitfall in M7B	Dec-Jan	1	
	Undet . sp. 9	Pitfall in M1B	Dec-Jan	1	
	Undet . sp. 10	Pitfall M7 and Malaise M3	Nov-Jan	6	
	Undet . sp. 11	M3 intercept trap & M7 pitfall	Aug-Jan	2	
	Undet . sp. 12	Pitfall in M1B	Dec-Jan	1	
	Undet . sp. 13	Pitfall R7C	Dec-Jan	1	

	Undet . sp. 14	Pitfalls in M3	Dec-Jan	3	
	Undet . sp. 15	Pitfall in U4	Dec-Jan	1	
	Undet . sp. 16	Leaf litter in M1 & Pitfall R7	2/12/12	3	
	Undet . sp. 17	Pitfall M3E	Dec-Jan	1	
	Undet . sp. 18	Pitfall R7D	Dec-Jan	1	
	Undet . sp. 19	Pitfall in M1B	Dec-Jan	1	
	Undet . sp. 20	Malaise trap in R3	Dec-Jan	1	
Darkling beetles	**Tenebrionidae**				
	Periatrum helmsi	Leaf litter in M4 & M1	Dec- Feb	3+	N
Ironclad beetles	**Zophoridae**				
	Notocoxelus sp.	Pitfalls in M1, M3, R2	Dec-Jan	3	N
	Unidentified sp. 1	Leaf litter	Feb	1	N
	Unidentified sp. 2	Pitfall trap M5 F	Dec-Jan	1	N
DRAGONFLIES	**ODONATA**				
Smiths dragonfly	*Procordulia smithii*	Swept near 2nd bridge	11/1/12	common	N
Blue-spotted hawker	*Aeshna brevistyla*	Swept near 2nd bridge	11/1/12	common	N
Blue damselfly	*Austrolestes colensonis*	Swept near 2nd bridge	11/1/12		N
Red damselfly	*Xanthocnemis zealandica*	Swept near 2nd bridge	11/1/12		N
Stick insects	**Phasmidatidae**				
	Acanthoxyla sp.	Mature 3	12/1/12		N
BUGS	**HEMIPTERA**				
	Aradidae	M1 leaf litter & soil (with ants)			
Spittle bug	*Carystoterpa ?vagans*	R3 Malaise trap	22/2/13	1	N
	Diomocornis sp.	Ex. *Grisilina*	19/10/12	1	
	Myerslopia sp.	M1 leaf litter	Dec2012	1	
	Rhopalimorpha ?obscura	U5 soil	17/1/13	1	
Planthopper	Cixiidae	M3 Malaise trap	22/2/13	1	
SPIDERS	**ARANEAE**				
	Allotrochosina schauinslandi	U2 worm sampling	15/1/13		
	Anoteropsis adumbrata	Open grassland sites	-11/1/12	common	N
	Arachnura feredayi				E
	Cambridgea foliata	Weta motel	8/11/12	common	
Trap door spider	*Cantuaria* sp.				
	Clubiona huttoni	Malaise Trap M3	-8/11/12	common	N
	Clubiona peculiaris	Malaise Trap M3	-23/1/13		
	Diaea sp.	Malaise Trap M3	-3/10/12		
Nursery web	*Dolomedes minor*	Grassland, gorse, open sites	-11/1/12	common	N
	Haplinis sp.				?
	Meta rufolineata	Under Scotsmans Bridge	11/1/12		?
	Orsinome lagenifera	Under Scotsmans Bridge	11/1/12		N
Funnel web	*Porrhothele antipodiana*	Malaise trap in Mature 3	3/10/12		N
	Segrestridae -unknown genus	Malaise Trap R3	-8/11/12		
	Sidymella sp.	Pitfall traps	-11/1/12		N
	Tetragnatha sp.	Malaise trap	-8/11/12		
	Theridiidae – unknown genus	Pitfalls			
	Zealaranea trinotata	Malaise Trap M3	-23/1/13		
HARVESTMAN	**OPILIONES**				
	Black long legged	Pitfall traps	-11/1/12		N
	Short legged brown	Pitfall traps	-11/1/12		N
	Pantopsalis luna	Pitfall traps			
Mite-like harvestman	*Aoraki denticulata*	M1 litter & M1 & M6 pitfalls	2/12/11	common	N

WETA, CICADAS	**ORTHOPTERA**				
Wellington tree weta	*Hemideina crassidens*	Weta motels R1 and M1+		common	N
Cave weta	*Talitropsis sediloti*				N
Ground weta	*Hemiandrus* n. sp.	Malaise trap (1 & 3)	-12/1/12	common	N
	Pleiopletron n. sp.				
Chorus cicada	*Amphipsalta zelandica*	On trees in R1 during summer	2013	common	N
COCKROACHES	**BLATTODEA**				
	Celatoblatta vulgaris	Foam wraps, lizard lodges		common	N
WASPS, ANTS	**HYMENOPTERA**				
Spider egg parasite	*Baus* sp.	Pitfall traps	-11/1/12	common	N
	Diapriidae indet. sp.	Pitfall traps		common	
Spider wasps	*Priocnemis* sp.	Malaise trap in Mature 1	-12/1/12		N
Ants	**Formicidae**				
	Huberia brounii	Pitfall traps			
Striated ant	*Huberia striata*	Pitfall traps			
	Pachycondyla castaneicolor				
	Prolasius advenus				
FLIES	**DIPTERA**				
Robber flies	**Asilidae**				
Robber fly	Unidentified sp.	Caught mating on flower		common	N
Humped-back flies	**Phoridae**				
	Species 1	Pitfall traps	-11/1/12	common	N
	Species 2	Pitfall traps	-11/1/12	common	N
Black fly/Sand fly	**Simuliidae**				
	Austrosimulium sp.	Aquatic sampling	11/1/12	common	N
Hoverfly	**Syrphidae**				
	Allograpta sp. 1	Malaise trap	-12/1/12	2	N
	Allograpta sp. 2			2	
Large hoverfly	*Melangyna novaezelandae*	Photographed	20/2/13		
Midges	**Chironomidae**				
	Paradixa sp.	Aquatic sampling	11/1/12		N
Craneflies	**Tipulidae**				
	Acantholimnophila cf *maorica*	Malaise trap in M3	-23/2/13		
	Amphineurus cf *hudsoni*	Trap	Dec-Jan		
	Amphineurus cf *insulsus*	Trap	Dec-Jan		
	Amphineurus cf *senex*	M1			
	Atarba cf *filicornis*	M1			
	Austrolimnophila argus	Interceptor trap 5B	-24/9/12		
	Austrolimnophila cf *atripes*	Interceptor trap 5B	-24/9/12		
	Chlorotipula **not** *viridis*	Trap	Dec-Jan		
	Discobola cf *giberrina*	Malaise trap in M3	-7/3/13		
	Gynoplistia sp.	Trap	Dec-Jan		
	Gynoplistia cf *dispiloides*	M1			
	Leptotarsus cf *alexanderi*	Trap	Dec-Jan		
	Leptotarsus cf *huttoni*	Malaise trap R3	-21/1/13		
	Leptotarsus cf *sinclairi*	Malaise trap in M3	-7/3/13		
	Limonia sp.	Trap	Dec-Jan		
	Limnophilella serotina	Trap	Dec-Jan		
	Molophilus sp.	M1			
	Zelandoglochina cf *cubitalis*	Malaise trap in M3	-23/2/13		
	Zelandoglochina melanogramma	Malaise trap in R3	Dec-Jan		

Native bird species

Taxonomic Name	Maori Name	Common Name
Anthornis melanura	Korimako	Bellbird
Eudyptula minor	Kororā	Blue penguin
Rhipidura fuliginosa	Pīwakawaka or Tīwakawaka	Fantail
Gerygone igata	Riroriro	Grey Warbler
Hemiphaga novaeseelandiae	Kereru	Wood pigeon
Porphyrio porphyrio melanotus	Pukeko	Purple Swamphen
Chroicocephalus scopulinus	Tarapunga or Akiaki	Red billed Gull
Chrysococcyx lucidus	-	Shining Cuckoo
Zosterops lateralis	Tauhou	Silvereye/Waxeye
Vanellus miles	-	Spur-winged Plover
Prosthemadera novaeseelandiae	Tui	Parson bird
Gallirallus australis	Weka	-
Procellaria westlandica	Tāiko	Westland black petrel

Exotic bird species

Taxonomic Name	Maori Name	Common Name
Turdus merula	-	Blackbird
Fringilla coelebs	-	Chaffinch
Carduelis carduelis	-	Goldfinch
Carduelis chloris	-	Green finch
Prunella modularis	-	Hedge sparrow/Dunnock
Passer domesticus	-	House sparrow
Carduelis flammea	-	Redpoll
Alauda arvensis	-	Skylark
Turdus philomelos	-	Song thrush

Aquatic vertebrate

Taxonomic name	Maori name
Galaxias fasciatus	Banded kokopu
Galaxias argenteus	Giant kokopo
Galaxias maculatus	Inanga
Anguilla australis	Shortfinned eel

Pest mammals

Taxonomic name	Common name
Trichosurus vulpecula	Brushtail possum
Mustela erminea	Stoat
Rattus spp.	Rat
Mus musculus	Mouse
Capra hircus	Goat

PCRP planted native floral species

Taxonomic name	Maori name	Common name
Aristotelia serrata	Makomako	Wineberry
Astelia solandri	Kowharawhara	Swamp Astelia
Carex secta	Makuru	Pukio
Carpodetus serratus	Putaputaweta	Marbleleaf
Coprosma grandifolia	Kanona	-
Coprosma lucida	Karamu*	-
Coprosma propinqua	Mingimingi	-
Coprosma robusta	Karamu*	-
Cordyline australis	Ti Kouka	Cabbage Tree
Cortaderia richardii	Toetoe	-
Cyperus ustulatus	Toetoe, Upoko-Tangata	Giant Umbrella Sedge, Coastal Cutty Grass
Dacrycarpus dacrydioides	Kahikatea	-
Dodonaea viscosa	Akeake	-
Fuchsia excorticata	Kotukutuku	Tree fucshia
Fuchsia procumbens	-	Creeping Fuchsia
Griselinea lucida	Puka, Akapuka	Shining Broadleaf
Hebe salicifolia	Koromiko	-
Hedycarya arborea	Porokaiwhiri	Pigeon Wood
Hoheria sexstylosa	Houhere	Lacebark
Macropiper excelsum	Kawakawa	-
Melicytus ramiflorus	Mahoe	Whiteywood
Metrosideros robusta	Rātā	Northern Rata
Myrsine australis	Mapou	Red Matipo
Myrsine salicina	Toro	-
Olearia avecenafolia	-	Oleria
Phormium tenax	Harakeke	Flax
Pittosporum eugenoides	Tarata	Lemon Wood
Pittosporum tenuifolium	Kohuhu/Kohukohu	Black Mapou

Podocarpus totara	Totara	-
Pseudopanax crassifolius	Horoeka	Lancewood
Rhopalostylis sapida	-	Nikau palm
Schefflera digitata	Pate	Seven Finger
Sophora microphylla	Kowhai	-
Weinmannia racemosa	Kamahi	-

Non-planted native floral species of the PCRP and Nikau Scenic Reserve

Taxonomic Name	Maori Name	Common Name
Acaena anserinifolia	Piripiri	Bidibid
Anarthropteris lanceolata	-	Lance fern
Ascarina lucida	-	
Asplenium bulbiferum	-	Hen & chickens fern
Asplenium flaccidium	-	Drooping spleenwort
Asplenium polyodon	Petako	-
Astelia solandri	-	-
Blechnum capense	-	-
Blechnum chambersii	-	-
Blechnum colensoi	-	-
Blechnum novae-zelandiae	Kiokio	-
Callistriche stagnalis	-	-
Calystegia tuguriorum	Powhiwhi	Native bindweed
Carex dissita	-	Carex bush sedge
Carex geminate	-	-
Carex maorica	-	-
Carex subdola	-	-
Carex virgata	-	-
Carpodetus serratus	Putaputaweta	Marbled leaf
Clematis paniculata	-	-
Collospermum hastatum	-	-
Coprosma areolata	-	-
Coprosma australis	-	-
Coprosma rhamnoides	-	-
Coprosma robusta x C. propinqua	-	-
Coprosma rotundifolia	-	-
Coprosma spathulata	-	-
Coprosma tenuicaulis	-	-
Coriaria arborea	-	-
Corybas trilobus	-	-
Cyathea medullaris	Mamaku	Black fern
Cyathea smithii	Katote	Soft tree fern
Cyathodes juniperina	-	-

Dacrydium cupressinum	Rimu	-
Dianella sp.	-	-
Dicksonia squarrosa	Wheki	-
Earina autumnalis	-	-
Elaeocarpus dentatus	-	-
Freycinetia banksii	Kiekie	-
Fuchsia perscandens	-	-
Galium palustre	-	marsh bedstraw
Griselinia littoralis	-	-
Haloragis erecta	Toatoa	Shrubby Haloragis
Histiopteris incisa	-	Water fern
Hoheria ovata	-	-
Hoheria sextylosa	-	Lacebark
Hydrocotyle novae-zelandiae	-	-
Hymenophyllum revolutum	-	-
Hymenophyllum scabrum	-	-
Hypolepis spp.	-	-
Juncus canadensis	-	-
Lastreopsis hispida	-	-
Lindsaea trichomanoides	-	-
Loxogramme dictyopteris	-	-
Lycopodium billardieri	-	-
Metrosideros diffusa	-	Rata vine
Metrosideros fulgens.	-	-
Metrosideros perforata	-	Rata vine
Metrosideros robusta	-	Northern rata
Microlaena avenacea	-	-
Microsorum pustulatum	Kowaowao	Hound's tongue
Microsorum scandens	-	Fragrent fern
Muehlenbeckia australis	-	-
Muehlenbeckia axillaris	-	-
Myriophyllum propinquum	-	-
Parsonia heterophylla	-	New Zealand jasmine
Phymatosorus diversifolius	-	-
Pittosporum colensoi	-	-
Polystichum richardii	-	-
Potamogeton cheesemanii	-	-
Prumnopitys ferruginea	-	-
Prumnopitys taxifolia	Matai	-
Pseudopanax discolor	-	-
Pseudowintera axillaris	Horopito	Pepper tree
Pyrrosia eleagnifolia	-	Leather-leaf fern
Ranunculus rivularis	-	-
Rhipogonum scandens	-	-
Ripogonum scandens	Kareao	Supplejack
Rubus australis	-	Swamp lawyer

Rubus cissoids	-	-
Rubus schmidelioides	Tataramoa	Bush lawyer
Rumohra adiantiformis	-	Climbing shield fern
Schefflera digitata	Pate	-
Scirpus nodosus	-	-
Scirpus reticularis	-	-
Selaginella sp.	-	-
Senecio minimus	-	-
Solanum nigrum	-	-
Tmesipteris spp.	-	-
Trichomanes reniforme	-	-
Typha orientalis	-	-
Uncinia uncinata	-	-
Metrosideros diffusa	-	-
Metrosideros perforata	-	-
Microlaena avenacea	-	-
Microsorum pustulatum	-	-
Microsorum scandens	-	-
Muehlenbeckia australis	--	-
Muehlenbeckia axillaris	-	-
Myriophyllum propinquum	-	-
Parsonia sp.	-	-
Phymatosorus diversifolius	-	-
Pittosporum colensoi	-	-
Polystichum richardii	-	-
Potamogeton cheesemanii	-	-
Prumnopitys ferruginea	-	-
Prumnopitys taxifolia	Matai	-
Pyrrosia eleagnifolia	-	-
Ranunculus rivularis	-	-
Rhipogonum scandens	-	-
Rubus cissoids	-	-
Rumohra adiantiformis	-	-
Scirpus nodosus	-	-
Scirpus reticularis	-	-
Selaginella sp.	-	-
Senecio minimus	-	-
Streblus heterophyllus	Turepo	Small-leaved milk tree
Tmesipteris spp.	-	Fork fern
Trichomanes reniforme	-	-
Trichomanes venosum	-	-
Typha orientalis	-	-
Uncinia uncinata	-	-

Appendix II

Glossary of plant species abbreviations

Abreviation	Scientific name
ACA ans	*Acaena anserinifolia*
ANA lan	*Anarthropteris lanceolata*
ARI ser	*Aristotelia serrata*
ASP bul	*Asplenium bulbiferum*
ASP fla	*Asplenium flaccidum*
ASP pol	*Asplenium polyodon*
BLE nov	*Blechnum novae-zelandiae*
CAL tug	*Calystegia tuguriorum*
CAR dis	*Carex dissita*
CAR ser	*Carpodetus serratus*
CLE pan	*Clematis paniculata*
COP gra	*Coprosma grandifolia*
COP luc	*Coprosma lucida*
COP pro	*Coprosma propinqua*
COP rob	*Coprosma robusta*
COP hyb	*Coprosma robusta x C. propinqua*
COP rot	*Coprosma rotundifolia*
COP spa	*Coprosma spathulata*
COR aus	*Cordyline australis*
CYA med	*Cyathea medullaris*
CYA smi	*Cyathea smithii*
DAC dac	*Dacrycarpus dacrydioides*
DAC cup	*Dacrydium cupressinum*
DIC squ	*Dicksonia squarrosa*
DOD vis	*Dodonaea viscosa*
FRE ban	*Freycinetia banksii*
FUC exc	*Fuchsia excorticata*
GRI lit	*Griselinia littoralis*
GRI luc	*Griselinia lucida*
HEB sal	*Hebe salicifolia*
HED arb	*Hedycarya arborea*
HIS inc	*Histiopteris incisa*
HOH sex	*Hoheria sextylosa*
HYM rev	*Hymenophyllum revolutum*
HYM sca	*Hymenophyllum scabrum*
LIN tri	*Lindsaea trichomanoides*
LYC bil	*Lycopodium billardieri*

MEL ram	*Melicytus ramiflorus*
MET dif	*Metrosideros diffusa*
MET per	*Metrosideros perforata*
MET rob	*Metrosideros robusta*
MIC pus	*Microsorum pustulatum*
MIC sca	*Microsorum scandens*
MYR aus	*Myrsine australis*
MYR sal	*Myrsine salicina*
OLE avi	*Olearia avicennifolia*
PAR het	*Parsonsia heterophylla*
PHO ten	*Phormium tenax*
PIT ten	*Pittosporum eugenioides*
PIT eug	*Pittosporum tenuifolium*
POD tot	*Podocarpus totara*
PSE cra	*Pseudopanax crassifolius*
PSE dis	*Pseudopanax discolor*
PSE axi	*Pseudowintera axillaris*
PYR ela	*Pyrrosia elaeagnifolia*
RHO sap	*Rhopalostylis sapida*
RIP sca	*Ripogonum scandens*
RUB aus	*Rubus australis*
RUB fru	*Rubus fructicosa*
RUB sch	*Rubus schmidelioides*
RUM adi	*Rumohra adiantiformis*
SCH dig	*Schefflera digitata*
SOL nig	*Solanum nigrum*
SOP mic	*Sophora microphylla*
STR het	*Streblus heterophyllus*
TME sp.	*Tmesipteris* sp.
TRI ven	*Trichomanes venosum*
WEI rac	*Weinmannia racemosa*

