

# RESTORATION RESEARCH

**Punakaiki Coastal Restoration Project: 2014 - 2016**



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# 1. Executive Summary

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This report addresses Lincoln University objectives and deliverables for the 2014-2016, in addition to existing 6-month reporting. This is the final report of the current agreement. The Living Lab Draft Masterplan is attached as appendix in section 13.3.

During this period, the Faculty of Agricultural and Life Sciences has utilized the PCRCP site as a valuable location to conduct ecological and restoration research and teaching. Research activities have focused on:

- Best practice templates and the establishment of critical species assemblages in the restoration trajectory,
- Understanding the relationship between biotic assemblages, soil rhizosphere chemistry and chronosequences in the restoration trajectory,
- Quantifying the benefits of nature conservation, biodiversity and ecosystem services in this unique coastal sand plain forest matrix.

The aim of the on-going monitoring programme and research component of the PCRCP project was

- to provide the science base to demonstrate the benefits of the restoration activity,
- to ensure the continuity of baseline data to support ongoing and future research programmes,
- to inform the interpretation centre and trail,
- to provide useful work activities for volunteers and students and community groups beyond planting trees,
- to quality assure the restoration effort.

The research aims have been achieved, largely through field studies associated with three postgraduate students and several summer scholars. There has now been substantial scientific study of the PCRCP site, from the initial baseline and benchmark studies through to repeated monitoring of the restoration trajectory over a 5-year period. The site has provided an invaluable location both for research activity and for undergraduate teaching. New knowledge has been gained of biodiversity and species assemblages of flora and fauna, and this has informed restoration practice. The site provides a diverse range of soils and habitats that are now well defined. The ongoing research challenge is to understand and enhance the restoration trajectory, with particular

attention (i) to more than 100 other plant species that are mostly epiphytes that can be established, and (ii) to the establishment of faunal biodiversity (invertebrates and vertebrates). The present report contains an update of the Hahner & Bowie (2013) report.

The proportion of native to exotic birds in the restoration areas is trending upwards. Regenerating seedlings have been at a density of >200 per m<sup>2</sup> and it is highly likely that species including silvereyes, bellbirds, tui and weka are contributing to seed dispersal. Dung beetles are a known indicator for restoration success worldwide and results from pitfall trap data and behavioural work at PCRCP suggest that this taxa will also provide a useful proxy for return of ecosystem services including nutrient cycling and secondary seed dispersal. Other taxa such as wasps and grassland spider specialists (*Anoteropsis hilaris* and *Dolomedes minor* in particular) are found in mature sites in relatively low numbers and will diminish in restoration plantings over time. Leaf litter invertebrate extraction is a very sensitive method for determining specialised species of this microhabitat.

Species such as a mite-like harvestman (*Aoraki denticulata*), weevil species, mite species and a spotted earthworm all show great promise as indicators of change in the restoration plantings. The moth fauna has shown a significant trend higher diversity, and the proportion of common species found in mature and restored has also trended higher. Tree weta appear to be very mobile and colonised restoration sites quickly. The species present is a known seed disperser and will provide ecosystem services within the restoration sites. Recent rodent tracking indices indicate that the abundance is down on 2013 survey which may well be environmental effect rather than a response to the restoration efforts.

The PCRCP site has provided a valuable teaching resource. It is now an established field location for two residential field courses from Lincoln University (ECOL202, Biodiversity, 50-100 undergraduate

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students, and ELLS/ECOL697, 10-15 postgraduate students). The site is used extensively for undergraduate and Honours projects, and for summer scholars. In collaboration with Open Polytechnic we now have an accredited Diploma course in Restoration Ecology.

Following the gifting of the land by Rio Tinto to the Department of Conservation in 2010, and its subsequent gazetting as the Te Ara Tāiko Nature Reserve, the sandplain forest will continue to naturally develop, providing an unrivalled opportunity to monitor and investigate the onward trajectory and associated ecosystems services. Lincoln University will continue to make every effort to continue research and teaching and teaching activities at the site. Conservation Volunteers planting led by James Washer has provided knowledge of more than 30 plant species that can be established relatively easily and proficiently. His work has provided a valuable collaboration that has greatly informed the research effort. Our engagement with all partners has been highly valued. We are grateful to Rio Tinto for enabling this project, and particularly to Stuart Rhodes for his collegiality, support and encouragement.

## 2. Introduction

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After the first phase of restoration activities in the PCRP (2008-2013), an ongoing partnership agreement was arranged between Rio Tinto, Department of Conservation (DOC), Conservation Volunteers New Zealand (CVNZ) and Lincoln University, to cover the period 2014-2016. The partnering vision was updated to reflect and build on the progress made during the initial PCRP term:

“The Punakaiki Coastal Restoration Project (PCRCP) aims to restore the sand plain forest on the Te Ara Taiko Nature Reserve, land previously used for grazing and mining on the northern Barrytown flats, that spans the mountains to sea. This will protect and enhance the unique ecological values of the Punakaiki area, which include the only nesting ground of the Westland Black Petrel, natural habitat of the Blue Penguin and the remnant sand plain forests bearing Nikau Palms and Rata trees many hundreds of years old.”

(Agreement to extend the Westland Petrel partnering agreement (Simpson Grierson, 19/12/13)

Key partnership objectives were identified, which included the shared objective to ensure a sustainable future for the Te Ara Taiko nature reserve and adjacent conservation lands, which reflected the partners shared commitment to a collaborative approach to ecological restoration, and a belief in the value of research, innovation, education and community engagement. A continuation of the assisted restoration process towards a functioning sand-plain [or wetland] ecosystem involved the planting of over 150,000 eco-sourced trees, shrubs and flaxes has in effect, established the foundations of this change. Further work over the last three years (2014-2016) has built on this by enhancing diversity and protecting the first five years' investment.

These objectives were to protect and enhance the existing restored areas, so further developing the knowledge base on the site in order to improve and increase the collective science of nature conservation and restoration in NZ and globally, as well as providing interpretive and educational resources to foster knowledge [and engagement] in and around species protection and restoration. More specifically, the new partnership agreement aimed to develop “internal” and alternate funding towards project self-sufficiency. The PCRCP is planned to become an integral part of the Punakaiki visitor experience through the development of high quality visitor experiences, and provide a world class model of a collaborative approach to nature conservation.

The restoration work over the three-year period included specific tasks to enhance the existing plantings through under-planting to increase species diversity and to enhance connectivity of remnants; contain the spread of gorse and blackberry, and to develop the nursery capacity to a point of project self-sufficiency.

A project implementation plan has been prepared, aiming to demonstrate conservation leadership through partnerships.

Conservation at the PCRCP should develop economic and business opportunities, and demonstrate enduring value for New Zealand citizens. Research and monitoring will be carried out around biodiversity and offsets to build up global knowledge about sustainability. Research findings during the three-year period provide a “living lab” for the development of research skills, to increase opportunities to educate citizens about biodiversity and species protection. Future plans for the PCRCP aim to create a positive experience for volunteers, visitors and stakeholders in order to increase numbers of people involved in conservation by providing hands-on experience for development of restoration-based skills. In turn, this will provide an evidence base for expert volunteer recruitment and management, and develop a flagship partnership showing innovation and expertise.

This report, which documents research and monitoring activity and findings from 2014-2016, provides an update to Hahner and Bowie (2013).

# 3. The Punakaiki Coastal Restoration Project

## 3.1 Introduction to the research site

The Punakaiki Coastal Restoration Project (PCRP), located in Punakaiki, New Zealand, aims to restore lands that were once utilized for mining and agriculture. Current management of the restoration project involves a partnership between Rio Tinto, Conservation Volunteers New Zealand (CVNZ), the Department of Conservation (DOC) and Lincoln University. A comprehensive description of the PCRP, including experimental sites and climatic variables was carried out by Hahner and Bowie (2013); a brief summary is given below.

The project area is located approximately 4km south of Punakaiki on SH 6, the main West Coast road (Figure 3.1). The PCRP site is located in the northern part of the Barrytown flats, a strip of coastal sand-plain between the foothills of the Paparoa Range and the Tasman Sea. The area comprises 80.5 ha, and adjoins the northern boundary of the Nikau Scenic Reserve. The Barrytown flats were originally covered with forest and wetland (Boffa Miskell, 2007), but the landscape has been entirely changed due to forest clearance, mining and agriculture (Wilms, 1985). 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.).

In the first year of monitoring 2011-2012 four transects were setup parallel to the coastline to reduce bias caused by a series of shingle terraces. In subsequent years seven transects were used. Each transect contained a mature forest site, a restoration site and an unplanted exotic grassland site. Different parts of the Nikau Scenic Reserve were used for five reference sites while a small remnant further north was used for two reference sites. The Nikau Scenic Reserve is a 20.2 ha of mature coastal sand-plain forest which gained legal protection in 1961 (Don, 1986). The plant complex communities are representative of the surrounding areas with coastal shingle ridge low forest through to taller kahikatea-northern rata forest and considered to be a unique landscape 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 seven restoration sites used for the transects were planted between August 2009 and August 2012 from a range of 34 native species (Hahner and Bowie, 2013). Control plots were dominated by a range of exotic grasses with scattered native *Carex* and *Juncus* species and had a buffer of >20m to other plantings.

Restoration at the PCRP aims a positive and lasting impact on the social, economic and environmental values of the unique location. In the first phase of the project, over 150,000 eco-sourced trees, shrubs and flaxes have been planted, and in effect, established the foundations for the restoration project. In June of 2012, Lincoln University signed a one-year research agreement with Rio Tinto to investigate and identify early indicators of restoration success,

which have been presented in the Lincoln University Wildlife Management Reports No. 50 (Bowie et al., 2012) and No. 52 (Hahner and Bowie, 2013). Lincoln University has been specifically involved in conducting surveys and research in the PCRP since 2011. Published results from this period include ten months of in-field data collection, literature reviews and interviews.

As issues such as environmental degradation, climate change and land-use change have heightened impacts on the stability of the world's ecosystems, restoration ecology is becoming an increasingly important part of the solution (Hobbs and Norton, 1996). As restoration ecology is still a relatively new field of science there is still need for the development of standardised methods and measures of success in a project (Ruiz-Jaen and Mitchell Aide, 2005; Young, 2000; Zedler, 2000). In order for restoration ecology to be seen in a more serious light this is a vital step, which could be key in developing solutions for some of the Earth's most challenged ecosystems (Barrett, 1994; Bullock et al., 2011).

Ecological restoration can reverse habitat destruction, increase the natural biodiversity and resilience and return the ecosystem services to provide a structural and functional community (de Bello et al., 2010; Holl and Aide, 2011; Ruiz-Jaen and Mitchell Aide, 2005; Wortley et al., 2013). Restoration is performed worldwide to potentially repair human damage however measures to assess the effectiveness of restoration programs are varied in their complexity and usefulness (Ruiz-Jaen and Mitchell Aide, 2005; Wortley et al., 2013).

The main motivations for restoration ecology can be broken down into four main areas (Hobbs and Norton, 1996). The first area is to rehabilitate degraded land used for productive purposes such as agriculture and forestry (Hobbs and Norton, 1996). High levels of soil erosion, low soil fertility and nutrient loading have serious implications on yield rates, which will contribute to the growing issue of global food security (Barrett, 1994). Restoration ecology also identifies the need to protect and conserve conservation values in protected and productive landscapes (Hobbs and Norton, 1996). Increased pollution levels, fragmentation of habitats, detrimental effects of invasive species and other forms of environmental degradation have led to the realisation that conserving biodiversity solely in protected areas will not be enough in the long-term (Hobbs and Norton, 1996; Lamb et al., 2005). Therefore more research is focusing on how to incorporate ecological practices into agricultural practices, without having an economic impact (Bullock et al., 2011). The last main area of focus is the restoration of highly degraded



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but localised sites, such as mining sites that have been subjected to both physical and chemical degradation (Hobbs and Norton, 1996). Restoration ecology is being increasingly challenged by climate change due to changing biophysical environments, which will affect the ability to restore the function and success of an ecosystem (Harris et al., 2006).

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). However many of New Zealand ecosystems are under threat from anthropogenic pressure (Bowie et al., 2016; Holdaway et al., 2012), while global warming and sea level rise will exacerbate the issues.

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## 3.2 Research activities from 2013 until present

Lincoln University has been continuing data evaluation in 2013; a last monitoring period including species surveys have been completed in 2015. Based on these comprehensive data sets, including previous surveys, several projects have been carried out in the PCRCP in form of summer scholarships, and Masters and PhD theses.

A summer scholar, Claire McCorkindale, has finished a report on "Ecological restoration at Punakaiki- measuring the ecological changes through time", as well as data analyses on leaf litter invertebrates, based on litter sampling in Summer 2015/16.

Young-Nam Kim (PhD student) has carried out a second comprehensive earthworm survey at the PCRCP site. An identification has been carried out on the basis of DNA barcoding. With this latest survey, a total of six native and eight exotic earthworm species could have been identified at the PCRCP site. Young-Nam has completed his PhD which includes several chapters related to the earthworms at the PCRCP.

Tao Zhong (PhD student) has submitted his thesis on analyses of different soil profiles for P fractionation and soil mineral analysis, as well as analyses from soil and excrement collected from abandoned parts of the Petrel colony. In collaboration with Hannah Franklin, he re-evaluated the complete data set of restoration indicators based on the 2012 / 2013 surveys, with multivariate statistical approaches.

Ross Carter-Brown has continued worked on the site in an extension of a summer project. His research has involved the use of bird perches to facilitate regeneration of native plants throughout restration areas. His research also is looking at seeds dropped at natural roosts in the Nikau Reserve and seed predation.

The present final report includes and explores data derived from these projects. Specifically, research activities at Lincoln University were focused on the evaluation and importance of different soils (chapter 4), the role of vegetation (chapter 5), invertebrates and leaf litter invertebrates (chapter 6), identification and importance of earthworms (chapter 7), bird surveys (chapter 8) and pests



Figure 3.1: Euro League of Life Science (ELLS) postgraduate students at the PCRCP site

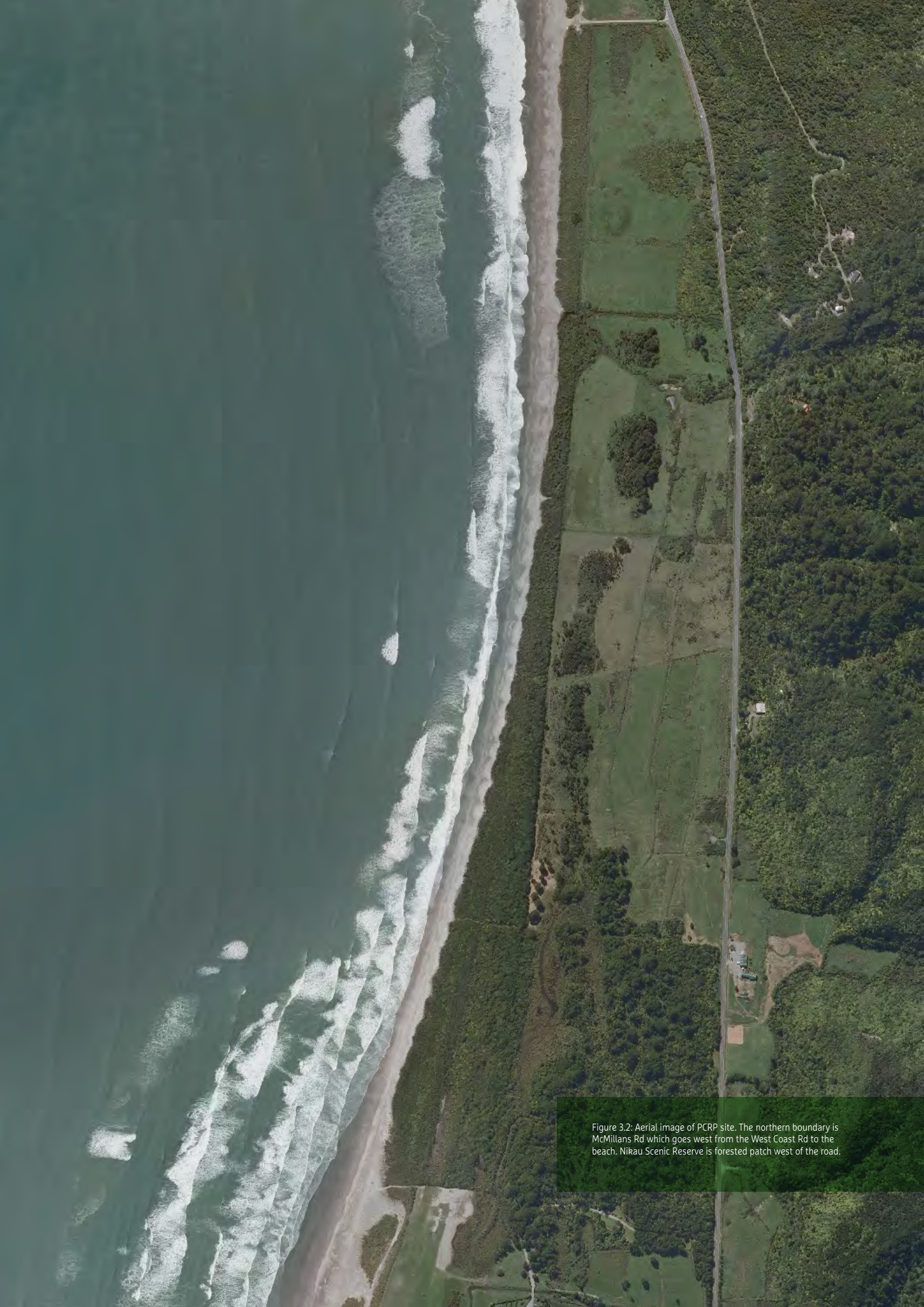


Figure 3.2: Aerial image of PCRP site. The northern boundary is McMillans Rd which goes west from the West Coast Rd to the beach. Nikau Scenic Reserve is forested patch west of the road.

## 4. Soil characterization and classification in the PCRP

Information in this section is largely taken from Smith et al. (2016): Punakaiki Coastal Restoration Project: A case study for a consultative and multidisciplinary approach in selecting indicators of restoration success for a sand mining closure site, West Coast, New Zealand. *Catena*, 136, 91-103. Please refer to this study for more information and references.

The soil geomorphology, together with the chemical and morphological properties has informed our understanding and interpretation of the ecological dynamics of the site. The coastal sand plain comprises a series of relict shorelines of sand dunes and gravel ridges with an intervening low lying sand plain with lagoon-swamp deposits, formed by coastal progradation. The relict shorelines form a soil chronosequence, with the oldest shorelines closest to the marine cliff. The study of soil-flora-fauna interactions on this chronosequence formed a key part of Hongtao Zhong's PhD study (Figure 4.1).

Alluvial fans have been deposited throughout the evolution of the sand plain, and are of varying ages. These heavier textured fans are poorly drained and deeper closer to the marine cliff. They are more prevalent in the northern part of the site. We identified four distinct soil landscapes within the PCRP:

1. Well drained sand and gravel shorelines / ridges / plains forming a chronosequence from old to young (Utopia – Mahinapua – Karoro – Okari).
2. Alluvial fans, poorly drained (Kamaka - Kamaka – shallow).
3. Poorly-very poorly drained swales within the sand plain (Waiwero)
4. Poorly-very poorly drained swales/back swamp/lagoon features (Rotokohu).

### 4.1 Geomorphic evolution and soil development in a coastal sand plain landscape

The coastal sand plain has formed south of Punakaiki 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. Ilmenite 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 are proximal to the postglacial marine cliff, cut into Miocene marine sediments (silts, mudstones) of the Blue Bottom Group. 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 consequently of varying ages. These alluvial fans are more prevalent and constitute a deeper deposit both closer to the marine cliff, and also in the northern part of the site.

Here, they often bury existing land surfaces and buried soils are common. The marine cliff represents the mid-Holocene high sea stand and a series of marine terraces are preserved in the Miocene deposits, due to continuing



Figure 4.1: Leachate sampling from different soil horizons (Hongtao Zhong) in a soil pit at the PCRP project site

tectonic uplift. The prograding coastal sand plain has thus evolved from the Mid-Holocene period (approx. the last 5–6 ka) to the present day. Different aged surfaces on the prograded sand plain exist, with the youngest surfaces closer to the present day shoreline. This chronosequence is a common feature of prograding coastal systems; similar systems have been extensively studied in New Zealand; for example, at Haast, West Coast, South Island. At PCRP, soils are developed on a range of surfaces, of variable age and are summarized in Table 4.1. An understanding of the soil geomorphology as well as the chemical and morphological properties, will inform our further understanding and interpretation of the ecological dynamics of the site.

## 4.2 Soil profile description

Soil pits measuring approximately 1m<sup>2</sup> and 1–2 m deep were excavated within each of the 21 transect plots and a representative soil profile from each pit (except for R2 and M4) described in 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 standard procedures. Soils were sampled from all horizons and the two surface horizons were prepared for laboratory analysis for pH, total N, C, C/N ratio, major and trace elements, according to standard procedures.

Sub-samples were oven-dried and subsequently microwave digested in a solution of 5 M HNO<sub>3</sub> and H<sub>2</sub>O<sub>2</sub>. Samples were then analysed using standard ICP-OES methodology (Varian 720-ES Inductively Coupled Plasma Optical Emission Spectroscopy fitted with an SPS-3 auto sampler and ultrasound nebulizer). The aim of the soil profile description and chemical analyses was to identify potential variables that may influence the restoration of floral and

Table 4.1: Soil landscape relationships for the coastal sand plain system, PCR (Smith et al., 2016).

Soil series (Wilms, 1985)	NZ soil classification (Hewitt, 1998)	USDA soil taxonomy (Soil survey Staff, 2014)	Soil profile characteristics (Wilms, 1985)
Well drained sand and gravel shorelines/ridges/plains			
*Okari Young soils - less developed than Karoro	Orthic Recent	Udipsamment	Recent soil with a weakly developed A horizon over C horizon
Karoro	Orthic Brown	Dystrudept	Weakly structured A horizon, slight B horizon development
Mahinapua (More developed than Karoro soils)	Sandy Brown	Dystrudept	Weakly structured A horizon; reasonably thick, strongly developed B horizon
*Utopia (More developed than Mahinapua)	Acid Brown	Dystrudept	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	Orthic Brown	Dystrudept	Friable A horizon overlying massive, slightly mottled B horizon. Buried soils and illinite sands at depth.
Kamaka (Shallow variant - alluvial fans over sand)	Orthic Brown	Dystrudept	Thin friable A horizon overlying sand or buried soils at depth
Poorly – very poorly drained swales			
Waiwero (Organic matter with significant additions of alluvium)	Fluvial Recent	Udifluent	Successive additions of peat and alluvium, thicker than 70 cm. Occasional wood and stones in profile.
Poorly / very poorly drained swales or back swamp/lagoon features			
*Rotokohu (Peat, with slight additions of alluvium)	Mesic Organic	Haplohemist	Saturated weakly / strongly decomposed organic matter over sand

\*soil series not present in Transects 1-7

## 4.3 Pedology of the soil-landscape

At the PCRP, soils are developed on a range of surfaces which differ in both age and mode of formation; the soil – landscape relationships for the coastal sand plain system are described in Table 4.1. Soils for this area of the West coast have been described previously; two soil series have been identified for the sand plain landscape chronosequence: Karoro and Mahinapua with the latter soil being distinguished by brighter 7.5 YR hue colours in the B horizon. The Karoro soil was newly described in this report.

Three soil series define the chronosequence on the sand plain: Okari (weakly developed soil with an A C horizonisation); Mahinapua (A B C horizonisation with distinctive yellowish brown 10 YR Hues in the B horizon) and Utopia (A B C with an ironpan developed below the A horizon). Furthermore, Karoro is the dominant soil series developed on the coastal sands (in the vicinity of the PCRP), but inclusions of Okari can occur close to the shoreline and inclusions of Mahinapua near to the marine cliff. The Mahinapua soil series was not clearly defined in terms of B horizon colour. We have interpreted this prior survey data as reinforcing the fact that the soils on the sand plain chronosequence clearly exist in a continuum, but with different interpretations of the central concepts around the constituent soil series. We thus allocate Transect 1 (the oldest shore-line surfaces in the study) to the Mahinapua soil series, based on a greater expression overall of pedogenesis in the profile. The youngest shoreline surface in the study (Transect 3) is allocated to the Karoro soil series. At the PCRP, we identified 5 distinct soil landscapes, in relation to Transects 1–7. These were developed on the following: well drained sand and gravel shorelines (chronosequence of Mahinapua–Karoro soil series; Transects 1 and 3); alluvial fans (Kamaka soil series—Transect 5); alluvial fans, shallow variant (Kamaka shallow variant — Transect 6); alluvial fans over sand (Kamaka soil series with buried soils at depth —Transects 4 and part of 7); and poorly drained swales within alluvial fans (Kamaka and Waiwero series — Transect 2). The soils and associated landscapes sampled and described at the PCRP site for Transects 1 to 7 are given in Table 4.2.

### 4.3.1 Chronosequence developed on well-drained sand and gravel shorelines: Mahinapua — Karoro soil series (Transects 1 and 3)

These well drained soils developed on sand exhibit an Ah, Bw, C profile development. R1 and M1 soils 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 38 cm depth. Localised iron pan formation at 1 m+ in M1 is most likely associated with the greater volume of water flux in the soil profile at depth, aided by macro rooting patterns of trees and shrubs. 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 46 - 60 cm is evident (Figure 4.2, a, c, e). In contrast, Transect 3 is closer to the present shoreline (M3 is approximately 150 m from the present high water mark). The soils on this transect from U, R and M profiles are all developed in a gravel–sand matrix. 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 inorganic matter from U3, to R3 and to M3. As with M1, the deepest B horizon exists in the M sites (Figure 4.2, b, d, f).

Table 4.2: Soil series present in each plot, per transect (Smith et al., 2016).

Transect	Mature	Replanted	Unrestored
1	Mahinapua	Mahinapua	Mahinapua
2	Kamaka	n.d.	Waiwero
3	Karoro	Karoro	Karoro
4	n.d.	Kamaka	Karoro
5	Kamaka	Kamaka	Kamaka
6	Kamaka - shallow	Kamaka - shallow	Kamaka - shallow
7	Kamaka	Kamaka - shallow	Kamaka - shallow

### 4.3.2 Soils developed on alluvial fans: Kamaka soil series (Transect 5) and kamaka–kamaka shallow variant (Transects 6 and 7)

Transect 5 is close to the foot of the Miocene marine cliff, to the east of State Highway 6. All three profiles show silty alluvial material overlying ilmenite sand, suggesting alluvial fan deposition over a sand plain. With distance from the marine cliff, the thickness of the distal fan material decreases. R5 which occupies a proximal position to the cliff, has fan material to 90 cm

depth, overlying sand; while the distal U5 and M5 profiles have respectively 15–20 cm fan material over loamy sand to sand. Both U5 and M5 are classified as Kamaka, shallow variant and both were poorly drained, exhibiting mottling at depth.



Figure 4.2: Soil profile from treatment plots on chronosequence of Transect 1 (oldest sand dune shoreline — Mahinapua soil series) and Transect 3 (youngest gravel ridge — Karoro soil series). a) Restored 1, b) Restored 3, c) Unplanted 1, d) Unplanted 3, e) Mature 1, and f) Mature 3 (Smith et al., 2016).

### 4.3.3 Soils developed on alluvial fans over sand: Kamaka soil series with buried soils at depth (Transects 4 and part of 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. Profile R4 contained several buried soils and different horizons which we interpret as the natural pattern of stream channels on fan surfaces; where periodic avulsion and a change in stream flow direction, have caused local scouring of a shallow channel surface.

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

Some low-lying parts of the landscape within the sand plain/alluvial fan surface contain drainage channels and creeks. These are prone to regular flooding events (resulting in sediment aggradation) 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. The soil profile is characterised by layers of partly decomposed organic matter (large, woody flood debris) and sandy-silty alluvial material, sometimes i

ncluding 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.

## 4.4 Soil chemical analysis

Examination of the soils from Transects 1 and 3 represent a chronosequence of old and young shoreline surfaces respectively; Transect 1 being a sandy dune ridge (proximal to the mid-Holocene aged marine cliff) and Transect 3 a gravel ridge (proximal to the present shoreline). Data from the Ah and Bw horizons of Transects 1 and 3 are presented in Table 4.3.

Carbon, C/N ratio, Fe and Ca were consistently higher in both the Ah and Bw horizons in the soils from Transect 1. This is consistent with these soils being older; with a greater amount of secondary minerals being released during weathering of the parent material and a greater accumulation of carbon, especially in M1 and M3. In contrast, potassium and magnesium concentrations were lower in Transect 1.

Table 4.3. Comparison of Transects 1 and 3 in Mature (M1, M3), Restored (R1, R3) and Unplanted (U1, U3) plots in the two surface soil horizons (Ah and Bw), (Smith et al., 2016).

	M1						M3					
	U1	R1	M1	R3	M3	U3	U1	R1	M1	R3	M3	U3
Carbon	1.2	1.5	1.8	1.6	1.9	1.3	1.1	1.4	1.7	1.5	1.8	1.2
C/N	15	18	22	16	20	14	12	16	19	17	21	13
Fe	10	12	15	11	14	8	7	9	11	10	13	6
Ca	5	6	8	5	7	4	3	4	5	6	7	3
K	2	3	4	2	3	1	2	3	4	3	4	1
Mg	1	2	3	1	2	0.5	1	2	3	2	3	0.5

When we examine the soil chemistry data from all transects, the soil variability across the PCRFP site tends to outweigh the three treatment variables within each of the seven transects. The values for soil pH (Figure 4.3) illustrate this. In the Ah and Bw soil horizons, unplanted plots have lower pH than restored plots. The

mature plot soils have significantly higher soil pH only in Transects 4 and 5, located respectively at the extreme north-east and south-west corners of the site.