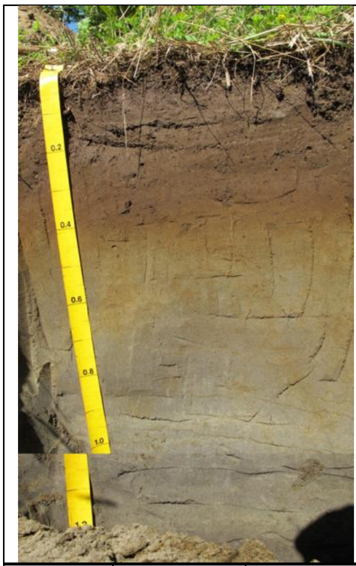
Appendix III

Soil pit descriptions

Survey:PCRP	Pit Code:M1	Date:21/1/13	Author: Jason
GR:42.14411 S 171.33073 E	Images:3349-48 3358-59	Within Nikau Reserve	ELEVATION 18m LOCATION 093

Ah	0-20cm	10YR 3/1 Silt loam Moderately developed crumb structure Peds 1-2cm breaking to 5mm Strength- very weak deformable. Non-indurated Slightly sticky Plastic 10% roots common extremely fine. Few fine. Few medium Indistinct boundary
Bw1	20-40cm	10YR3/1 Sandy loam Structure weak/blocky peds 3cm breaking to 0.5cm very weak very friable non-indurated slightly sticky plastic slightly fluid rounded rod / rounded rod clasts 9cm Fresh to slightly weathered granite (sample)rounded rod 2cm sandstone / Positive Liquefaction test < Bw2 Indistinct boundary
Bw2	40-55	10YR 3/2 loamy sand Single grain structure rounded rod 7cm slightly weathered (sample) Very weak Brittle Friable Very weak induration Slightly sticky non-plastic, slightly fluid Roots 1%coarse 1%microfine roots indistinct boundary
C	55+	10Yr 3/2 sand Single grain structure Very weak Brittle Very weak induration Non-sticky Non-plastic Non-sensitive 1% extremely fine roots

Survey:PCRP	Pit Code:R1	Date:21/1/13	Author:CS
GR:42.14363 S 171.33060 E	Images: 3353-57	Aka "mature forest" Samples per horizon	ELEV: 16m LOCATION (092)



Ah	0-18cm	10YR3/3 Fine sandy loam Moderately to strongly developed crumb structure 2cm dia Weak strength friable Very weak induration Moderately plasticSlightly sticky Peds blocky 1-0.5cm Rare rounded 0.5-1cm clasts Quartz- slightly discoloured No mottling Roots 2-5% in root mat at top Roots-microfine 5% Diffuse boundary. Smooth.
Bw	18- 38cm	10yr3/3 sandy loam Moderate sub-angular blocky structure 2cm peds Breaking to <5mm weak strength Brittle/(friable) slightly plastic Rare skeletal- rounded strongly discoloured 5cm-1cm pitted sandstone Roots-2% Very fine Boundary to BC diffuse to occluded smooth & occasional
BC(f)	38- 53cm	10yr3/6 sand Apedal single grain no skeletal inclusions Very weak structure Very friable Non-indurated Non-sticky Worm burrows (10YR 3/3 Mottling fine faint med – coarse distinct Roots-2% Very fine Boundary to C diffuse to occluded 10%
C	53cm-	5Y 4/2 Single grained very weak very friable Non-indurated Non-plastic Mottling very few fine faint (10YR 4/4) Roots between 50-60cm – 1-2% very fine 10YR 4/4 Fe staining layers Fe stains between 80-100cm 1.2m+ darker ilmenite (3352)

Survey:PCRP	Pit Code:U1	Date:22/1/13	Author:Jason
GR:42.14133 S 171.33080	Images:-3396 Photos 3392-	Fm between 2BC and 2C :refer p101	LOCATION 094

	3384(profile)	not numbered	

Ah	0-10	10YR 3/2(fine sand)silt loam (ZL) Medium to strongly developed crumb structure 2cm blocks break to 0.5cm Weak friable strength Non-indurated, slighty sticky 5% extremely fine & 1%microfine roots Boundary- smooth and abrupt
Bw(g)$_1$	10- Varies 22/33	10YR 3/2 Sandy loam (SL) blocky 4cm break to 0.5cm Brittle fracture Weak strength Very weak induration Slightly sticky Non-plastic Mottle-2.5YR 2.5/4 Few(5%) very fine and distinct Roots – 1% microfine Boundary Bfm1
Bfm$_1$	33	2.5YR 3/6 to 2.5/4 Boundary – wavy sharp
Bw(g)$_2$	34-45	10 YR 3/2 Sandy loam Blocky structure weak brittle Very weak induration Slightly sticky Non-plastic Limestone and Granite gravels Mainly in top half of horizon Rounded to well rounded disk 6cm to <1cm some iron concretion coating rare ghosts Mottles 2.5YR2.5/4 very few extremely fine in top half of horizon Roots 1% microfine Boundary Bfm2
Bfm$_2$	45	2.5YR 3/6 Boundary – wavy sharp

2Bw	46?-60	10YR3/3 Loamy sand Single grain structure Strength weak to slightly firm Brittle to very weak induration Non sticky Non plastic Granite to Sandstone rock is well rounded 2cm-1cm rare 5cm very slightly gravely Fresh to slightly weathered very rare ghosts 1cm sandstone No mottles Roots 1%-<1%
2BC	60-110cm	2.5Y3/3 Sand (S) Strength weak to very weak Brittle Non-indurated Non-sticky Non-plastic Mottles 5YR3/4 Very few Extremely fine Faint No roots
fm	105-108??	2.5YR 3/6 Boundary wavy distinct
2C	110-160	2.5Y4/1 Sand Single grain structure Weak strength Friable Non-indurated Non-Plastic Non-sticky No clasts Many fine horizontal laminations Wavy <1cm Distinct to prominent contrasts Illminite 2.5Y3/1 Iron staining 7.5YR ¾ Distinct laminate illminite at base Boundary Wavy sharp
?2b3fm	160?	2.5YR 3/6

Survey: PCRP	Pit Code:M2	Date:14/3/13	Author: Jason
GR: Not noted 	Images: 1186-1209	GPS'd as Soil Pit M2 photos	

1 Ah	0-13cm	10YR2/3 Loamy silt Moderate to well developed crumb 3cm breaking to 2mm Strength weak Friable Non-indurated Non-sticky Non-plastic No mottles Roots 1%Fine 2%Very fine 5%Microfine Boundary diffuse smooth
2	13-31cm	10YR3/2 Loamy silt Moderate to well developed crumb 3cm breaking to 2mm Weak Friable Non-indurated Non-sticky Non-plastic 18cm - One large stone 25cm long 12cm thick unknown width at No mottles Roots 1%Very fine 2%extremely fine Boundary Indistinct smooth
3	31- Varies45/50cm	10YR4/2 Loamy silt Moderate to well developed 3cm breaking to 2mm Strength Weak Friable Non-indurated Non-sticky Non-plastic 25% greywacke 1.5 x 2.5cm to 10x8cm Mottles 5% 5YR4/6 Roots 2%extremely fine 1%microfine Boundary sharp wavy
4 Bfm	Varies 50- 51/45-46cm	2.5YR3/6 and 2/1 Sand Well developed Very firm Brittle Non-sticky Non-plastic Weakly indurated No mottles No roots Boundary Sharp wavy
5	Varies 46- 70/50-60cm	10YR3/4 Sand Single grain Weak Friable Non-indurated Non-sticky Non-plastic Greywacke Rounded column shaped 2.5x3 cm to 2.5x5cm Mottles 5%2.5YR4/8 Roots 1%extremely fine Boundary Distinct wavy

6	Varies Lensoid Pinches out at 70 / 60-72cm	10YR4/2 Sand Moderate to well developed blocky crumb 3cm breaking to 4mm Slightly firm Friable Non-indurated Non-sticky Non-plastic Mottles 50%2.5YR5/8 and 3/4 Boundary Abrupt wavy
7	Varies Lensoid pinches out at 70/ 72-89cm	10Yr4/1 Sand Single grain Weak Friable Non-indurated Non-sticky Non-plastic Mottles 2%5YR5/8 Boundary Sharp wavy
8 Bfm	Varies 70-80/78-81cm	5Yr4/6 and 2/1 Well developed Firm Brittle Non-sticky Non-plastic Weakly indurated No mottles Boundary Sharp wavy
9	Varies 72-80/81-92cm	7.5YR4/4 Sand Single grain Weak Friable Non-indurated Non-sticky Non-plastic No mottles Boundary Indistinct wavy
10	Varies 80/92-110cm	10YR3/2 Sand Single grain Weak Friable Non-indurated Non-sticky Non-plastic

Survey: PCRP	Pit Code: U2	Date:23/1/13	Author: Jason
GR:42.14156 S 171.32953 E  	Images: 3494-3498	Large log at 70cm 6cm diameter Fibrous root matter and roots at 85cm Waiwhero soil type	LOCATION 103 ELEVATION 10m

Ah	0-5cm	10YR3/2 Silt loam Moderate to well developed crumb 2cm breaking to 5mm Very weak Friable Non-indurated Slightly sticky and Plastic Roots 5%very fine Boundary abrupt smooth
Bw(f)$_1$	5-25cm	10YR4/2 Sandy loam Well developed block 3cm breaking to 5mm Strength Very weak Brittle Non-indurated Non-sticky Non-plastic 5cm Concretion at 20cm depth Mottles 5YR3/4 5% extremely fine faint Roots 2% extremely fine 1%microfine Boundary abrupt smooth
bAh	25-27cm	7.5YR3/1 Too thin to test but looks organic Horizon indicated by root traces and colour and faint features Mottles 10YR3/6 Boundary abrupt smooth

bBw(f)$_2$	27-70cm	7.5YR3/1 Loamy sand Weakly developed block 2cm breaking to 1cm Strength Very weak Brittle Non-indurated Non-sticky Non-plastic Large Greywacke clast 10cm at 40cm depth 1% 2cm sub-rounded to well rounded Quartz Mottles 5YR3/4 10%extremely fine faint to prominent coarse Roots 1%microfine Boundary Abrupt wavy
2bAh	Varies Lensoid 58-70cm	10YR2/2 Sandy loam Blocky well developed 3cm breaking to 1cm Very weak + Friable Non-indurated Slightly sticky Plastic No mottles Roots 10% medium fibrous Boundary abrupt smooth
2bBw	70-80cm	10YR3/2 Sandy loam Moderately developed blocky 1-2cm Very weak + Friable Non-indurated Slightly sticky Plastic Roots 2%microfine 2%extremely fine Boundary abrupt smooth
2bBC	80-83cm	2.5YR3/1 Sand Single grain very weak Friable Non-indurated Non-sticky Non-plastic Roots 2%extremely fine 1%Coarse Boundary abrupt smooth
3bBw	Varies 83-90/96cm	10YR2/1 Sandy loam Weak blocky 6cm breaking to 5mm Very weak Brittle Non-indurated Non-sticky Non-plastic Roots 5%microfine 55extremely fine 1%fine Boundary abrupt wavy
3bBC	Varies 90/96-120cm	2.5Y3/2 Sandy loam Mottles 2.5Y4/4 Few Very fine Distinct Roots 2%microfine 2% extremely fine 1%fine Boundary sharp irregular Bfm 2.5YR3/2
3bC	120-130+cm-	No notes

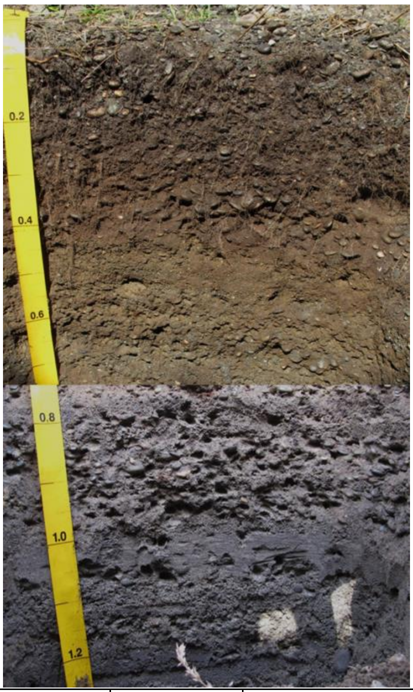
Survey:PCRP	Pit Code:M3	Date:22/1/13	Author:Jason
GR:42.14388 S 171.32669 E 	Images:3442-3 3436-3439 3453-3454		LOCATION 099

SURFACE	0cm	Well rounded disk and blade Very large to small pebbles
Ah	0-30cm	10YR2/1 Silt loam Very weak Friable Non-indurated Slightly sticky Plastic Extremely gravely Small to large well rounded disk and blade pebbles Roots 5%microfine 5%extremely fine 10%very fine 10%medium 2%coarse Boundary wavy abrupt
Bw	30- 80cm	10YR2/2 Gravely No consistence measured as too gravely – Extremely gravely Small to large well rounded disk and blade pebbles to 60cm Moderately gravely small to large well rounded disks and blades pebbles slightly discoloured (iron staining)60-80cm Roots 10%extremely fine 5%very fine 2%coarse Boundary wavy sharp
C	80-100+	2.5Y3/2 Sand Strength very weak Very friable Non-indurated Non-sticky Non-plastic 80-95 coarse sand with very slightly gravely small to medium pebbles 95-100 very coarse sand 100+ alternating layers of medium large pebbles and very coarse sand

Survey: PCRP	Pit Code:R3	Date:23/1/13	Author: Carol Smith
GR:42.14356 S 171.32697 E 	Images:3445-3452		LOCATION 100 ELEVATION: refer to GPS

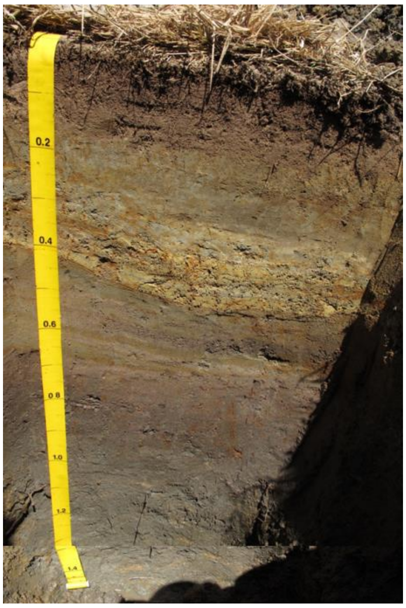
Ah	0-30cm	10YR2/2 Silty sand Well developed crumb structure 3mm peds Very weak Very friable Non-indurated Non-sticky Non-plastic 10% Quartz grains amongst peds Slightly gravely fresh to slightly discoloured Granite Quartz Green (Chlorite?)rounded disks and blades Very large pebbles grading to small to medium pebbles 0-10cm Very large pebbles and small to medium pebbles 10-35cm Medium to large-Medium to small pebbles Roots 10% microfine 5%extremely fine 2%very fine 1%medium Boundary abrupt smooth
Bw	30-50cm	10YR3/4 Loamy sand Very weak development granular/crumbs to single grains adhering with roots and organic matter Very weak Very friable Non-indurated Non-sticky Non-plastic Imbrication varies 10-15% Fe staining /colour in matrix where compressed around clast faces Lithology as before Extremely gravely Iron staining on clasts Medium pebbles 35-50cm Roots 1%microfine 2%extremely fine 1%veryfine Boundary abrupt smooth
BC	50-105cm	7.5YR3/4 Coarse sand Single grain Very weak Very friable Non-indurated Non-sticky Non-plastic 50-60cm Small pebbles 60-70cm Medium to large pebbles in medium to fine sand matrix Fe staining of medium fine sand matrix where compressed against pebble clasts Colour taken from here No roots 70-80cm Coarse sand 80-90cm Small to medium pebbles 90-100cm Large pebbles and Coarse sand

		No roots Boundary distinct smooth
C	105cm+	2.5Y4/2 Sand Single grain Very weak Very friable Non-indurated Non-sticky Non-plastic 100cm + Gravel to Very coarse sand Lithology as before fresh to slightly discoloured No roots

Survey: PCRP	Pit Code:U3	Date:22/1/13	Author: Carol Smith
GR:42.14148 S 171.32727 E 	Images:3423-3435	All clasts imbricated max of 10%-15%	LOCATION 098

Ah	0-10cm	10YR2/2 Coarse sand Moderately developed crumb structure 1cm breaking to 2mm strength very weak Friable Non-indurated Slightly sticky Plastic Slightly gravely well rounded medium pebble disks and blades of fresh Greywacke and slightly weathered Granite Fresh Quartz Boundary abrupt smooth
Bw_1	10-30cm	10YR3/2 Coarse sand Structure weakly developed sub-angular blocky 5mm Strength very weak Very friable Non-indurated Non-sticky Non-plastic Moderately gravely well rounded medium pebble disks and blades of fresh Greywacke and Slightly weathered Granite Roots 10%microfine 1%extremely fine Boundary distinct smooth
Bw_2	30-42	7.5YR3/2 Coarse sand Structure weakly developed sub-angular blocky 5mm Strength very weak Very friable Non-indurated Non-sticky Non-plastic Moderately gravely well rounded medium to large pebble disks and blades of fresh Greywacke and slightly weathered Granite Roots 10% microfine Boundary distinct wavy

BC	42-78cm	10YR4/3 Coarse sand (42-55) to medium to large pebbles (55-70 cm) then medium sand (70-78cm) Single grain very weak Very friable Non-indurated Non-sticky Non-plastic Moderately gravely well rounded medium to large pebble disks and blades of Fresh Greywacke and Slightly weathered Granite Very rare iron staining localised on clasts No roots Boundary distinct wavy
C	78-120cm	2.5Y4/1 Large to Very large pebbles 78-98cm then medium sand 98-102cm then Coarse sand 102cm + Single grain Very weak Very friable Non-indurated Non-sticky Non-plastic Moderately gravely to slightly gravely Well rounded disks and blades of Fresh Greywacke and Slightly weathered Granite Very rare iron staining localised on clasts 80cm -100cm large to very large pebbles No roots Laminations of illminite Shell fragment at 90cm

Survey: PCRP	Pit Code:R4	Date:24/1/13	Author: Carol Smith
GR:42.13781 S 171.32809 E 	Images: 3518-3521	Au in every horizon Fine textured fan deposit 4C 4Bg and soil development 4bBg channel erosion surface alternating layers of sand and organic matter 3bBw(f)-swamp? Erosion surface Fe pan low energy depositional environment –clays infilling gack channel 2Bg Channel overtopped by Aeolian sands – current soil development therein	LOCATION 106 ELEVATION 1m

Ah	0-15cm	10YR3/3 Silt loam Moderately to well developed crumb 3cm breaking to 5mm Friable Non-indurated Lightly sticky Plastic Roots 5%microfine Boundary Abrupt wavy
Bw(g)	Varies 15-30cm	10YR4/3 Loamy sand Weak sub-angular blocky 3cm breaking to <L5mm Strength very weak Brittle Non-indurated Non-sticky Non-plastic Mottles 5YR3/4 low chroma 2.5Y5/2 Common very fine to fine distinct Roots 1%microfine Boundary Sharp wavy
2Bg	Varies 30-52cm	2.5Y6/4 Light clay with silt loam fine sandy at very top Massive Strength very weak &deformable Non-indurated Moderately sticky Very Plastic Mottling 5YR4/6 Low chroma 5Y4/6 Common very fine to fine prominent Few medium prominent Roots 1%microfine Boundary Bfm Sharp wavy

3bBw(f)	Varies 44-70cm	10YR4/2 Sandy loam Single grain Very weak Friable Non-indurated Non-sticky Non-plastic Mottling 2.5Y4/4 lenses Common medium prominent Roots 1%microfine Organic layer silty sandy loam(refer photo for depth) Boundary sharp wavy
4bBg	70-110cm	10YR4/2 Sandy loam Weakly developed blocky 3cm breaking to 1cm Very weak Brittle Non-indurated Slightly sticky and Plastic Mottles 5YR4/6 Few very fine prominent around macropores and old roots channels Boundary distinct wavy
4C	100-120cm	2.5Y4/1 Clay loam Massive Strength Very weak Brittle Non-indurated Slightly sticky and Plastic Roots 1%microfine 1%very fine

Survey: PCRP	Pit Code: U4	Date:24/1/13	Author:
GR:42.13673 S 171.32869 E 	Images: 3539-3541	Eastern wall: pp129 Ilmenite sand at depth Cross bedding visible on Northern Wall if pit Sloping at 7-12-19° Aggrading dune system=occasional hiatus =OM accumulation Fe staining on eastern wall sloping 7° to water –laminations meeting cover Gold flecks throughout the profile	LOCATION 107 ELEVATION 10m

Ah	0-20cm	10YR4/2 Sandy loam Weakly developed crumb 5mm Strength Very weak Friable Non-indurated Non-sticky Non-plastic 7cm depth Slightly discoloured 4cm Well rounded Greywacke disk 4cm diameter 10cm discrete Sandy lense upper boundary a thin Fe pan2cm thick Roots 5% microfine Boundary Sharp irregular
Bw(f)	Varies 20-30/20-40cm	20-25cm 2.5Y6/2 Medium Sand Single grain Very weak Very friable Non-sticky Non-indurated Non-plastic Mottles 20-30cm (see photo) 7.5YR4/4 Roots 1%microfine between 20-30cm circular and lamina
BC$_1$	Varies 30-65/40-65cm	From 45cm 2.5Y3/1 Coarse sand BC1 more indurated than BC2 + more brown mottles /Common mottling Turbation burrows at 40-70cm Boundary sharp irregular (see photo)
BC$_2$	65-145cm	2.5Y3/1 Coarse Sand Single grain Medium sand size 90cm –Slightly discoloured Well rounded 5cm Greywacke Mottles Few (one class less than BC2) Boundary sharp irregular Bfm 2.5YR2.5/4
C	145cm+	2.5Y2.5/1 Sand Single grain Very weak Very friable Non-indurated Non-sticky Non-plastic No mottles No roots

Survey:PCRP	Pit Code:M5	Date:22/1/13	Author:Jason
GR:42.14769 S 171.33063 E 	Images:3414-3417	Notes: no clasts- soil development all in sand Bw(f) + BC induration BC>Bw(f) All roots in Ah no root penetration to Bw(f)	LOCATION 097

Ah	0-18cm	10YR 3/2 Silt loam Well developed crumb structure 10-5mm Strength very weak Friable Non-indurated Slightly sticky Plastic Roots 2%extremely fine 1%microfine 2%very fine 1%coarse Boundary sharp wavy
Bw(f)	18-38cm	10YR3/4 Loamy sand Blocky structure 10cm break to 5mm Strength very weak Brittle Non-indurated Non-sticky Non-plastic Mottles 5YR3/4 Very few Fine Faint Roots 1% microfine in top of horizon See notes top Boundary distinct wavy
BC	38-75cm	2.5Y3/2 Loamy sand Structure massive Strength very weak to weak Brittle Very weakly indurated Non-sticky Non-plastic Boundary abrupt smooth
C	75-120cm	2.5Y3/1 Sand Single grain Very weak Very friable weakly indurated Non-sticky Non-plastic Positive liquefaction (Thixotropic??) – water seeping in at C

Survey:PCRP	Pit Code:R5	Date:22/1/13	Author:Jason
GR:42.14554 S 171.33182 E 	Images: 3397- 3407	Beach sand at base Buried soil slowly aggrading clay/colluvial deposit	ELEVATION 14m LOCATION 095

Ah	0- 15cm	10 YR3/2 Silt loam Moderately strongly developed crumb Weak strength Friable Non indurated Slightly sticky Very plastic Boundary distinct smooth
Bw(g)	15- 27cm	10YR 3/4 Silt loam matrix Blocky 4cm breaking to 0.5cm Very weak Brittle Very weak induration Non sticky Non-plastic Mottles 7.5YR 4/6 Very few Very distinct Very rare rounded rod 4cm Roots 2% extremely fine Boundary wavy abrupt Bfm 27cm
Bg	28- 40cm	10YR3/4 . Matrix= 2.5Y4/2 Blocky 10cm breaking to 5mm Very weak Brittle Very weak induration Plastic Slightly sticky <1% 1cm Sandstone Rounded disk Slightly weathered 3cm Mottles 7.5YR4/6 Common fine prominent Roots 2% extremely fine Boundary Bfm 5YR4/6 wavy abrupt -sharp
bBw(g)	40- 70cm	7.5YR 4/6 Clay loam Blocky structure 4cm breaking to 5mm Very weak Brittle Very weak induration Slightly sticky <1% Granite + Greywacke well rounded Moderately weathered Mottling 5YR3/4 Very fine distinct Roots 1%extremely fine

		Vermiform? Photo 3406 and 3407 Boundary 3Fm distinct smooth-sharp worm casts
2bBw	70- 90cm	7.5YR 4/6 Fine sandy loam Blocky 6cm breaking 5mm Strength weak Brittle Very weak induration Slightly sticky and plastic Back-filled worm casts Roots <1% microfine Vermiform fabric 75-85cm Vertical structures Boundary abrupt smooth
3C	90- 120cm	Sand Massive Weak Brittle Very weak induration Non-plastic Non-sticky Illminite 5Y3/2 Iron stain 7.5YR 3/4

Survey:PCRP	Pit Code:U5	Date:22/1/13	Author:Jason
GR:42.14668 E 171.33131 S 	Images:3408+9 3408-3413		LOCATION 096

Ah	0-15cm	10YR 2/2 Silt loam Weak to moderate crumb structure 5-10mm Strength very weak Friable Non-indurated Slightly sticky Plastic Roots very fine 20% Boundary abrupt smooth
Bw(g)	15-25cm	10YR 3/2 Sandy loam Blocky structure 4cm breaking to 5mm Strength very weak Brittle Non-indurated Non-sticky Non-plastic Mottling common fine prominent Sandstone 1cm slightly weathered rounded disk 5cm slightly weathered sandstone Roots 10% extremely fine 1% microfine Boundary sharp wavy
Br_1	25-40cm	2.5Y 3/1 Sandy loam Structure blocky 6cm breaking to 1cm Strength very weak Brittle Non-indurated Non-sticky Non-plastic No mottling Root decay insitu 2% microfine 2%extremely fine 1%very fine decayed Boundary distinct smooth
Br_2	40-80cm	2.5YR 3/1 Loamy sand Structure blocky 4cm breaking to 5mm Strength very weak Crumbling Very friable Non-indurated Slightly sticky Non-plastic Mottles 5YR3/4 few fine and prominent Concretion 5% Root decay insitu 2% microfine 2% extremely fine Very slightly gravelly 1% Slightly weathered Well rounded disks 4cm-2cm Greywacke Boundary distinct smooth

C	80cm-	5Y2.5/1 Sand(Ilmenite) Single grain structure Strength very weak Very friable Non-indurated Non-sticky Slightly fluid 2%Roots 2%Extremely fine 1%Very fine Illminite 5Y3/4check with photo Very slightly gravelly Slightly weathered well rounded disks and spears 10cm-1cm Sandstone Positive Liquefaction test

Survey: PCRP	Pit Code:M6	Date:23/1/13	Author: Jason
GR:42.14568 S 171.32932 E 	Images: 3493-3483 Scotsman’s Ck 3481-82		LOCATION 102 ELEVATION 15m

Ah	0-10cm	10YR2/2 texture: Moderate to well developed crumb 5mm fibrous Strength Very weak Very friable Non-indurated Slightly sticky Plastic Roots 1% microfine 2% extremely fine 10%very fine Boundary smooth abrupt
$Bw(g)_1$	10-40cm	10YR4/3 texture: Moderately developed blocky Strength very weak Brittle Non-indurated Non-sticky Non-plastic Mottles 10YR4/6 and 2.5Y5/2 10% Very fine Faint Roots 2%microfine 5% extremely fine 2% very fine 2% fine Boundary distinct smooth
$Bw(g)_2$	40-110cm	10YR5/4 texture: Blocky Moderately to strongly developed 2cm breaking to 5mm strength Very weak Very weak induration Non-sticky Non-plastic Mottles 10YR4/6 and 2.5Y5/2 Very fine Faint Roots 2%extremely fine 5%fine 1%medium Boundary abrupt smooth
bBw(f)	110-130cm	10YR4/4 texture: Blocky moderately to strongly developed 2cm breaking to 5mm Strength Very weak Very friable Non-indurated Non-plastic Mottles 7.5YR3/4 Very few Extremely fine and distinct No roots Boundary abrupt smooth

2bC		Texture: Single grain Very weak Very friable Non-indurated Non-plastic Mottles 7.5YR3/4 Very few Very fine Distinct No roots

Survey: PCRP	Pit Code: R6	Date:24/1/13	Author: Carol Smith
GR:42.14194 S 171.32849 E 	Images:3499-3505		LOCATION 104

Ah	0-10cm	10YR2/2 Silt loam Moderate to well developed crumb 5mm aggregates Strength Very weak Friable Slightly sticky Plastic Non-indurated No mottles Boundary abrupt smooth
Bw(f)	Varies 10- 18/24cm	7.5YR3/1 Sandy loam Moderate to well developed 4cm breaking to 2mm nut Strength Very weak Brittle Non-indurated Non-sticky Non-plastic Mottles 2.5YR3/4 Few Very fine Distinct Roots 2%microfine 1%extremely fine Boundary abrupt wavy
Bg_1	Varies 18- 24/24- 36cm	2.5Y2.5/1 Loamy sand Single grain moderately developed sub-angular blocky 3cm breaking to 5mm Strength Weak Brittle Non-indurated Non-sticky Non-plastic Lithology Greywacke well rounded disks and spheres 2-3mm Fresh and slightly discoloured Mottles 2.5YR2.5/4 Common extremely fine to very fine and prominent between 40-50cm Roots 5%microfine 1%extremely fine Boundary distinct wavy
Bg_2	Varies 36- 40/50cm	Bg_2 varies 2.5Y3/1 Sand Single grain moderately developed sub-angular blocky 3cm breaking to 5mm Strength Weak Brittle Non-indurated Non-sticky Non-plastic location for concretions Roots extremely fine 5% (often located within concretionary tubules) Concretions around macropores 6-10mm (samples) Mottles 2.5YR2.5/4 Roots 5%microfine 1%extremely fine

BC	Varies 50-65cm/40-70cm	2.5Y3/1 Sand Single grain Strength Very weak Very friable Non-indurated Non-sticky Non-plastic Flakes of Gold 0.1mm <1% No sample Mottles 10YR3/4 Few very fine faint Very few extremely fine prominent Roots 1%Very fine Boundary distinct wavy
C	Varies 65/70-84cm	2.5Y2.5/1 Sand Single grain Strength Very weak Very friable Non-indurated Non-sticky Non-plastic Flakes of Gold 0.1mm <1% (sample) also in BC Mottling 10YR 3/4 Very few microfine distinct No roots

Survey:PCRP	Pit Code:U6	Date:23/1/13	Author: Carol Smith & Jason?
GR:42.14122 S 171.32858 E 	Images:3473-3480	Notes addendum below description	LOCATION 101

Ah	0-10	10YR 3/2 Sandy loam Well developed Sub-angular blocky structure 4cm breaking to 5mm Very weak Brittle Non-indurated Non-sticky Non-plastic Roots 5%microfine Boundary abrupt wavy
Bw(f)	10-20 Varies- 30cm	10YR3/2 Loamy sands Moderately developed sub-angular blocky structure 3cm breaking to 5mm Very weak Brittle Non-indurated Non-sticky Non-plastic Mottles Few Very fine Faint Few isolated pods of clay material Roots 1%microfine NOTE horizon a mix of > sandy material than Ah Boundary abrupt wavy
BC	20- 50cm Varies 30- 45cm	2.5Y3/1 and 2.5Y2.5/1 Loamy (Ilmenite) sand Structure varies from single grain to massive Strength Very weak Friable Non-indurated Slightly sticky to Plastic Mottling Very few Coarse Prominent and Few Very fine Faint and distinct Inclusions of Fe 5YR3/4 and clay 2.5Y5/2 (see pp115) No roots noted NOTE horizon highly disturbed mix of Ilmenite and clay from depth but iron segregation in-situ Numerous in-filled burrows 5-10mm diameter Boundary abrupt wavy

BC_2	Varies Lensoid 45-52cm pinching out at 50cm	10YR4/3 loamy sand Structure Weak blocky Strength Very weak Friable Non-indurated Non-sticky Non-plastic Mottling 2%extremely fine Faint Roots 1%microfine Boundary abrupt wavy
$bBw(f)_1$	50-70cm	10YR3/2 Silt loam Well developed blocky 5cm breaking to 5mm strength Very weak Brittle Non-indurated Slightly sticky Plastic Mottles 5YR3/4 Few Very fine Distinct Roots 1% microfine 1%extremely fine Boundary abrupt wavy
2bBg	70-76cm	10YR5/3 light clay Moderately developed blocky 4cm breaking to 5mm Strength Weak Brittle Non-indurated Moderately sticky Very plastic Mottles 5YR ¾ 2% Extremely fine Prominent Roots 1%extremely fine Burrows 1-2mm infilled with material from horizon above and below Boundary abrupt wavy
$3bBw(f)_2$	76-80cm	10YR3/1 Sandy loam Weakly developed blocky 4cm breaking to 5mm Very weak Brittle Non-indurated Slightly sticky Non-plastic Mottles 5YR3/4 (in macropores) Few extremely fine and Faint to distinct Roots 1% Extremely fine 1% microfine Boundary abrupt smooth
$3bBw(f)_3$	80-95cm	2.5Y2.5/1 Loamy sand Moderately developed blocky 5cm breaking to 5mm Strength Very weak Brittle Non-indurated Non-sticky Non-plastic 1% clasts Well rounded disks Greywacke Mottles 5YR 3/4 Many medium prominent No roots Boundary abrupt smooth
3C	95-120	2.5Y2.5/1 Sand Single grain Strength Very weak Very friable Non-indurated Non-sticky Non-plastic Concretions lining pores Mottles 5YR3/4 few very fine distinct

NOTES		NOTES 80cm - numerous root/tree fragments 10-15cm diameter Deposition history- Ilmenite beach sand covered by skim of clay from material the > sand Stable land surface soil development Erosion events strip clay from elsewhere and redeposit it along with sand Ilmenite etc more sand Aeolian ? Deposited on top Soil formation bioturbation at 40cm or dredging!