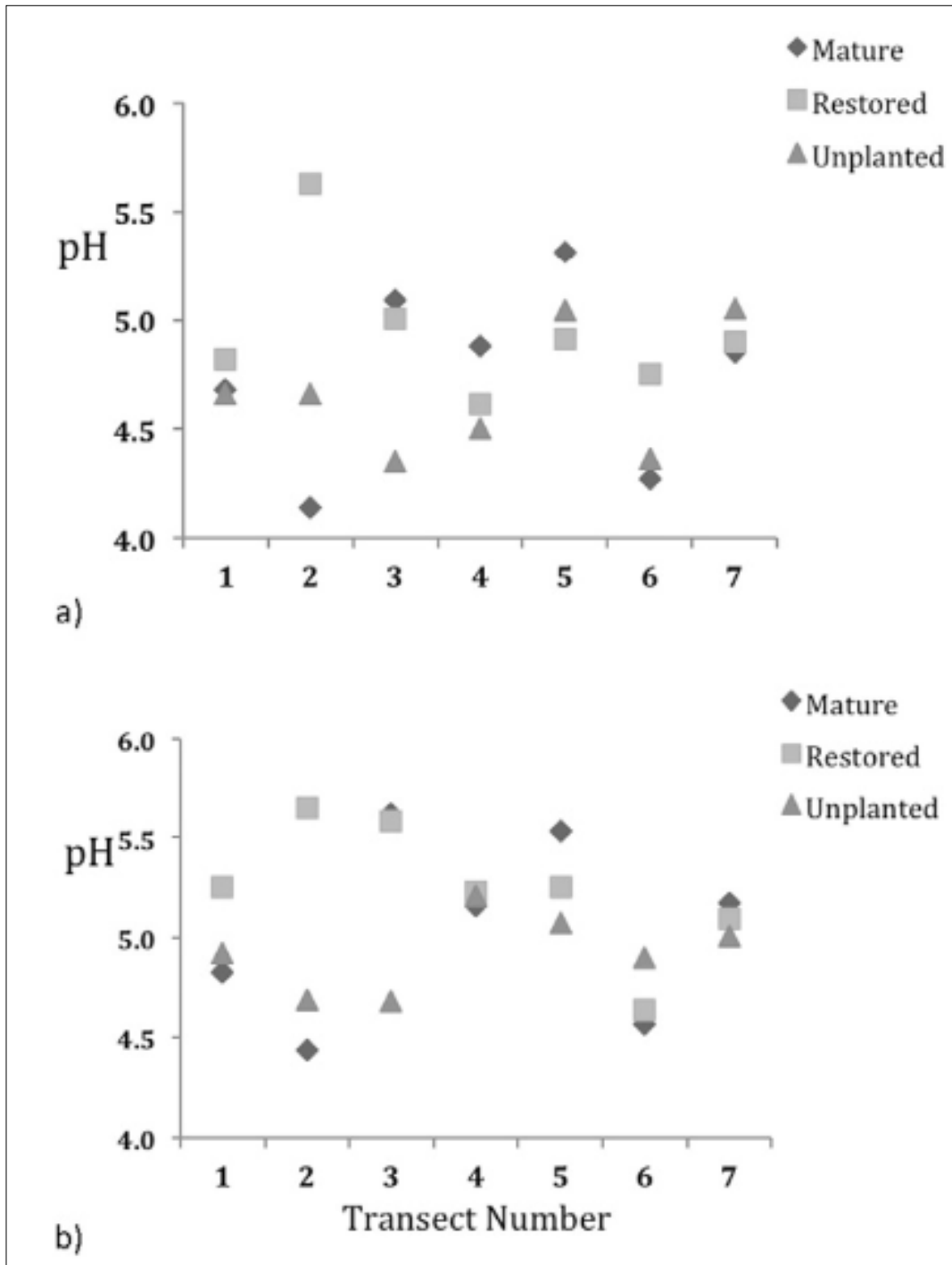


Figure 4.3: Figure 13. Soil pH in a) upper (Ah) and b) lower (Bw) horizons, across the 7 transects in Mature, Restored and Unplanted plots. a) Ah horizon, b) Bw horizon. Refer to Table 4.2 for transect soil details (Smith et al., 2016).



Total soil carbon concentrations (Figure 4.4) in mature plots were lower than other plots in only the Bw horizon in Transect 5, which was located on the east side of the highways and in the Nikau Scenic Reserve. There was inconsistent variation between soil N concentrations in mature, restored and unplanted plots (Figure 4.5, a & b). Higher N in Mature plots in Transects 2 and 4 may reflect places where cattle 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; consistently higher C/N ratios were evident in the mature plot soils (Figure 4.5, c).

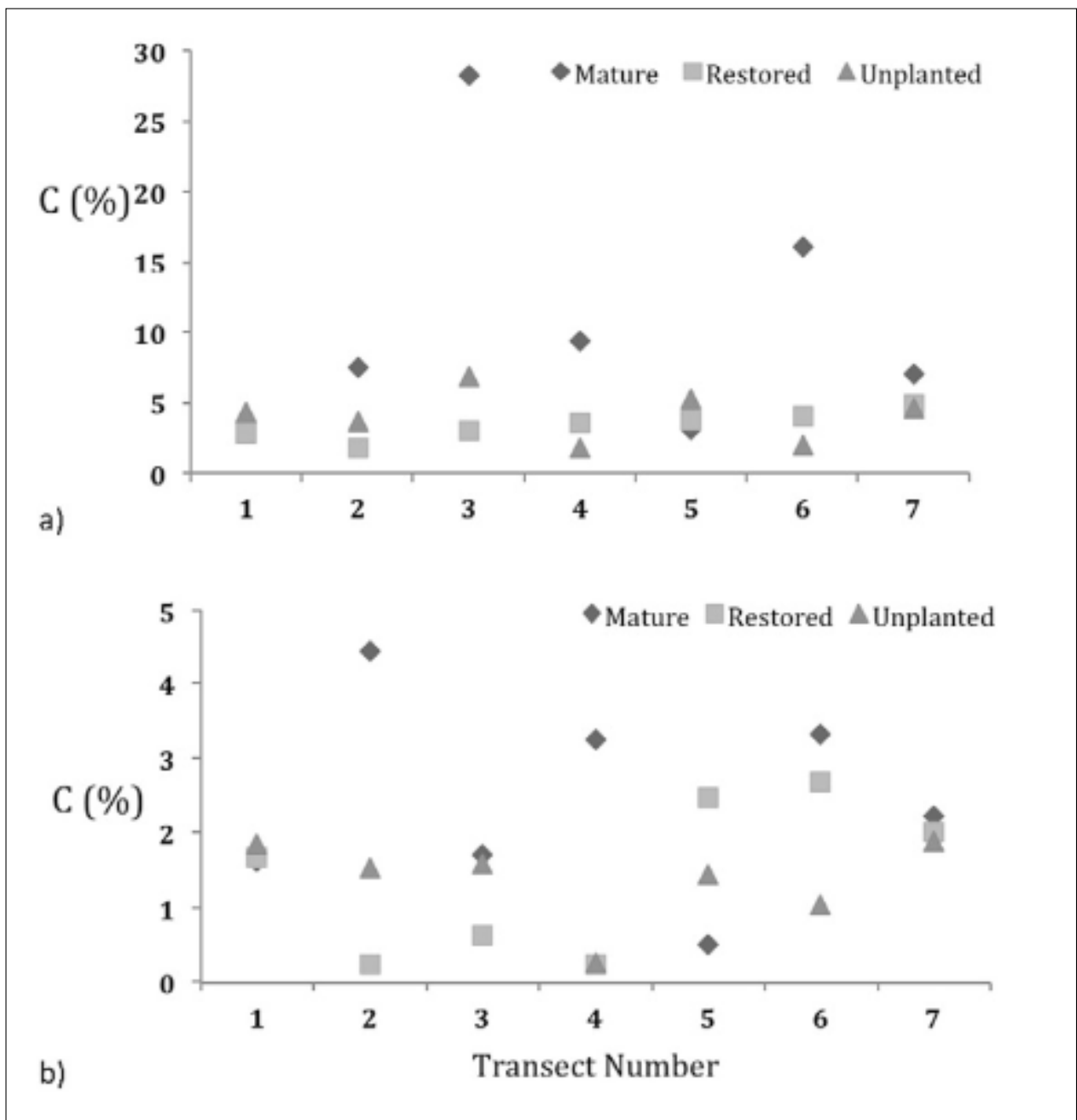


Figure 4.4. Total carbon concentrations in a) upper (Ah) and b) lower (Bw) soil horizons, across the 7 transects in Mature, Restored and Unplanted plots. Refer to Table 4.2 for transect soil details (Smith et al., 2016).

Lower concentrations of P in mature plots, were only evident in plots on eastern side of the Nikau Scenic Reserve (Figure 4.6, c). Two other plots in Nikau Scenic Reserve (M3 and M6) had higher P, possibly due to differing soil types in those areas (M3 well drained Karoro soil and M6 a kamaka shallow variant). Higher concentrations of K, Zn and Mg are evident in some mature plot soils (Figure 4.6, a, b and d), 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.

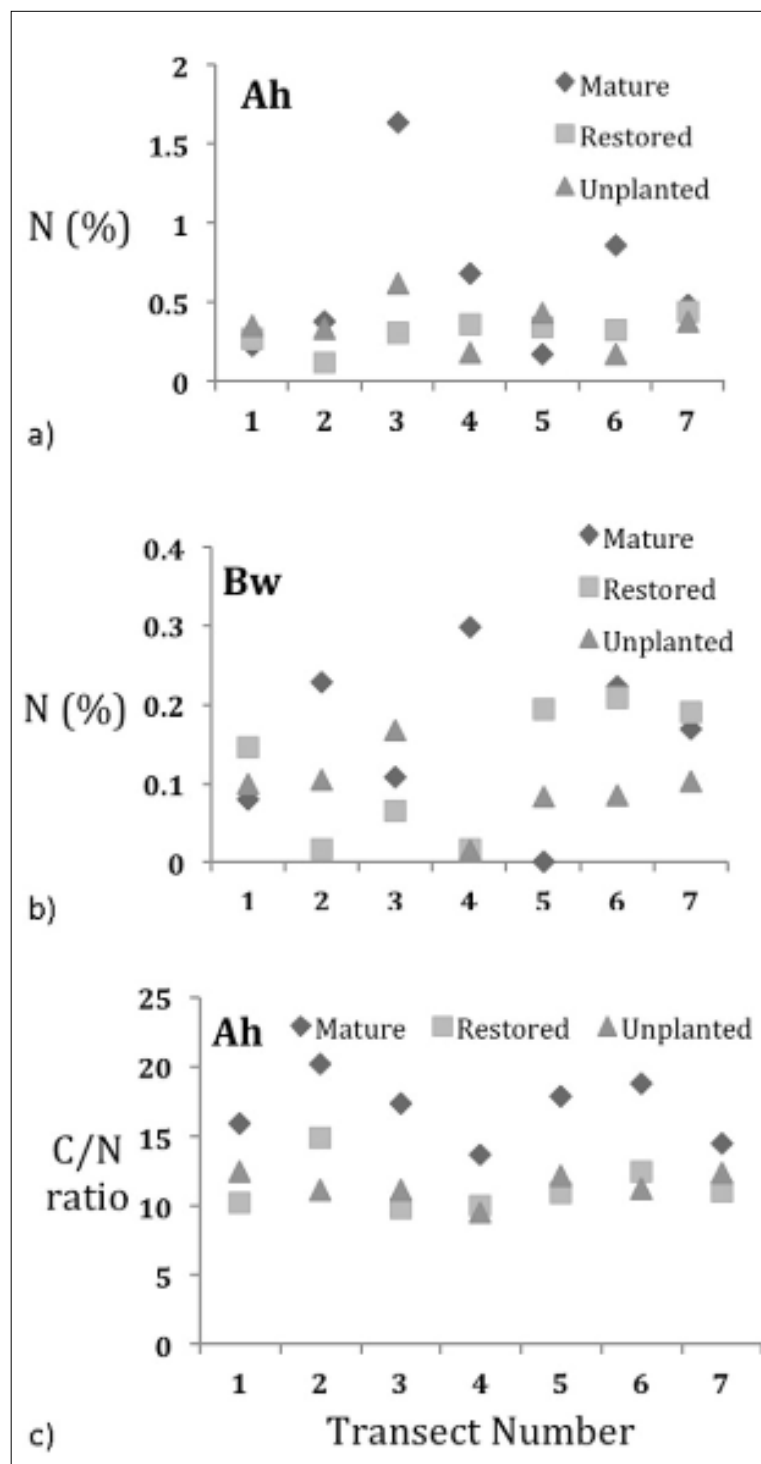


Figure 4.5. Total nitrogen concentrations in a) upper (Ah), b) lower (Bw) soil horizons, and c) soil C/N ratios (Ah only) across the 7 transects in Mature, Restored and Unplanted plots. Refer to Table 4.2 for transect soil details (Smith et al., 2016).

A number of other patterns of dispersion of soil chemistry data are evident across the site. Sodium (Figure 4.6, f) concentrations were higher in the four plots on the seaward side of the site, but only in mature vegetation stands. This may reflect less rainfall infiltration reaching the soil surface through closed vegetation canopies.

When we apply multivariate analyses to the soil chemistry data, we can identify groupings according to treatment. By applying hierarchical clustering, the data separate into two main clusters and several smaller assemblages. Sites 1, 2 and 5 and all unplanted plots (except U3 Ah and Bw) fall into the upper cluster, with sites 3, 4, 6 and 7 falling into the lower cluster. While there are clear similarities between groups of mature and unplanted

plots; the distance between the groupings of mature plots are possibly the largest of all. These two groupings coincide with some rudimentary spatial clustering: with sites 1, 2 and 5 in the south-west part of the site and sites 3, 4, 6 and 7 in the west and north-west. The historic usage of the plots (in terms of agricultural land management practices) could not be factored into the analysis and this confounding variable may have contributed to the spatial clustering, especially as the soil chemistry data was from the Ah and Bw horizons. Further explanatory reasons were not evident from these data and will require further investigation (Figure 4.7).

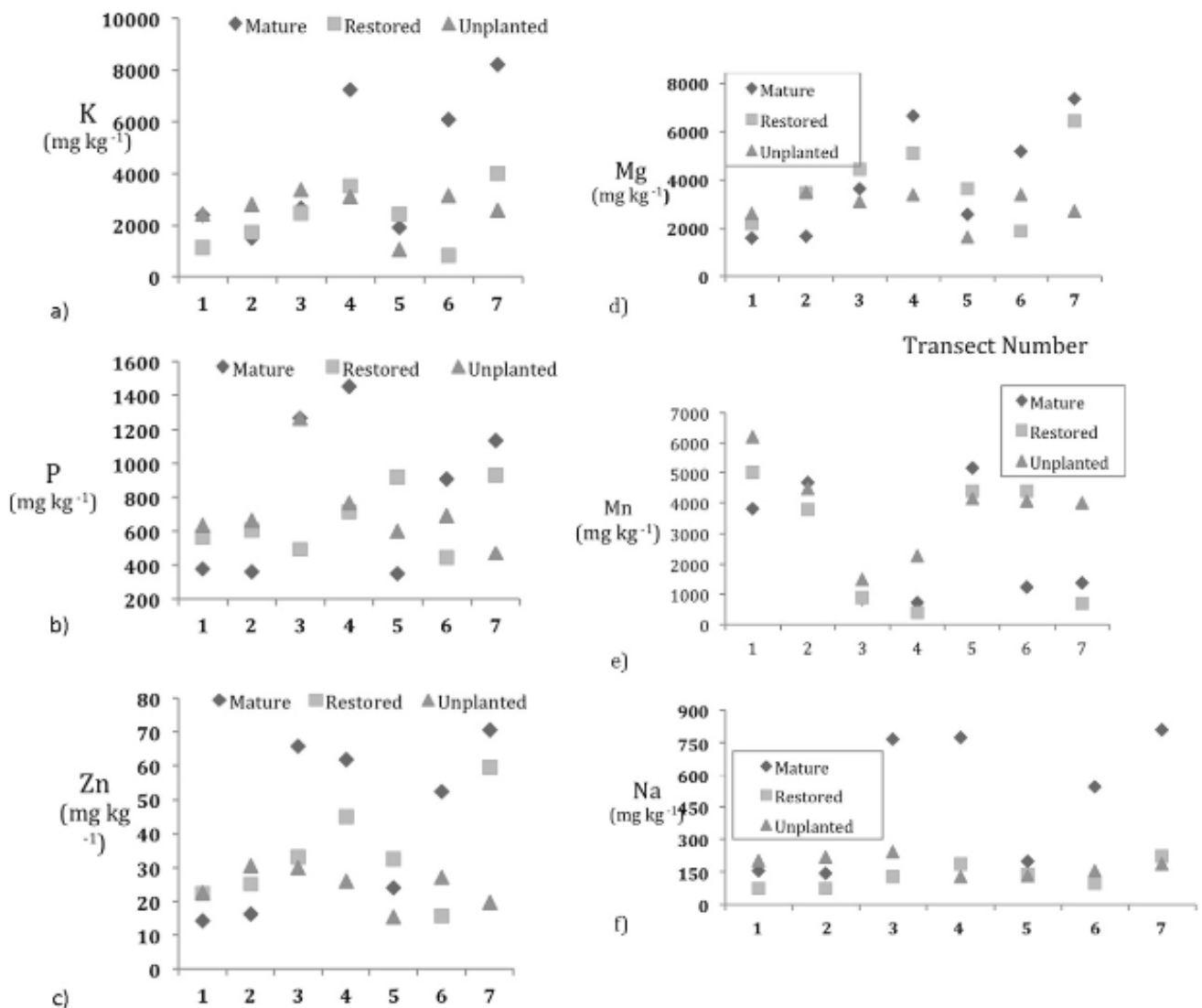


Figure 4.6. Total concentrations for a) P, b) K, c) Zn, d) Mn, e) Mg concentrations and f) Na concentrations in upper (Ah) soil horizon, across the 7 transects in Mature, Restored and Unplanted plots. Refer to Table 4.2 for transect soil details (Smith et al., 2016).

The difference in soil types is directly related to their pedogenesis and the geomorphology of the site (alluvial fans, prograding shorelines and drainage swales). This in turn accounts for the variability of the soil chemical data. For example, transects 4 and 7 are sited on alluvial fans and can be considered to be part of the stated intention of siting each transect with their three treatment plots on a uniform surface was to eliminate any confounding variables arising from differences in soil type and previous land management (pilot scale mining, stock grazing). However, only four out of the 7 transects displayed the same soil series in all three treatment plots (Transects 1, 3, 5, and 6).

Clearly at this stage of restoration of the site, the differences in the above-ground faunal indicators will be driven by changes in vegetation composition and canopy closure; while below ground indicators such as earthworms and other faunal communities will be more influenced by the existing soil type. From the results of our baseline ecological survey and soil investigations at this stage

of the restoration process, indicators of restoration success include above-ground fauna which represent the dynamic components of the ecosystem; dung beetles, weta, moths, leaf-litter invertebrates and birds. These mobile faunae can quickly become established in suitable ecological niches within the PCR. Less mobile below ground fauna will demonstrate a lag response between the establishment of the restoration vegetation and faunal presence in that area. Differences in soil chemistry between treatment plot swill also demonstrate a lag response to the establishment of restoration vegetation: chemical parameters will be driven by the exchanges within the soil rhizosphere-plant system. Within that system, there will be some parameters which are more dynamic and subject to a quicker response time; pH, mobile cations and anions on soil exchange sites. Changes in soil C, N as well as P fractions will occur for a longer time period.

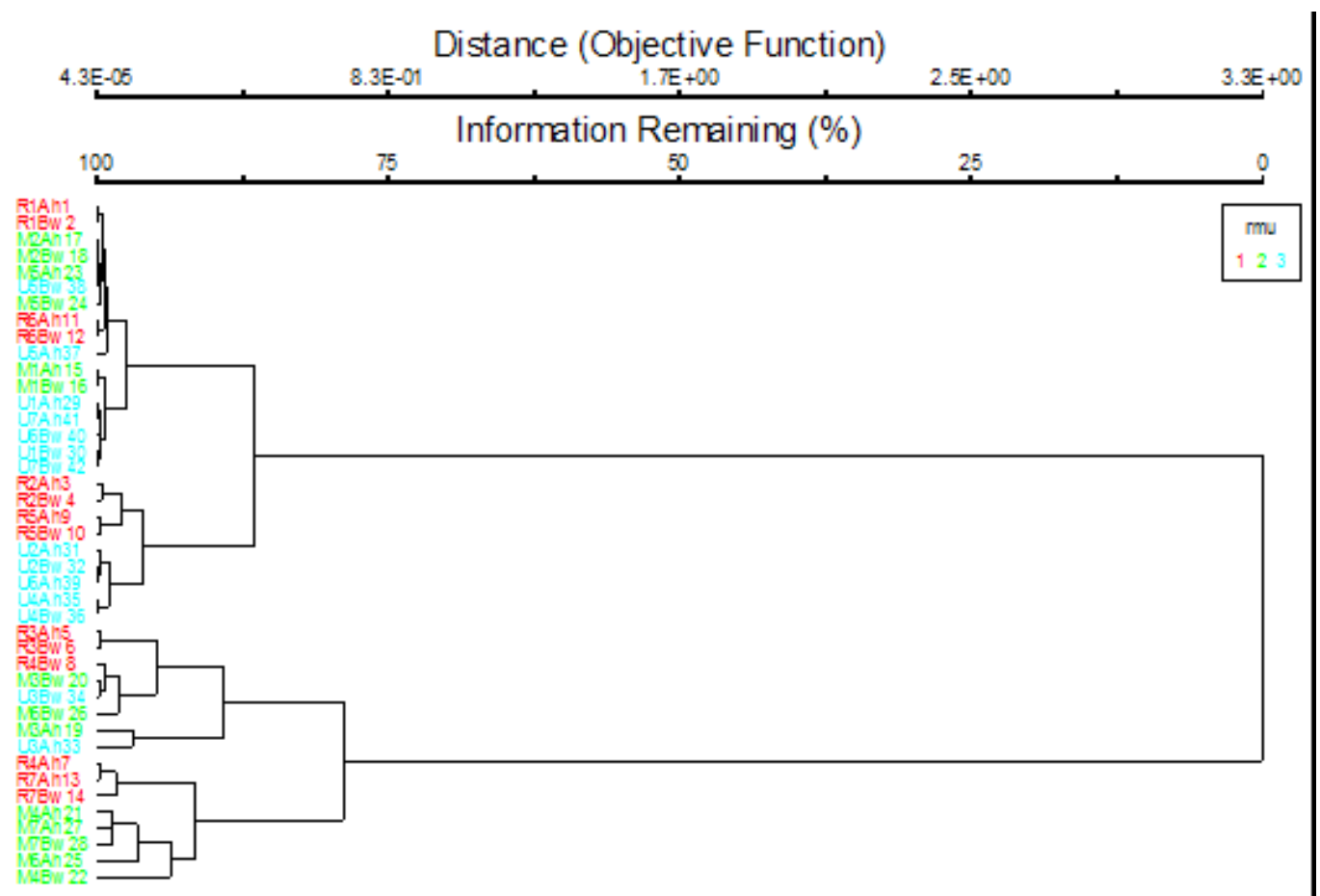


Figure 4.7. Dendrogram using hierarchical clustering of the soil chemistry data set for the Ah and Bw soil horizons. Algorithms are used to connect objects to form clusters based on their distance; the y-axis marks the distance at which the clusters merge. R, M, U refer to restored, mature and unplanted sites respectively (Smith et al., 2016).

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## 4.5 Conclusions

The seven transects selected for study in the present project did not provide consistent differences in the soil chemistry between the three treatments (mature, restored and unplanted plots). Straightforward treatment effects were not evident; instead, a more complex but potentially more interesting picture emerges. Two variables that could not be factored into the analysis were the detailed historic usage of the plots and the underlying variability of the soil types across the plots which appear to play a large part in determining the chemical characteristics of the soil. 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 time frame, or else that restoration work has been carried out in parts of the site that are chemically distinct. Further research is reported in the PhD thesis of Hongtao Zhong (Submitted September 2016, see attached summary).

Nonetheless, soil chemistry data do allow separation of the three treatments using multivariate analysis. Soil chemical factors that allow this distinction appear to include a) carbon and nitrogen concentrations and C/N ratios were all higher in mature stands; and b) soil P concentrations were substantially lower in some mature vegetation plots, particularly on the upper eastern terraces. Variability of P across the site was found to vary by a factor of 4–5, without an obvious chronological explanation.

# 5. Plant development and monitoring

## 5.1 Transect and plots establishment

Seven transects were set out in the studied area which include an unplanted, a restored plot (with native plantings) and a mature plot, used as reference (Figure 5.1). The transects were all in a North-South direction in order to attempt to obtain a similar soil substrate within each transect. Five of the mature plots were located within the Nikau Scenic Reserve, adjacent to the

restoration area and the other two used a forest remnant located to the north of the reserve. In each transect, 10 m x 10 m plots were established in each plot. Each plot was delineated with bamboo canes and colored ribbon in each of the four corners and one in the center.



Figure 5.1. Aerial photograph showing the positions of each plot within the PCRP site.

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## 5.2 Preparation for vegetation surveys

In the restored plots, all planted trees were labeled with an aluminum tag. The tagging process was started in the southwest corner heading towards the southeast corner, then turning around and heading back again in a parallel zig-zag pattern. In the mature plots, all trees with stems higher than 1.3 meters and larger than five centimeters DBH (Diameter at Breast Height) were labeled with aluminum tags. The tags were nailed onto the north side of the largest trunk at eye level. The tagging process used is the same as described for restored plots. A detailed method description how vegetation surveys have been carried out is described in chapter 5, plant development and monitoring.

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## 5.3 Measuring the ecological changes through time

This study focused on the restoration of vegetation at PCRP with the aim to identify the most suitable pioneer species and secondary species. Identifying the pioneer species from this study will be useful for future restoration projects in similar habitats along the West Coast. The study also attempted to determine the length of time it takes for native forest to regenerate on degraded land to a point where it can be self-sustaining and no longer needs human management.

### 5.3.1 Vegetation surveys and monitoring methods

Plants in the restoration plots have been planted between 2009 and 2015 and replanted biannually. In order to monitor the plants present within vegetation plots of the restoration project, methodology was adapted from Kanowski and Catterall (2007). Within each plot all live species of native trees and shrubs were labelled with a metal nursery plant tag around the base of the tree. The numbering system began in the south west corner, moving towards the south east corner in a parallel line before following back to the south west and continuing in this pattern. Each plant was identified and measured for height, maximum width, minimum width, basal diameter (using callipers) and diameter at breast height (DBH).

For each measurement, protocols were followed to ensure the consistency in the data obtained. If the tree was too tall to be measured with a measuring tape, a clinometer (Suunto, Finland) was used to measure the angle between eye level and the crown

base. The tree height ( $H_{tree}$ ) was determined by the following calculation,

$$(1) \quad H_{tree} = d_{tree} * \tan(\text{angle}) + h$$

whereas  $d$  represents the distance from the tree, and  $h$  the distance from ground to eye level, respectively. To measure the maximum and minimum width of each tree, the widest point was found and at the same height the smallest width was recorded. These measurements were then used to calculate the area of an ellipse according to equation (2), which was used to determine the ground cover or canopy cover,

$$(2) \quad \text{area} = \pi * \text{max radius} * \text{min radius}$$

whereas  $\text{radius} = \text{width}/2$ . The basal diameter and DBH were measured using callipers. For the basal diameter the width of the base of the tree was taken at right angles and recorded. The DBH was only recorded if the tree height was 1.4 metres or taller. If the tree forked below or near the DBH, the measurement was taken at the narrowest part of the stem below the fork. If the tree split into several trunks close to ground level, each trunk was measured and DBH was calculated by taking the square root of the sum of all squared trunk stem DBH's.

Canopy cover for each plot was in addition measured and analysed by digital means. Photographs were taken using the fisheye lens on the 'fisheye2 setting' from each corner, and in the centre of each plot (Figure 5.2). The photographs were then processed using ImageJ (National Institute of Health, experimental system 2004) to calculate the number of black and white pixels, with the black area representing the canopy cover. The mean from each point was taken to give one value of canopy cover for each restoration plot.

In the center of each 10 m<sup>2</sup> plot, a 1 m<sup>2</sup> section was chosen assess the composition of ground cover, using a modified "Braun-Blanquet method" (Braun-Blanquet, 1932). Categories of vegetation included grasses, herbs, ferns, vines and scramblers, tree seedlings and shrubs, moss, leaf litter and woody debris <100 mm diameter, coarse woody debris >100 mm diameter, rock and soil. In contrast to previous monitoring operations, all 1 m<sup>2</sup> squares were marked to allow repeated monitoring of the exact same location.

In order to determine potential relationships between

native seedling regeneration and leaf litter cover, ground cover measurements were carried out in all restoration plots around each tree in 1 m<sup>2</sup> plots. The number and species of native seedlings in each 1 m<sup>2</sup> plot were counted, and a ground cover percentage was calculated using the modified “Braun-Blanquet method” (Braun-Blanquet, 1932). Measured categories were according to the 1 m<sup>2</sup> square in the center of the plot, as described above. To minimise the disturbance of the 1 m<sup>2</sup> plot around each tree, the ground cover composition was measured first before any other measurements of the tree were taken.

### 5.3.2 Characteristics of the Nikau Scenic Reserve and remnant forest

Results from a vegetation survey indicate that the plant species composition and diversity is similar in the Nikau Scenic Reserve (M1-M3, M5, M6) and in the remnant forest (M4, M7), significantly higher compared to restoration plots (Figure 5.3). A complete list of vegetation present at the PCRP site is included in the appendix (13.1). In both locations, similar dominant species were detected, however only a few species are specific to the remnant forest. These few species belong to the ground cover vegetation and shrubs levels, specifically *Histiopteris incisa*, *Solanun nigrum*, *Acaena anserinifolia*, *Pseudowintera axillaris*, *Rubus fruticosus*, *Schefflera digitata* and *Coprosma robusta*. Ground cover vegetation in the mature plots was mainly composed of *Blechnum novae-Zelandiae*, *Carex dissitta* and some Tree fern species, whereas the shrubs level was dominated by *Coprosma rotundifolia* and *Coprosma robusta* x *propinqua* hybrids. These two levels are more developed in the remnant forest in terms of canopy cover, and have more species on average. In the Nikau Scenic Reserve, the shrubs level is generally absent except for the plots M3 and M6.