Survey:PCRP	Pit Code:M7	Date:13/3/13	Author: Jason
GR: 	Images:1144-181	GPS Soil Pit M7	

1 Ah	0-10cm	10YR3/2 Silt loam Moderate to well developed crumb to sub-angular blocky 5cm breaking to 2mm Strength very weak Very friable Non-indurated Non-sticky Non-plastic 2 % Mottles 10YR6/2 Roots 1%Fine 5%Extremely fine 10%Microfine Boundary Distinct occluded
2	10-15	10YR6/2 Silt loam Moderate to well developed crumb 10cm breaking to 2mm Strength very weak Friable Slightly sticky Plastic Non-indurated Mottles 7% 10YR3/3 2% 2.5YR3/4 Roots 2%Extremely fine 5%microfine Boundary abrupt occluded

3	Varies 12/15-15/22	5Y8/2 and 2.5Y6/2 loamy silt Moderate to well developed crumb 5cm breaking to 2mm strength very weak Friable Non-sticky Slightly plastic Non-indurated Mottles 3%10YR3/3 1%7.5YR5/8 Roots 1%extremely fine Boundary diffuse smooth
4	Varies 22/15-28/25	2.5Y6/2 and 5Y8/2 loamy sand Moderate to well developed crumb 5cm breaking to 2mm Very weak Friable Slightly sticky Slightly plastic Non-indurated Mottles 1% 10YR3/3 3% 7.55/8 Roots 1%microfine Boundary Abrupt smooth
5	Varies 28/25-35/48	7.5YR7/8 and 2.5Y5/3 Silty loam Moderately developed crumb 5mm breaking to 2mm Very weak Sticky Slightly plastic Non-indurated Mottles 3%10YR 2%7.5YR5/8 Roots 1%extremely fine Boundary Abrupt smooth
6	Varies 35-38/37-41cm	10YR3/4 Silty loam Moderate to well developed crumb Very weak 5cm breaking to 2mm Sticky Plastic Non-indurated Mottles 25% 7.5YR5/8 No roots Boundary Abrupt smooth
7	Varies 38-44/41-44	2.5Y7/1 and 25Y5/1 Silty clay Well developed 5cm breaking 2mm Strength weak Non-indurated Very sticky Very plastic Mottles 25% 7.5YR5/8 No roots Boundary Abrupt smooth
8	Varies 44-52/49	2.5Y5/1silty clay Well developed 5cm breaking to 5mm Strength weak Non-indurated Very sticky Very plastic Mottles 7% 5YR4/8 and 3/6 No roots Boundary Sharp smooth
9	Varies 52/49-59/62	10YR4/1 loamy silt Moderate to well developed crumb 10cm breaking to 2mm Strength Very weak Very friable Non-indurated Sticky Slightly plastic Mottles 2% 2.5YR3/6 No roots Boundary Sharp wavy

10	Varies 59/62-89/91	2.5Y5/1 Sandy clay loam moderate to well developed crumb 5cm breaking to 2mm Strength Very weak Very friable Non-indurated Sticky Slightly plastic Mottles 10% 2.5YR3/6 No roots Boundary Indistinct smooth
11	Varies89/91-105/112	2.5Y5/1 Sand Very well developed Strength Very weak Very friable Non-indurated Non-sticky Non-plastic Mottles 2% 7.5YR5/8 No roots Boundary Sharp wavy
12 Bfm_2	Varies 105-107/122-124cm	5YR2/1 and 2.5YR2/4 Very well developed Strength Very firm Brittle Non-sticky Non-plastic weakly indurated No mottles No roots Boundary Sharp wavy
13	107/124-120cm	2.5Y4/3 Sand Single grain Strength Very weak Very friable Non-indurated Non-sticky Non-plastic No mottles No roots

Survey: PCRP	Pit Code:R7	Date:24/1/13	Author: Carol Smith
GR:42.13801 S 171.32938 E 	Images: 3509-3516	Ilmenite &Au beach gravels covered by fine fan deposit soil development &charcoal Buried by another fan deposit – soil development	LOCATION 105

Ah	0-10cm	10YR3/3 Silt loam Well developed crumb 4-10mm Strength Very weak Friable Non-indurated Slightly sticky Plastic Roots 2%extremely fine 1%microfine Boundary smooth abrupt
Bw(g)	10-30cm	10YR4/3 Silt loam Well developed sub-angular blocky 5cm break to 5mm Stregth Very weak Brittle Non-indurated Non-sticky Non-Plastic Mottles 7.5YR4/4 Low chroma 10YR5-4/2 Common Very fine distinct Roots 10%microfine 1%extremely fine Boundary wavy abrupt
bBg_1	Varies 30-46/50cm	7.5YR3/2 Silt loam Moderately developed blocky 6cm breaking to 1cm Strength Very weak Brittle Non-indurated Slightly sticky Plastic Mottles 2.5Y3/6 Common Very fine prominent Roots 1%extremely fine 1%microfine Worm casts7.5YR2.5/2 Numerous 5-10mm charcoal Large burnt wood deposit 50cm Boundary wavy abrupt

bBg_2	Varies 46-90/50-100cm	10YR3/2 Fine sand silty loam Blocky 6cm breaking to 1cm Strength Very weak Brittle Non-indurated Slightly sticky +Plastic Numerous 5-10mm charcoal to 65cm depth Mottles common distinct Roots 1%extremely fine 1%fine Boundary sharp wavy
2bBCg	Varies 90-120/100-120cm	2.5Y4/2 Loamy sand Single grain Strength very weak Very friable Non-indurated Non-sticky Non-plastic Small flecks of Au throughout horizon Mottles 5YR4/6 Common Very prominent Roots 1%extremely fine 1%fine Boundary sharp wavy
3C	120cm	7.5YR3/3 Gravel Well rounded clasts Discontinuous Fe stain on surface Small large medium pebbles in coarse to very coarse Fe stain sand matrix plus Au flecks

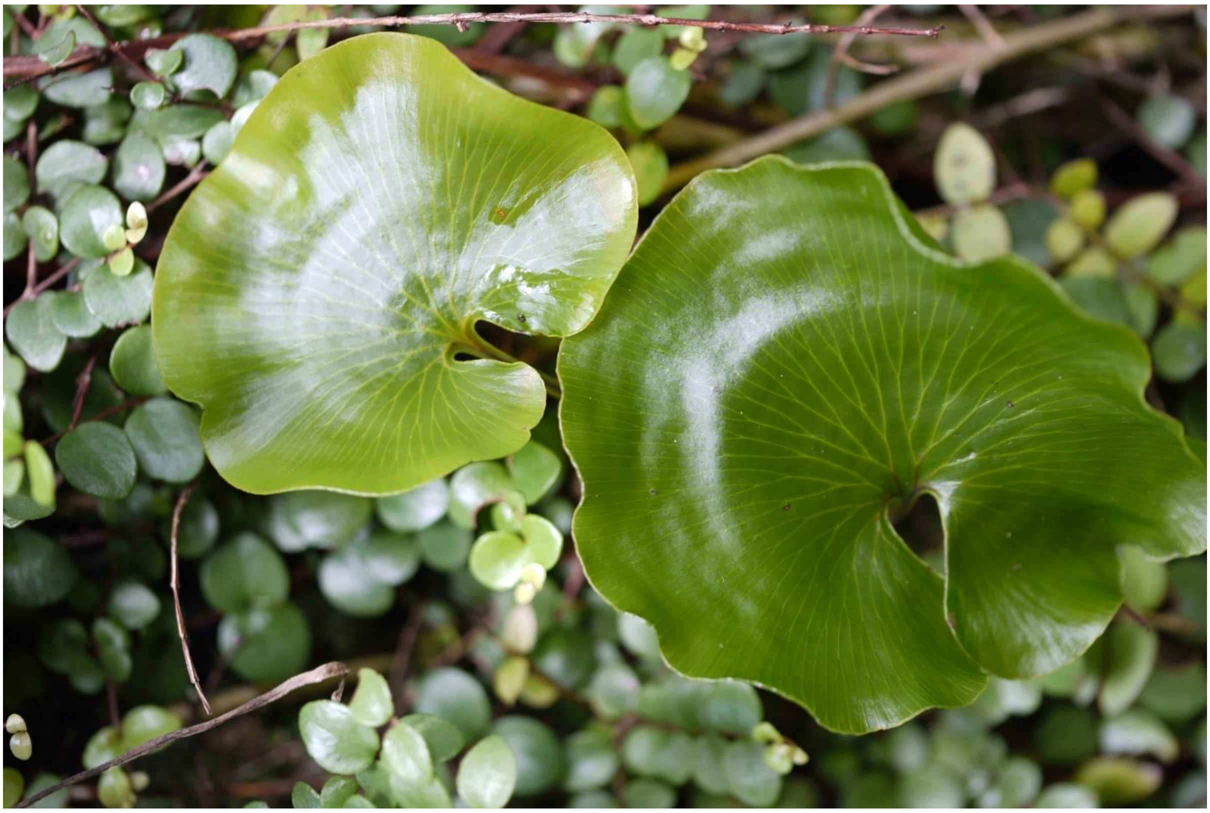
Survey: PCRP	Pit Code:U7 amphipod	Date:25/1/13	Author: Carol Smith?
GR:42.13863 S 171.32930 E 	Images: 3593-3611	Describe Eastern wall photo of western wall due to sun on ½ eastern wall	LOCATION 108 ELEVATION 0m

Ah	0-8cm	10YR2/2 Sandy loam Well developed crumb 1cm-5mm Strength very weak Friable Non-indurated Non-sticky Non-plastic Roots 5%microfine 2%extremely fine Boundary Abrupt wavy
Bw(g)	8-23cm	10YR4/2 Loamy sand Weak to moderate sub-angular blocky4cm breaking to 5mm. Strength Very weak Brittle Non-indurated Non-sticky Non-plastic Well rounded spherical to disk Greywacke 5-3cm + 1-2cm slightly discoloured pebbles at around 15cm depth Low chroma 10YR4/1 Mottles 5YR3/4 Very few Fine Faint Roots 2%microfine 2%extremely fine 1%very fine Boundary sharp irregular Bfm
Bfm	23cm	2.5YR3/6 Highly convoluted Broken by bioturbation from Bwg
Bw(f)	23- 42cm	10YR4/4(darker) 10YR5/4(lighter) Loamy sand /sand Single grain –very weak blocky Strength Very weak Brittle Non-indurated Non-sticky Non-plastic Laminations common wavy horizontal 1-2mm thick very fine distinct Mottles 5YR3/4 Roots 1%microfine

		Boundary abrupt wavy
BC	42- Varies 74/80	Varies (Ilmenite) 2..5Y3/2 pale 2.5Y6/2(more quartz) Sand Mottles 5YR3/4 really faint Boundary distinct wavy
C	Varies 74/80- 150cm	2.5Y3/1 Sand Single grain strength very weak very friable Non-indurated Non-sticky Non-plastic No roots No mottles Dominated by Ilmenite Some quartz layers Gravels at 150cm

Appendix IV
Student report 1

Opportunities for the facilitation of non-planted native species establishment within the restoration plantings at the Punakaiki Coastal Restoration Project



Kidney fern on rata, in Nikau Scenic Reserve. Photo: Nick Dickinson, January 2013.

Ross Carter-Brown

A summer scholarship report prepared by Ross Carter-Brown, supervised by Professor Nick Dickinson

Abstract

Research was carried out at the Punakaiki Coastal Restoration project, 4km south of Punakaiki on the northern end of the Barrytown flats. The objective was to identify opportunities for the facilitation of non-planted native species within the restoration plantings by:

1. Qualifying the differences in species assemblages between the reference sites and the restoration site
2. Evaluating the effectiveness of canopy closure and shading of existing restoration plantings "How quickly will canopy closure occur?"
3. Quantifying the establishment of native species within existing gorse patches; investigating opportunities to restore native wood the restoration site to provide an opportunity for establishment of epiphytic native plant species
4. Identifying key host species (e.g. tree fern spp., rata stumps) using Nikau Scenic Reserve as a reference
5. To focus on the requirements of ferns and nikau palms to establish in the area.

The main outcomes of the study was the expansion of existing species lists for the reference and restoration sites, the canopy in the restoration plantings are closing rapidly, the canopy cover in the reference site and the mature gorse stands are not significantly different but the canopy cover in the restoration plantings is significantly lower than the former, the gorse plots with the highest canopy cover and the lowest ground cover had the highest abundance, diversity and evenness of native woody seedlings, *Dicksonia squarros* and *Metrosideros* spp. supported the highest diversity of epiphytes, *Metrosideros* spp supported a relatively high number of terrestrial species growing epiphytically whereas *Rhopalostylis sapida* supported only true epiphytes. A number of recommendations are made regarding the future management of the restoration project and future research.

Introduction

The Punakaiki Coastal Restoration Project (PCRP) is a partnership between Rio Tinto, the Department of Conservation (DOC) and Conservation Volunteers. Conservation Volunteers are charged with restoring the 80ha site to coastal sand-plain forest. This land was previously owned by Rio Tinto and was gifted to DOC in 2010, with the aim of restoring it to near its original state for future generations. Rio Tinto is currently funding the restoration with the aim of planting 100,000 trees over five years. Planting started in May 2009 and continues today. The PCRP is located ~4km south of Punakaiki on State Highway 6 with Nikau Scenic Reserve (NSR) on its southern border, with the majority of the restoration site covering the strip of land between the highway and the sea (M. Bowie, C. Mountier, S. Boyer, & N. Dickinson, 2012).

NSR is the main reference site for the restoration project; along with some forest fragments within the restoration site itself. PCRP and NSR are all part of the Punakaiki Ecological District and the northern part of the Barrytown Flats (M. Bowie et al., 2012). A majority of the Barrytown Flats have been heavily modified by land clearance, drainage, mining and agriculture (Wilms, 1985b). There have been a number of ecological studies carried out in the area previously including the Barrytown Baseline Ecological Survey 1985-1986 which included NSR and some parts or the restoration site (G. Don, 1986) and most recently the Baseline Survey for the Punakaiki Coastal Restoration Project (M. Bowie et al., 2012).

There is a substantial mismatch between planted woody species at PCRP and the assemblage of species found in the Nikau Scenic Reserve. This is based on sound ecological theory and the logical assumption that early successional species will provide an appropriate nursery for other plants. Over 30 woody species have been planted in the restoration plots, although about 12 species are substantially more abundant (Washer, 2013). The main factors that limit native plant establishment at the PCRP are sensitivity to lack of canopy cover, competition from exotic grasses and lack of appropriate habitat or niche space (Dickinson, 2012). Canopy cover can result in reduced photosynthetically active radiation (PAR), more stable temperatures in the understory, increased soil fertility, and altered plant water relations (Bellow & Nair, 2003).

Prior to the settlement of Europeans in New Zealand, Myrtaceae (*Kunzea ericoides* and *Leptospermum* scoparium) were the dominant early successional species on formally forested areas. In lowland areas Gorse (*Ulex europaeus*) is considered a persistent invasive woody weed, but its role in vegetation restoration is becoming more recognised (Meurk & Hall, 2006; Walker, Lee, & Rogers, 2003; P. A. Williams, 2011). This spiny-leaved woody shrub has extremely long lived seeds, but is relatively short lived with a maximum recorded age of 47 in New Zealand (Druce, 1957). Under mild conditions in places that were formerly forested, in the absence of grazing or fire, gorse can be replaced by native broadleaved plants in 20-30 years (Druce, 1957; J. J. Sullivan, Williams, &

Timmins, 2007; Wilson, 1994). Gorse and succession in New Zealand has been relatively well studied with at least 8 published sources concerning their role (Hill, Gourlay, & Barker, 2001; W. G. Lee, Allen, & Johnson, 1986; Partridge, 1989; J. J. Sullivan et al., 2007; Wardle, 1991; P. Williams, 1983; P. A. Williams, 2011; Wilson, 1994).

The aim of this research is to inform future management of the site by identifying the situations and locations where non-planted native species (NPNS) will gain a foothold within the restoration plots.

The objectives are:

1. To qualify the differences in species assemblages between NSR, remnants (M7 and M4) and PCRP.
2. To evaluate the effectiveness of canopy closure and shading of existing restoration plantings in provision of opportunity for NPNS establishment. Additionally to evaluate how quickly will canopy closure occur?
3. To quantify the establishment of native species within existing gorse patches
4. To investigate opportunities to reintroduce native logs to PCRP, to provide an opportunity for establishment of epiphytic/parasitic/companion native plant species. Identify key host species (e.g. tree fern spp., rata stumps) using Nikau Scenic Reserve as a reference
5. To focus particularly on the requirements for ferns and Nikau palm to establish within the PCRP.

Methods

Species assemblages (objective 1)

The differences in plant species assemblages between NSR, remnants (M4 & M7) and the PCRP restoration plantings were completed partly through the comparison of existing historical plant species lists compiled largely from data collected by BioResearches Ltd. (G. Don, 1986) for NSR and the restoration site, and current plant species lists provided by CVNZ (Washer, 2013) for the restoration area. This information was combined with new information obtained from the gorse and epiphyte studies (as described below).

Canopy closure (objective 2)

Data from studies carried out on the restoration plots assessing canopy area by Mountier (2011) in December of 2011 and Segrestin and Chassagneux (2013) was compared to determine the rate of canopy closure in the restoration plantings. The methods for calculating canopy area in the restoration plots was adapted from Kanowski and Catterall (2007) by Mountier (2011). This involved measuring every plant within 10m x 10m plots for height, maximum and minimum width, basal area, and DBH (where applicable). Height and maximum width were used to calculate the canopy area. A paired T-test was carried out using Rstudio (2012) to test for significance.

Gorse as a nurse crop (objectives 3 and 5)

The study site was located towards the northern end of the PCRP parcel of land, just west of the road. Four 10m x 10m and one 6m x 16.7m were set up in the mature gorse stands at the eastern edge of the site, bordering the road. These plots were then divided into quarters which were then systemically surveyed for native woody seedlings. All seedlings >50mm in height were identified and had their heights recorded. In addition to this we also recorded the species on any native plants not meeting these criteria. The ground cover (defined as an low growing green vegetation) in each quadrant (of the plot) was visually estimated by consensus of the two observers. Canopy cover in each quadrant was measured by taking a photograph of the canopy using Nikon Coolpix 950 with attached fisheye converter FC-E8 0.21x (Nikon lens), held 30cm above the ground in the middle of the quadrant. The photo was taken in 'Fisheye2' mode (rectangular, combined max. aperture F3.3, normal).

The canopy photos were analysed using ImageJ (1997). Images were opened in ImageJ individually, then were split in to 3 channels, red, green, and blue. A binary (black and white) was made from the blue channel, and then a histogram was generated to display the number of black (open/closed) and white pixels (open/closed). Finally a percentage of 'cover' (closed) was calculated from these. This method was adapted from 'The Ecological Forester' (2011).

All data was collated in Microsoft Excel 2010, and a species list was compiled. Seedling species richness, Simpson's Diversity, seedling abundance m^2, mean ground cover and mean canopy cover were calculated. GLMs (generalised linear model) were run in Rstudio (2012) with Simpson's Diversity as explained by mean ground cover, mean canopy cover and their interactions; and with seedling species richness as explained by mean ground cover, mean canopy cover and their interactions. In addition to this an ANOVA with Tukey's HSD was run with the mean canopy cover on the restoration, mature and gorse plots to check for significant differences.

Epiphyte study (objective 4 and 5)

Three epiphyte host species of (possible) importance were identified, namely *Rhopalostylis sapida* (nikau palm), *Dicksonia squarrosa* (wheki, rough tree fern), and *Metrosideros spp.* (Rata, specifically *M. diffusa, M. fulgens* and *M. perforata*) in NSR. Due to difficulty identifying the Rata's to species *post hoc*, with photos, all three were grouped together as one RTU (recognisable taxonomic unit). A variable number of each species was selected in NSR just west of the road and at a second site east of the swamp (in NSR). The entire circumference of the lowermost two meters of each individual host tree was sampled, recording the presence/absence of species growing epiphytically, the DBH of the host tree was also recorded.

The results were collated in Excel 2010 and a species list compiled. In addition to this each species was classed as either a 'true epiphyte' or a 'terrestrial plant growing epiphytically'. Rstudio was used to run a GLM with host species as explained by host DBH, RTU richness, and their interactions. A (Pearson's) Chi-squared test was also run with host species, true epiphyte, and 'terrestrial' as factors.

Light/shade requirements (objective 5)

Four NPNS were selected including *Coprosma rotundafolia, Freycinetia banksii, Macropiper excelsum,*and *Rhopalostlis sapida.*Canopy photos were taken 30cm above the ground, above 3-6 juveniles of each species, spread throughout NSR. The images were analysed in the same way as previously, using ImageJ (Rasband, 1997). Summary statistics were generated in Excel.

Results

Species assemblages

A total of 23 native plant species were found in the five 100m² gorse plots (Appendix I, Table 3), including 14 species of woody natives (>50mm in height)(Fig. 8). A further 30 species were found during the epiphyte study (Appendix I, Table 4). These were combined with the species described in the historic Bioresearches Ltd. (1986) species list (excluding species outside the study area) and altogether 75 species were identified as being present in the reference site, Nikau Scenic Reserve and in the mature gorse on the restoration site (Appendix I, Table 2).

Canopy closure

There was a marked increase in canopy area (m²) for all restoration plots measured between December 2011 and January 2013 (Mountier, 2011; Segrestin & Chassagneux, 2013) (Fig. 1 and 2). The paired t-test confirmed that there was a significant difference (P = 0.03571, T value = 3.1148, D.F. = 4) in canopy area between the two sampling periods. This indicates increases of between 1760.98% and 399.43%, or a mean of 825.24% in 12 months (Fig. 2).

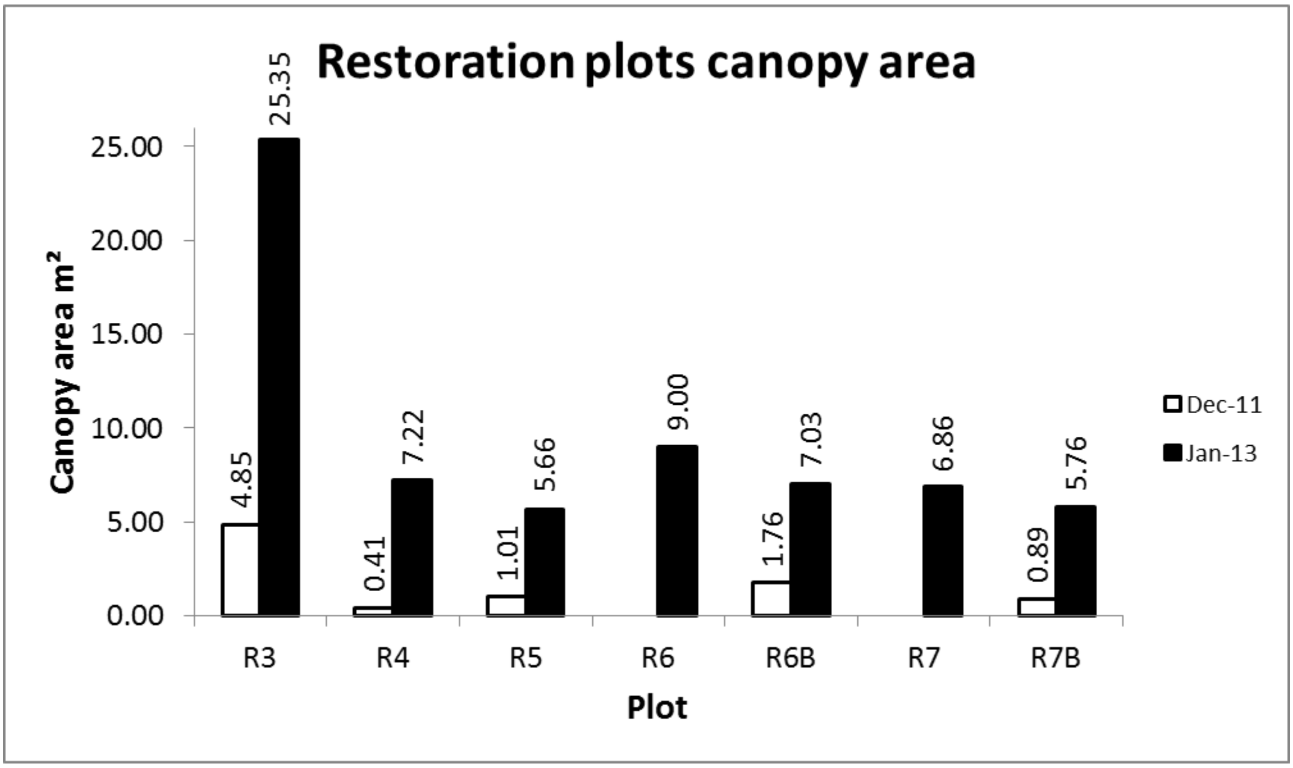


Figure 1. Canopy area m² for restoration plots sampled in December 2011 compared to the plots sampled in January 2013. Note that R6B and R7B were not sampled in 2011. A paired T-test confirmed that there was a significant difference (P = 0.03571, T value = 3.1148, D.F. = 4) between the two sampling periods.

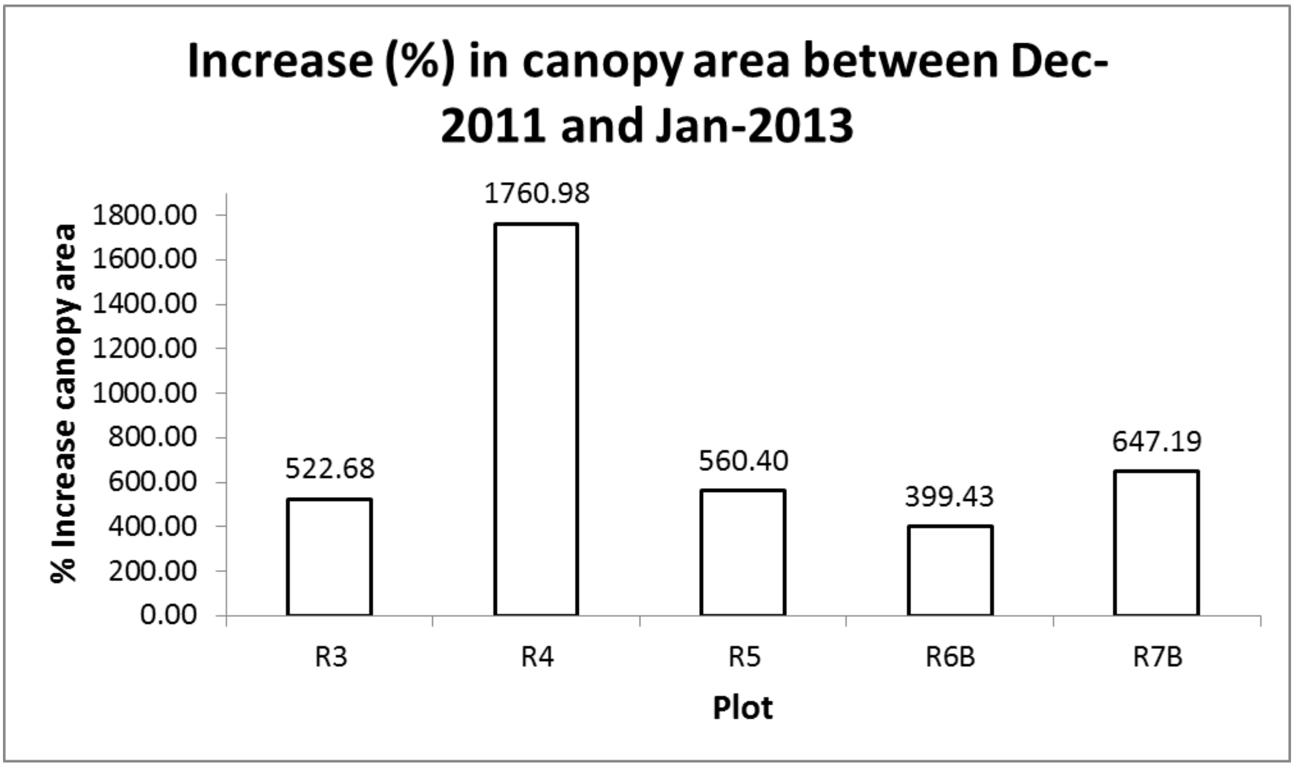


Figure 2. Precent increase in canopy area m² for restoration plots sampled in January 2013 when compared to the plots sampled in December 2011. Note that R6B and R7B were not sampled in 2011 so are not included in this comparison.

An ANOVA, with Tukey's HSD was run comparing the mean canopy cover of the mature (79.95%), restoration (14.89%), and gorse plots (79.33). The results show that restoration and mature plots were significantly different (P = 0, D.F. = 2, F value = 82.459), the restoration and gorse plots were significantly different (P = 0, D.F. = 2, F value = 82.459), and the mature and gorse plots were not significantly different (P = 0.99, D.F. = 2, F value = 82.459) (Fig. 3).

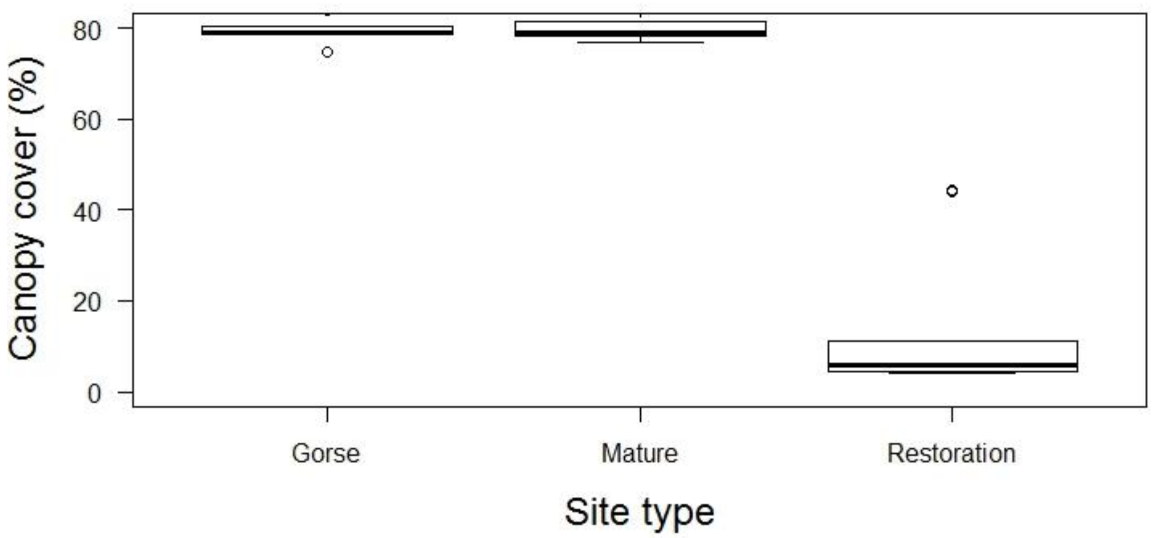


Figure 3. Mean canopy cover of all gorse, mature and restoration plots. ANOVA with Tukey's HSD comparing mean canopy cover of the gorse plots (79.33%), mature plots (79.95%), and restoration plots (14.88%). D.F. = 2, F value = 82.459, P = 8.65^{-10}. Mature:gorse P = 0.99, restoration:gorse P = 0, restoration:mature = 0.

Gorse as a nurse crop

A total of 23 native plant species (Appendix I, Table 3) were found in the 5 gorse plots. These included 14 woody species (Fig. 8), the focus of this study, and two tree ferns, four other ferns, nikau palm and a climber (*Muehlenbeckia sp*.). The key findings are that plots with the highest diversity (and evenness) and abundance of native species also had the highest canopy cover and the lowest ground cover. However these were not statistically significant (Figs. 4 and 5).

The GLM (general linear model), incorporating all five plots, with Simpson's Diversity (Fig. 6) as explained by mean canopy cover, mean ground cover, and their interactions were all not statistically significant (mean canopy, P = 0.150, T value = 4.158; mean ground, P = 0.204, T value = 3.017; mean canopy: mean ground, P = 0.203, T value = -3.027; D.F. = 4). The GLM with species richness (of native woody seedlings 50mm<) as explained by mean canopy cover, mean ground cover, and their interactions were all not statistically significant (mean canopy, P = 0.286, T value = 2.075; mean ground, P = 0.570, T value = 0.801; mean canopy: mean ground, P = 0.573, T value = -0.794; D.F. = 4). The GLM of seedlings per m² (Fig. 7) as explained by mean canopy cover, mean ground cover, and their interactions was not significant (mean canopy, P = 0.106, T value = 5.936; mean ground, P = 0.146, T value = 4.294; mean canopy: mean ground, P = 0.146, T value = -4.298; D.F. = 4) (Fig. 4.).

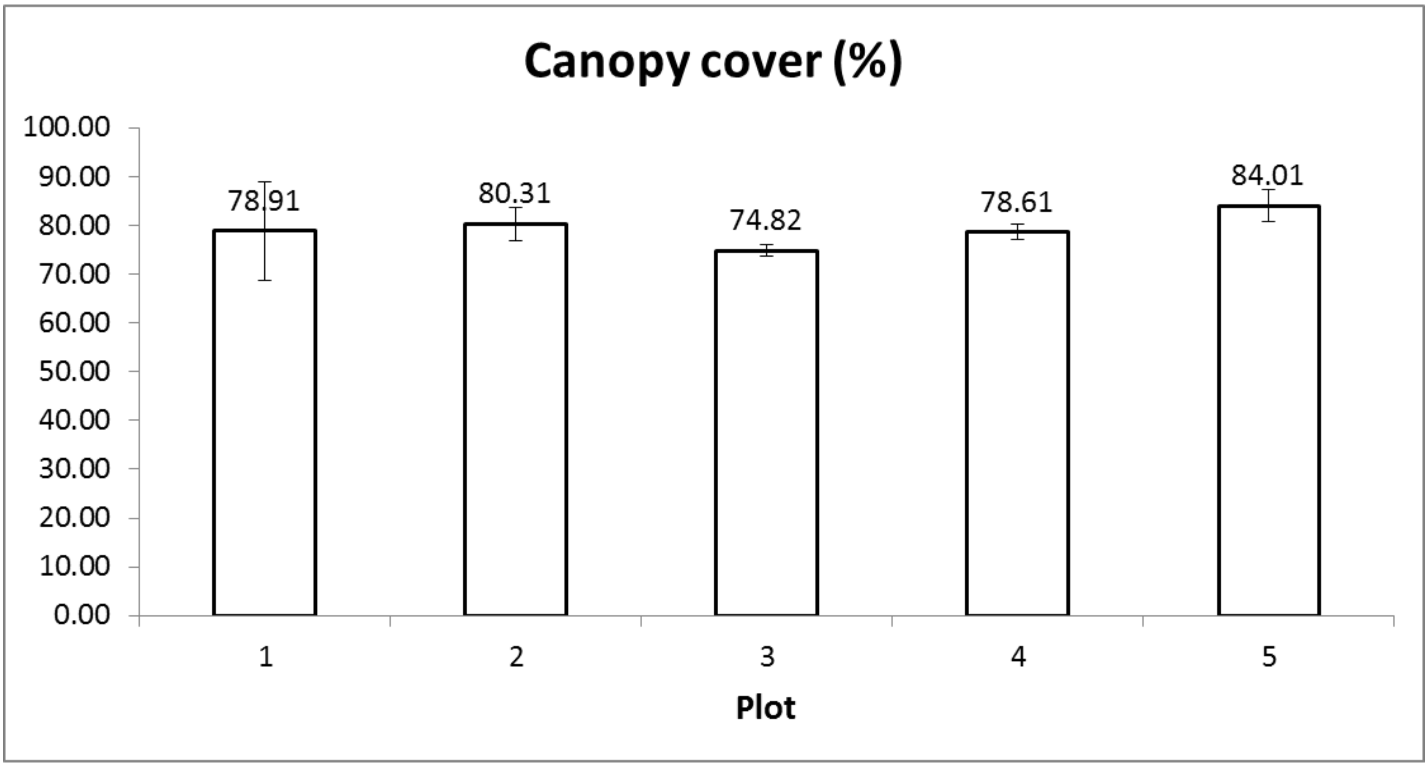


Figure 4. Canopy cover (%) of the 5 gorse plots. There was no significant correlation between canopy cove and Simpson's Diversity Index (P = 0.150, T value = 4.158), species richness (P = 0.286, T value = 2.075), seedlings m² (P = 0.106, T value = 5.936) or ground cover .

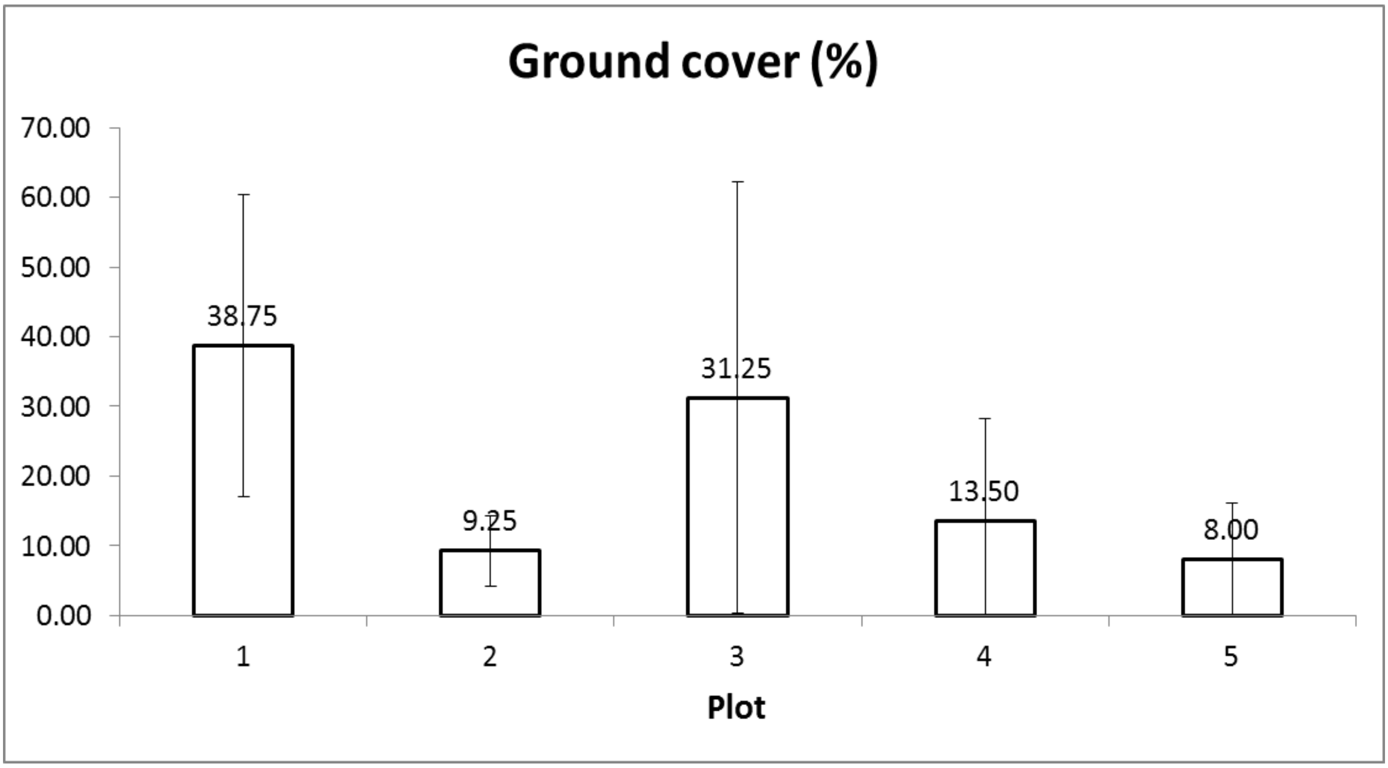


Figure 5. Ground cover (%) of the 5 gorse plots. There was no significant correlation between Simpson's Diversity Index (P = 0.204, T value = 3.017), species richness (P = 0.570, T value = 0.801), or seedlings m² (P = 0.146, T value = 4.294)