Figure 5.2: Canopy cover analysis using fish-eye lens images at the PCRP site (Claire McCorkindale) (Photo: Mike Bowie)



In both Nikau Scenic Reserve and remnant forest, the subordinate trees level is mainly composed of *Coprosma grandifolia*, *Dicksonia squarrosa* and *Myrsine salicina*, whereas the tall trees level is mainly composed of *Hedycarya arborea*, *Melicytus ramiflorus*, *Cordyline australis* and *Rhopalostylis sapida*. In the remnant forest, *Rhopalostylis sapida* is the most abundant species of this level. These levels are more developed in the Nikau Scenic Reserve than in the remnant forest in terms of canopy cover and have more species on average. In all mature plots, the giant trees level is mainly composed of *Weinmannia racemosa* and *Dacrycarpus dacrydioides*. This level is more developed in the remnant forest than in the Nikau Scenic Reserve in terms of canopy cover, but contains a lower species richness.

against 8.4 trees with DBH > 10 cm per 100 m<sup>2</sup> in forests at various localities in New Zealand (Bellingham et al., 1999). The most developed layer in terms of canopy cover is the subordinate trees layer, constituting a lower canopy mainly composed of *Coprosma grandifolia*, *Dicksonia squarrosa* and *Myrsine salicina*. This high density and the high canopy cover (80.53%) caused by these upper layers implicates the low development of the lower layers, whereas a shrubs layer is almost absent (with a canopy cover <5%) and the ground cover vegetation is reduced (with a canopy cover around 13%). The poor canopy cover of the lower layers is accompanied with a high leaf litter depth. The ground cover is composed by on average 72.5% of leaf litter, 20.5% of fine wood debris (<10 cm diameter), 4.5% of coarse woody debris (>10 cm diameter) and 2.5% of others (rocks,

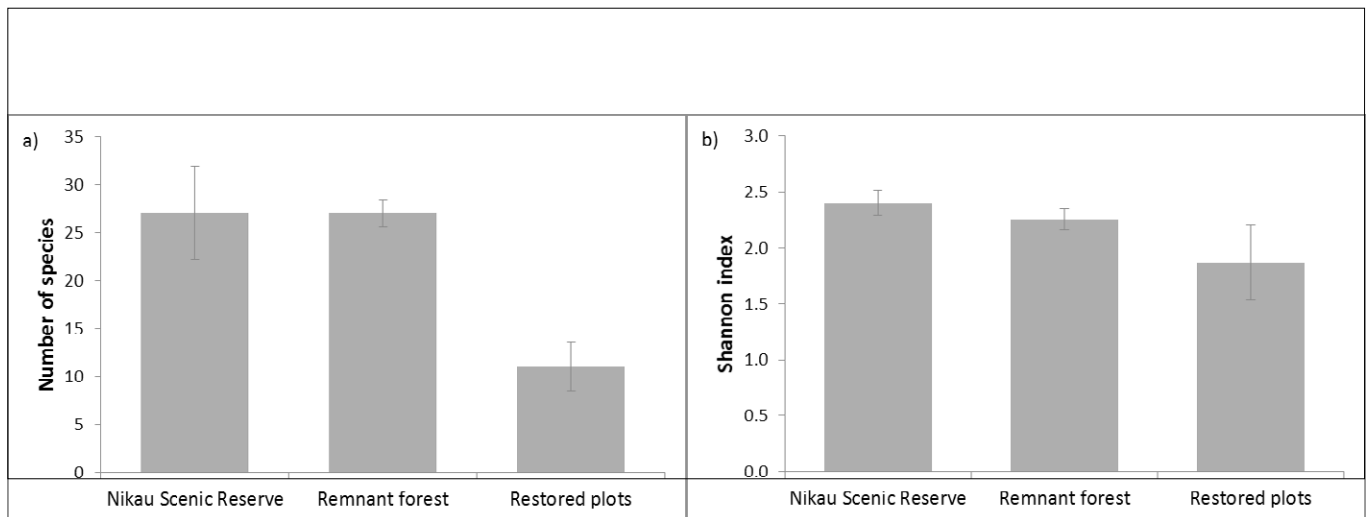


Figure 5.3. Average species number (a) and diversity (b) in mature (Nikau Scenic Reserve and Remnant forest) and restoration plots.

The Nikau Scenic Reserve consists of small emergent *Weinmannia racemosa*, *Metrosideros robusta*, and *Dacrycarpus dacrydioides* over an upper canopy of tall *Melicytus ramiflorus*, *Hedycarya arborea*, *Rhopalostylis sapida* and *Cordyline australis*, which reaches about 10 meters. This is characteristic of a warm and high fertility site in the Punakaiki Ecological District (DeVelice et al., 1988).

The emergent *Dacrycarpus dacrydioides* generally appears in sites of higher soil fertility than other New Zealand conifers (DeVelice et al., 1988). This is consistent with the fact that the Nikau Scenic Reserve is located on young geological surfaces, high in fertility in a mild climate. *Dacrycarpus dacrydioides* also feature an advanced stage of succession (DeVelice et al., 1988). It is a very slow growing species which can reach more than 50 meters in mature forests. In the Nikau Scenic Reserve, this species do not reach more than 12 meters which means that the forest is still maturing.

The canopy cover in the three upper layers (subordinate trees, tall trees and emergent trees) indicate a very high density of trees, with on average 18.2 trees with DBH > 10 cm per 100 m<sup>2</sup>

bared soil and apparent roots). Epiphytes showed the high species richness with on average 9.14 species per 100 m<sup>2</sup> and the second higher canopy cover.

### 5.3.3 Some variations in the vegetation of the Nikau Scenic Reserve

In comparison to the characteristics described above, some variations were observed in plots M1 and M5, which could be considered as “edge effects”: The density in tagged trees was greatest in these plots (41 individuals on average), with leaf litter depths around 9 cm compared to <5 cm in other mature plots. Most of the tree in these plots belong to the subordinate trees layer, hence species richness is lowest (27 species per plot on average). Plots M1 and M5 are located in a transition area between a closed milieu (the mature forest) and an open milieu (the highway 6). Thus, because of this edge effect, the light and water

conditions are different, promoting a high number of subordinate trees (and so the high number of tagged trees), including tree ferns. In addition to such edge effects, differences in the soil structure may have affected water and nutrient movement, hence favored certain tree species.

The plot M3 is characterized by a distinct ground cover composition compared to other mature plots in the Nikau Scenic Reserve. The ground cover of the plot M3 is mostly composed of rocks (70%), whereas the leaf litter and fine woody debris are reduced to 12% each. There is also a small part of bare soil (3%), and leaf litter depths are lowest among all mature plots (1.13 cm on average). This different soil structure can affect physical

parameters, such as soil moisture, temperature and root distribution, and hence originate in changes which were observed in the plot. The number of tagged trees in M3 was low (16 individuals), and a smaller number of species (26 species), with significantly lower diameter at breast height (DBH) was observed compared plots M2 and M6, located in the deep mature and undisturbed forest. Moreover, the presence of the species *Dacrydium cupressinum* indicates a low soil fertility (DeVelice et al., 1988).



Figure 5.4: Student involvement in vegetation surveys and measurements at the PCRP  
(Photo: Mike Bowie)

### 5.3.4 The remnant forest - a disturbed area

The remnant forest is at the northern part of the PCRP site, located on the seaward side of the road. This area has been under farm management until 2010, whereas the Nikau Scenic Reserve was established in 1961. The remnant forest area has suffered from partial forest clearance for farming purposes, where only the tallest trees were kept as stock shelter while bushes and subordinate tree species were cleared to allow livestock passage. These actions however did not affect the plot biodiversity, indicated by their Shannon index of 2.3, which is not significantly different compared to the Nikau Scenic Reserve (2.4). A similar number of species was detected in the Nikau Scenic Reserve and the remnant forest (27 species per plot on average), which indicates that logging might have reduced the number of species of subordinate and tall trees, but in turn may have created new ecological niches allowing the installation of new species on the ground cover or as shrubs.

In mature plots located in the remnant forest, the ground cover composition was not significantly affected compared to the Nikau Reserve, and leaf litter as well as fine woody debris were major parts of the ground cover. However, the disturbance caused by farming clearly affected the structure of the remnant forest. By logging, farmers considerably reduced the subordinate and tall trees layers in terms of canopy cover (the subordinate trees lost 61.3% of the canopy cover and the tall trees lost 28.29% of the canopy cover) and number of species (the subordinate trees lost 0.57 species per plot and the tall trees lost 2.5 species per plot) and favored the growth of giant trees which have a canopy cover 29.5% higher than in the Nikau Scenic Reserve.

## 5.4 Native forest restoration on degraded land

### 5.4.1 Results from vegetation surveys and measurements

Plant height in the restoration plots consistently increased with each year, with a more rapid increase observed after four to five (1107.9 mm), and six to seven years (2923.7 mm), respectively (Figure 5.5, a). Out of all restoration plots R1 – R4, plot R1 was the first plot planted, with a growing period of to date between six and seven years. This plot showed largest plant heights (Figure 5.5, a) and largest canopy area per plant (Figure 5.5, b). The average tree height of native mature, tagged trees in the Nikau Scenic Reserve was measured with 4967.1 mm (Figure 5.5, a), which is by 2043.36 mm on average larger compared to tree height in R1. The average canopy area per plant showed an increase between 4-5 years (0.414 mm<sup>2</sup>) and 5-6 years (2.84 mm<sup>2</sup>) of plant growth (Figure 5.5, b).

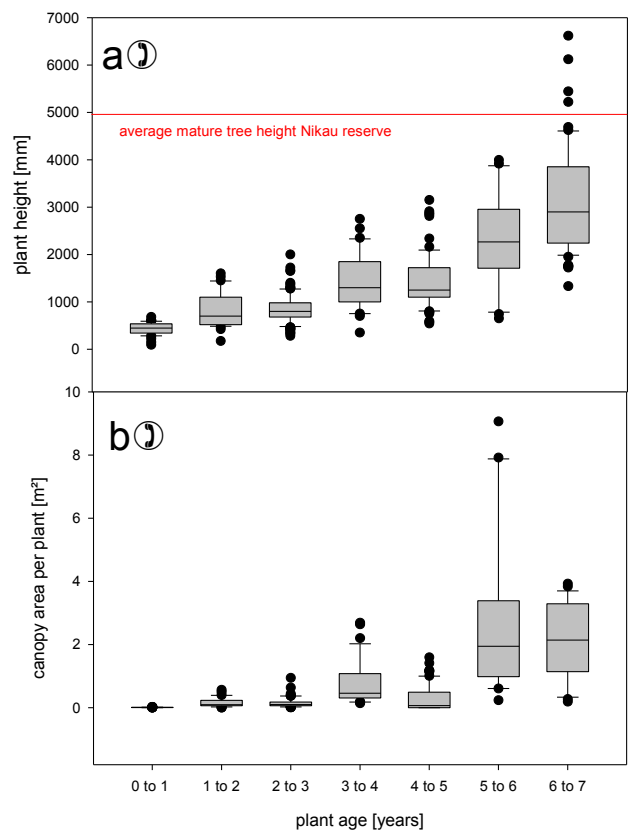


Figure 5.5: Average plant height (a) and canopy area per plant (b) in the restoration plots according to planting times for each site

The mortality rate as investigated in 2015, approx. 4 years after planting, varied between restoration plots (Figure 5.6). For R1 only two plants died throughout the monitoring period, which was the lowest number of all the restoration plots. In contrast, R4 had the highest mortality rate with 33 out of 40 plants dying throughout the monitoring period. Generally the biggest decline was observed in the final monitoring round in 2015, particularly in R4 where all

*Aristotelia serrata* (ARLser) and *Dodonaea viscosa* (DODvis) died (Figure 5.6). In contrast only three species, *Aristotelia serrata* (ARLser), *Weinmannia racemosa* (WEIrac) and *Cordyline australis* (CORaus) declined in numbers in the 2013 monitoring round.

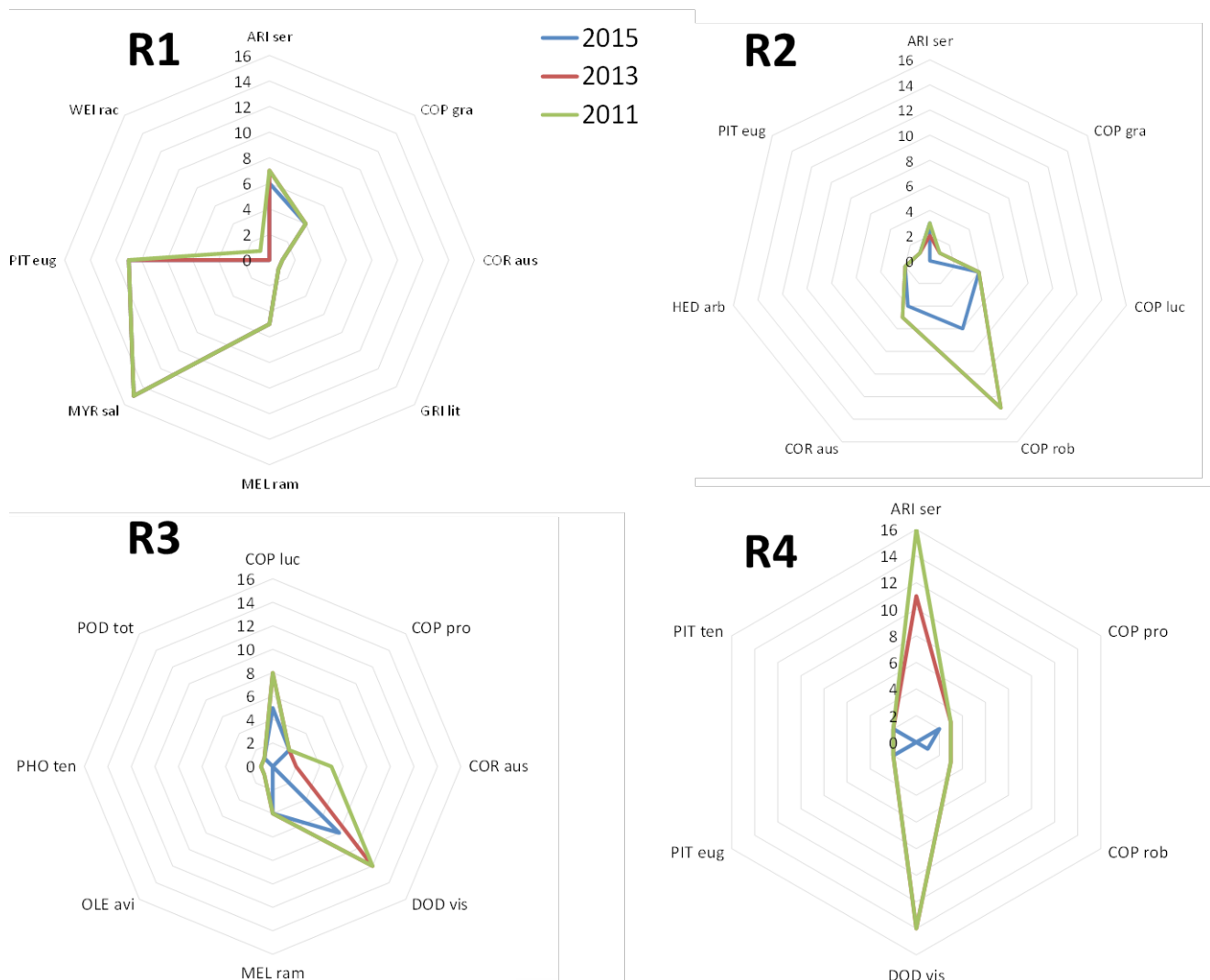


Figure 5.6: Mortality of plant species during monitoring period in restoration plots R1 – R4

Survival rates were shown for plant species with > 5 individuals planted (Figure 5.7). Due to a heavy weather event following substantial plant loss on R4, species found in R4 were not included in this calculation. *Myrsine salicina* (MYRsal), *Pittosporum eugenoides* (PITeug) and *Melicytus ramiflorus* (MELram) showed

a 100 % survival rate, whereas lowest survival rates were observed for *Cordyline australis* (CORaus) and *Coprosma robusta* (COProb) at 45.5% and 46.1% respectively (Figure 5.7, a).

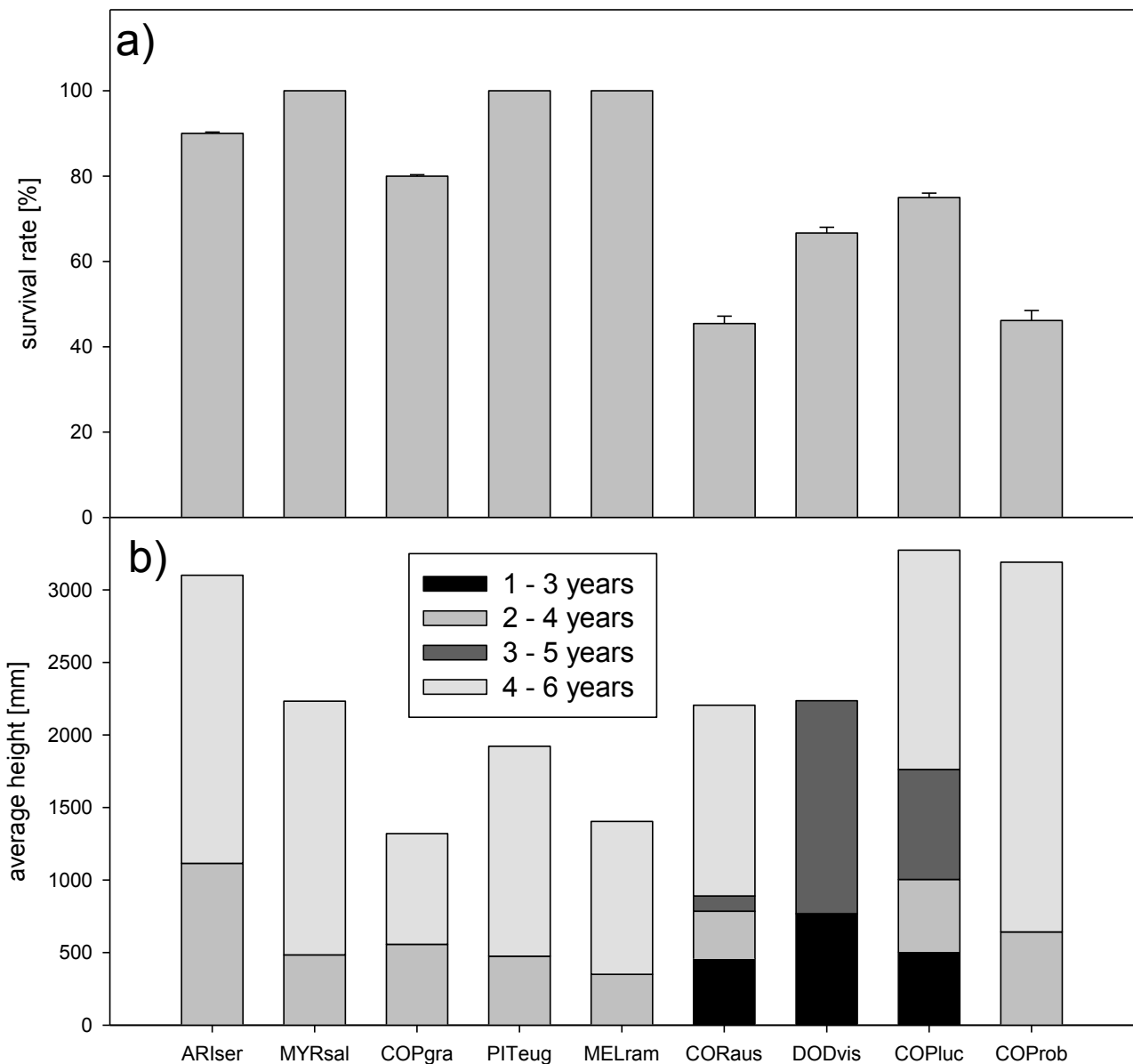


Figure 5.7: Average survival rate (a) and average plant height (b) of plant species with more than 5 individuals planted

Whilst *Aristolelia serrata* (ARLser) had a slightly lower survival rate (90%) than MYRsal, *P. eugenoides* (PITeug) and *M. ramiflorus* (MELram), its growth rate was highest among these three species after two to four years (1115 mm) and four to six years (1985 mm) (Figure 5.7, b). *Coprosma grandifolia* (COPgra) recorded a survival rate of 80% and the smallest growth rate in the four to six-year period (762.5 mm) among the top five species with highest survival rates

The presence of native seedling regeneration was observed in the 2015 monitoring process in R1, R2 and R3, but not R4. To explain this observation, the relationship between the average

an identifiable stage. *C. grandifolia*, *C. lucida* and *C. robusta* all had lower survivorship rates when planted as pioneer species. This indicates

that these species perform better once canopy cover has been established and there is less competition with exotic weed species.

Table 5.2: Relationships between average leaf litter cover, average canopy cover, exotic ground cover and seedling number in individual restoration plots R1 – R4.

plot	litter cover [%]	exotic ground cover [%]	canopy cover [%]	seedling numbers
R1	53.2	37.7	81.2	16
R2	27.4	69.6	39.2	7
R3	35.6	60.9	44.0	11
R4	0	100	8.7	0
<b>vs. litter cover [R<sup>2</sup>]</b>	-	0.9564	0.9976	0.9830
<b>vs. exotic ground cover [R<sup>2</sup>]</b>	0.9564	-	0.9742	0.9463
<b>vs. canopy cover [R<sup>2</sup>]</b>	0.9976	0.9742	-	0.9834
<b>vs. seedling numbers [R<sup>2</sup>]</b>	0.9830	0.9463	0.9834	-

leave litter cover, average exotic ground cover, average canopy cover and number of native seedlings were compared using regression analysis (Table 5.2). Each restoration plot was at a different growth stage, with oldest restoration site, R1, having the highest level of canopy cover (81.17%), followed by R2 and R3 (39.19% and 44.04%), whereas R4 showed lowest canopy cover with only 8.65% (Table 5.2). As the canopy cover increased, the exotic ground cover decreased (Table 5.2: R<sup>2</sup>=0.97), leading to the increase in the leaf litter cover (Table 5.2 R<sup>2</sup>=0.98). The higher the level of leaf litter cover and the greater the extent of canopy cover, the higher the number of native seedlings present (Table 5.2). The native tree species found in R1 are six to seven years old and a mean of 16 seedlings were found in the 1 m<sup>2</sup> plot under each tree. R4 is four to five years old and zero native seedlings were found under each tree due to the complete exotic ground cover.

Overall, the most commonly found seedlings in the restoration plots were *C. grandifolia* (60.42%), followed by *C. aerolata* (13.23%), *D. dacrydoides* (7.61%), *C. lucida* (6.84%), with the majority of native seedlings located in R1. The percentage presence of the *Coprosma* species would have been higher if the juveniles were at

#### 5.4.2 Restoration success and future perspectives

According to results of plant growth and mortality, each restoration site has shown various potential for the re-establishment of native forest. Trees in the restoration plots have grown to a large enough size, so that using the maximum and minimum widths to calculate the canopy cover was a useful indicator. Our study shows that re-establishment of native species on degraded agricultural and mining land is possible by using good ecological and management practices. There were varying rates of success within the restoration plots, which may be explained by the difference in the time of planting, the soil profile of each site, weather events and human interference. Plot R1 displayed the highest average plant height, largest average canopy cover, highest percentage survival rate of native trees and largest number of native regeneration seedlings of all the restoration sites. It was also one of the first of the restoration plots to be planted. Its location was

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further away from the coastal strip, so it was not as exposed to the coastal breeze and spray as R3 and R4. Restoration plot R1 is located on the same dune shoreline land surface as a mature forest stand, on well drained soils that developed on sand on a Karoro soil series (Hahner and Bowie, 2013; Wilms, 1985). The soil was not stony due its distance from the coastal strip allowing the plants to form extensive root networks more easily. However, due to the degradation of the land through land-use change there were no existing root networks found in the soil profile from previous native forest (Hahner and Bowie, 2013). In terms of the native seedling regeneration, *C. grandifolia* was the most dominant regenerating species, but had a low survival rate. This may indicate an r-strategy, in order to colonise a new area and outcompete other species (Grime, 2006).

Plot R4 was the least successful of the restoration plots, with only seven out of forty plants surviving. The ground cover was still 100 % exotic weeds, likely due to the small height of the plants and hence small canopy cover of only 8.65 %. However, this can mainly be attributed to human interference, as livestock were grazing in the reserve after the 2013 monitoring round, which led to extensive localised damage within the plot. Prior to this event the growth rate of R4 was similar to the other plots according to the planting year. Plot R4 was planted on a Kamaka soil series that is characterised by alluvial fan deposits over a sand plain and poor drainage (Hahner and Bowie, 2013; Wilms, 1985). Due to this interference, data collected in 2015 was not included in the data analysis for survival rate and average mortality calculations.

The restoration plot R2 was planted a few months later than R1, hence plant age in this plot is between six and seven years, similar to R1. However, the height of the plants, canopy cover and seedling regeneration is significantly lower than recorded in R1 and the mortality rate of native species higher. This could be attributed to the difference in soil profile, with R2 located on a Waiwero soil series that is characterised by layers of partly decomposed organic matter and sandy-silty alluvial material (Hahner and Bowie, 2013; Wilms, 1985). The soil is poorly drained and often waterlogged due to drainage channels and creeks in low lying areas in the sand plain that are prone to regular flooding events, as well as a high water table (Hahner and Bowie, 2013). Native tree seedlings generally perform better in moist, not waterlogged soils.

In relation to R2, R3 showed slightly higher growth rates, greater area of canopy cover and a higher native regeneration despite being planted one year later. Plot R3 is located in close proximity to the coastal beach on a Karoro soil series, which was developed on a gravel-sand matrix and is characterised as a well-draining soil (Hahner and Bowie, 2013; Wilms, 1985). This indicates that native restoration of the selected species occurs best on well-draining soils. Restoration plot R3 showed a higher mortality rate, as it was severely affected by a storm event in 2014. Due to a higher stone content in the upper horizons, the trees were more easily uprooted compared to other restoration plots. Soil with high stone

content is likely to retain less water, therefore plant species that are more sensitive to drought, such as *D. viscosa*, succumbed to drought in the summer of 2012 (James Washer, pers. comm.).

In order to successfully restore degraded land, pioneer species need to be hardy and tolerant to a range of adverse conditions, as well as able to outcompete exotic weed species (Wong, 2003). Whereas *M. salicina*, *P. eugenoides*, *M. ramiflorus* showed a 100 % survival rate, *A. serrata* had the highest growth rate at the PCRCP site. We recommend the use of these plant species in future restoration plantings, since they suggest these plant species as most suitable as pioneer species in future restoration plantings, since they will allow canopy cover to increase more rapidly, resulting in a quick suppression of exotic weed species. An increasing leaf litter cover subsequently supports other native species such as *C. robusta* and *C. lucida*, which then can be used in secondary plantings to increase the species richness.

## 5.5 Epiphytes in the PCRP

Although R1 was found the most successful restoration plot, key groups of taxa were missing when compared to the mature sites in the adjacent Nikau Scenic Reserve. There were no epiphytes, very few species of moss, lichens, fungi or ferns, and very few native bird species present (Bowie et al., 2012). Dead mamaku tree ferns and punga logs with epiphytes attached have been translocated from a neighboring local site, leaning against the native trees in plot R1 to encourage colonisation of epiphytes (Figure 5.8).

The layers of vines and epiphytes are similar in species composition between the Remnant forest and the Nikau Scenic Reserve, with the same species dominant at both sites. However, the average numbers of species as well as the vine level's canopy cover is lower in the Remnant forest, whereas the epiphyte level showed a better development. Whereas in the Remnant forest, a smaller number of epiphyte species per plot was detected compared to the Nikau Scenic Reserve, the canopy area covered by the epiphytes in the remnant forest was 38.93% greater than in the Nikau Scenic Reserve. Thus, in the remnant forest, only

non specific epiphyte species (e.g., *Metrosideros perforata*, *Metrosideros diffusa*, *Asplenium flaccidum*, *Microsorium pustulatum*) were detected, their canopy cover was better developed than in the Nikau Scenic Reserve, likely because of increasing sunlight available at the epiphyte level due to the partial tree removal in the remnant forest.

Restoration hence should be accentuated on species from the subordinate trees layer and tall trees layer, which are the most abundant in the Nikau Scenic Reserve. In order to favor a high diversity of epiphyte species, host species which allow the growth of various types of epiphyte species should be used in the restoration. *Dicksonia squarrosa*, *Hedycaria arborea* and *Weinmania racemosa* are the species recommended. In order to have very specific epiphytes species (*Lycopodium billardieri*, *Trichomanes venosum* and *Hymenophyllum revolutum*), *Dicksonia squarrosa* and *Weinmania racemosa* are essential and have to be planted in the restoration.



Figure 5.8: Epiphytes on punga log placed into restoration site (R1) to encourage epiphyte colonisation in PCRP restoration sites (Photo: Mike Bowie).



## 5.6 Seedling establishment

### 5.6.1 Methodology and statistical analysis

Seedling establishment was recorded over a 12-month period starting in 2014 to determine the abundance and diversity of native seedlings establishing at the PCRP naturally, and variables that may affect establishment. Within R1, 8 vegetation plots were set-up, measuring 2 x 2m, and were placed at random under closed canopy. They were set-up on 27th February 2014. The corners of each plot were marked with bamboo stakes and flagging tape. All existing seedlings were tagged to avoid them being counted later. We recorded ground cover estimates for each plot including any area that was unavailable for the establishment of seedlings such as rocks, existing trees and swords of pasture grass. Canopy cover was measured as described in 5.3.1.

After 12 months all seedlings were counted and identified, excluding seedlings that were tagged as present prior to the start

of the survey. Ground cover and canopy cover was also measured again and a mean for each plot was calculated using the 'before' and 'after' measurements. All statistical analyses were carried out in RStudio Version 0.99.473. Linear models (LM) were run with 'seedlings per m<sup>2</sup>' as the response variable with 'ground cover' and 'canopy cover' as the explanatory variables; and the interaction between the two explanatory variables.

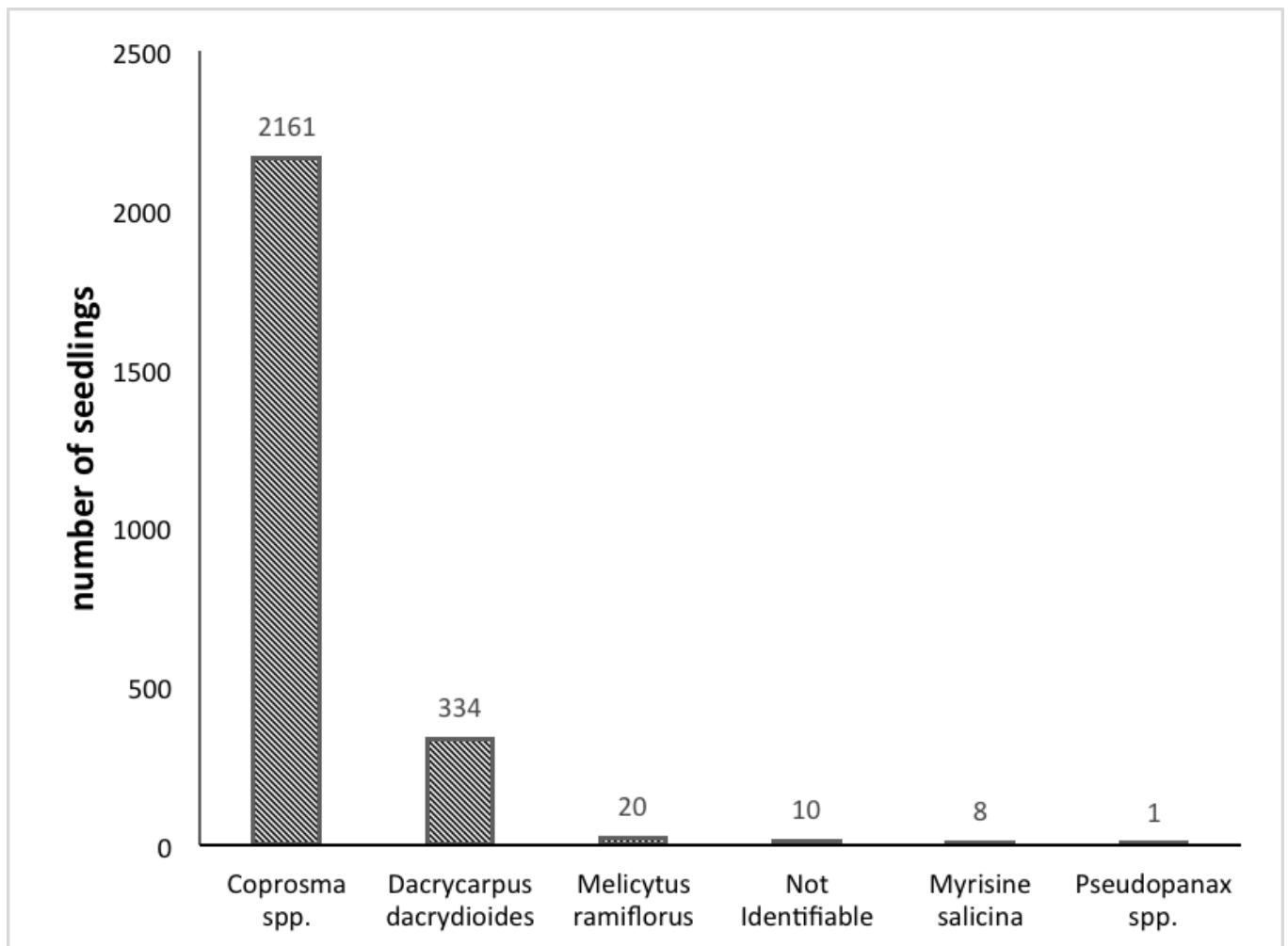


Figure 5.9: Seedlings established over 12 months in eight 2 x 2m plots in R1 at PCRP. Not all seedlings were able to be identified to species due to their small size. Mean seedlings per m<sup>2</sup> = 79.19.