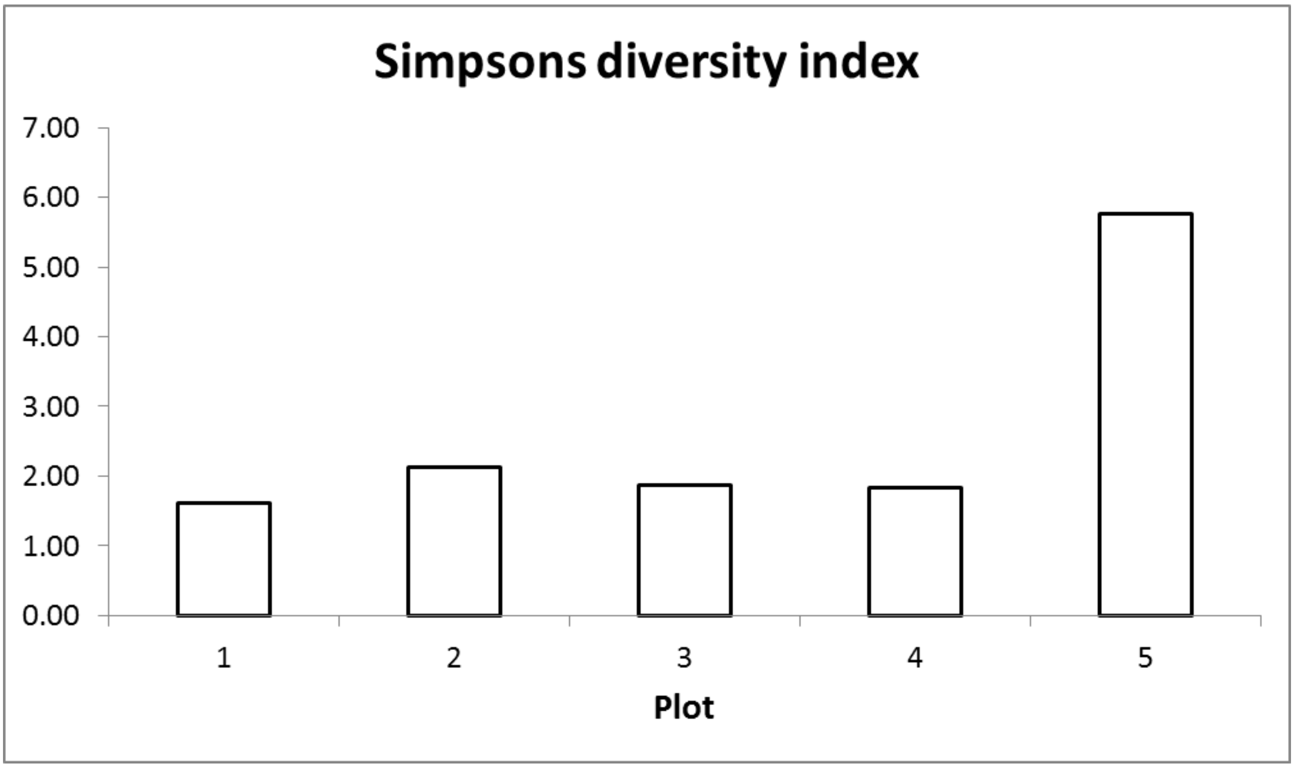


Figure 6. Simpsons Diversity Index of the 5 gorse plots. There were no significant correlations with either canopy cover (P = 0.150, T value = 4.158) or ground cover (P = 0.204, T value = 3.017).

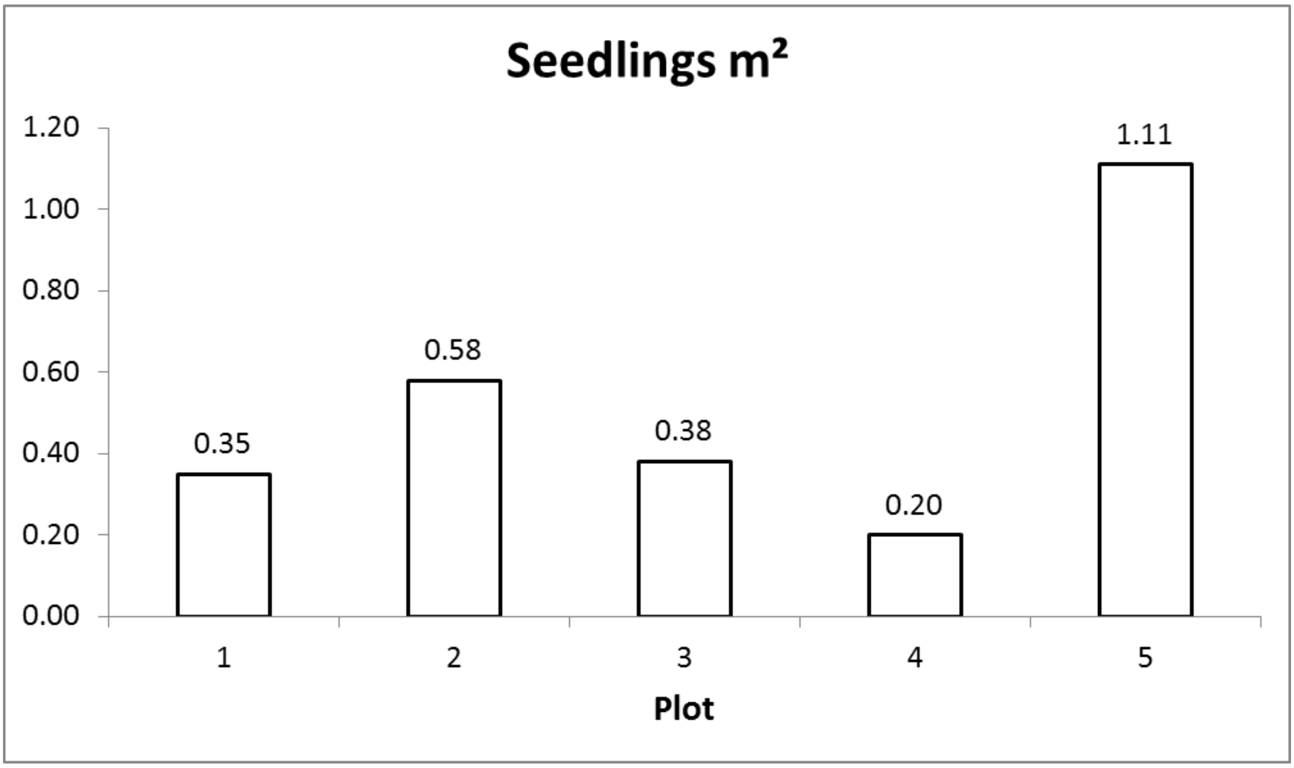


Figure 7. Seedlings per m² of the 5 gorse plots. There were no significant correlations with

either canopy cover (P = 0.106, T value = 5.936) or ground cover (P = 0.146, T value = 4.294).

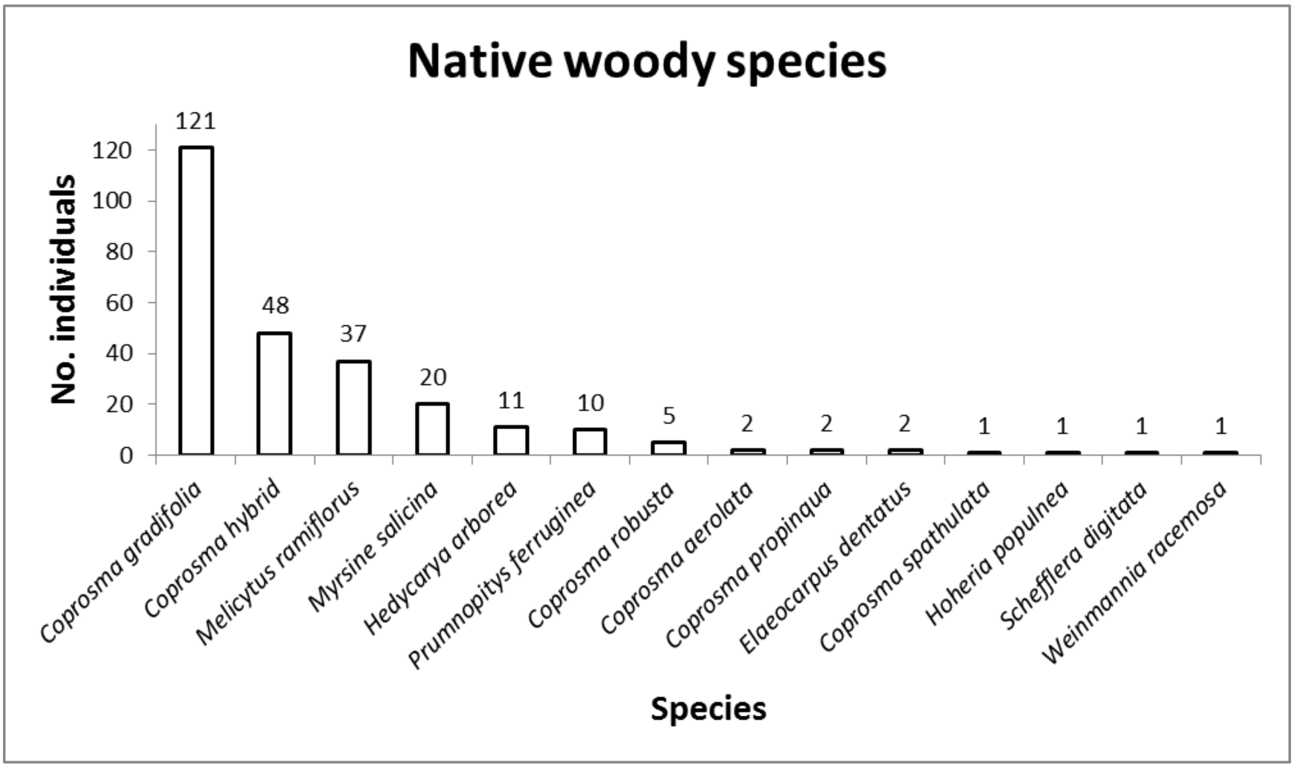


Figure 8. The abundance of each of the 14 native woody species found in the 5 gorse plots.

Epiphyte study

A total of 30 plant species (Appendix I, Table 4) were found growing epiphytically on the lowermost 2m of the 3 host species sampled. Of these 30 species, 20 were true epiphytes (their normal growth habit) while the remaining 10 species are classed as terrestrial plants growing epiphytically (Fig.10). The key findings are that *Rhopalostylis sapida* only supported true epiphytes on the individuals that were sampled, and that *Dicksonia squarrosa* supported a (relatively) high number of terrestrial species. *D. squarrosa* and *Metrosideros spp.* had higher RTU richness than *R. sapida*.

The Chi-squared test showed that there was a significant difference (P = <0.001, X-squared = 15.81, D.F. = 2) between the number of true epiphytes and terrestrial species in relation to host species (Fig. 10). The GLM of host species as explained by host DBH, RTU richness, and their interactions was not significant (host DBH, P = 0.901, T value = 0.127; RTU richness, P = 0.256, T value = 0.1.181; host DBH:RTU richness, P = 0.439, T value = -0.794; D.F. = 18) (Fig. 9).

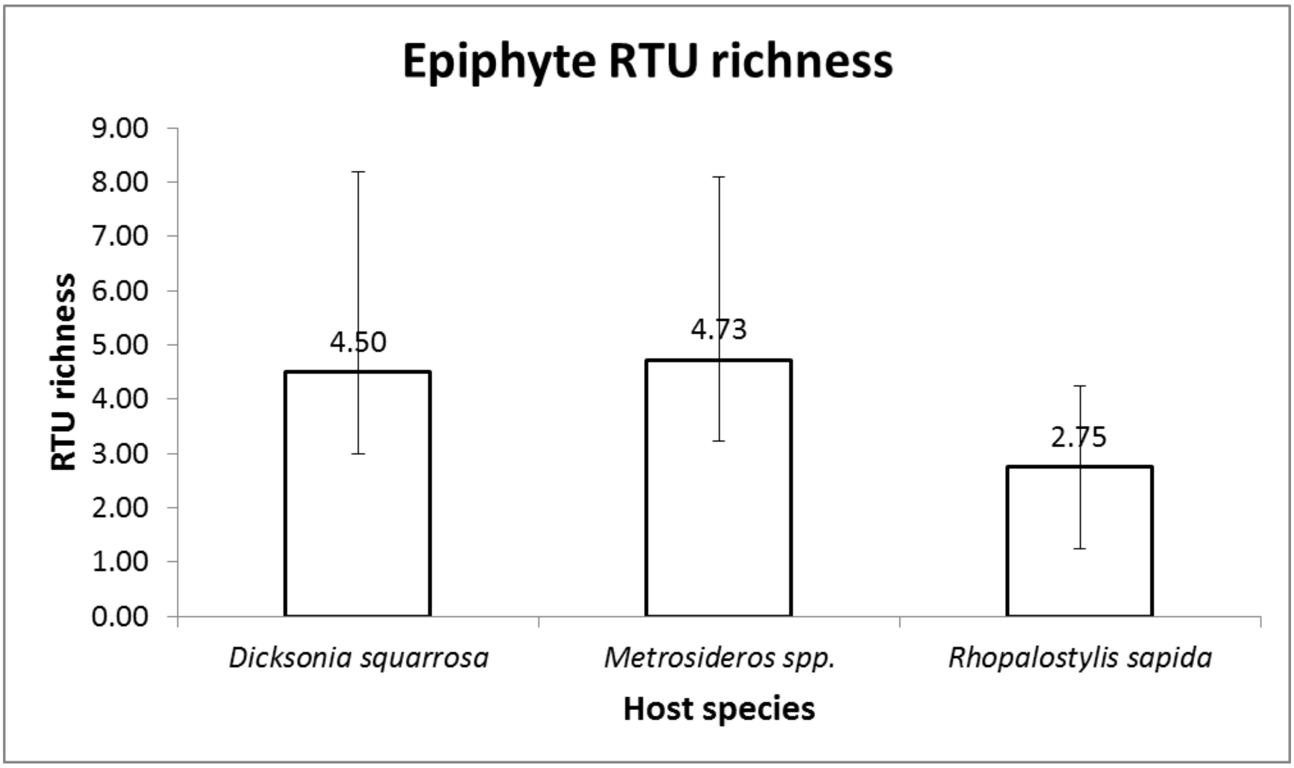


Figure 9. Epiphyte RTU richness of three host species. *D. squarrosa* SD = 3.70, *Metrosideros spp.* SD = 3.38, *R. sapida* SD = 1.50. The GLM of host species as explained by host DBH, RTU richness, and their interactions was not significant (host DBH, P = 0.901, T value = 0.127; RTU richness, P = 0.256, T value = 0.1.181; host DBH:RTU richness, P = 0.439, T value = -0.794; D.F. = 18).

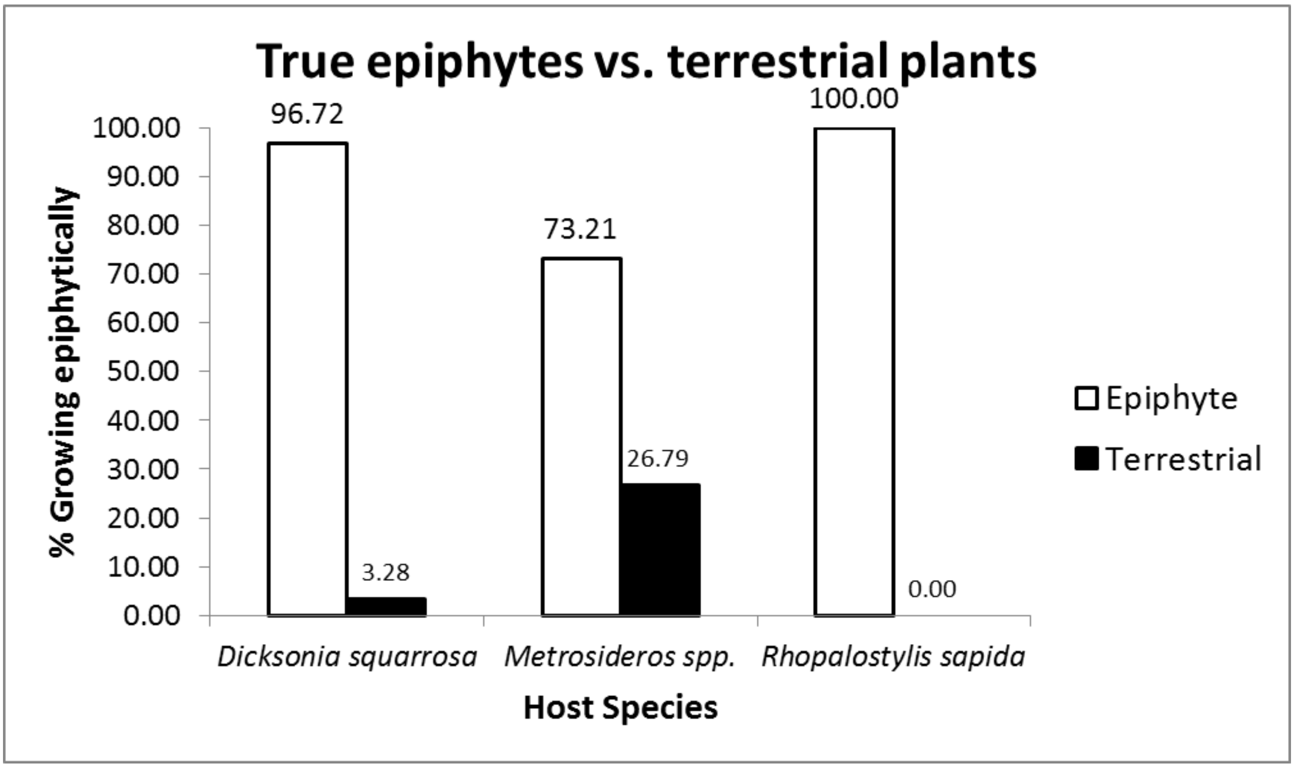


Figure 10. The percentage of true epiphytes or terrestrial species growing epiphytically on three host trees. The Chi-squared test showed that there was a significant difference (P = <0.001, X-squared = 15.81, D.F. = 2) between the number of true epiphytes and terrestrial species in relation to host species.