## 5.6.2 Seedling results and discussion

In total 2534 seedlings were counted in the eight 2 x 2m plots, giving an average of 79.19 seedlings per m<sup>2</sup> (Figure 5.9). Six recognised taxonomic units (RTUs) were identified. Due to the small size of seedlings, with some lacking true leaves, it was not possible to identify every seedling to species.

The LM of 'seedlings per m<sup>2</sup>' as explained by the interaction of 'ground cover' and 'canopy cover' was not significant ( $p=0.1162$ ). The LM of 'seedlings per m<sup>2</sup>' as explained 'canopy cover' described a negative linear correlation that was significant ( $p=0.06418$ ,  $R^2=0.4608$ ) at the 93%

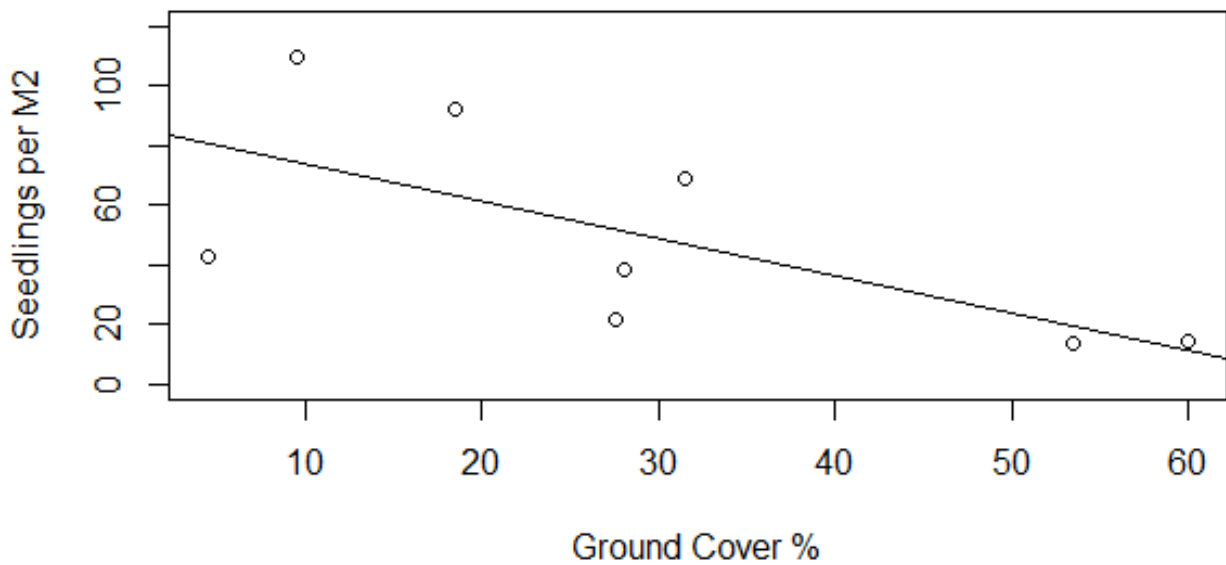


Figure 5.10: Seedlings per m<sup>2</sup> as explained by percentage of canopy cover in R1, found in eight 2x2m plots over a 12-month period.  $P=0.06418$ ,  $R^2=0.4608$ ,  $n=8$ ,  $DF=6$ .

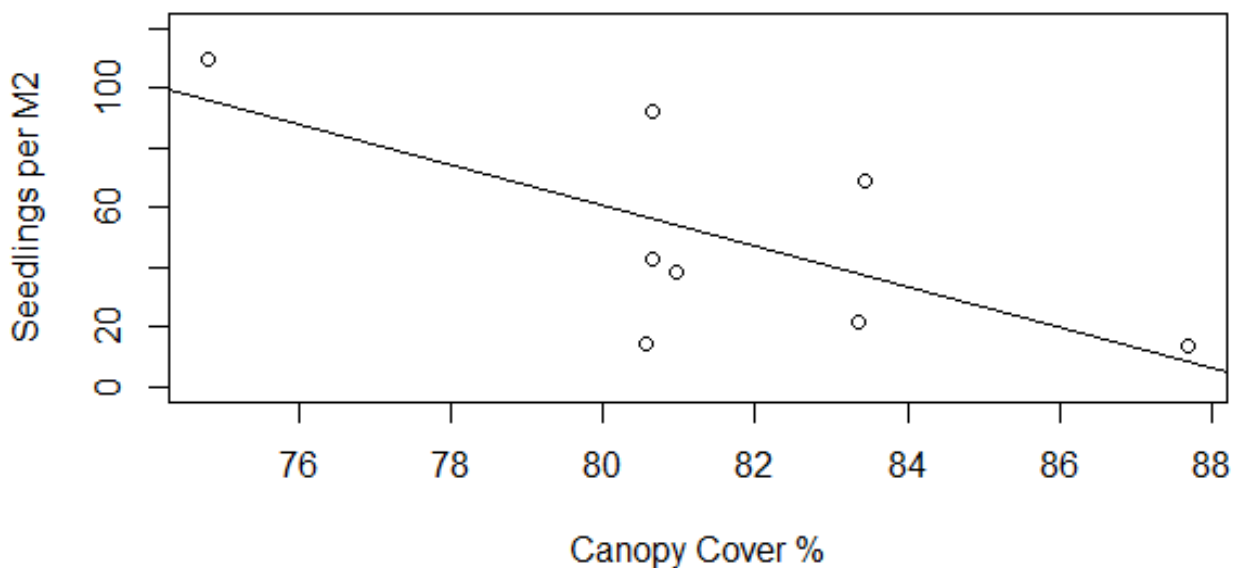


Figure 5.11: Seedlings per m<sup>2</sup> as explained by percentage of ground cover in R1, found in 8 2x2m plots over a 12-month period.  $P=0.06978$ ,  $R^2=0.4472$ ,  $n=8$ ,  $DF=6$ .

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significance level (Figure 5.10). The LM of 'seedlings per m<sup>2</sup>' as explained by 'ground cover' found a negative linear correlation and was significant ( $p=0.06978$ ,  $R^2=0.4472$ ) at the 93% significance level (Figure 5.11). Overall the seedling establishment over a 12-month period in R1 can be described as high in terms of abundance, with a mean of 79.19 seedlings per m<sup>2</sup>. However, having found only 6 RTUs the diversity is relatively low when compared to the understorey of the reference site, Nikau Scenic Reserve (NSR).

The abundance of food resources in the Nikau Scenic Reserve relative to the restoration plots, detract birds from visiting the restoration sites, as it is not an efficient use of their energy

(Morgan et al., 2012). Without bird species visiting, with the exception of weka (Figure 5.12), seed dispersal into and beyond from the plots is limited (Clout and Hay, 1989). Little is known about the role of invertebrates, but research has shown that taxa such as ants, dung beetles and weta may play an important ecosystem service role of seed dispersal (Dominguez-Haydar and Armbrecht, 2011; Duthie et al., 2006; Jones et al., 2012; Morgan et al., 2016; Wandrag, 2012). These missing factors indicate that the restoration plots are not at a self-sufficient stage, however the success of R1 in particular has shown that it is possible to restore degraded agricultural and mining land through regeneration of native forest.



Figure 5.12: Weka commonly observed around restoration sites are known to contribute towards seed dispersal (Photo: Mike Bowie)

## 6. Invertebrates

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### 6.1 Invertebrate indicators of restoration success of a sandplain forest on the West Coast of New Zealand

Invertebrates because of their substantial diversity, biomass, and significant roles in ecosystem services have been used extensively as indicators of restoration success (Derhé et al., 2016; Lomov et al., 2006; Majer et al., 2007; McGeogh, 1998).



Figure 6.1: Robberfly, a significant predator at the PCR research site (Photo: Mike Bowie)

## 6.2 Methodology: Restoration, reference and control sites

### 6.2.1 Leaf litter invertebrates

Leaf litter was sampled from each of the 21 transect plots once during the months of December and January 2012 (Bowie et al., 2012), in January 2013 (Hahner and Bowie, 2013) and January 2015/6. Litter was collected from within a 21 x 30 cm 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 to the soil/mineral layer and placed bags and then transferred into Tullgren funnels (Southwood, 1978) fitted with 15 Watt light bulbs. Sample containers with 70% ethanol were placed beneath the funnels and left for one week. Species were counted and identified to Recognisable Taxonomic Units (RTU).



Figure 6.2: Cicada are often seen & heard in the restoration plots at the PCRP (Photo: Mike Bowie)

### 6.2.2 Pitfall traps

Pitfall traps (80 mm diameter) 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 180 mm) was positioned above the hole to deflect rain, prevent debris from falling into the hole and reduce disturbance from weka. The pitfall traps were 350ml plastic 'honey pot' containing 100 mL of monopropylene glycol (antifreeze) as a preservative. Traps were set from 13th December 2011 to 11th January 2012 (29 days), and from December 17th, 2012 to January 9th, 2013 (23 days). The sampling period was reduced due to predicted high rainfall and the possibility of flooding occurring into the pitfall traps. Dec 2015 to 20 January 2016.

### 6.2.3 Weta motels

Invertebrate refugia called weta motels (Bowie et al., 2006; Bowie et al., 2014) were made of untreated pine with an entrance hole in the bottom. They are 50 x 50 x 250 mm long with a hole of 15 mm in diameter. Weta motels were used to monitor Wellington tree weta, *Hemideina crassidens* (Blanchard) (Orthoptera: Anostostomatidae). Three motels were attached to trees in mature sites and to stakes in restored and unplanted sites using lacing wire in each plot. Weta motels were set out on 30th Nov and 1st of Dec 2011, and were monitored on 13th January 2012, 19 November 2013, 30 July 2014 and 17 September 2015. The number of tree weta was recorded in each motel.

## 6.2.4 Wooden discs

Wooden discs for monitoring ground-dwelling invertebrates and lizards (Bowie and Frampton, 2004) were cut from a *Pinus radiata* tree on site (Figure 6.3). The diameter of the discs varied between 320 mm and 460 mm however a mixture of sizes were used in each plot so the total area of ground covered by discs was approximately 0.47 m<sup>2</sup> per plot. Ground cover was removed so discs are in direct contact with soil. Four discs were used in each plot. Wooden discs were set out on 1st Dec, 2011, and monitored on 13th January 2012, 2014 and 2016.

## 6.2.5 Moths

Moth monitoring was conducted in mature and restoration plots simultaneously using two identical light traps fitted with 60 Watt incandescent bulbs (Hahner and Bowie, 2013). The traps were a wooden box fitted with a removable lid fitted with 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. Traps were placed in middle of restoration plots and at least 20m into the mature forest. Trapping commenced approximately half an hour after sunset for approximately three hours' duration on 11th January 2012, February 12th and March 10th, 2013, 19 & 20 February 2015, and 28 February 2016.



Figure 6.3: Wooden discs cut on site were used in monitoring ground-dwelling invertebrates and lizards (Photo: Mike Bowie)

## 6.3 Invertebrate monitoring results

### 6.3.1 Leaf litter invertebrates

#### *Aoraki denticulata*

The mite-like harvestman *Aoraki denticulata* was only found in leaf litter from mature sites until the summer of 2015 when they were also found in restoration sites (Figure 6.4).

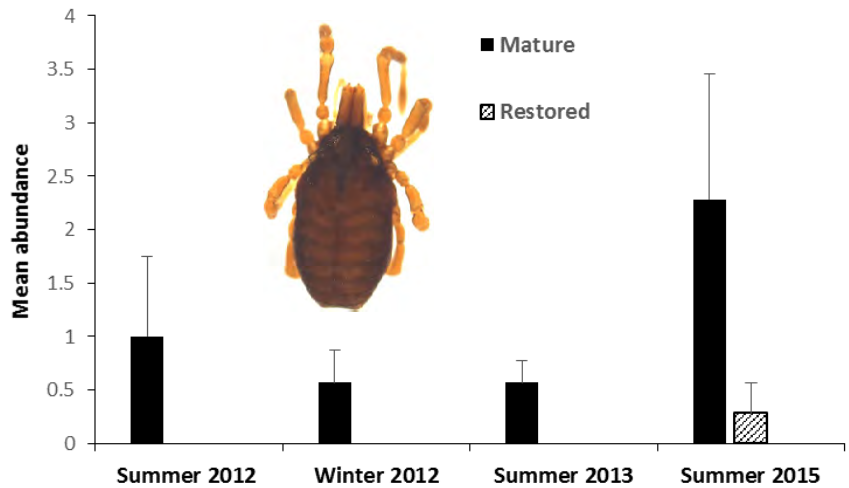


Figure 6.4: Mean abundance of harvestmen (*Aoraki denticulata*) sampled on four occasions ( $\pm$  se). Significant differences ( $p < 0.05$  between) treatments are indicated by different letters above bars (Photo: Mike Bowie).

#### Weevils

Similar to the trend found with *Aoraki denticulata*, weevils were only found in mature leaf litter samples until the summer of 2015, where they were found in restoration sites (Figure 6.5).

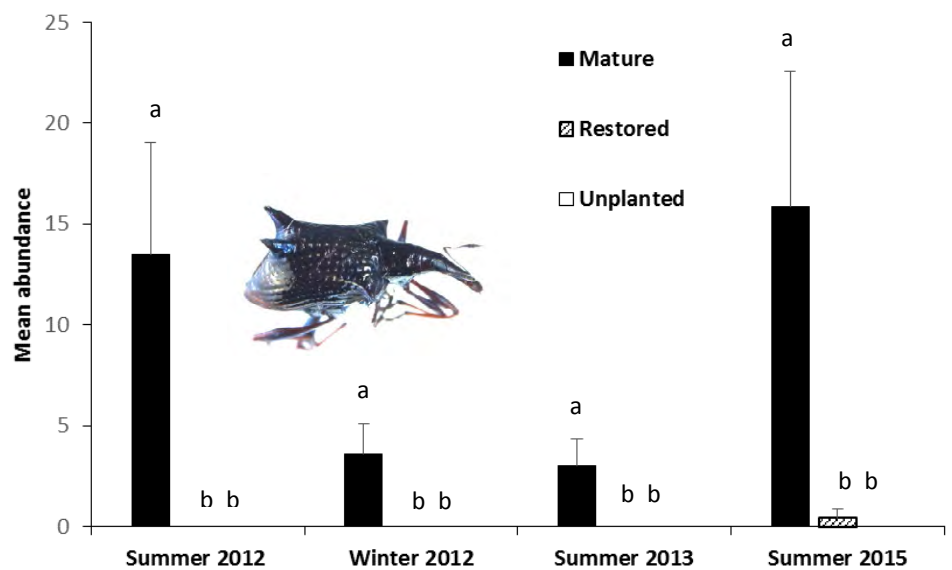


Figure 6.5: Mean abundance of weevils sampled on four occasions ( $\pm$  se). Significant differences  $p < 0.05$  between treatments are indicated by different letters above bars (Photo: Mike Bowie).

## Mites

Approximately 35 mite species (Recognisable Taxonomic Units) were identified in the leaf litter collected, with a large proportion from the Oribatidae family. Seven species were found to be most abundant in the mature forest leaf litter and potentially very useful as indicator species. Two Oribatidae (RTU 4 & 6) and one Uropodina (RTU 16) look to be the most reliable indicators as they

have the highest mean percent present in mature sites, with the lowest mean presence of 83%. In comparison to previous monitoring rounds, there have been increased numbers of these indicator species found in the restoration sites (Figure 6.6).

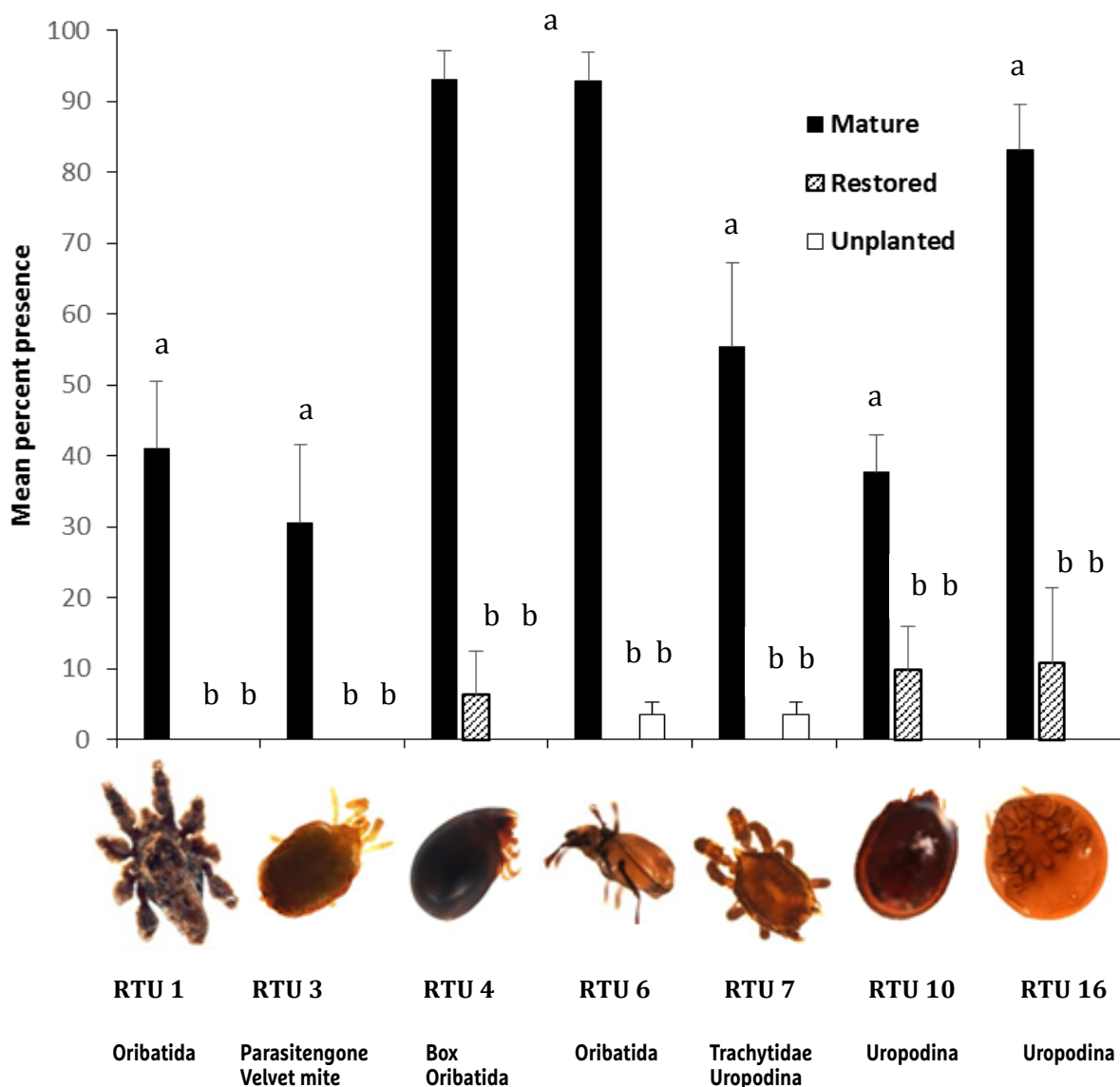


Figure 6.6: Mean presence of mites identified as indicator species over three litter samples across mature, restored and unplanted transects ( $\pm$ se). Mites shown within the figure are identified according to the Recognisable Taxonomic Unit (RTU). Significant differences ( $p < 0.05$  between) treatments are indicated by different letters above bars (Photos: Mike Bowie).



## Beetles

Beetles excluding rove beetles (Staphylinidae) and weevils (Curculionidae) were found to be very abundant in the summer of 2012 and 2013, but were found in significantly less numbers in winter 2012 and summer 2015 in the mature sites (Figure 6.7). 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.

A new species of small spotted earthworm has only been found in leaf litter from mature sites (Figure 6.8). Significantly greater abundance of these were found in mature sites ( $p \leq 0.05$ ) in the summer 2002 sampling. However, there has been a decrease in abundance in the mature leaf litter, with none found in the summer of 2015. It is unknown what has caused this continued drop in numbers and is of concern.

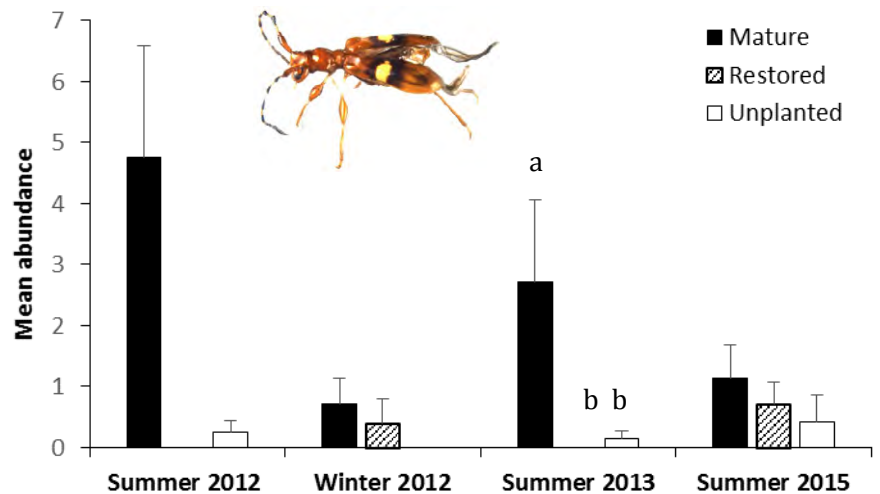


Figure 6.7: Mean abundance of beetles (excluding Curculionidae & Staphylinidae) in leaf litter sampled on four occasions ( $\pm$  se) (Photo: Mike Bowie).

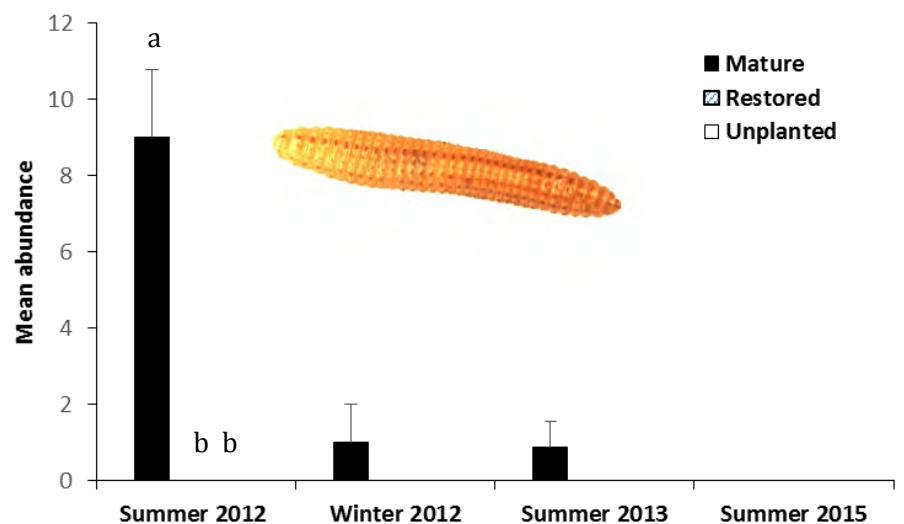


Figure 6.8: Mean abundance of 'spotted' earthworms ( $\pm$  se) in leaf litter samples (Photo: Mike Bowie).

## Lepidoptera (moths)

A total 876 moths were collected and 137 moth species from 21 families were identified from the moth trapping between 2012 and 2016 (see appendix for complete list).

Seven of the species were exotic, four of which were found in the mature forest only. Figure 6.9 shows a selection of moths collected at the PCRP site.

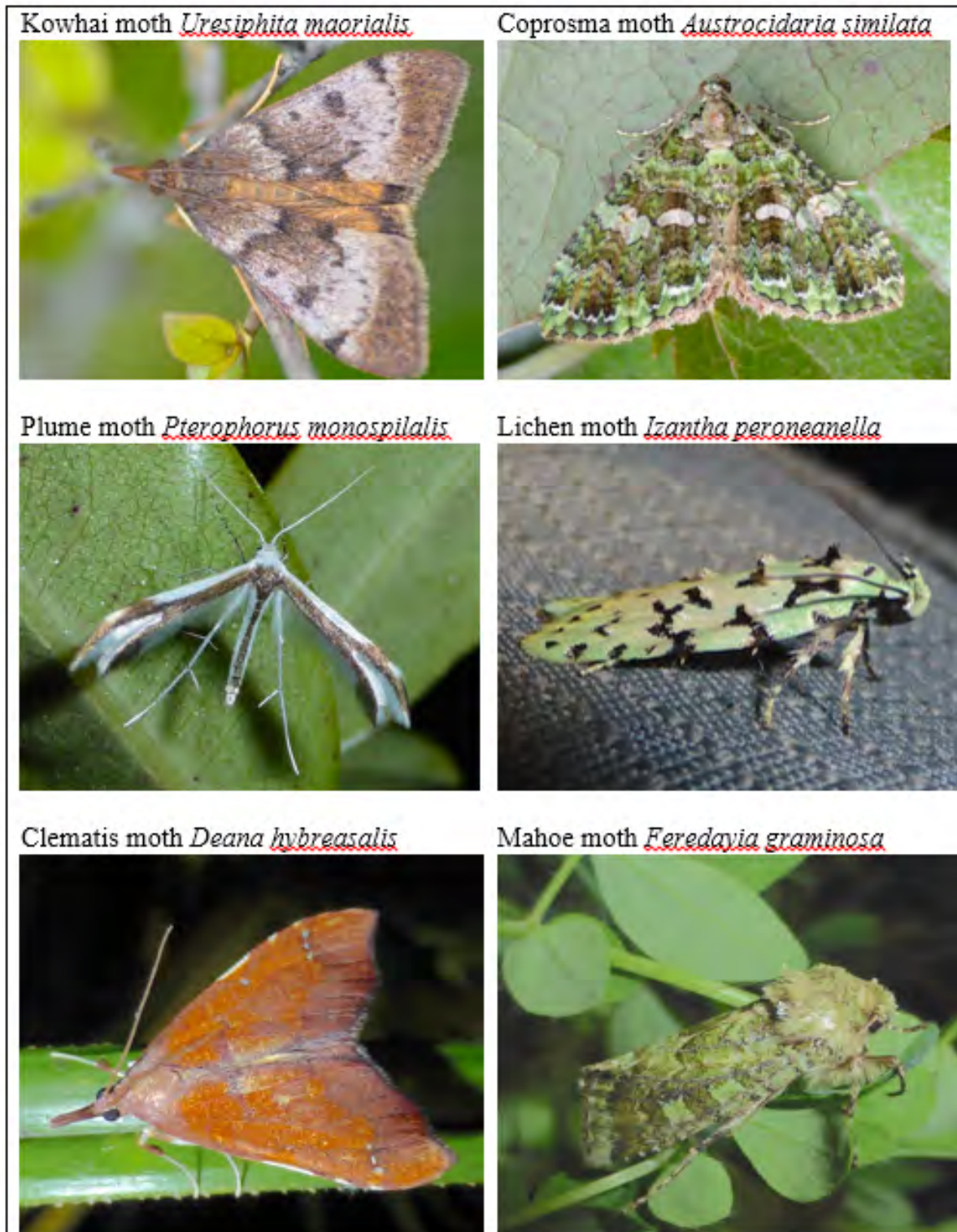


Figure 6.9. Selection of moths collected at the PCRP site (Photos: Mike Bowie).

Over all dates 104 native species were collected from mature sites and 81 from restoration plantings, and 77.9% of moth species caught in mature sites that were also caught in restoration plots. Over the four years that moths were trapped, the diversity caught in restoration increased significantly ( $R^2 = 0.9968$ ,  $P=0.0016$ , Figure 6.10) and proportion of the same species as mature fauna increased but not significantly ( $R^2 = 0.8998$ ,  $P=0.051$ , Figure 6.11).

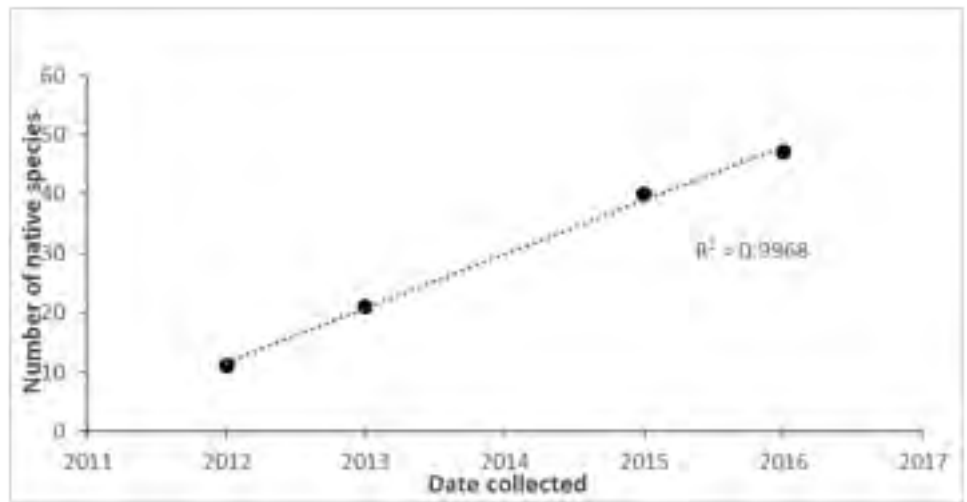


Figure 6.10: Number of native moth species collected in restoration plots over time

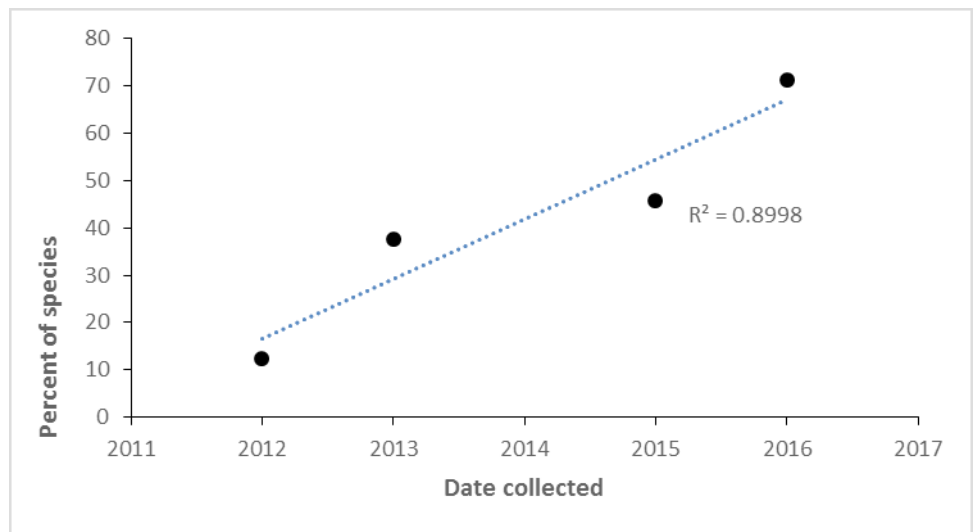


Figure 6.11: Percent of moth species found in mature sites also found in restoration sites

## Wooden discs

Total earthworms were always highest in the unplanted grassland controls. In the 2002 survey the sites were significantly ( $p \leq 0.05$ ) from each other (Figure 6.12). Mean abundance of exotic earthworms were also significantly higher in unplanted sites in 2012 ( $p \leq 0.05$ ). No exotic earthworms were found in mature sites in 2014 and 2016 (Figure 6.13).

Significantly fewer exotic snails (*Oxychilus* sp.) were found in the mature sites than in the unplanted or restored sites in 2016 (Figure 6.14).

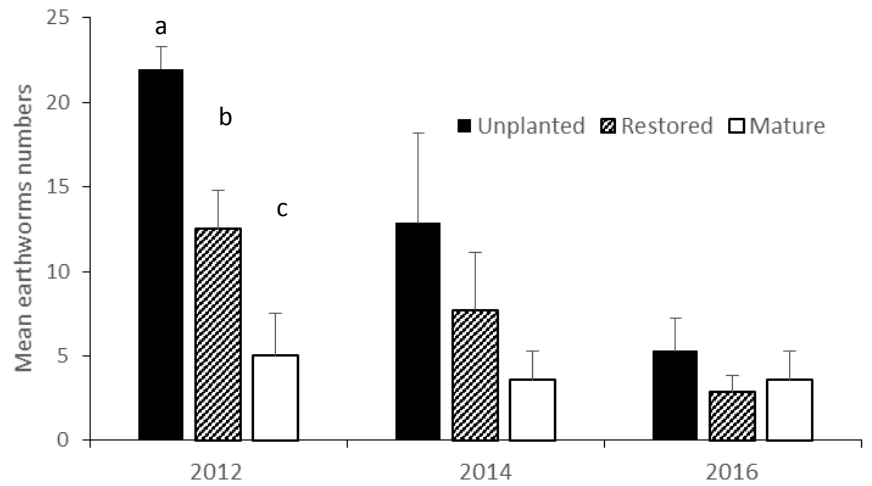


Figure 6.12: Mean total earthworms under discs in transects. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.



Figure 6.13: Mean exotic worm numbers under discs in unplanted, restored and mature sites in 2012, 2014 & 2016. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.

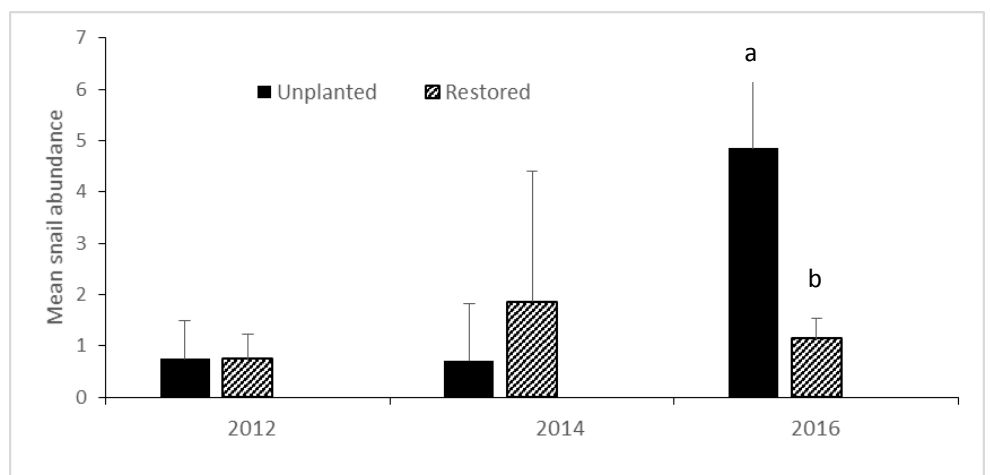


Figure 6.14: Mean abundance of exotic snails (*Oxychilus* sp.) in transects from 2012 to 2014. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.

## Tree weta

The Wellington tree weta *Hemideina crassidens* (Blandchard) is the resident species at Punakaiki. The first monitoring 1.5 months after the placement of weta motels at PCRCP yielded no tree weta however two cave weta were found in the mature sites. Subsequent monitoring after 48, 56 and 70 months yielded significantly more weta in the mature sites ( $p \leq 0.05$ ). Restoration sites also had weta, whereas the unplanted control sites only had weta at the 56 months sampling period (Figure 6.15, 6.16).

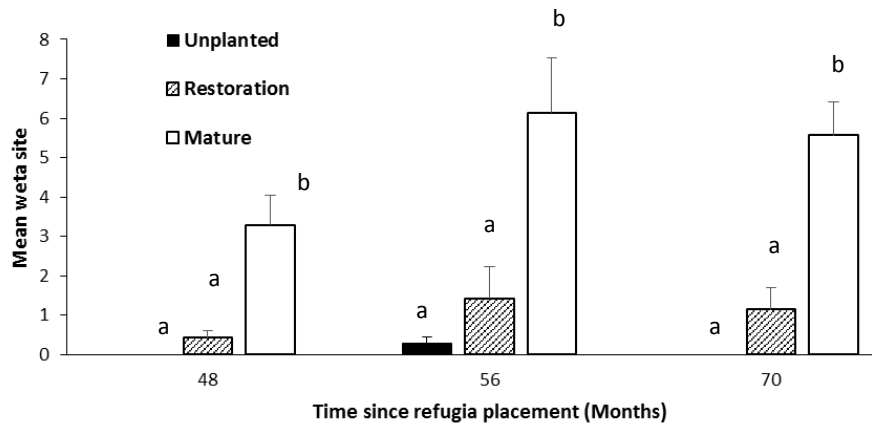


Figure 6.15: Mean tree weta present per transect site. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.



Figure 6.16: Wellington tree weta (*Hemideina crassidens*) in weta motel at the PCR site are known seed dispersers (Photo: Mike Bowie)

### 6.3.8 Pitfall traps

Dung beetles (*Saphobius edwardsi* and *S. lesnei*) were found in significantly higher abundance in the mature sites (Figure 6.17) than in the restoration and unplanted control sites over all sampling dates ( $p \leq 0.05$ ).

The small beetles (excluding carabids, staphylinids and dung beetles) were more abundant in mature sites for all three years monitored but were only significantly higher in 2016 (Figure 6.18).

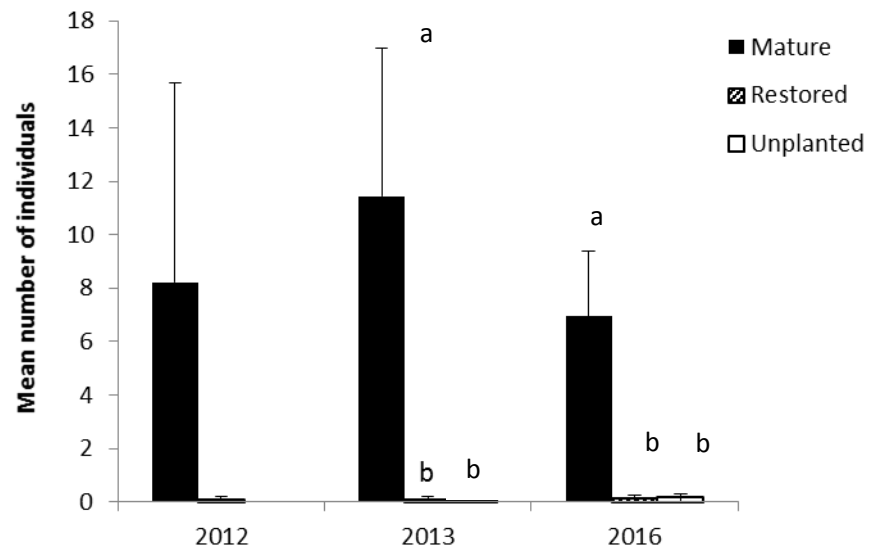


Figure 6.17: Mean dung beetle abundance in transect pitfall traps between 2012-6. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.

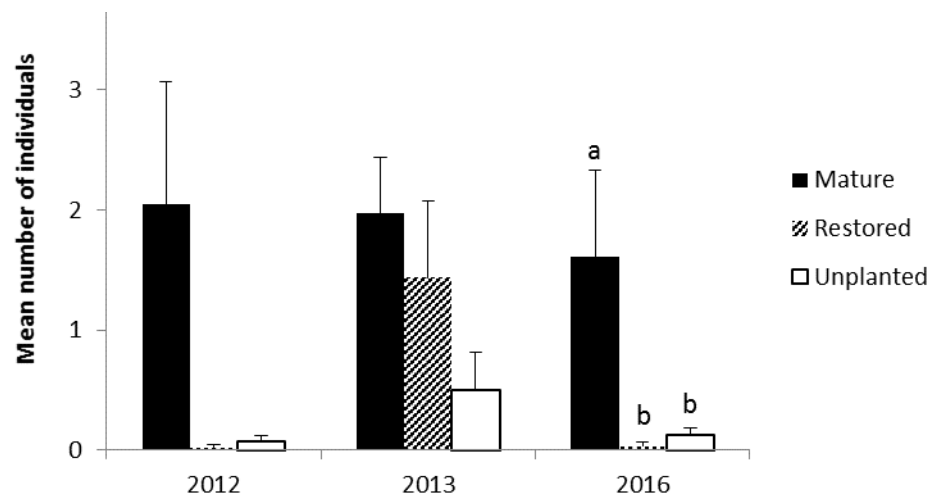


Figure 6.18: Mean abundance of small beetles in transect pitfall traps. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.

Abundance of Hymenoptera (wasp taxa) was significantly less in mature forest sites than restoration and unplanted sites apart from 2016 sampling (Figure 6.19), which shows restoration sites to be not significantly different ( $p \leq 0.05$ ).

Grassland spiders (*Anoteropsis hilaris* and *Dolomedes minor*) were significantly more abundant in unplanted and restoration plantings than in mature sites for 2012 and 2013, however in 2015 abundance in restoration plantings did not differ from mature or unplanted sites (Fig 6.20).

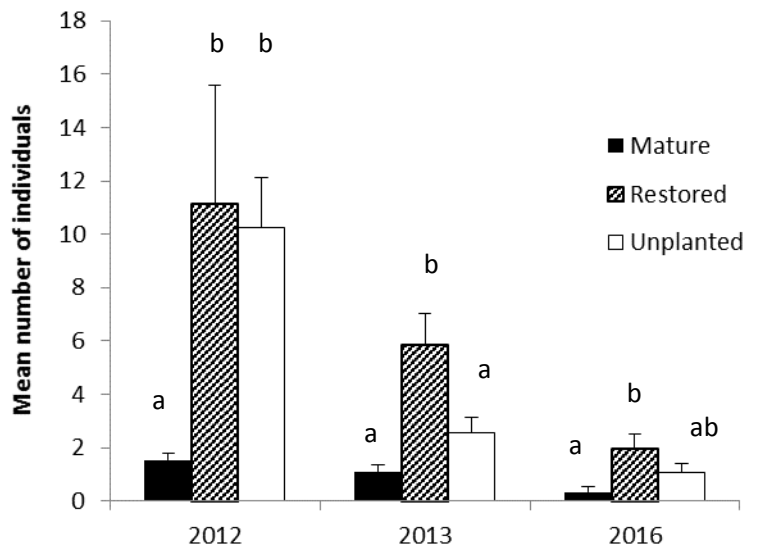


Figure 6.19: Mean abundance of Hymenoptera (wasps) in transect pitfall traps over time. Significant differences  $p \leq 0.05$  between treatments are indicated by different letters above bars.

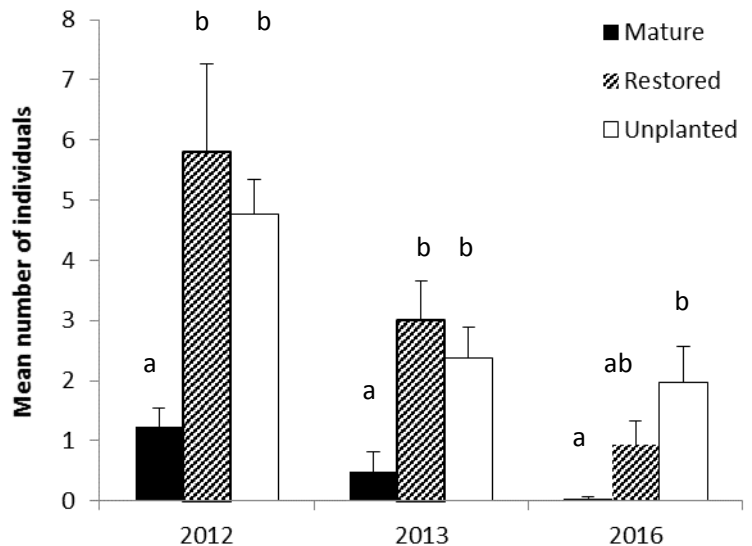


Figure 6.20: Mean abundance of spiders (*Anoteropsis hilaris* and *Dolomedes minor*) in transect pitfall traps. Significant differences ( $p \leq 0.05$ ) between treatments are indicated by different letters above bars.





Figure 6.21: Nursery web spider *Dolomedes minor* were very common in the unplanted and more open younger restoration sites at the PCRP site. (Photo: Mike Bowie)

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## 6.4 The role of invertebrates as restoration indicators at the PCRCP site

### 6.4.1 Leaf-litter

The mite-like harvestman *Aoraki denticulata* was only found in leaf litter from mature sites until the summer of 2015 when they were also found in a restoration site (Figure 6.4). These predatory harvestman, although small, are very distinctive, making them a good indicator species. Results from the latest leaf litter analyses show small numbers of harvestman for the first time colonising a restoration site (R1), indicative of a restoration milestone.

### 6.4.2 Weevils

Up to 32 species of weevil were identified but over 50% of those found in leaf litter samples were a small leaf litter dwelling species called *Geochus tibialis*. Similar to the trend found with *Aoraki denticulata*, weevils were only found in mature leaf litter samples until the latest 2015 sampling, where they were also found in restoration sites (Figure 6.5). Very few weevils were located in the restored plot (R1), which indicates the habitat is only beginning to become suitable for the survival of weevils.

Plant litter composition does influence fauna composition (Wardle et al., 2006) so is not surprising to find differences between the exotic grass litter and the mature litter at the PCRCP. 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 et al., 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 (Grant et al., 2007; Swift et al., 1979). 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 and Proctor, 2013).

### 6.4.3 Lepidoptera

Herbivory by Lepidoptera is a significant ecosystem service (de Bello et al., 2010) and represent the majority of terrestrial biotypes (Fox et al., 2011). The moth fauna at the site was diverse with 139 species and restoration sites were quickly colonised by them

(Figure 6.8, 6.9). The close proximity of mature remnants is likely to be an important consideration for the speedy colonisation and establishment of species in restoration sites. The large diversity in moth families collected, 21 in total, is similar to the number found in the UK

Moths and their larvae also provide a huge food resource for insectivorous birds and invertebrates. This ecosystem service is key to the overall functionality of the restoration. Birds such as grey warbler, fantail, and weka are the main species on site to gain from the increasing moth fauna.

### 6.4.4 Tree weta

Tree weta were found in weta motels 48 months after refugia placement however it is highly likely they were present well before then as other species have shown occupation can be a matter 12 months or less (Bowie et al., 2006; Bowie et al., 2014). Tree weta although predominately vegetarian also have invertebrates in their diet (Gibbs, 2001). They are also known to disperse smaller seeds eaten as berries and therefore provide a useful ecosystem services (Burns, 2006; Duthie et al., 2006). Tree weta were shown to increase the germination rate through ingestion showing they are true seed dispersers (Duthie et al., 2006). Two of the berry species (*Fuchsia exorticata* and *F. procumbens*) present at PCRCP are known to pass *H. crassidens* intact and there may well be others (Duthie et al., 2006; Shields et al., 2016).

### 6.4.5 Pitfall traps

Dung beetle abundance showed the most clearcut results in terms of a species dominant in the mature sites at PCRCP. Their roles in soil dung decomposition, nutrient cycling, soil aeration and drainage, and secondary seed dispersal makes them key ecosystem service providers (Andresen and Levey, 2004; Brown et al., 2010; Derhé et al., 2016; Gollan et al., 2013; Nichols et al., 2008; Vulinec, 2002). Due to their sensitivity to perturbations (Nichols et al., 2008) dung beetles are acknowledged as excellent bioindicators as they are relatively easy to identify and are often considered as a proxy for taxa (Bicknell et al., 2014). The

species found at the PCR ( *Saphobious edwardsi* and *S. leseni* ) have been investigated as secondary seed dispersers (Shields et al. 2016) from dung of known primary seed dispersers Wellington tree weta *H. crassidens* (Duthie et al., 2006). Surprisingly, in the absence of native mammalian herbivores in New Zealand dung beetles still have a strong preference for a variety of dung including that of cow and sheep (Jones et al., 2012).

#### 6.4.6 Mites

Approximately 35 species (Recognisable Taxonomic Units) of mites were identified in the leaf litter collected, with a large proportion from the Oribatidae family. Seven species were found to be most abundant in the mature forest leaf litter (Figure 6.6) and potentially very useful as indicator species. Two Oribatidae (RTU 4 & 6) and one Uropodina (RTU 16) look to be the most reliable indicators as they have the highest mean percent present in mature sites, with the lowest presence present at 83 per cent. In comparison to previous monitoring rounds, there have been increased numbers of these indicator species found in the restoration sites.

Seven species were found to be largely in the mature forest leaf litter 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

#### 6.4.7 General discussion

Several studies have found that apterous insects or poor fliers are slow dispersers (Moir et al., 2005). Body size could also be a consideration given larger moths are generally stronger fliers and smaller species. Although weta are apterous some can move large distances (Watts et al., 2012). Tree weta usually live in galleries inside tree cavities by day but emerge to forage on arboreal foods at night, with only gravid females descending to the ground for oviposition in soil (Gibbs, 2001). Moth diversity has increased in the restoration plantings over the monitoring period and it is clear that moths are generally good dispersers. Lepidoptera are a diverse fauna in New Zealand with 1684 species of moths alone (Graeme, 2011). Moths are excellent taxa as indicator species given ecosystem service roles in nutrient cycling and pollination (Fox, 2013; Merckx and Slade, 2014), represent most terrestrial biotypes and are relatively easy to identify (Fox et al., 2011). Smaller species that have only recently (2015) been found in litter of restoration sites include the small harvestman (*Aoraki denticulata*) and weevils which demonstrates early signs of colonisation as part of the restoration trajectory. The apparent decrease in the small spotted earthworm is of some concern.

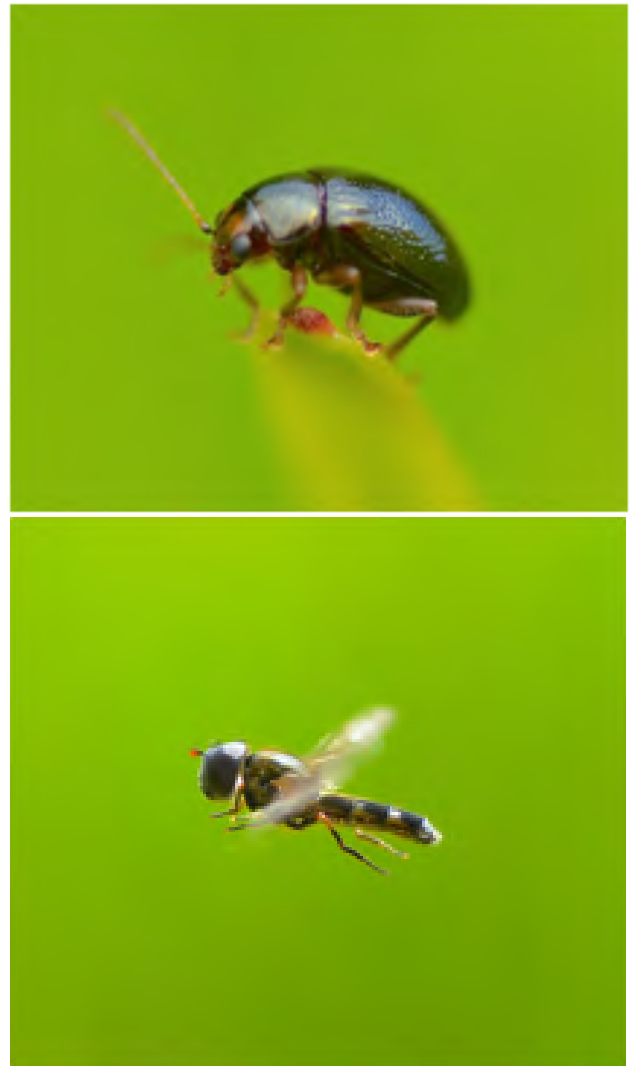


Figure 6.22: Biocontrol beetle (*Eucolaspis* sp., left) found on blackberry, and hoverfly (*Allograpta* sp., right) photographed at the PCR site (Photos: Mike Bowie)



Figure 6.23: Biocontrol agent *Tyria jacobaeae* (Cinnabar moth) larvae feeding on ragwort at PCRP (Photo: Mike Bowie)

## 7. Earthworms

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Information in this section is largely taken from Kim (2016): Interactions between Soil Biogeochemistry and Native Earthworms in New Zealand (PhD Thesis: Youngnam Kim, PhD award July 2016). Please refer to this study for more information and references. It should be noted that the PCRPs site was one of five sites studied in this thesis, but also provided the reference for all studies.

### 7.1 Summary of interactions between soil biochemistry and native earthworms in New Zealand

Despite apparently similar burrowing and feeding behaviours to introduced Lumbricid earthworms, native Megascolecidae species, with more than 179 recognised species, have become isolated in natural vegetation remnants on the margins of agricultural lands. Long-term geographic isolation has provided high endemic earthworm diversity in New Zealand, but they appear to have a poor ability to adapt to anthropogenic disturbance. Although earthworms are well known as 'soil engineers', there is lack of knowledge of the role of endemic earthworms in New Zealand's soil ecosystems. The aims of the present PhD study were to identify endemic earthworm preferences for and influences on soil biogeochemistry, and to investigate interactions between the drilosphere of native earthworms and the rhizosphere of native plants.

Species of earthworms, collected from native vegetation, natural remnants and restoration sites in Canterbury and on the West Coast of South Island, were identified using DNA barcoding with 16S and COI. Thirteen endemic and nine exotic species were identified and, of these eight abundant earthworms were selected for this study: 5 endemic taxa identified as *Deinodrilus* Sp.1 (epigeic), *Maoridrilus transalpinus* and *Maoridrilus* Sp.2 (anecic), *Megascolecidae* Sp.1 and *Octochaetus multiporus* (endogeic) and 3 exotic species: *Eisenia fetida* (epigeic), *Octolasion cyaneum* and *O. lacteum* (endogeic). Six native species and 8 exotic species were identified at Punakaiki (Table 7.1), reproduced according to Kim (2016).

Both endemic and exotic earthworms preferred agricultural soils to a native forest soil. Litter of ryegrass was preferred to that of native plants. Some native plant litters, such as *Coprosma robusta*, were also favoured by endemic earthworms, which preferred less acid soils to a larger degree than high organic matter soil. Earthworm species could also be separated on the basis of their effects on soil biogeochemistry, in terms of organic matter consumption, nutrient mineralisation, soil microbial

biomass and greenhouse gas emissions from the soil. Earthworm inoculation of soils increased more mobile forms of key nutrients, N and P, and emissions of N<sub>2</sub>O and CO<sub>2</sub> from an agricultural soil. Lesser differences were found between native and exotic earthworms than between functional (burrowing) groups.

Native earthworms increased plant growth, particularly of *L. perenne*, and had a marked interaction with root morphology of two native species of tea trees (*Leptospermum scoparium* and *Kunzea ericoides*). They also stimulated microbial activity in the rhizosphere soil. An anecic species, *M. transalpinus*, enhanced rates of root nodulation of a leguminous shrub (*Sophora microphylla*), enhancing critical concentrations of nitrate, but also reducing nitrous oxide emissions. *Maoridrilus* spp. enhanced plant productivity in biosolids-amended soils, but raised some potential environmental concerns through increased N<sub>2</sub>O emissions in biosolids-amended soil (<50 % treatments). They also significantly increased ammonium and nitrate in soil, microbial activity and soil concentrations of soluble copper. The functional role of native earthworms is summarized in Figure 7.1 (Kim, 2016).

The results of this research showed that endemic earthworms could play a critical role providing soil ecosystem services in New Zealand's production landscapes. Novel habitats within agricultural management systems provide an important refuge for threatened species conservation. Enhanced restoration of native vegetation into agricultural landscapes will enhance the dispersion and sustainability of communities of native earthworms. It is concluded that an integrated understanding of plant growth and microbial communities with earthworm functionality is essential for effective management of soil biogeochemistry and to inform ecological restoration on former agricultural land.

Conclusions of seven experimental chapters are shown here in the context of the Aims and Objectives. Aims of this research were to investigate how earthworms have survived in highly disturbed landscapes alongside invasive species, whether and how they have (i) adapted to the modified soil biogeochemistry of agricultural land and, and (ii) whether they play a role in influence the functionality of these soils. This research project has provided fresh insights into the status and ecology of native earthworms in human-modified soils in New Zealand. It was found that their exclusion from agricultural pastures is not due to an inability to adapt to modified soil physicochemistry. It is considered most likely that they were not resistant to vegetation clearance, land disturbance or the ensuing environmental conducts (e.g. changed temperature and moisture).

Table 71: Distribution of 22 earthworm taxa, 13 of endemics and 9 of exotics collected from soils in New Zealand's South Island. Species presence is indicated by "V". Species were classified as endemic or exotic and named after DNA barcoding and morphological identification.

Classification	Species name	Sampling sites				
		Punakaiki	Bankside	Banks Peninsula	Eyrewell	Lincoln
Endemic species	<i>Deinodrilus</i> sp.1	V				
	<i>D. gorgon</i>	V	V			
	<i>Maoridrilus transalpinus</i>			V		V
	<i>Maoridrilus</i> sp.1			V		
	<i>Maoridrilus</i> sp.2					V
	<i>Octochaetus multiporus</i>			V		V
	<i>O. kenleei</i>	V	V			
	<i>Megascolecidae</i> sp.1	V				
	<i>Megascolecidae</i> sp.2	V				
	<i>Megascolecidae</i> sp.3	V				
	<i>Megascolecidae</i> sp.4				V	
	<i>Megascolecidae</i> sp.5				V	
	<i>Megascolecidae</i> sp.6					V
Exotic species	<i>Amyntas corticis</i>	V				
	<i>Aporrectodea caliginosa</i>	V	V	V	V	V
	<i>Dendrobaena octaedra</i>	V				
	<i>Fridericia magna</i>	V				
	<i>Lumbricus rubellus</i>	V				
	<i>Lumbricidae</i> sp.		V	V	V	V
	<i>Megascolex laingii</i>	V				
	<i>Octolasion cyaneum</i>	V	V	V		V
<i>Octolasion lacteum</i>	V					

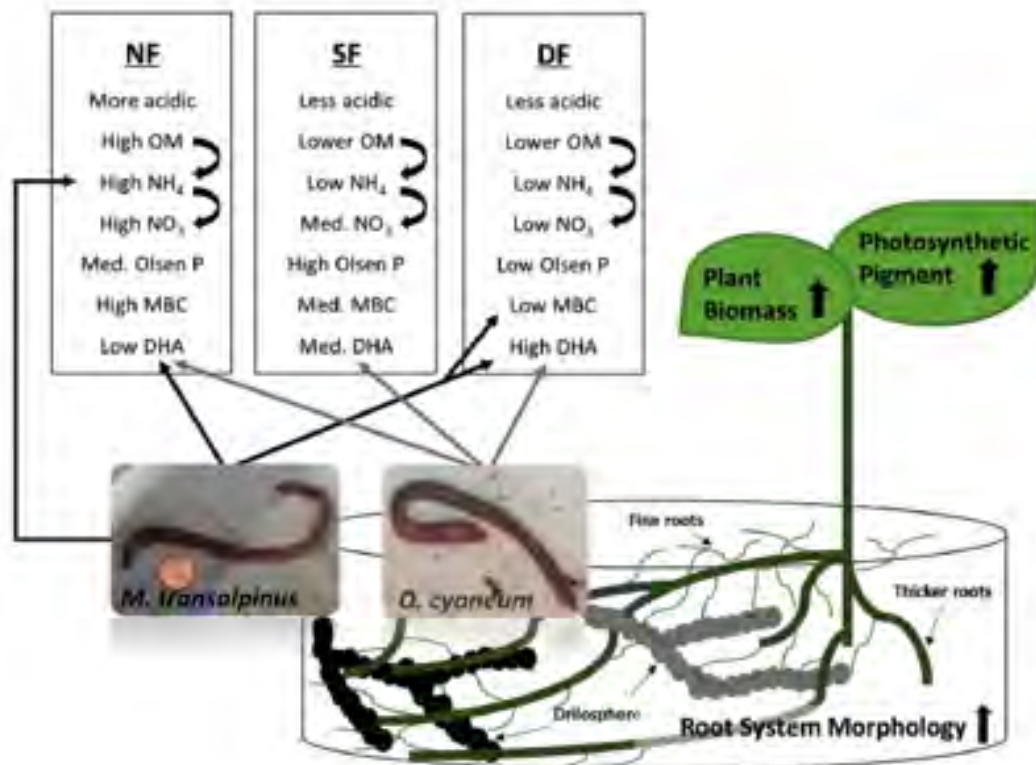


Figure 7.1: Interpretation of results of mesocosm experiment. Positive effects of *M. transalpinus* (black) and *O. cyaneum* (grey) are indicated using arrows (Kim, 2016).