Light/shade requirements

All the species measured, in the reference site Nikau Scenic Reserve was found under mean canopy cover ranging from 74.24% to 79.73% (Fig. 11).

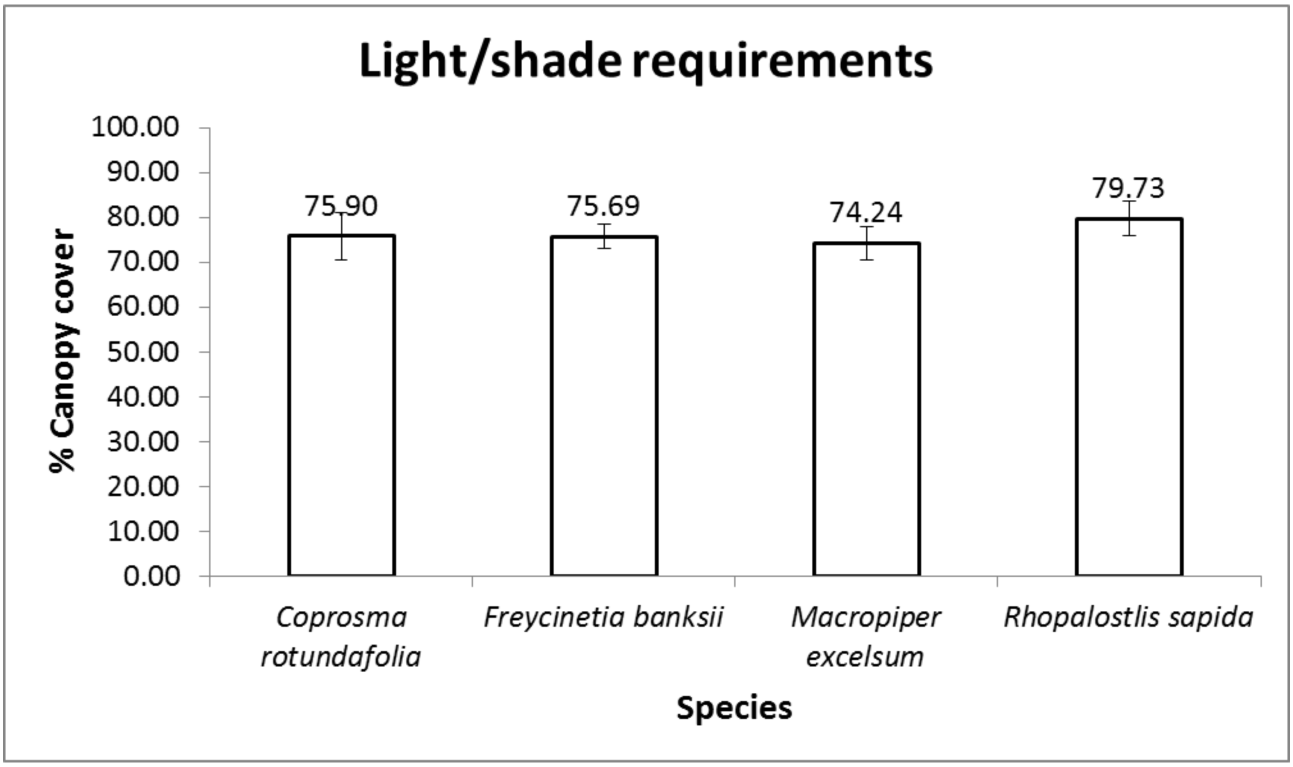


Figure 11. Mean canopy cover of species sample in NSR, *C. rotundafolia* SD = 5.34*, F. banksia* SD = 2.72*, M. excelsum* SD = 3.66*, R. sapida* SD = 3.88.

Discussion

In total 75 species were identified as being present in the reference site, NSR and self-seeded under mature gorse in the restoration site, that have not been planted in the restoration plantings. The reason for this disparity is that the initial restoration plantings were a small number of primary successional species, planted for the purpose of closing the canopy as rapidly as possible to shade out the grass, to allow other natives to establish (M. Bowie et al., 2012; Washer, 2012). It is also noteworthy that to date no ferns have been planted if the restoration plots. The main reason for this is the lack of sufficient canopy cover to date, the difficultly of propagating ferns, and lack of knowledge of propagation techniques by CVNZ (Washer, 2012).

The canopy cover in the restoration plots (14.89%) overall was significantly lower than in the mature (79.95%) and the gorse (79.33%) plots. However canopy closure in the restoration plots sampled is occurring rapidly, with an increase on mean of 824.24% over 12 months. At this rate plots R1 and R3 will likely be suitable for the planting of shade tolerant native plants including ferns within the next 12 months. It is important to note that this method does not take into account canopy height and architecture which can affect the quality and quantity of the light reaching the plants below (e.g. PAR, sun flecks etc.) (J. Sullivan, 2013).

The results show that the mature gorse provided an effective nursery for the self-establishment of native species. In total 23 native species self-established in the five 100m² plots, including a number of ferns and a liana. This was made possible by the gorse shading out the grass to allow native seeds/spores to germinate and providing similar canopy cover (79.33%) to the reference site(79.95%), NSR. This also gives us an indication of what species are likely to establish un-assisted, and do not need to be actively planted, and which species will need help to establish. This also indicates that gorse may be left to assist the reestablishment of native species if there is inadequate funding to undertake active restoration. However this approach takes much longer than active restoration and often follows a different successional trajectory than would occur in an un-modified natural ecosystem, or under a canopy of other native species(J. J. Sullivan et al., 2007; P. A. Williams, 2011).

Research by Sullivan et. al. (2007) comparing community composition of gorse and kanuka stands in similar localities (to each other), and at comparable successional stages, found that they were markedly different. A number of groups of plants were absent or less common in the gorse stands than in the kanuka stands. Their findings were consistent with a study at Hinewai Reserve, Banks Peninsula, where Wilson (1994) found that mixed hardwoods replaced gorse on a site formerly occupied by beech forest. In addition to this, Sullivan et. al. (2007) and other studies found that these differences occurred at a number of trophic levels including bird communities (P. A. Williams & Karl, 2002), invertebrates (Harris, Toft, Dugdale, Williams, & Rees, 2004), and soil microfauna (Yeates & Williams, 2001). However we must also keep in mind that kanuka is not a dominant primary successional species on the West Coast (Crowe, 2004). Also the restoration area (and gorse) is very close to abundant seed/spore sources in nearby mature forest, NSR, and secondary forest on the eastern side of the road (author, pers. obs.).

When considering succession in the gorse stands and in the restoration site as a whole we must take into account the surrounding biota, topography and landscape processes (e.g. erosion, hydrology), fire, and the history of human disturbance (Cook, Yao, Foster, Holt, & Patrick, 2005; Derussche, Escarre, & Lepart, 1980; J. J. Sullivan et al., 2007). The succession at the restoration site is likely to be greatly influenced by seed dispersal over short distances. A majority of seed dispersed by small birds such as silver eyes will drop within 100m of the source (C. Burrows, 1994; Stansbury, 2001). Larger birds like kereru are also known to disperse 79-88% seed up to 100m from the parent tree (Wotton, 2007). It is also noteworthy that woody species (both native and introduced) of a few years growth may be effective at shading out pasture grasses but may be too low to serve as perches for birds (Karen D. Holl, 1998). A combination of canopy closure from restoration plantings and in places gorse to shade out pasture grasses, with the addition or perching structures will most likely greatly enhance the establishment of NPNS (Duncan & Chapman, 1999; Karen D. Holl, 1998; Karen D Holl, Loik, Lin, & Samuels, 2000; Zanini & Ganade, 2005)

The results from the epiphyte study show that *Dicksonia squarrosa* and *Metrosideros* spp. support a number of species that only growing epiphytically, and *Rhopalostylis sapida* to a lesser extent. Additionally Ratas also create conditions similar to that of the soil by accumulating plant matter that breaks down into a hummus that supports a number of terrestrial species. It is noteworthy that only the first two meters of these host species were sampled, and it is likely that there are a large number of species growing in the upper reaches of these trees that we have missed.

Unfortunately due to time constraints only 4 of the 15 NPNS selected were sampled. The four species *Coprosma rotundafolia, Freycinetia banksii, Macropiper excelsum,* and *R. sapida* had fairly similar shade requirements, being found under mean canopy cover of 76.39% which was lower than was found in the mature and gorse plots that were sampled.

Recommendations and future research

- Control of immature gorse in areas intended for future restoration plantings should continue, but should not be employed in areas with mature gorse, and in areas with no plans for restoration plantings. The gorse in these areas will supress grass growth and allow natural succession to take place, with the aid of bird perches (see below) to increase seed rain.

- Bird perches should be established in planted areas with sufficient canopy closure and pasture grass die back to increase seed rain in the restoration area. Perches combined with the control of pasture grasses has been shown to be an effective method of increasing the establishment of seedlings where there are seed sources nearby (Duncan & Chapman, 1999; Karen D. Holl, 1998; Karen D Holl et al., 2000; van Andel & Aronson, 2012; Zanini & Ganade, 2005).

- Tree fern logs sourced from nearby forestry sites should be distributed around the planted areas of the restoration site to encourage the establishment of epiphytes and terrestrial plants, as well as to provide habitat for invertebrates.

- More focus should be given to propagating NPNS to plant out as canopy closure becomes sufficient for establishment of these plants .

- Ferns should be propagated and planted in areas with sufficient canopy cover and dieback of pastures grasses. Plots R1 and R3 are likely to be suitable for planting ferns by summer 2013/2014.

- No resources should be used to propagate and plant out species that have been shown to establish by themselves in reasonable numbers (where there is adequate dieback of pasture grasses), except for the explicit purpose of shading out pasture grasses. Examples of planted species that are self-establishing include: *Coprosma robusta, Hedycarya arborea, Melicytus ramiflorus,* and *Myrsine salicina*.

- A study/monitoring program should be implemented to measure the effectiveness of the perches in terms of seed rain and the role of any seed predation that may be taking place.

Benefits of the scholarship

I gained experience planning and implementing a comprehensive field study from start to finish. During this time I spent four weeks doing fulltime fieldwork and a significant amount of time doing statistical analysis and report writing. I learnt how plan a field project, better plant identification, how to modify methods in the field to overcome problems, the benefits of collaboration with other researchers for mutual benefits, an intermediate understanding of the statistical programming language “R”, and improved skills in the systematic researching of pertinent literature.

I believe this scholarship has greatly improved my skills as a field ecologist and researcher.

Acknowledgements

This research would not have been possible without the assistance of the following people and organisations (in no particular order):

- Ecology Department (Lincoln University) for funding this research
- Professor Nick Dickinson (Lincoln University) for supervising this research including overseeing the project proposal and development of methods.
- Jason Hahner (Lincoln University) for logistical support, assisting with fieldwork, plant identification and for reviewing the project proposal and this report
- Jules Segrestin and Agathe Chassagneux for sharing their data with me
- James Washer (CVNZ) for providing accommodation and local knowledge of the area and restoration project
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Appendix V
Student report 2

Chronosequence and description of soils at Punakaiki and implications for restoration

ECOL699

Punakaiki Report

Hongtao Zhong

19/11/2012

Abstract

Punakaiki Coastal Restoration Project (PCRP) is a joint effort between the Department of Conservation, Rio Tinto, Conservation Volunteers and Lincoln University. It is important to restore Punakaiki coastal plain, in order to enhance the local environments, to help petrel migration. It is also hoped to quantify the success of the restoration and explore the feasibility of biodiversity offset. The PCRP study area has distinct feature of different age of pursuing soil development and the adjacent unique Nikau Scenic Reserve as a reference ecosystem. The aims of this study are to find out the implications of soil chronosequence and vegetation differences on soil chemical properties and soil invertebrate populations. Results indicate that soil chronosequence and vegetation variances do have implications on soil nutrient status (particularly nitrogen and phosphorus) and soil faunal recolonization. It is recommended to undertake in-depth study in the Nikau Scenic Reserve with regard to whether there are differences in vegetation compositions along with old-, middle- and young- age soils. This will provide valuable information to direct PCRP implementation, such as species selection and how species suitability corresponds to different soil ages and nutrient status.

Introduction

The Punakaiki Coastal Restoration Project (PCRP) is collaboration between the Department of Conservation (DoC), Rio Tinto and Conservation Volunteers. The Lincoln University research team is responsible for ecological monitoring and research. Realizing the importance of ecological restoration for disused land, Rio Tinto planned to initiate an ecological restoration project at the West Coast, New Zealand. In 2010, the 80 ha land property located at the Brarrytown Flat was gifted to the DoC for stewardship and also funding restoration practices. Conservation Volunteers is a non-governmental organization, which is fully responsible for the PCRP's management and implementation, in particular tree planting and volunteer input.

Plate 1 Punakaiki Coastal Restoration Project area in Google Map.

The PCRP initially planned to plant 100,000 trees over 5 years, and by October of 2012 88,010 trees have been planted since started from May 2009. In terms of the species selection for revegetation, PCRP has referenced to the Nikau Scenic Reserve, which is natural mature forest and adequate for a reference ecosystem (Bowie et al., 2012). There are over 30 native tree species have been selected for revegetation, including *Coprosma spp., Pittosporum spp., Cordyline australis, Phormium tenax, Oleria ilicifolia, Grisilinea lucida, Carex secta and Fuschia procumbens* (Bowie et al., 2012).

Several goals were established. First of all, PCRP is to create a safe forested corridor for West Land petrel (*Procellaria westlandica)* from breeding site to the sea (Bowie et al., 2012). This is significant because it is the only remaining breeding ground for them at mainland New Zealand (Bowie et al., 2012). Secondly, PCRP is promising to establish measurable and credible indicators for determination of successful ecological restoration. Additionally, as proposed by Rio Tinto, PCRP aims to investigate the practicality of value and financialize the success of ecological restoration.

Previous studies had been conducted, such as the Barrytown Flat Baseline Biological Survey 1985-1986 (Don, 1986; as cited in Bowie et al., 2012), the Soils of the Barrytown Flat, Westland (Wilms, 1985), natural area assessment for the Grey District Council (e.g. Boffa-Miskell, 2006; as cited in Bowie et al., 2012) and most recently the Baseline Survey for the Punakaiki Coastal Restoration Project (Bowie et al., 2012). They had comprehensively covered from overall environmental qualities, floral and faunal biodiversity and geological and soil studies.

From a pedogenic chronosequence perspective, PCRP areas have distinct soil map in terms of old-, middle- and young- age soil development. On the other hand, because of the presence of the Nikau Scenic Reserve, vegetation differences between mature forest, restored landscapes and unplanted lands are distinct. They may have potential implications on sustainable PCRP management and ongoing research. This study aims to: 1) investigate the consequences of soil chronosequence on A horizon development, nutrient status and invertebrate population; 2) investigate the differences of A horizon development, nutrient status and invertebrate population between mature and restored vegetation; and 3) assess whether a knowledge of soils is an effective and valuable component of the restoration effort.

Methodology

Study site area

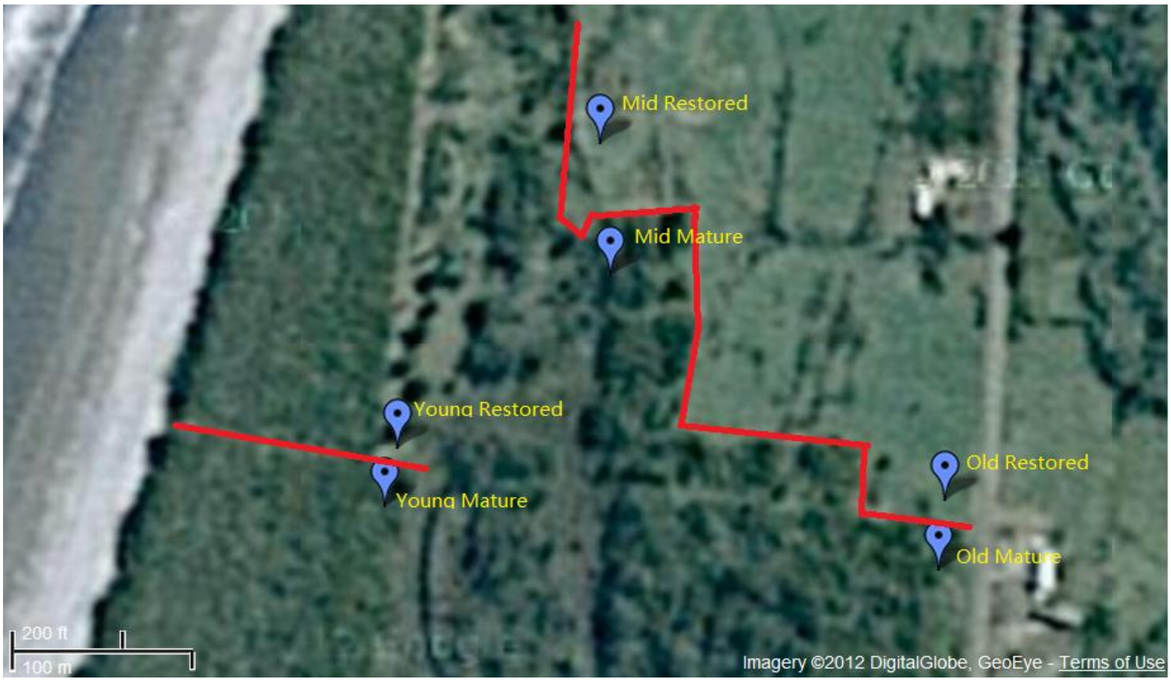

Plate 2 Study sites with brief bush edge in red line and sampling locations.

The present study area is the south part of Punakaiki Coastal Restoration Project area. It is the joint area between the Nikau Scenic Reserve and restored landscape. As shown at Picture 2, the six blue marks are study locations, and the red lines indicate approximate edge between the Nikau Scenic Reserve and restored landscape. The present six study locations have been located at soils with different ages in closely parallel based on elevation. Additionally, they are set along the edge between mature forest and adjacent restored areas. They perfectly match the study aims.

In terms of the local environmental conditions, the climate on the study areas of the West Coast is warm/temperate and wet. The annual rainfalls is between 2,000 mm - 4,000 mm; mean temperature is around 10 - 12 °C; and annual sunshine hours are from 1,600 hr to 1,800 hr (Bowie et al., 2012).