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## 7.2 Objective 1: Investigation of the interactions of native and introduced earthworms with soils and plant rhizospheres in production landscapes of New Zealand [Chapter 3]

Native and exotic earthworms are found to co-exist in agricultural landscapes in New Zealand. They are shown to modify plant growth, nitrogen mobility and greenhouse gas emission. The main differences between earthworm functionality were found to be between different ecological groups, rather than between taxonomic groups. It is argued that a move towards sustainable systems and current restoration practices will probably enhance the dispersion of native earthworms.

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## 7.3 Objective 2: Molecular identification and the distribution of New Zealand earthworms in human-modified soils [Chapter 4]

A total of 15 undescribed Megascolecidae taxa from native vegetation, restoration plots and agricultural pasture was identified using DNA barcoding. Eight taxa were identified in genera of *Octochaetus*, *Maoridrilus* and *Deinodrilus*. In terms of phylogenetic separation, the 16S-based phylogeny clearly separated Megascolecidae from Lumbricidae. Compared to native taxa, exotic earthworms were disturbed wider environmental conditions, with more resistance to acidic soil and low organic resources. This work illustrated the rudimentary nature of our knowledge of earthworm taxonomy and soil ecology in New Zealand.

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## 7.4 Objective 3: Endemic earthworms in a sheep-farmed soil: implications for soil nutrients, environment and conservation [Chapter 5]

Native species were found to coexist with exotics in remnants of native vegetation within intensive sheep-farmed landscapes, and they could survive in modified pasture soils. This work indicated that native earthworms are unlikely to be compromised by a gradual accrual of nutrients, they increased soil concentrations of exchangeable minerals including N, P, Ca, K, Mg, and Na. Individual species of both natives and exotics could be separated on the basis of their modification of soil biogeochemistry. This work supports the idea that less intensive farm management systems (e.g. with reduced tillage) may allow the expansion and increased diversity of native species.

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## 7.5 Objective 4: Integration of earthworm burrowing, growth of a leguminous shrub and nitrogen cycling in a mesocosm experiment [Chapter 6]

Growth of a native legume *Sophora microphylla* grew better in the presence of soil burrowing earthworms. The native earthworm *Maoridrilus transalpinus* modified soil biogeochemistry (e.g. enhancing nitrate and dehydrogenase enzyme activity) and rates of root nodulation, but also reduced nitrous oxide emissions. The findings of this experiment indicated that earthworm-mediated soil aeration, modification of moisture conditions in the rhizosphere and drilosphere, and comminution of organic matter modify microbial communities and influence the N cycle. It is argued that the functionality of native earthworms could be valuable for effective management of soil N in ecological restoration on former agricultural land.



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## 7.6 Objective 5: Investigation of the potential role of New Zealand native earthworms (Megascolecidae) as ecosystem engineers on agricultural land [Chapter 7]

The native *Maoridrilus transalpinus* had high survivorship on agriculture soils within pasture management systems. This species appeared to play an equivalent or more substantial role to exotic *Octolasion cyaneum* in the rhizosphere of ryegrass. Modification of morphology of the drilosphere and root system, stimulation of nutrient dynamics (e.g. nitrogen) and microbial communities, and enhancement of plant-availability of nutrients were evident. These effects increased plant biomass and photosynthetic pigments. This further supports the argument that native earthworms may have functional roles in modern and future agroecosystem management.

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## 7.8 Objective 7: Earthworm feeding and burrowing behaviours: observation studies [Chapter 9]

Earthworm preference was shown to be variable depending on soil pH and availability of native plant litters. All earthworms preferred lesser acid soils amended with lime. Of the native plants litters, *C. robusta* litter was the most palatable of the species tested. Nutrient content of litter (N, Ca, K, P, S, and Zn) influenced litter palatability and earthworm preference, particularly of endemic *M. transalpinus*. These studies indicated that earthworm sensory abilities, such as olfactory and visual reactions to food sources, allowed foraging for food resource in soils with surprisingly accurate capacity of navigation. Earthworms were also shown to modify rhizosphere structure, and there was a knock-on effect of plant root preferentially growing around drilospheres.

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## 7.7 Objective 6: Biochemical impacts of endemic *Maoridrilus* earthworms (Megascolecidae) in biosolid-amended soil [Chapter 8]

Two native *Maoridrilus* spp. proved to be efficacious in the context of biosolid disposal to land. They increased mobile N, microbial communities, and soluble Cu in soil. Both species also increased N<sub>2</sub>O emissions from soil, and more so than did the compost earthworm *E. fetida*. *Maoridrilus* earthworms have the potential to enhance plant productivity in biosolids-amended agriculture and ecological restoration soils, but this work showed they may raise additional environmental concerns in terms of greenhouse gas emissions.

## 8. Birds

The steep escarpment to the eastern boundary of the reserve provide the sole breeding site for the Westland Black Petrel (*Procellaria westlandica* or Tāiko (Jackson, 1958 as cited in Best and Owen (1974), which is listed as vulnerable on the IUCN Red List of Threatened Species. One of the original project aims was to plant forest below the petrel's flight path to prevent human development disturbing the bird behaviour. Additionally, a comprehensive bird monitoring was undertaken in restoration and mature sites.

Five-minute bird counts were used in four paired restoration sites (R) and forest sites (F) that were >150m apart (Figure 8.1, 8.3). All bird counts were undertaken in the morning (8am to midday) and were only recorded within the specific habitats from the monitoring locations on seven occasions between 2011 and 2016.



Figure 8.1: Bird monitoring locations at the PCR. Green dots are forest sites and the orange dots are the restoration sites

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Native forest birds recorded in restoration sites included: tui, bellbird, grey warbler, kereru (Figure 8.2, 8.4), weka, silver eye and fantail. The mean proportion of native birds mature forest has remained level ( $R^2 = 0.0058$ ) whereas the proportion of native birds has increased in the restoration plots ( $R^2 = 0.4861$ ). This indicates that the trend for native birds is on the increase but the mean value of the native bird proportion is 0.79 and 0.39 for the forest and restoration sites respectively.

The upward trend of native birds in restoration plots is positive but mature reference sites have a mean of 3.2 bird species compared to 1.3 in the restoration plantings. The presence of berry eating bird species (including tui, bellbird, silvereye, kereru and weka) is positive in terms of the ecosystem service of seed dispersal and weka have been observed eating *Coprosma robusta* and *C.*

*grandifolia* berries in restoration site one. Weka droppings have been observed with numerous *Coprosma* seeds and seedlings have successfully established from these (James Washer, pers. comm.). The artificial bird roosts established at the site did not appear to increase the native seed rain and it was assumed that sufficient natural roosting sites in mature sites was sufficient for the demand. Pollination services by native birds are likely to be provided by tui, bellbird and silvereye, all of which were recorded in restoration plantings, although in low numbers.



Figure 8.2: New Zealand wood pigeon (Keruru) is one of key seed dispersers at the PCRP (Photo: Mike Bowie)

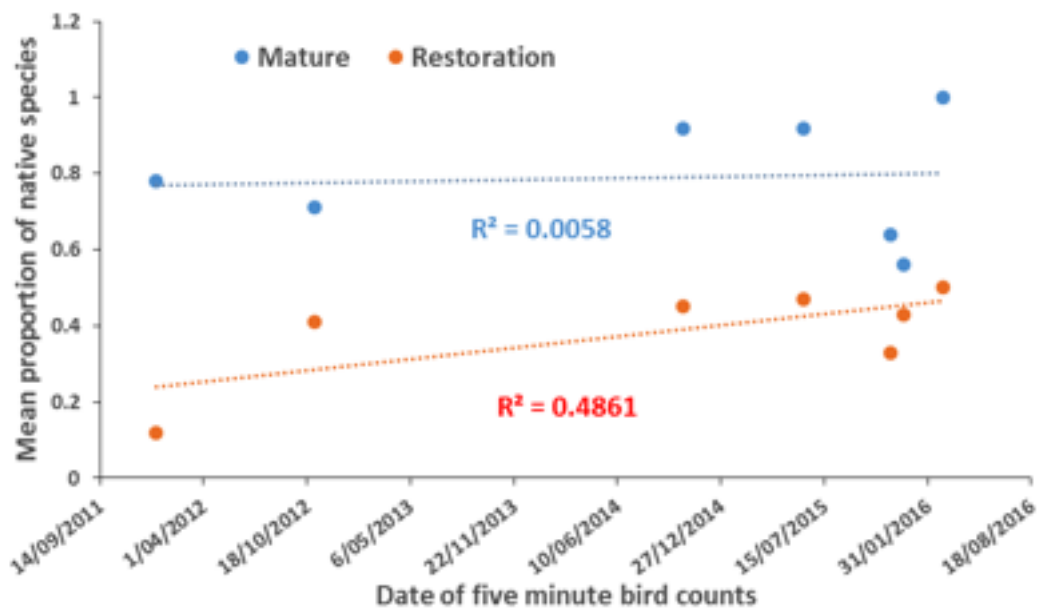


Figure 8.3: The mean proportion of native birds and mature forest and restoration plots



Figure 8.4: Bellbird in a mature plot are important pollinators and seed dispersers at the PCR site (Photo: Mike Bowie)

## 9. Mammalian Pests

Five lines 10 of tracking tunnels were placed at the PCRP site at 50m spacing, three in restoration areas and two in the Nikau Scenic Reserve. Tracking cards were baited with peanut butter and left over one night.

Only rats were found on tracking tunnels in 2016 with considerable less found compared with the 2012 results (Figure 9.1, 9.2). Only one rat track was found in restoration areas in the latest survey and the Nikau Scenic Reserve appears to be the main source of the rats.

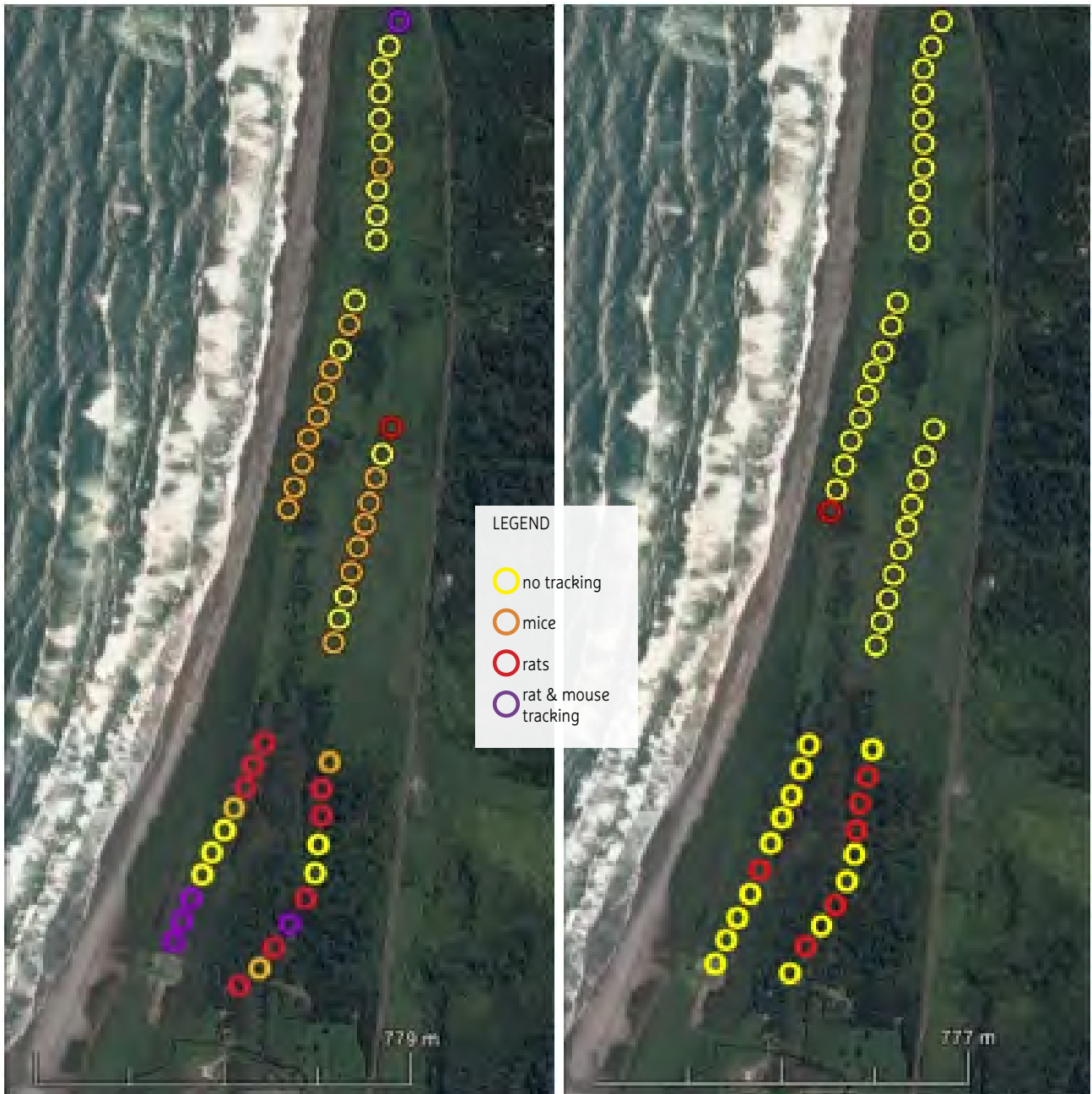


Figure 9.1: Maps showing tracking tunnel results from 2012 (left) and 2016 (right). Yellow = no tracking; Orange = mice; Red = rats; purple = rat & mouse tracking

The decrease in apparent abundance of rats in the recent survey could be the result of a rainy summer period prior to monitoring. Mice in particular are susceptible to rain particularly when their holes become water logged. The presence of mustelids (stoats, weasel and ferrets) could also reduce the rodent numbers and this may require some additional monitoring using egg or meat

bait. Mustelids are a threat to birds including the Westland black petrels further east of the restoration sites so it is important these pests are monitored at least annually to ensure they do not build up in numbers sufficiently to pose a problem.

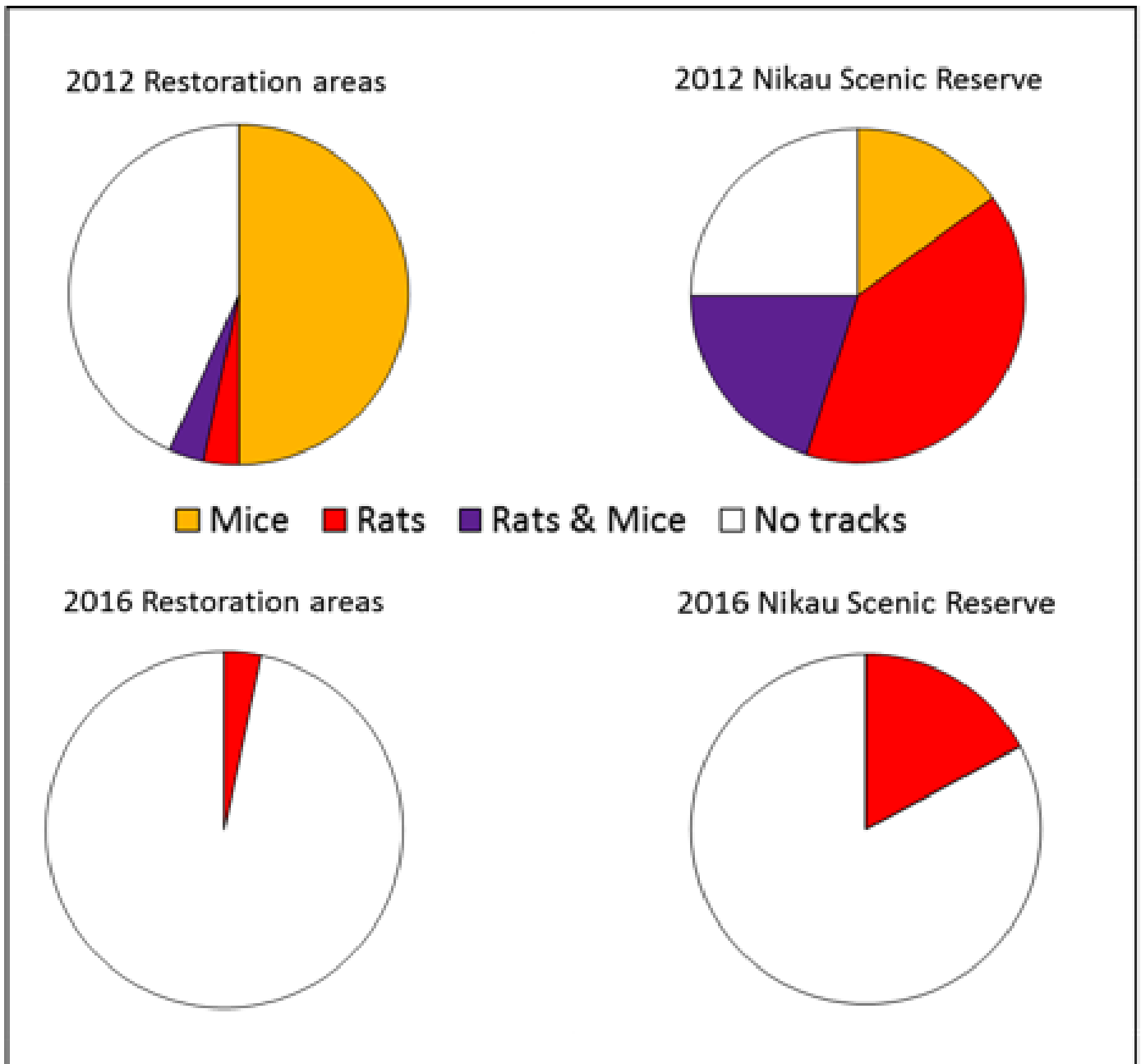


Figure 9.2: Graphs showing tracking tunnel results of rodents at Nikau Scenic Reserve and areas under restoration between 2012 and 2016.

# 10. Ecosystem study: Links and relationships in the PCRP

Information in this section is largely taken from Zhong (2016 submitted): (PhD Thesis: Soil Chemistry and Ecology on a Restoration Trajectory of a Coastal Sandplain Forest, Punakaiki, New Zealand; Hongtao Zhong, submitted). Please refer to this study for more information and references.

## 10.1 Soil Chemistry and Ecology on a Restoration Trajectory of a Coastal Sandplain Forest, Punakaiki, New Zealand

This research was carried out in order to better understand the interactive role of vegetation and soil biogeochemistry on an ecological restoration trajectory on the West Coast of New Zealand. The Punakaiki Coastal Restoration Project (PCRCP) was developed to restore degraded land to a more natural vegetation, resembling the original sandplain forest that has largely disappeared. Ecological restoration at the site in terms of practice and research has mainly focused on plant establishment and faunal colonization. The present study investigated whether restoration of soils is an integral part of this process. The project aimed to understand whether ecological restoration significantly modifies soils and, vice versa, whether physio-chemical variability of soils significantly influences the restoration trajectory. This research is based on a combination of laboratory, glasshouse and field-based study.

Incubation of native plant litters in soil was found to change soil chemical properties, including nitrogen (N) dynamics. It was found that two native species, *Kunzea robusta* and *Olearia paniculata*, may have the potential to ameliorate concerns associated with nitrate leaching and nitrous oxide production. Restored vegetation at the study site modified the dynamics of dissolved organic carbon (DOC) and mobile N in soil solution and increased rates of N mineralization. Interactions between vegetation and soil biota have significantly impacted these changes; changed soil conditions have also altered the composition of soil faunal communities. Study of soil pedogenesis revealed a formerly unknown spatial variability of the soil template. As soils have aged this has been reflected in a loss of soil total phosphorus (P), increase of occluded P and an increasing proportional importance of soil organic P. The dynamics of soil P fractionation on a short-term soil chronosequence across the site provided a better understanding of the response of soil biogeochemistry to the trajectory of ecological restoration on old and young soils. Key parameters were shown to be soil pH, organic matter, organic P and the variability of different P fractions.

Detailed comparison of remnants of New Zealand Flax and Nikau

Palm, and abandoned agricultural grassland provided an opportunity to investigate the effects of these different types of vegetation on soil development. Multiple variables were found to be significant, including differences in plant physiology, soil organisms, hydrological gradient of an alluvial fan, and guano deposition, all of which modified soil P fractionation and secondary iron/aluminium (Fe/Al) minerals. In a glasshouse experiment, soil dehydrogenase activity and biologically based P (CaCl<sub>2</sub>-P, citrate-P and HCl-P) were significantly increased through interactions of earthworms and guano; the dynamic of soil P was modified by additional interactions with flax plants.

The relationships between soil chemistry, biodiversity and plants on the restoration trajectory at PCRP were synthesized using multivariate analysis. A conceptual model was developed, elucidating changes of soil physico-chemistry on the restoration trajectory. Success of the PCRP restoration and establishment of flora and fauna are strongly influenced by soil variability, but the developing plant communities also substantially modify soil physico-chemistry. The study illustrates that a preliminary investigation of site-specific soils should be an essential part of restoration practice.

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## 10.2 Synthesis of the Findings [Chapter 8, Zhong (2016 submitted)]

### 10.2.1 Introduction

This chapter aims to investigate the relationships between soil chemistry, biodiversity and plants on the restoration trajectory at PCRP. Soil development is a complex process that is controlled by factors of time, parent materials, climate, topography, and biota. Plants, soil animals and microorganisms contribute to soil development, modifying and mediating the soil environment and soil quality, but the interactive influence of these biota remains poorly understood. A soil-centric concept suggests that soil biogeochemistry supports and determines the biodiversity of vegetation, and belowground faunal and microbial communities. In this thesis, I have attempted to also consider the opposite – how biota modify the soil.

Restoration of degraded ecosystems aims to restore vegetation cover, and the ecosystem functions and services that soils support. It follows that the restored vegetation significantly contributes to the recovery of soil functionality. The development of vegetation not only provides physical protection of soils from

surface runoff and erosion, but also starts the nutrients cycling, via plant litter accumulation and decomposition, as well as plant rhizosphere processes, that initiates recovery of ecosystem functions; at the same time increased size and diversity of soil faunal and microbes can accelerate this cycling process (average 27%).

Therefore, it is hypothesized in the present study that some degrees of soil and ecosystem properties have been recovered on the restoration trajectory. Restoration of native plants was initiated in the middle of 2009 in the Punakaiki Coastal Restoration Project (PCRCP). Successful establishment of restored vegetation was evident in the recent few years (Figure 5.7, 5.8), and accumulation of plant litter was evident (Figure 10.1). Along the progressive development of native vegetation cover, both soil chemistry and biodiversity have been modified to some extent from conditions in the unplanted grassland towards the reference mature forest.



Figure 10.1: Leaf litter accumulating within the oldest restoration plot, R1 (photo by James Washer, 2013)



## 10.2.2 Materials and methods

Data sets from monitoring work at the PCRP sites were collated using soil data (collected by J. Hahner, C. Smith and the author) supplemented by monitoring data from several other studies over the study period. A glossary of plant species can be found in Table 13.2, Appendix. Soil Li, Ni, Cr, As, Cu and Pb concentrations from the data set were not included in the analysis, because they have relatively low ecological relevance. Soil data were then split into Ah and Bw horizons. Invertebrate data were more variable due to the difficulty of identification to species levels and in obtaining comparable quantitative data. This is slightly problematic as the data set contained some species level data (e.g. *Dolomedes minor*) and some “group” data (e.g. snails, native earthworms). Soil mite data were grouped into Recognisable Taxonomic Units (RTU)

The data set were analysed by Hannah Franklin using the Principal Components Analysis (PCA) and Detrended Correspondence Analysis (DCA) separately. Both PCA and DCA are unconstrained ordination methods to extract gradients of maximum variation of data. However, when analysing heterogeneous ecological data that contain many zeros, PCA may produce so called “horse shoe” artefact, which does not differentiate dissimilar ends of the gradient in matrix. In comparison, DCA is based on a unimodal model of species distributions, which is close to the theory of community ecology; at the same time DCA removes the autoregressive conditional heteroscedastic (ARCH) effect via detrending.

PCA was conducted on the Ah soil data each site, using the Euclidian distance function on standardised data (scaled and centred). Ordination of soil data was conducted by Non-Metric Multidimensional Scaling (NMDS). The DCA was conducted on standardized data (standardized by the maximum to account for the presence of zeros in the data). The difference between each point in the resultant space was then compared to see how different or similar two ordinations were. Analyses were conducted using R, Version 3.0.1 (R Development Core Team, 2010, R Foundation for Statistical Computing, Vienna, Austria, <http://www.r-project.org/>).

In this chapter, these multivariate data analyses are interpreted in the context of the results as presented from the present study (in Chapter 4 and 5). A conceptual model is developed for the restoration trajectory.

## 10.2.3 Synthesis

Correlations of soil chemistry between Ah and Bw soil horizons at PCRP showed that soil pH was positively correlated; as were soil base cations (K, Na, and Mg) (Figure 10.2). The PCRP site is highly influenced by marine spray, which brings significant amounts of base cations into this coastal sandplain forest ecosystem. At the same time, under the super-humid climate, the well-drainage sandy soils at the present study site tend to face continuous losses of weathered cations downwards. However, this correlation could be biased because PCRP soils are rather complex with three different stages of vegetation cover (Mature, Resorted and Unplanted plots), and three major soil types developed from sand dunes, alluvial fans over sand plain, and peatland. In addition, soil chronosequence was presented at PCRP (particularly Transect 1 and 3).

The PCA results showed that the first three principal component (PC) axes explained 80% of the ordination in soil data, with the PC1 accounted 46% and PC2 and PC3 explaining 18% and 15% respectively (data not shown). PC1

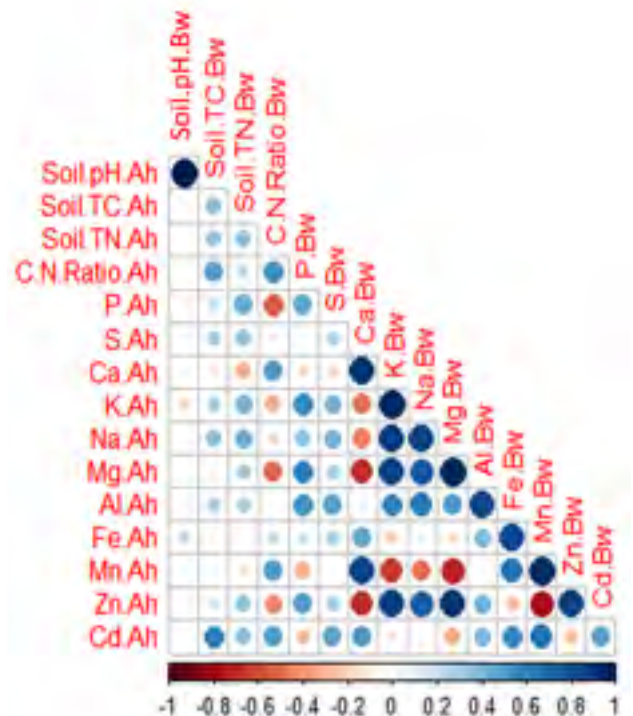


Figure 10.2: Correlation heat-plot comparison soil Ah and Bw horizons. The increasing degree of blue coloration indicates stronger positive correlation, and vice versa red coloration means negative correlation (Zhong, 2016 submitted).

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was weighted most strongly by Ca and Mn in the positive direction, and Zn, Na and P in the negative direction; PC2 was weighted most strongly by Al in the positive direction, and Total C (TC), Total N (TN) and C:N ratio in the negative direction (Figure 10.3, a). Mature sites are the most spread in ordination space, in particular M3 locates in the bottom-left corner with significantly higher soil organic C contents (evident in Chapter 5). Restored and Unplanted sites were a little confused, but they clumped between the mature sites. Overall, soils are relatively spread among the three stages of vegetation types.

The potential restoration trajectory were not quite well-presented, apart from Transect 4 and 7 locate at the northern end of PCRP site, which soils developed at alluvial fan over sand plain. The restoration trajectory in Transect 4 and 7 presented that soils have been restored away from the “unplanted” and towards the direction of mature soils. It may be promising that these soils will be more different in terms of soil chemistry and be further away from their unplanted counterparts with longer restoration times. However, this was not shown in older restored Transect 1 and 2, and with Transect 3 and 6 moving toward opposite direction. Possibly due to high heterogeneity of soil across the PCRP site and short-term frame since restoration planting, the lack of patterns is not unexpected.

By further incorporating ecological data (plant species and invertebrate) into Detrended Correspondence Analysis (DCA), potential relationship between plant composition and soil chemistry variables were investigated via vector fitting in mature plots. Site M3 was more dissimilar than others in terms of plant composition and related soil chemistry (Figure 8.4). M3 has more PSE.cra (*Pseudopanax crassifolius*), MYR.aus (*Myrsine australis*), SOP.mic (*Sophora microphylla*), GRI.luc (*Griselinia lucida*) and DAC.cup (*Dacrycarpus cupressinum*); and this might be related to higher soil TC, TN, S, Na and Zn contents in M3 soils. M4 and M7 are close together in terms of DAC.dac (*Dacrycarpus dacrydioides*), as well as soil K contents. The *Cyathea* spp. and *Dicksonia squarrosa* pulled in opposite directions on the DCA axis two; so that M2 has most *Cyathea* spp. and M5 has most *D. squarrosa*. And, this might be related to soil pH and C:N ratio between M2 and M5. Previous studies have indicated that plant composition could be influenced by the distribution of soil resources. This potential relationship was not investigated in Restoration plots, given the fact that native species for re-planting were selected based on empirical experiences of site manager.

Assuming that any movement of invertebrate should be random, vector fitting was also conducted with the soil variables to investigate any relationships with the distribution of the invertebrate in Mature, Restoration and Unplanted plots (Figure 10.5). The invertebrate communities were much more similar among Mature plots dominated by native earthworms (e.g. Megascolecidae sp.1 and *Deinodrilus gorgon*), mites (e.g. Oribatida, Trombididae, and Uropodina), weevils (Curculionidae) and cockroaches (*Celatoblatta vulgaris*), and this could be

related to soil C:N ratio. In contrast, Restoration and Unplanted plots have more exotic earthworms (e.g. *Lumbricus rubellus*), snails (*Oxychilus* spp.) and spiders (*Dolomedes minor*), which might be related to soil pH and clay minerals (Fe and Ca). The grey dashed arrows, which are the simulative movement trajectory of the invertebrate community, indicated that R1, R2, R3 and R7 had invertebrate communities shifting away from their corresponding “Unplanted state” to be more similar to the reference mature sites. R4 has shifted relatively little, while R5 and R6 shifted in a similar direction but is not towards the mature sites. In comparison with PCA results, the restoration trajectory of soils were relatively more promising as reference Mature soils were all clumped, meaning that most of restored soils could move towards to them, except for Transect 5. This potential relationships between soil chemistry and fauna communities has been suggested previously.

To further investigate any potential relationships between the distribution of invertebrate with plant composition, vector fitting was conducted on Mature and Restoration plots (no plant data available for the unplanted grassland), although restored plantings were not random. Patterns in invertebrate distribution among sites were similar when unplanted sites were removed. (Figure 10.6). Plant species of *Metrosideros robusta*, *Coprosma grandifolia*, *Griselinia lucida*, *Dicksonia squarrosa* and *Meliclytus ramiflorus* were more associated with native earthworms, mites, weevils and cockroaches in mature sites. However, *Coprosma* spp., in particular existing exotic mixture grasses, might relate to the distribution of snails and exotic earthworms. Previous studies had investigated the influences of soil biota on the vegetation changes alongside ecological succession. In addition, Harris (2009) also suggested that changes of soil microbial communities had important role in recovering the ecosystem functions in ecological restoration, in terms of nutrient cycling, structural formation and plant interactions.

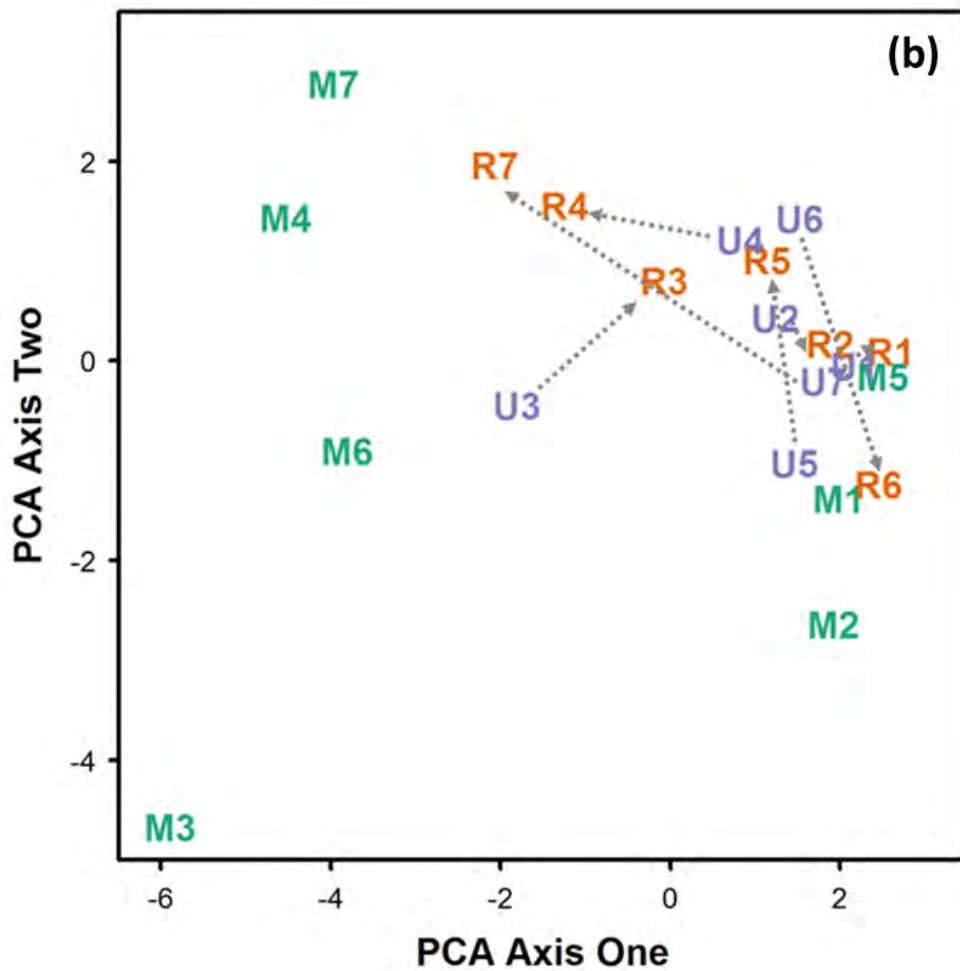
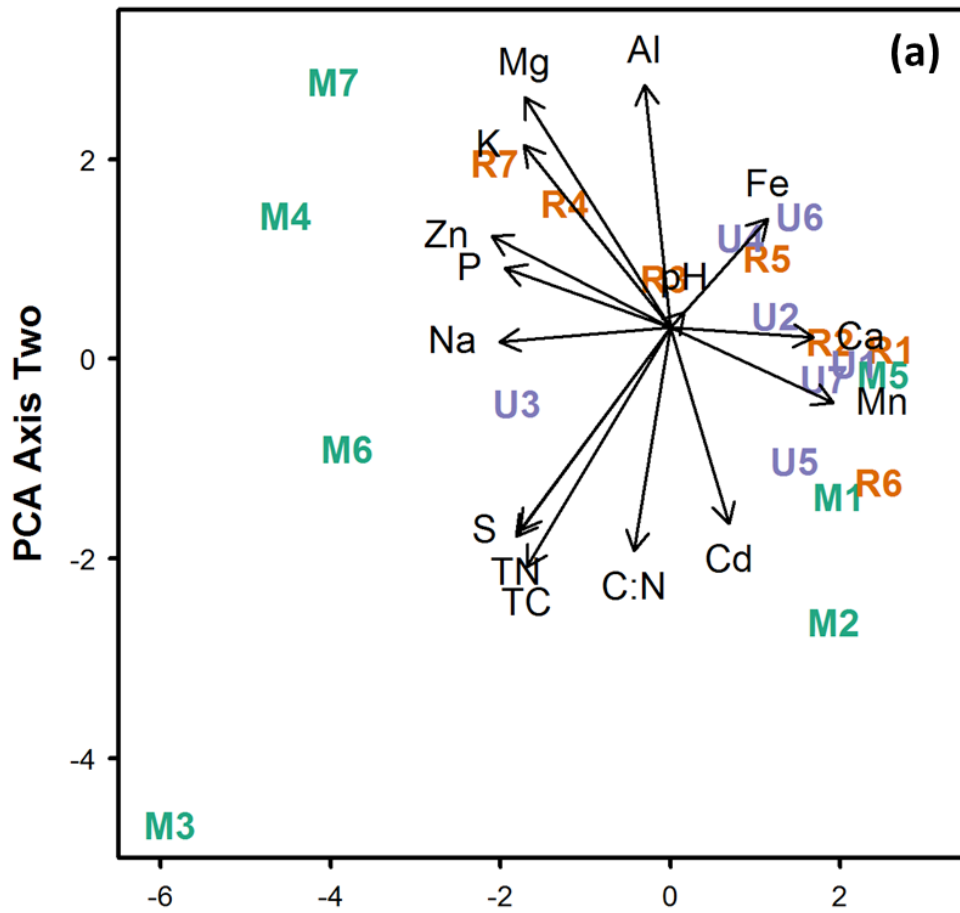


Figure 10.3: PCA ordination of Ah soil chemistry with bi-plot arrows showing the axes loadings (a), and (b) the relative spread of Mature, Restored and Unplanted sites. Dashed arrows indicate the potential trajectory of restored soil away from the "unplanted state" (Zhong, 2016 submitted).

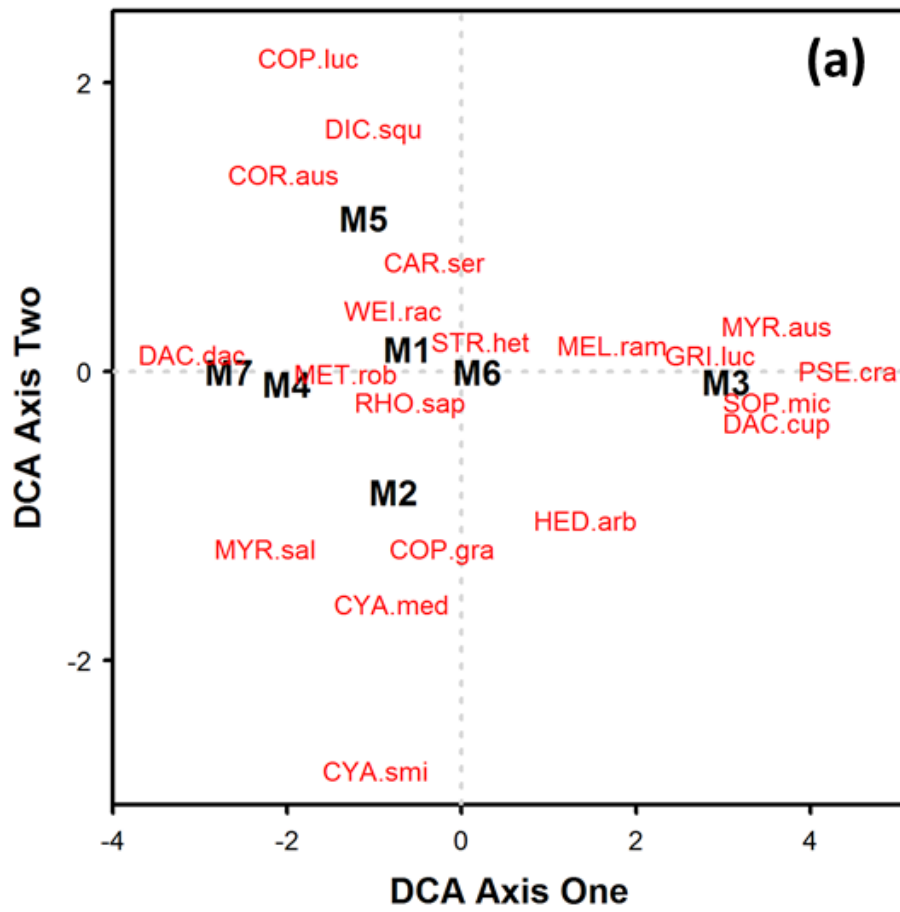
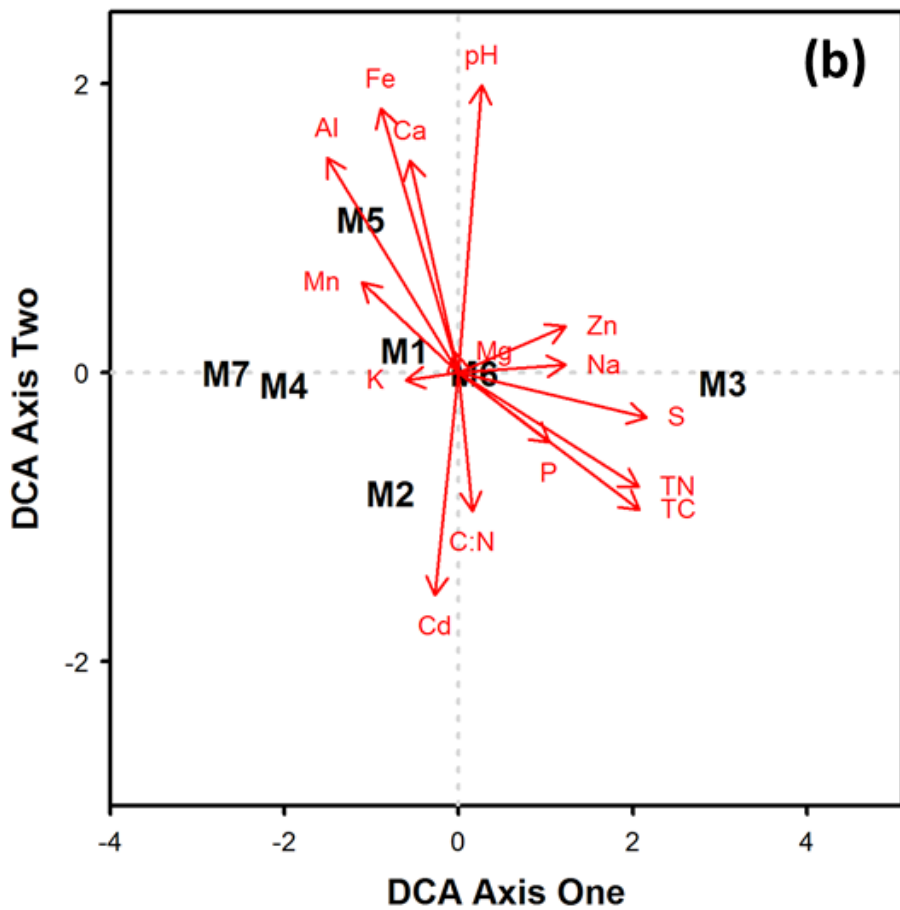


Figure 10.4: DCA of plant data at the Mature sites (a) showing the plant species scores, and (b) showing the results of vector fitting of the soil data to the plant DCA ordination (Zhong, 2016 submitted).



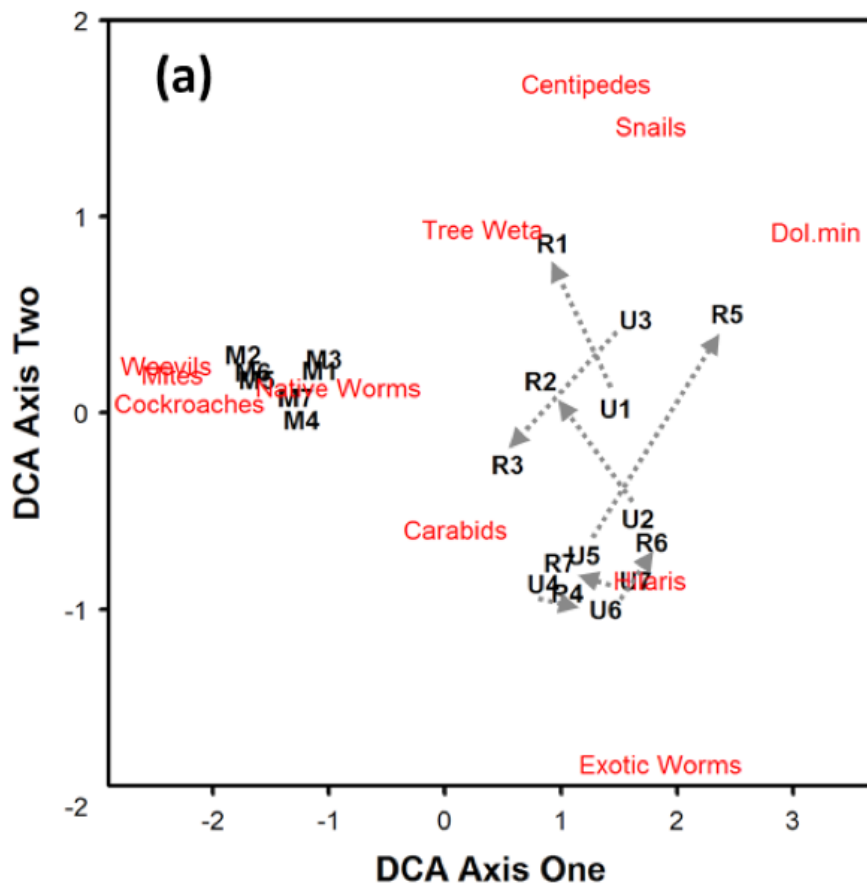
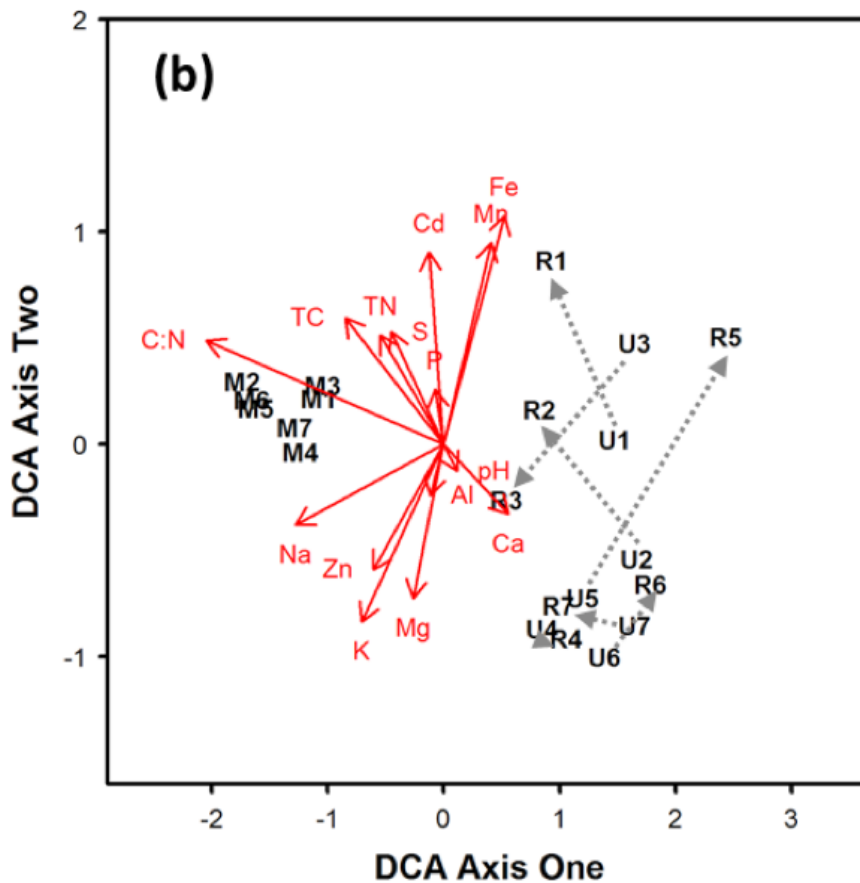


Figure 10.5: DCA of invertebrate data at the Mature, Restored and Unplanted sites (a) showing the invertebrate scores, and (b) showing the results of vector fitting of the soil data to the invertebrate DCA ordination. Dashed arrows indicate the potential trajectory of restored state away from the "unplanted state" (Zhong, 2016 submitted).



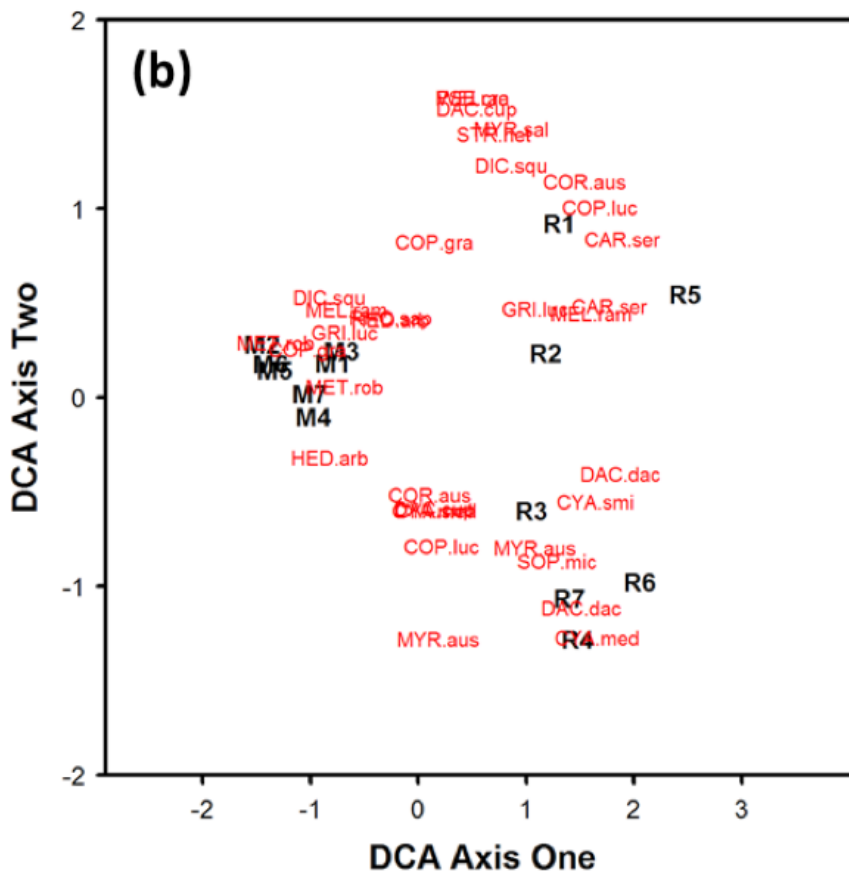
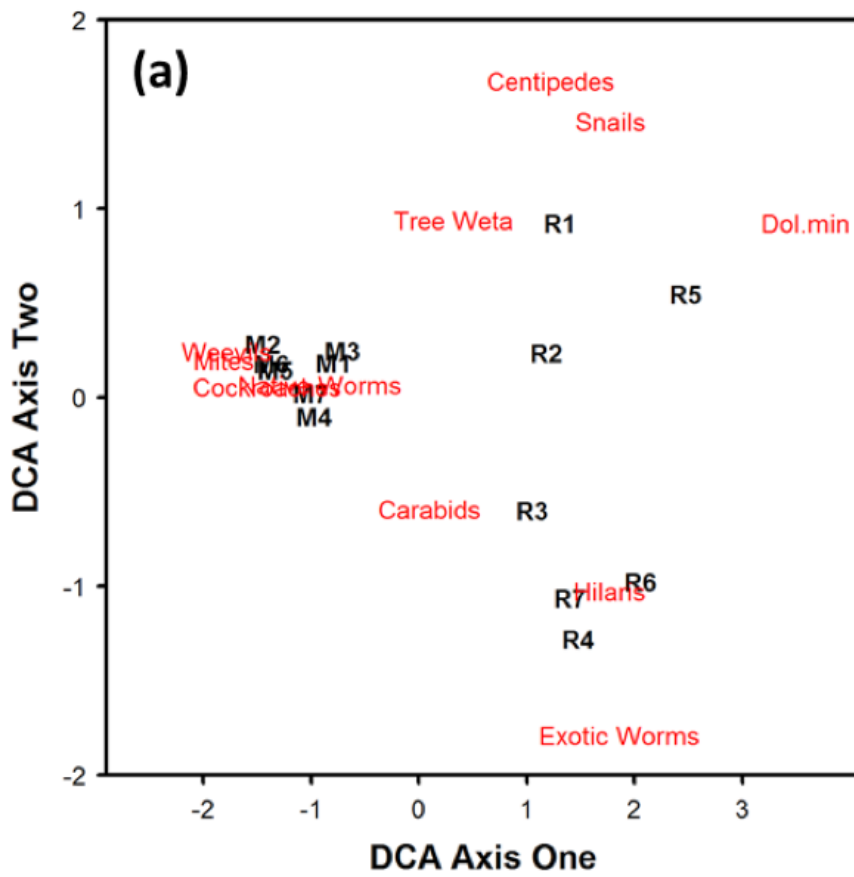


Figure 10.6: DCA of invertebrate data at the Mature, and Restored sites (a) showing the invertebrate scores, and (b) showing the results of vector fitting of the plant species to the invertebrate DCA ordination (Zhong, 2016 submitted).

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The conceptual model showed that has been developed propose the following trends occur with the progression of the ecological restoration (Figure 10.7):

- i. Native earthworms, as key soil invertebrate, started to re-colonize the restoration soils as native plants become established, living alongside exotic earthworms that were in the grassland former; the number of native earthworms are likely to continue to increase and eventually colonize the developing native forest.
- ii. Leaf litter started to accumulate and decompose in the restored sites, which lowered the soil pH to some extent and brought about a gradual increase of soil organic matter and decomposer communities;
- iii. Fast-growing plants in the restoration plots have promoted nutrient cycling mainly via increased soil microbial activity (as reflected in soil microbial biomass carbon and phosphorus) and demand for nutrients;
- iv. In terms of nitrogen mineralization and dissolved organic carbon, the increased rate of nutrient cycling is likely to slow down and plateau alongside ecosystem development in the longer term.
- v. Interactions between soil nutrients, plants (litter and rhizosphere) and soil biota (e.g. earthworms and microbes) make a significant contribution to the promotion of nutrient cycling and ecosystem development.
- vi. Soil Organic P, Microbial P and Occluded P increased as restored ecosystem developed along with promotion of soil weathering and competition between soil organisms and weathered minerals;
- vii. Total soil P, Primary Mineral P and Secondary Mineral P decrease in the restoration stands and this is likely to continue in the longer term; these losses could be more intense in the super-humid climate and with the high leaching potential of sandy soils at Punakaiki;
- viii. Ecosystem nutrient status will develop from N-limiting to P-limiting if no major disturbances occur, but external nutrient inputs from seabird guano could potentially mitigate or delay reaching a 'terminal steady state' and an associated reduction of forest standing biomass and productivity.

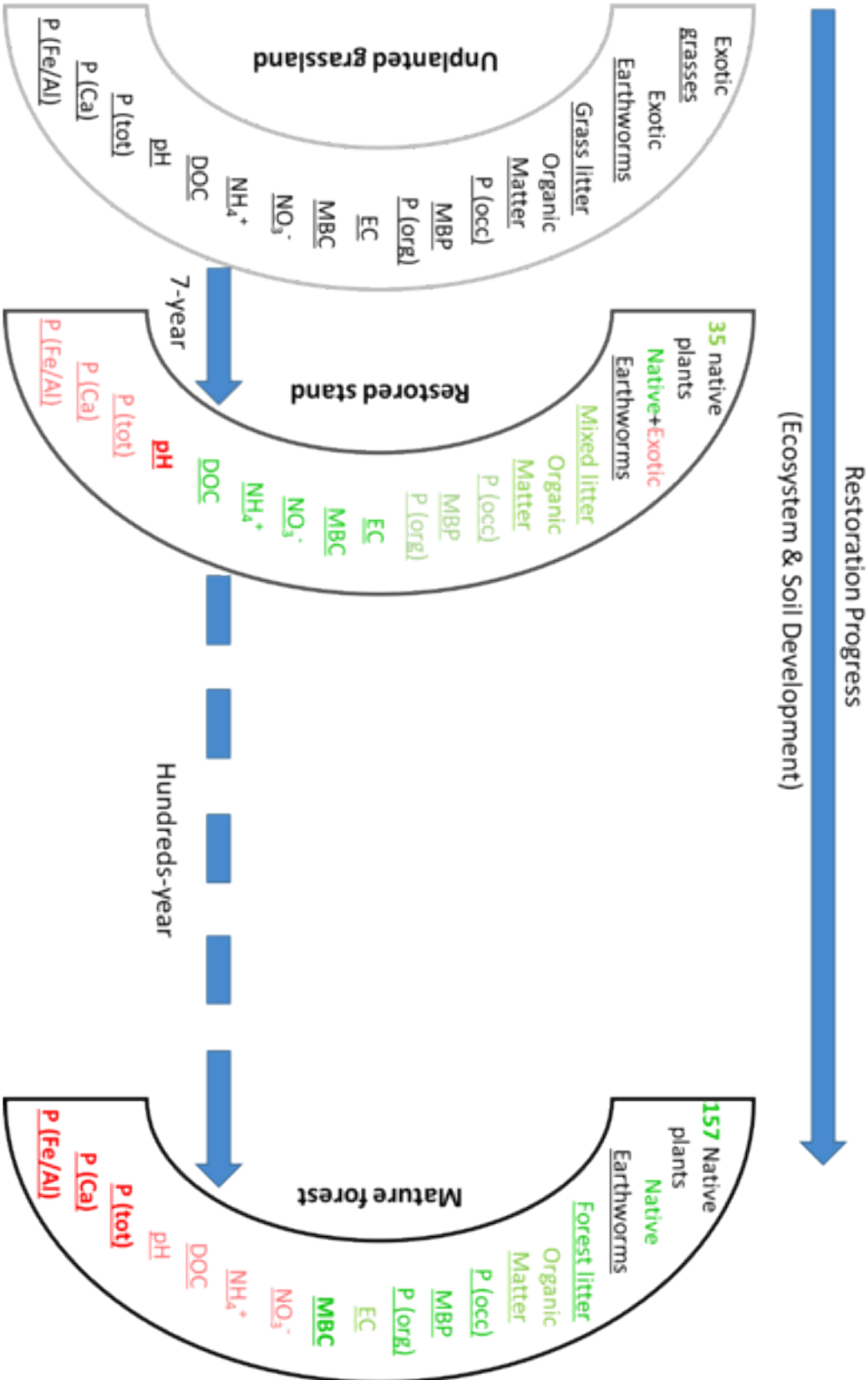


Figure 10.7: Conceptual model of changes of soil biogeochemistry on the restoration trajectory from the unplanted grassland to Restoration stand to reference Mature forest at PCR. Coloration is refer to increases and decreases in the stock market; green indicate increases while red indicate decreases; the brighter and bolded parameters mean more increases or decreases (Zhong, 2016 submitted).





Figure 10.8: Orchid (*Earina mucronata*) in Nikau Scenic Reserve at the PCR site (Photo: Mike Bowie)

# 11. Future perspectives of the PCRP

## 11.1 The Punakaiki living lab

By aiming to restore the sandplain forest, the vision of the PCRP is to protect and enhance the unique ecological values of the Punakaiki area. This will ensure a sustainable future for not only the Te Ara Taiko Nature Reserve, adjacent conservation lands but more importantly, a sustainable future for the immediate vicinity. This approach incorporates an implicit belief in the collaborative value of research, innovation, education and community/ stakeholder engagement.

A sustainable future for the PCRP site based on tourism, education and research is underpinned by the environmental and ecological values of the site. These values are informed by the research programme, so monitoring of the ecological restoration is an integral part of both the master plan living lab concept, and of the overarching vision.

The Living Lab is the proposed approach to offer a framework for just such a sustainable future. This initiative by Mick Abbott and colleagues in SOLA at Lincoln University, has incorporated concepts and outputs from the scientific research programme. A brief overview of the Punakaiki Living Lab follows, and in Section 13.3.

The Punakaiki Living Lab offers a new set of National Park –type experiences, where instead of just walking and sightseeing, opportunities for seed-raising, planting, species monitoring, pest - control, citizen science and volunteering are offered. This project will initiate a shift from the current ‘take only pictures, leave only footprints’ policy of National Parks toward a ‘hands on’ engagement of local communities and visitors in the conservation of NZ environment. Through these participative experiences, visitors will leave a positive mark on the natural environment and take home not only pictures, but also knowledge, skills and ownership.