Soil sampling

Sampling locations are (refer to blue marks in Plate 2):

Old restored site, S 42.14383°, E 171.33066°;

Old mature site, S 42.14417°, E 171.33061° is 20 m south from bush edge;

Middle restored, S 42.14204°, E 171.32832°;

Middle mature, S 42.14269°, E 171.32839° is 28 m south form bush edge;

Young restored, S 42.14357°, E 171.32695°;

Young mature, S 42.14386°, E 171.32685° is 19 m south form bush edge.

Six 10*10 m quadrats were formed North and East from each described location. At each quadrat corner, 4 pogo stick (2*10 cm) samples of A horizon were collected and from same location as pogo auger sample with 250 ml of B horizon taken. Slightly more sample collected at young plots to compensate for high quantities of gravels. Invertebrate samples taken from points described above with an auger (6.9*10-12 cm).

Soil analysis (chemical and soil invertebrate analysis)

Samples were air-dried and sieved at the Field Service Center, Lincoln University. Soil pH values, electrical conductivity (EC), moisture content (MC), loss on ignition (LOI) were measured according to Laboratory Users Guide-Methods of Soil Analysis (Cresswell & Hassall, n.d.). Total soil carbon (TC) and nitrogen (TN) analysis were analyzed in Elementer Vario-Max CN Elemental Analyser, and soil trace elements analysis was analyzed in Varian 720-ES Inductively Coupled Plasma Optical Emission Spectrometer fitted with an SPS-3 auto-sampler and ultrasonic nebuliser. Soil invertebrate population was measured by Tullgren Funnel separation process and further physically counted for each sample (operated by Ross Carter-Brown).

Statistical analysis

Mann-Whitney U Test – two tailed was carried out on the data as to test the difference between two sets of data. In other words, U-test tells whether one group of number is significantly different, and also higher or lower than the other group. The reason is that data of this study is small sample size. We assumed that there may not be normally distributed for each group. Namely, the present study data are non-parametric. The assumption of normality has been violated in a t-test, particularly because of the sample size is small (Using Minitab 16, n.d.). Therefore it is recommended to apply Mann-Whitney U Test in two tailed.

We hypothesized that 1) null hypothesis: there is no significant difference between two groups; 2) alternative hypothesis: there is significant different between two groups. The results are present in table blow, where "√" indicates there is significant difference between mature and restored sites; "×" indicates there is no significant difference between mature and restored sites. In addition, the number "0.xxxx" shows the P-value from Mann-Whitney U Test.

Test Item	Result	Test Item	Result	Test Item	Result	Test Item	Result	Test Item	Result
pH	× 0.8099	TN	× 0.1282	Ca	× 0.6889	K	× 0.2980	Ni	× 0.1282
EC	√ 0.0051	C/N Ratio	√ 0.0051	Cd	× 0.4712	Li	× 0.5752	P	× 0.9362
MC	× 0.6889	Al	× 0.6889	Cr	× 0.8102	Mg	× 0.8102	Pb	× 0.3785
LOI	× 0.1282	As	× 0.2971	Cu	× 0.5752	Mn	× 0.2980	S	× 0.1282
TC	√ 0.0306	B	× 0.1735	Fe	× 0.0927	Na	√ 0.0306	Zn	× 0.9362

Table 12 Mann-Whitney U Test-two tailed results between mature and restored sites data

Results

Sites soil study

The Punakaiki Coastal Restoration Project is located on a coastal plain, which extends approximately from the present shoreline to the coastal cliff (refer to Picture 1 and Appendix 1). The coastal plain is roughly 6,000 years old and regarded as post-glacial. The coastal plain in the north part of the Barrytown Flat comprises sand dunes and marine sands in different ages. They are created by a prograding coastline, which is constructed by a building out of the shoreline by marine activity.

As indicated by Wilms (1985), the PCRP soils landscapes comprise colluvial and alluvial fans. The colluvial fans originally derive their material from the cliffs. Furthermore, in South Island, a hard sedimentary rock such as greywacke is common parent material for coastal soil development (McLaren & Cameron, 1996; Birkeland, 1999).

According to soil map shown in Appendix 1, small streams wash the coastal plain, where they assemble at low areas to form back swamps (refer to Appendix 1). These low lying areas were initially lagoons, followed by the development of sandy barrier or beach ridge by wave momentum during the prograding coastline. This is the area that peat and organic rich soils develop (C. Smith, *pers. comm*).

According to Appendix 1, as described in the current project as "old age soils" are better described as young near level fans Kamaka Soils (Km), "middle age soils" are younger dune Karoro Soils (Kr), "young age soils" are Back Swamps Waiwhero Soils (Ww) and "very young age soils" are stony foredunes. However, according to soil description (Table 2, below), our young age site soils do not have a relatively thicker A horizon, as what Waiwhero Soils usually have (C. Smith, *pers. comm*). This indicates that our young age sites are not located in Back Swamps Waiwhero Soils areas as described in soil map, Appendix 1 (Wilms, 1985). In other words, the soil boundary lines drawn on soil map Apeendix 1 may not accurate, probably because the inaccuracies of longitude and latitude data due to GPS technology in 1985 or low quality of aerial photo that it based on.

Old age soil	**Location: S 42.14383°, E 171.33066°; Elevation: 18 m**
Ah 0-30 cm	Color in 7.5YR 3/4 sandy loam; week crumb and moderately developed medium; many roots, gradual boundary.
C 30+ cm	Color in S7 3/2 sand;
Middle age soil	**Location: S 42.14204°, E 171.32832°; Elevation: 13 m**
Ah 0-10 cm	Color in 10Yr 2/2 extremely fine sandy loam; many roots; weakly developed; gradual boundary.
Bw 10-35 cm	Matrix color in 2.5Y 3/1, with 30 % mottling color in 5YR 4/8, very fine sand; diffuse boundary.
C 35+ cm	Matrix color in 10YR 3/1, with 5 % mottling color in 7.5Y 3/1, fine sand.
Young age soil	**Location: S 42.14360°, E 171.32704°; Elevation: 8 m**
Ah 0-10 cm	Color in 10YR 2/2 sandy loam; contains gravels class 5-10 cm long axis; weakly developed; many roots; diffuse boundary.
Bw 10-40 cm	Color in 10YR 3/3 sand; contains gravels class 4-7 cm; diffuse boundary.
C 40+ cm	10YR 4/4 sand; contains gravels class 3-5 cm long axis.
Very young soil (gravel ridge)	**Location: S 42.14344°, E 171.32584°; Elevation: 11 m**
Ah 0-10 cm	Color in 10YR 2/2 fine sand in matrix; coarse; very weak crumb structure; gravels all sizes throughout profile, from 3-8 cm largest ones to 1-2 cm smallest; very weak development; diffuse boundary;

Bw 30+ cm	Color in 10YR 3/2 sand; very weak apedal structure; gravels all sizes throughout profile, from 3-8 cm largest ones to 1-2 cm smallest;

Table 13 Site information and soil profile description of study sites

The actual longitude and latitude data of middle and young age soil sites for soil description and sampling were little different, because they carried out in two different dates and two GPS devises. These may lead to certain degree of uncertainty. From the above Table 1 we see that soils follow the overall trend in terms of the older soils, the thickener A horizon and in turn soil organic matter accumulation will present.

Soil chemical properties

Across all sites, pH values were all moderately acidic and pH 4.4 was lowest at the old mature site. This is probably explained by high aluminum concentrations present at all samples (Table 4), which considerably higher than New Zealand forest soil reference concentrations, because the hydrolysis processes of Al can lead to soil acidity. In addition, high annual rainfall has led to high potential of soil cations leaching, including basic ions Na^{+}, Mg^{2+}, K^{+}, Ca^{2+}, which further lower the soil pH. As well as, a slightly increased trend of pH from old to young mature forest sites exists (Figure 1), while there is no similar pattern at the restoration sites.

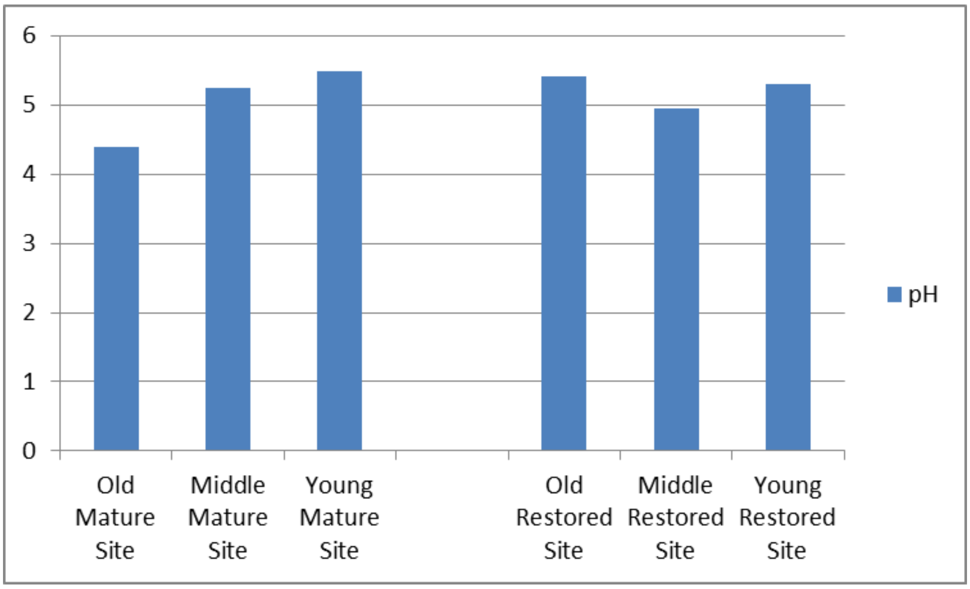

Figure 1. Soil pH values between different age soils and mature and restored vegetation.

As expected, surface soils in (A horizon) mature sites contain higher organic matter than that in restored sites, including total carbon, total nitrogen and organic carbon. Surprisingly, all the young soil age sites contained higher carbon and nitrogen concentrations than the old- and middle- age soils (Table 2). As well as the organic carbon (LOI), young sites almost have twice as much as middle-aged sites. In terms of soil organic matter decomposition rate and release of nutrients, the old mature site samples had the highest carbon to nitrogen ratio, which indicates a relatively slow release of SOM nutrients to soil pool.

Sites	pH	Moisture Content (%)	LOI (%)	TN (%)	TC (%)	C/N Ratio
Old Mature	4.385	35.05	4.38	0.5475	9.5450	17.4350
Middle Mature	5.24	35.92	3.86	0.4260	7.2255	16.9650
Young Mature	5.475	18.07	6.83	0.9425	14.2530	15.1300
Old Restored	5.41	27.63	2.16	0.2925	3.2515	11.1100
Middle Restored	4.945	26.87	1.65	0.2460	2.7945	11.3800
Young Restored	5.3	27.08	4.99	0.7195	8.6325	11.9950

Table 14 Soil major nutrients, moisture content and pH with different age soils and vegetation development.

Moreover, according to the C/N ratio data, all mature sites values are much higher than restored sites (Figure 2). It is apparent that restored sites are more able to decompose SOM than mature forest sites. This is probably due to a high demand of nutrients by new and fast-growing planted vegetation. A C/N ratio of 10-12 is normal for an arable soil (McLaren & Cameron, 1996), while restored sites have C/N ratio around 11. The fact is that restoration areas were modified from former pasture land uses (Bowie et al., 2012). So, this may be a possible explanation.

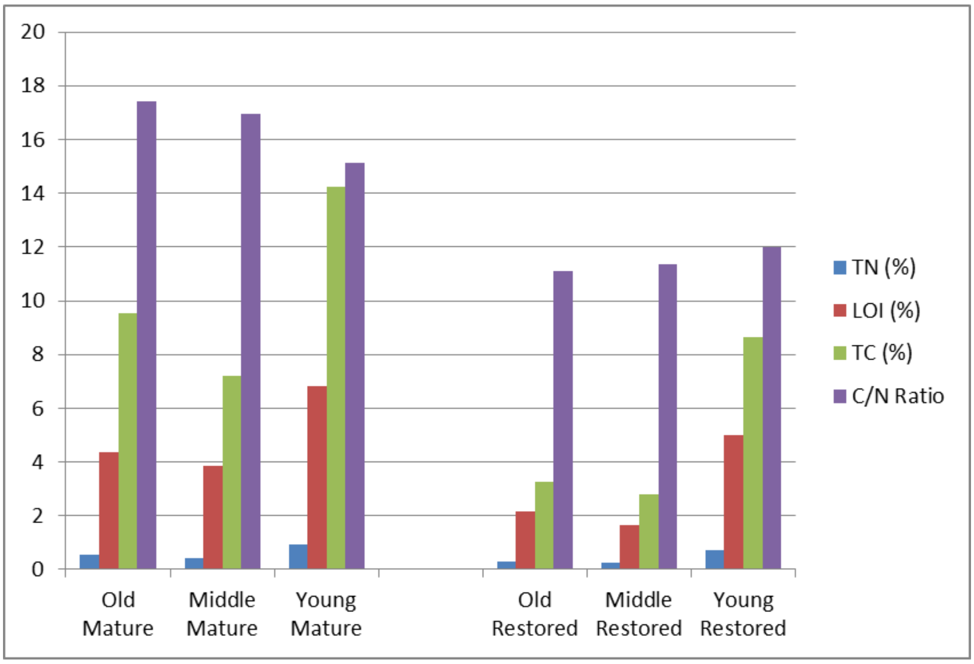

Figure 2 Comparison of soil organic matter properties.

Low moisture contents were present at the younger mature site, and the young mature site were lowest, probably because they have significantly higher gravel content than old and middle age sites (Table 3). High gravel content means low water holding capacity.

	Old Mature	Old Restored	Mid Mature	Mid Restored	Young Mature	Young Restored
M (total) (kg)	0.493	0.69	0.594	0.824	1.448	1.287
M (residual) (kg)	0.016	0.029	0.0078	0.025	0.874	0.693
Residue / gravel content (%)	3.25	4.20	1.31	3.03	60.36	53.85

Table 15 Gravel content between different age soils.

According to the soil trace elements results (Table 3), there are not significant toxic concentration evident, with reference to New Zealand forest soil reference concentrations. Across all sites, iron, manganese, aluminium and sulfur are considerably higher than New Zealand soil mean values, while copper, cadmium and phosphorus concentrations are lower than reference soil concentrations. It is clear that old mature forest soil has significantly low in nickel, zinc, lithium and magnesium compared to middle- and young- mature sites.

On the other, lower concentrations of K, Ca, Mg and Na mirror the lower pH at old mature sites. However, the overall concentrations of Na and K at mature forest soils are higher than restored sites soils. Moreover, Bowie et al. (2012) did find similar picture, as well as lithium concentration low in mature forest.

In contrast, young mature soils have significantly higher concentrations of arsenic, boron, zinc and sulfur, compared to others. At last, interestingly, lower phosphorus concentrations are detected at old age sites.

Sites	As	B	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Old Mature	2.33	2.51	0.06	22.54	1.83	11510	916.3	1.7	8.2	12.6
Middle Mature	2.52	2.82	0.02	34.77	3.80	15814	649.8	7.8	9.0	27.2
Young Mature	4.01	7.99	0.09	17.25	7.20	15090	597.9	8.8	13.8	44.9
Soil Reference	2.2	2.5	0.3	11.6	16.7	3861.4	129.8	3.4	13.3	45.6
Old Restored	2.5	2.0	0.06	27.3	1.7	22442	1455	4.1	8.8	17.6
Middle Restored	2.3	1.2	0.04	41.6	2.3	16914	971.9	4.2	7.4	17.3
Young Restored	3.0	4.8	0.13	16.1	5.7	14517	571.9	7.6	11.9	43.6

Table 16 Soil chemical elements concentrations at study sites, upper one trace element and lower one other cation (mg/kg)

Sites	Al	Ca	K	Li	Mg	Na	P	S
Old Mature	10501.8	5544.7	1222.7	2.8	843.7	159.1	457.7	516.4
Middle Mature	11801.6	5746.1	1101.5	15.5	1539.5	197.4	907.4	556.2
Young Mature	13329.8	7528.3	1678.9	16.8	1773.3	271.8	867.9	1142.2
Soil Reference	4663.9	2450.5	695.6	3.0	475.4	81.5	1155.1	305.3
Old Restored	14719.5	6984.3	1041.6	5.7	1036.3	93.5	581.9	306.8
Middle Restored	10669.9	6066.2	775.9	7.0	1181.7	74.2	689.8	331.9
Young Restored	12345.0	5225.2	1442.6	14.7	1666.4	180.7	920.7	796.3

Soil invertebrate characteristics

It is clear that *Acarina* and *Collembola* are most popular invertebrate re-colonizers, except there were no Collembola found at old mature forest sample site, although highest numbers of Acarina and Coleoptera were found here. In comparison, *Amphioda* and *Diptera* are uncommon, and they only re-colonize restored sites instead of mature forest. *Hemiptera were* only found in young age soil rather than old and middle age soils. In addition, *Diptera* and *Hemiptera* did not appear at old soils at all.

Site	Acarina	Amphipoda	Annelida	Coleoptera	Collembola	Diploda	Diptera	Hemiptera	Total Ind.
Old Mature	29		2	14		1			46
Middle Mature	13		1		8				22
Young Mature	5			5	25	1		14	50
Old Restored	10	3	4	4	27	1			49
Middle Restored	1	4	3	1	12		1		22
Young Restored	26				15	11	4	5	>61
Total	84	7	10	24	87	14	5	19	250

Table 17 Soil invertebrate population between different sites (analyzed by Ross Carter-Brown and used with permission).

Conclusion

Soil chronology, a complex pedology and historical usage of the site has determined and modified soil nutrients status and soil organic matter accumulation. Faster turnover of short-lived roots in grass land may influence soil organic matter build-up in a short term.

On the other hand, some basic ions such as Na^+ and K^+ accumulation at coastal forest can benefit from sea spay. Soil phosphorus long-term depletion has two possible reasons: soil chronosequence and ecosystem retrogression. However, it is important to identify the real reason of lower phosphorus concentration at PCRP mature forest in a detailed study. Extra P input from outside is critical for ecosystem's long term sustainability.

The present study provides valuable information with regard to the implications of soil chronosequence and vegetation difference on soil nutrient status and soil invertebrate recolonization. However, unknown field was posed, such as whether or not vegetation differences will exist in relation to different ages of soils. Future research areas are therefore proposed.

However, our results were not as clear as we hypothesized. A major limitation is that only A horizon soils were analyzed in the present study. In other words, the present study is only a snapshot of the whole PCRP soil study. This means that present results could not effectively and completely represent the real picture of PCRP site soil characteristics and related relationships. Therefore, more detailed and extended studies that include whole soil profile analysis are recommended.

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Appendix 1 Provisional soil map of study sites approximately (modified from Wilms, 1985)