The initial development of the Living Lab will focus on the western side of the site - creating a series of linked [staged] walkways and boardwalks that will provide visitors with a range of recreational and educational opportunities. The walkways will showcase the restoration activities and processes as well as leading people into one of the few remaining areas of sand-plain forest on the West Coast. Interpretation material on the site will be innovative and world-class-setting a new standard for natural area interpretation within National Park ‘gateways’.

The second phase of the development of the Living Lab initiative will see the development of a Visitor Centre - this will utilise the existing building and provide a range of amenities - and of course - information on the activities and opportunities provided within the Living Lab experience. The current site nursery which grows all the plants for the on-going restoration work will be expanded and re-modelled to allow and encourage easy interaction with visitors. Here we can tell another ‘story’ -that of the life-cycle of plants –in

particular, those naturally occurring on the site.

A key objective of the second phase is to engage visitors upon arrival—to provide visual, sensory and physical opportunities for interaction and connection with the site commencing upon arrival. Importantly from both an experiential and public safety perspective, visitors will park on this side and will gain access to the western side via a tunnel. [not over-bridge as pictured] This will provide a unique interpretive opportunity-telling the important story of soil development and soil-ecosystems.

The site nursery currently provides all the plant stock for the on-going restoration process-providing skill-based learning opportunities for volunteers and students alike. The Living Lab will enhance both the nursery itself-and the educational opportunities provided through allowing more open access and engagement with the nursery components. Visitors will be drawn through the area on arrival - immediately being engaged with the restoration processes. The nursery layout will be designed to allow for simple interpretive experiences including plant identification, and key species. Plants will be available to purchase - to take away or to support the restoration process - the latter particularly aimed at travellers who may wish to ‘off-set; their carbon footprint. For the more ‘hands-on visitor, they will be able to both purchase and plant - and then use an app to photograph and ‘track’ their trees. A detailed design and description of the Punakaiki living lab is attached separately.

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## 11.2 Conclusion

The overarching vision of the PCRP partnership agreement is to restore the sand plain forest, in order to protect and enhance the unique ecological values of the Punakaiki area. By doing so, this will build a sustainable future for not only the biophysical landscape of the Te Ara Taiko Nature Reserve and adjacent conservation lands, but also the wider Punakaiki community through a collaborate approach to research, innovation, education and community/stakeholder engagement.

The research programme undertaken at Lincoln University has included specific objectives. Devising best practice templates and the establishment of critical species assemblages in the restoration trajectory; understanding the relationships between biotic assemblages, soil rhizosphere chemistry and soil chronosequences in the restoration trajectory; and lastly to quantify the benefits of nature conservation, biodiversity and ecosystem services in this unique coastal sand plain forest matrix.

This body of work has informed the development of a proposed framework for a Master Plan- the “Punakaiki Living Lab”, which aims to foster an innovative “hands on” engagement with conservation. The first phase provides for this through creating a physical infrastructure which guides visitors through the site; providing active engagement with recreational and educational opportunities at different intensities of participation. The second phase includes the development of a visitor centre – which aims to facilitate the educational and community/stakeholder engagement.

There are several key recommendations for future research at the PCRP. Maintaining the site as a location for scientific research and for a long-term monitoring programme will inform and aid in the necessary quality assurance for the ongoing restoration programme. Such a monitoring programme would be unique in New Zealand, as the PCRP is possibly the most intensively studied restoration site in the country. Of equal importance is the opportunity to create/realise the “Punakaiki Living Lab” and by doing so, to deliver the detailed design to meet the specific requirements of the development. This is a truly innovative project and will provide the opportunity to showcase conservation/ citizen engagement developments in protected areas to a wider audience, both in Australasia and to world forums.

# 12. References

- Andresen E., Levey D.J. (2004) Effects of dung and seed size on secondary dispersal, seed predation, and seedling establishment of rain forest trees. *Oecologia* 139:45-54. DOI: 10.1007/s00442-003-1480-4.
- Barrett G. (1994) *Restoration Ecology: Lessons Yet to Be Learned*, in: A. D. Baldwin, et al. (Eds.), *Beyond Preservation: Restoring and Inventing Landscapes*, University of Minnesota Press, Minneapolis pp. 112-126.
- Bellingham P.J., Stewart G.H., Allen R.B. (1999) Tree species richness and turnover throughout New Zealand forests. *Journal of Vegetation Science* 10:825-832. DOI: 10.2307/3237307.
- Best H.A., Owen K.L. (1974) *Distribution of breeding sites of the Westland Black Petrel (Procellaria westlandica)*, Fauna Survey Unit Report No. 3 New Zealand Wildlife Service, Wellington. pp. 14pp.
- Bicknell J.E., Phelps S.P., Davies R.G., Mann D.J., Struebig M.J., Davies Z.G. (2014) Dung beetles as indicators for rapid impact assessments: Evaluating best practice forestry in the neotropics. *Ecological Indicators* 43:154-161. DOI: http://dx.doi.org/10.1016/j.ecolind.2014.02.030.
- Boffa Miskell. (2007), *Grey District Significant Natural Area Assessment Report prepared for the Grey District Council*.
- Bowie M., Mountier C., Boyer S., Dickinson N. (2012) *Baseline survey for the Punakaiki Restoration Project (50)*, Lincoln University, Christchurch.
- Bowie M.H., Frampton C.M. (2004) A practical technique for non-destructive monitoring of soil surface invertebrates for ecological restoration programmes. *Ecological Management & Restoration* 5:34-42. DOI: 10.1111/j.1442-8903.2004.00171.x.
- Bowie M.H., Hodge S., Banks J.C., Vink C.J. (2006) An appraisal of simple tree-mounted shelters for non-lethal monitoring of weta (Orthoptera: Anostostomatidae and Rhaphidophoridae) in New Zealand nature reserves. *Journal of Insect Conservation* 10:261-268. DOI: 10.1007/s10841-005-5594-3.
- Bowie M.H., Allen W.J., McCaw J., van Heugten R. (2014) Factors influencing occupancy of modified artificial refuges for monitoring the range-restricted Banks Peninsula tree weta *Hemideina ricta* (Anostostomatidae). *New Zealand Journal of Ecology* 38:132-138.
- Bowie M.H., Black L., Boyer S., Dickinson N.M., Hodge S. (2016) Persistence of biodiversity in a dryland remnant within an intensified dairy farm landscape. *New Zealand Journal of Ecology* 40:121-130.
- Braun-Blanquet J. (1932) *Plant Sociology - The study of plant communities* McGraw-Hill book company, inc., New York and London.
- Brown J., Scholtz C.H., Janeau J.-L., Grellier S., Podwojewski P. (2010) Dung beetles (Coleoptera: Scarabaeidae) can improve soil hydrological properties. *Applied Soil Ecology* 46:9-16. DOI: http://dx.doi.org/10.1016/j.apsoil.2010.05.010.
- Bullock J., Aronson J., Newton A., Pywell R., Rey-Benayas J. (2011) Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends in Ecology & Evolution* 26:541-549.
- Burns K.C. (2006) Weta and the evolution of fleshy fruits in New Zealand. *New Zealand Journal of Ecology* 30:405-406.
- Clout M.N., Hay J.R. (1989) The importance of birds as browsers, pollinators and seed dispersers in New Zealand forests. *New Zealand Journal of Ecology*, 12:27-33.
- Craig J., Anderson S., Clout M., Creese B., Mitchell N., Ogden J., Roberts M., Ussher G. (2000) *Conservation Issues in New Zealand*. Annual Review of Ecology and Systematics 31:61-78. DOI: doi:10.1146/annurev.ecolsys.31.1.61.
- de Bello F., Lavorel S., Díaz S., Harrington R., Cornelissen J.H.C., Bardgett R.D., Berg M.P., Cipriotti P., Feld C.K., Hering D., Martins da Silva P., Potts S.G., Sandin L., Sousa J.P., Storkey J., Wardle D.A., Harrison P.A. (2010) Towards an assessment of multiple ecosystem processes and services via functional traits. *Biodiversity and Conservation* 19:2873-2893. DOI: 10.1007/s10531-010-9850-9.
- Derhé M.A., Murphy H., Monteith G., Menéndez R. (2016) Measuring the success of reforestation for restoring biodiversity and ecosystem functioning. *Journal of Applied Ecology*:n/a-n/a. DOI: 10.1111/1365-2664.12728.
- DeVelice R.L., DeVelice J.W., Park G.N. (1988) *Gradient Analysis in Nature Reserve Design: A New Zealand Example*. *Conservation Biology* 2:206-217. DOI: 10.2307/2386106.
- Dominguez-Haydar Y., Armbrrecht I. (2011) Response of Ants and Their Seed Removal in Rehabilitation Areas and Forests at El Cerrejón Coal Mine in Colombia. *Restoration Ecology* 19:178-184. DOI: 10.1111/j.1526-100X.2010.00735.x.
- Don G. (1986) *Barrytown Flat Baseline Biological Survey, prepared for Grampian Mining Company by Bioresarches Limited*, Auckland, New Zealand.
- Duthie C., Gibbs G., Burns K.C. (2006) Seed dispersal by weta. *Science* 311:1575. DOI: 10.1126/science.1123544.
- Fox R. (2013) The decline of moths in Great Britain: a review of possible causes. *Insect Conservation and Diversity* 6:5-19. DOI: 10.1111/j.1752-4598.2012.00186.x.
- Fox R., Randle Z., Hill L., Anders S., Wiffen L., Parsons M.S. (2011) Moths count: recording moths for conservation in the UK. *Journal of Insect Conservation* 15:55-68. DOI: 10.1007/s10841-010-9309-z.
- Gibbs G.W. (2001) Habits and biogeography of New Zealand's Deinacridine and tusked weta species, in: L. H. Field (Ed.), *The biology of wetas, king crickets and their allies*, CAB International Publishing. pp. 35-55.
- Gollan J.R., de Bruyn L.L., Reid N., Wilkie L. (2013) Monitoring the ecosystem service provided by dung beetles offers benefits over commonly used biodiversity metrics and a traditional trapping method. *Journal for Nature Conservation* 21:183-188. DOI: http://dx.doi.org/10.1016/j.jnc.2012.12.004.
- Graeme A. (2011) *Flying under the radar*, Forest & Bird. pp. 54-55.
- Grant C.D., Ward S.C., Morley S.C. (2007) Return of Ecosystem Function to Restored Bauxite Mines in Western Australia. *Restoration Ecology* 15:S94-S103. DOI: 10.1111/j.1526-100X.2007.00297.x.
- Grime J.P. (2006) *Plant strategies, Vegetation Processes, and Ecosystem Properties* John Wiley & Sons, LTD., West Sussex, England.
- Hahner J.L., Bowie M. (2013) *Development and Testing Indicators of Restoration Success: Punakaiki Coastal Restoration Project (52)*, Lincoln University, Christchurch.
- Harris J.A., Hobbs R.J., Higgs E., Aronson J. (2006) *Ecological Restoration and Global Climate Change* *Restoration Ecology* 14:170-176.
- Hobbs R.J., Norton D.A. (1996) Towards a Conceptual Framework for Restoration Ecology. *Restoration Ecology* 4:93-110.
- Holdaway R.J., Wiser S.K., Williams P.A. (2012) *Status Assessment of New Zealand's Naturally Uncommon Ecosystems*
- Evaluación del Estatus de Ecosistemas Naturalmente Poco Comunes en Nueva Zelanda. *Conservation Biology* 26:619-629. DOI: 10.1111/j.1523-1739.2012.01868.x.
- Holl K.D., Aide T.M. (2011) When and where to actively restore ecosystems? *Forest Ecology and Management* 261:1558-1563. DOI: http://dx.doi.org/10.1016/j.foreco.2010.07.004.
- Jones A.G., Forgie S.A., Scott D.J., Beggs J.R. (2012) Generalist dung attraction response in a New Zealand dung beetle that evolved with an absence of mammalian herbivores. *Ecological Entomology* 37:124-133. DOI: 10.1111/j.1365-2311.2012.01344.x.
- Kanowski J., Catterall C. (2007) *Monitoring Revegetation Projects for Biodiversity in Rainforest Landscapes*. Toolkit Version 1, Revision 1. Marine and Tropical Sciences Research Facility, Cairns 52 pp.
- Kim Y. (2016) *Interactions between Soil Biogeochemistry and Native Earthworms in New Zealand*, Ecology, Lincoln University.
- Lamb D., Erskine P.D., Parrotta J.A. (2005) Restoration of degraded tropical forest landscapes. *Science* 310:1628-32. DOI: 10.1126/science.1111773.
- Lomov B., Keith D.A., Britton D.R., Hochuli D.F. (2006) Are butterflies and moths useful indicators for restoration monitoring? A pilot study in Sydney's Cumberland Plain Woodland. *Ecological Management & Restoration* 7:204-210. DOI: 10.1111/j.1442-8903.2006.00310.x.
- Majer J.D., Brennan K.E.C., Moir M.L. (2007) *Invertebrates and the Restoration of a Forest Ecosystem: 30 Years of Research following Bauxite Mining in Western Australia*. *Restoration Ecology* 15:S104-S115. DOI: 10.1111/j.1526-100X.2007.00298.x.
- McGeogh M.A. (1998) The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* 73:181-201. DOI: 10.1111/j.1469-185X.1997.tb00029.x.
- Merckx T., Slade E.M. (2014) Macro-moth families differ in their attraction to light: implications for light-trap monitoring programmes. *Insect Conservation and Diversity* 7:453-461. DOI: 10.1111/icad.12068.
- Moir M., Brennan K., Koch J., Majer J., Fletcher M. (2005) Restoration of a forest ecosystem: the effects of vegetation and dispersal capabilities on the reassembly of plant-dwelling arthropods. *Forest Ecology and Management* 217:294-306.
- Morgan D.K.J., Waas J.R., Innes J., Arnold G. (2012) Native bird abundance after Australian magpie (*Gymnorhina tibicen*) removal from localised areas of high resource availability. *New Zealand Journal of Ecology* 36: 1-7.
- Morgan S., Boyer S., Bowie M. (2016) Pilot trials of secondary seed dispersal potential from tree weta frass by the endemic dung beetle, *Saphobius edwardsi* in the Punakaiki Coastal Restoration Project, New Zealand, Punakaiki Coastal Restoration Project (53), Lincoln University, Christchurch.

- 
- Nichols E., Spector S., Louzada J., Larsen T., Amezcua S., Favila M.E. (2008) *Ecological functions and ecosystem services provided by Scarabaeinae dung beetles*. *Biological Conservation* 141:1461-1474. DOI: <http://dx.doi.org/10.1016/j.biocon.2008.04.011>.
- NIWA. (n.d.) *West Coast climate*, <https://niwa.co.nz/climate/national-and-regional-climate-maps/west-coast>.
- Ruiz-Jaen M.C., Mitchell Aide T. (2005) *Restoration Success: How Is It Being Measured?* *Restoration Ecology* 13:569-577. DOI: 10.1111/j.1526-100X.2005.00072.x.
- Shields M., Boyer S., Bowie M. (2016) *Pilot trials of secondary seed dispersal potential from tree weta frass by the endemic dung beetle, Saphobius edwardsi in the Punakaiki Coastal Restoration Project, New Zealand, Punakaiki Coastal Restoration Project, Lincoln University Wildlife Management Report 53*, Lincoln University.
- Smith C.M.S., Bowie M.H., Hahner J.L., Boyer S., Kim Y.N., Zhong H.T., Abbott M., Rhodes S., Sharp D., Dickinson N. (2016) *Punakaiki Coastal Restoration Project: A case study for a consultative and multidisciplinary approach in selecting indicators of restoration success for a sand mining closure site, West Coast, New Zealand*. *CATENA* 136:91-103. DOI: <http://dx.doi.org/10.1016/j.catena.2015.07.024>.
- Southwood T.R.E. (1978) *Ecological methods* John Wiley and Sons, New York.
- Swift M.J., Heal O.W., Anderson J.M. (1979) *Decomposition in Terrestrial Ecosystems*. Vol. 5, University of California Press, Berkeley. pp. 167-219.
- Vulinec K. (2002) *Dung Beetle Communities and Seed Dispersal in Primary Forest and Disturbed Land in Amazonia*. *Biotropica* 34:297-309. DOI: 10.1111/j.1744-7429.2002.tb00541.x.
- Walter D.E., Proctor H.C. (2013) *Mites: Ecology, Evolution & Behaviour* Springer Netherlands.
- Wandrag E.M. (2012) *Do mutualists matter? The role of pollinators, seed dispersers and belowground symbionts in the invasion success of Acacia*, Lincoln University.
- Wardle D.A., Yeates G.W., Barker G.M., Bonner K.I. (2006) *The influence of plant litter diversity on decomposer abundance and diversity*. *Soil Biology and Biochemistry* 38:1052-1062. DOI: <http://dx.doi.org/10.1016/j.soilbio.2005.09.003>.
- Watts C., Empson R., Thornburrow D., Rohan M. (2012) *Movements, behaviour and survival of adult Cook Strait giant weta (Deinacrida rugosa; Anostostomatidae: Orthoptera) immediately after translocation as revealed by radiotracking*. *Journal of Insect Conservation* 16:763-776. DOI: 10.1007/s10841-012-9461-8.
- Wilms T. (1985) *Soils of the Barrytown Flat, Westland*. Prepared for the Grampian Mining Company. New Plymouth, New Zealand.
- Wong M.H. (2003) *Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils*. *Chemosphere* 50:775-780. DOI: [http://dx.doi.org/10.1016/S0045-6535\(02\)00232-1](http://dx.doi.org/10.1016/S0045-6535(02)00232-1).
- Wortley L., Hero J.-M., Howes M. (2013) *Evaluating Ecological Restoration Success: A Review of the Literature*. *Restoration Ecology* 21:537-543. DOI: 10.1111/rec.12028.
- Young T.P. (2000) *Restoration ecology and conservation biology*. *Biological Conservation* 92:73-83. DOI: [http://dx.doi.org/10.1016/S0006-3207\(99\)00057-9](http://dx.doi.org/10.1016/S0006-3207(99)00057-9).
- Zedler J.B. (2000) *Progress in wetland restoration ecology*. *Trends in Ecology & Evolution* 15:402-407. DOI: [http://dx.doi.org/10.1016/S0169-5347\(00\)01959-5](http://dx.doi.org/10.1016/S0169-5347(00)01959-5).
- Zhong H. (2016 submitted) *Soil Chemistry and Ecology on a Restoration Trajectory of a Coastal Sandplain Forest, Punakaiki, New Zealand*, Ecology, Lincoln University.

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## 12.1 Research outputs

- Invertebrate indicators of restoration success in the Punakaiki ecological restoration project
- Punakaiki Coastal Restoration Project: a case study for a consultative and multidisciplinary approach in selecting indicators of restoration success for a sands mining closure site, West Coast, New Zealand – Journal Article
- Punakaiki Coastal Restoration Project: a case study for a consultative and multidisciplinary approach in selecting indicators of restoration success for a sands mining closure site, West Coast, New Zealand – Conference Abstract New Caledonia 2014
- Punakaiki Coastal Restoration Project: a case study for a consultative and multidisciplinary approach in selecting indicators of restoration success for a sands mining closure site, West Coast, New Zealand – Conference Abstract Korea 2014
- Pilot trials of secondary seed dispersal potential from tree weta frass by the endemic dung beetle, *Saphobius edwardsi* in the Punakaiki Coastal Restoration Project, New Zealand
- Development and testing indicators of restoration success: Punakaiki coastal restoration project
- Baseline Survey for the Punakaiki Coast Restoration Project
- Below-ground invasion, the coexistence of exotic and endemic earthworms in New Zealand soils
- Punakaiki Living Lab Research Project
- A part of our nature: building social and economic value through ecological restoration
- Punakaiki coastal restoration project: a partnership for closure and restoration of a mineral sands project site in New Zealand

# 13. Appendix

## 13.1 Plants species selection and favoured sites

PLANT SPECIES	PREFERRED LOCATION SOILS ENVIRONMENTS	AVOIDED LOCATIONS	GENERAL COMMENTS
<i>Coprosma robusta</i>	Wet, dry soils and beach gravels	Planted in all locations	Good first stage coloniser, produces lots of fruits, vulnerable to frost and hare damage, prefers open space
<i>Coprosma propinqua</i>	Wet, dry soils and beach gravels	Planted in all locations	Hardy first stage coloniser, prefers open space
<i>Coprosma grandifolia</i>	Wet, dry soils and beach gravels	Avoided exposed locations	Ideal in shaded, sheltered areas amongst previous plantings or under formed canopy
<i>Coprosma lucida</i>	Prefers dry soils and beach gravels	Avoided wet soils and exposed locations	Slow growing and vulnerable to hare and frost damage
<i>Melictyus ramiflorus</i>	Prefers dry soils and beach gravels	Avoided wet soils and exposed locations	Ideal in shaded sheltered locations amongst previous established colonisers, vulnerable to frost and wind damage
<i>Aristotelia serrata</i>	Prefers dry well drained soils	Avoided wet soils and exposed areas especially coastal areas subject to salt spray	Can be used as initial coloniser but can be vulnerable to frost and wind damage, fast growth and provides good initial canopy closure if planted with other colonisers
<i>Phornium tenax</i>	Wet, dry soils and beach gravels	Can be planted anywhere open, great in wet areas, avoided shaded areas, handles exposure and salt spray	Great to plant anywhere but if other species are planted in same area will be shaded out eventually but can provide initial shelter
<i>Cordyline australis</i>	Wet, dry soils and beach gravels	Avoided shaded areas as needs plenty of light	Vulnerable to hare damage, can handle grass competition
<i>Pittosporum eugeniodes</i>	Prefers dry well drained soils and beach gravels	Avoided wet soils and exposure to salt and wind	Good second stage coloniser once abit of shelter established, vulnerable to wind, frost and hare damage, fast growing and provides excellent initial canopy closure
<i>Pittosporum tenuifolium</i> colensoi	Prefers dry well drained soils and beach gravels	Avoided wet soils	Handles wind exposure, vulnerable to hare damage

<i>Myrsine australis</i>	Prefers dry well drained soils and beach gravels	Avoided wet soils	Does well on sheltered shadey areas, slow growing
<i>Carpodorus serratus</i>	Prefers dry and semi damp soils	Exposed locations	Grows well in shaded sheltered areas, not many planted on PCRP site
<i>Schefflera digitata</i>	Prefers dry and semi damp soils	Exposed locations	Grows well in shaded sheltered areas, doesn't handle direct sunlight frost or exposed locations, suitable for under canopy plantings
<i>Fuchsia excorticata</i>	Prefers dry and semi damp soils	Exposed locations and coastal areas	Grows well in shaded sheltered areas, handles frost but survival rates not high in general
<i>Fuchsia procumbens</i>	Dry soils and beach gravels	Exposed locations and wet soils	Unsuitable for general restoration planting, ground cover that can only handle planting under canopy
<i>Pseudopanax crassifolius</i>	Prefers dry soils and beach gravels	Wet soils and exposed areas	Slow growing, prone to hare damage and frost, more suited to planting under canopy or in sheltered shaded areas
<i>Hebe salicifolia</i>	Prefers dry soils but can tolerate wet soils	Beach gravels and salt exposure	Hard and fast growing, provides good mix with other first stage colonisers
<i>Weinmannia racemosa</i>	Prefers dry and semi damp soils	Exposed locations and salt exposure, wet soils	Can handle semi exposed locations but grows best in shaded, sheltered areas or under established canopy of initial colonisers
<i>Podocarpus totara</i>	Prefers dry soils and beach gravels	Exposed locations, salt exposure and wet soils	Prefers shaded, sheltered locations amongst initial first stage colonisers or under established canopy of initial colonisers, can handle exposed locations but growth rate is considerably slower



<i>Dacrycarpus dacrydiodes</i>	Wet, dry soils and beach gravels	Avoided open exposed areas	Prefers shaded sheltered areas amongst initial colonisers or under canopy of initial colonisers, can handle exposed locations but growth rate is considerably slower
<i>Olearia avicenniaefolia</i>	Prefers dry soils and beach gravels	Wet soils	Can handle open areas but provides a good mix with established colonisers, vulnerable to frosts
<i>Austroderia richardii</i>	Wet, dry soils and beach gravels	Can be planted anywhere in the open, avoided shaded areas	Great to plant anywhere but if planted amongst other species will eventually be shaded out, provides good initial shelter, vulnerable to hare damage
<i>Macropiper excelsum</i>	Prefers dry soils and beach gravels	Avoided exposed locations and wet soils	Unsuitable in any exposed locations, ideal in full sheltered, shaded areas and under canopy of initial colonisers, prone to frost and hare damage
<i>Sophora microphylla</i>	Wet, dry soils and beach gravels	Can be planted in most areas except full exposure to salt spray	Grows better amongst initial established colonisers, can be shaded out easily, very prone to hare damage and frosts
<i>Hoheria sexstylosa</i>	Prefers dry soils	Wet soils and beach gravels	Can handle open areas but provides a good mix amongst initial colonisers, prone to hare damage
<i>Myrsine salicina</i>	Prefers dry and wet soils	Avoided beach gravels	Best planted amongst established colonisers with shelter, slow growing and prone frost damage
<i>Dodonaea viscosa</i>	Prefers dry soils and beach gravels	Avoided wet soils and fully exposed areas with salt spray	Only planted in coastal strip with shelter from coastal forrest remnant as only naturally occurs in this area. Prone to frost damage but provides great canopy closure when established

<i>Hedycarya arborea</i>	Prefers dry soils	Avoided exposed areas and beach gravels	Unsuitable in any exposed area, does well under established canopy
<i>Griselina lucida</i>	Prefers no soil initially but will eventually put roots into the ground (hemiepiphyte)	Avoided planting directly into the ground and exposed locations	Unsuitable planted directly in the ground, does well planted in branch forks of mature trees or fence posts, starts life as an epiphyte and can handle exposure once established terrestrially
<i>Carex secta</i>	Wet, dry soils and beach gravels	Avoided shaded areas	Best planted in open wetland areas, hardy and fast growing
<i>Cyperus ustulatus</i>	Wet, dry soils and beach gravels	Avoided shaded areas	Best planted in open wetland areas, hard and fast growing
<i>Astelia grandis</i>	Wet, dry and beach gravels	Avoided exposed open locations	Best planted under established canopy and prefers shaded, sheltered areas
<i>Rhopalostylis sapida</i>	Wet, dry and beach gravels	Avoided exposed open locations	Best planted under established canopy and prefers shaded sheltered areas
<i>Metrosideros robusta</i>	Prefers dry soils if planted terrestrially, can also be planted as an hemiepiphyte as will eventually put roots down into the ground	Avoided exposed open locations, will handle exposure once established	Best planted under established canopy and prefers shaded, sheltered areas
<i>Prumnopitys ferruginea</i>	Prefers dry soils	Avoided wet soils and beach gravels	Best planted under established canopy and prefers shaded, sheltered areas

## 13.2 Moth species collected from light

R=Restoration sites; M=Mature sites

	YEAR: 2012		2013		2015		2016		TOTALS		Ecological Notes/ Hostplant		
	SITE:	R	M	R	M	R	M	R	M	R		M	
<b>FAMILY/ SPECIES</b>													
* = introduced													
<b>Arctiidae</b>													
<i>Utetheisa pulchelloides</i>												Polyphagous; seen during day	
<b>Batrachedridae</b>													
<i>Batrachedra</i> sp.							X				X	fern sori	
<b>Carposinidae</b>													
<i>Heterocrossa gonosemana</i>							X		X		X	<i>Hoheria</i> fruit	
<b>Cosmopterigidae</b>													
<i>Microcolona limodes</i>							X				X	dead wood	
<b>Crambidae</b>													
<i>Achyra affinalis</i> *							X				X	sod webworm	
<i>Deana hybreasalis</i>						X	X				X	<i>Clematis</i>	
<i>Diploseustis perieresalis</i>							X				X	<i>Carex</i> ?	
<i>Eudonia cataxesta</i>							X				X	mosses	
<i>Eudonia aspidota</i>						X	X				X	X	?
<i>Eudonia characta</i>							X				X	?	
<i>Eudonia chlamydota</i>							X	X			X	X	?
<i>Eudonia colpota</i>							X				X	?	
<i>Eudonia feredayi</i>						X					X	?	
<i>Eudonia leptalea</i>		X		X	X		X	X			X	X	sod webworm
<i>Eudonia melanaegis</i>		X									X		mosses
<i>Eudonia minualis</i>		X					X	X		X	X	X	mosses
<i>Eudonia octophora</i>							X				X		wetland/ <i>Juncus</i>
<i>Eudonia periphanes</i>							X				X		mosses
<i>Eudonia philerga</i>								X			X		mosses
<i>Eudonia pongalis</i>							X				X		?
<i>Eudonia submarginalis</i>		X	X				X	X	X		X	X	sod webworm
<i>Eudonia trivirgata</i>								X	X		X	X	?
<i>Gadira acerella</i>							X				X		mosses
<i>Glaucocharis chrysochyta</i>							X	X			X	X	mosses
<i>Glaucocharis lepidella</i>							X	X			X	X	mosses
<i>Hygraula nitens</i>				X	X		X				X	X	aquatic pond moth on herbs
<i>Musotima nitidalis</i>							X	X			X	X	ferns

<i>Orocrambus flexuosellus</i>	X		X		X	X	X	X	X	X	grass moth
<i>Orocrambus ramosellus</i>			X						X		grass bases
<i>Orocrambus simplex</i>						X				X	grassmoth
<i>Scoparia acharis</i>					X				X		mosses
<i>Scoparia dinodes</i>						X				X	mosses
<i>Scoparia halopis</i>						X				X	sod webworm
<i>Scoparia minusculalis</i>					X	X	X		X	X	mosses
<i>Scoparia ustimacula</i>							X		X		?
<i>Udea flavidalis</i>	X		X		X	X	X	X	X	X	herbs/ lianes
<i>Uresiphita maoralis</i>			X		X	X	X	X	X	X	<i>Sophora</i>
Indet. Crambidae			X						X		
<b>Depressariidae</b>											
<i>Agonopterix alstroemeriana*</i>						X				X	hemlock
<i>Eutorna symmorpha</i>						X				X	herb, miner/ <i>Selliera?</i>
<b>Elachistidae</b>											
<i>Cosmiotes ombrodoca</i>						X				X	mine grasses
<b>Erebidae</b>											
<i>Rhapsa scotosialis</i>				X	X	X	X	X	X	X	leaf litter
<i>Schrankia costaestrigalis</i>		X	X	X	X	X	X	X	X	X	<i>Juncus</i>
<b>Gelechiidae</b>											
<i>Anisoplaca achyrota</i>				X				X		X	<i>Hoheria</i> fruit
<i>Isochasta paradesma</i>							X		X		?
<i>Symmetrischema plaesiosema</i>						X	X		X	X	<i>Solanum</i> stems/fruits
<b>Geometridae</b>											
<i>Asaphodes aegrota</i>						X				X	herbs
<i>Austrocidaria anguligera</i>							X		X		<i>Coprosma</i>
<i>Austrocidaria callichlora</i>			X		X	X			X	X	<i>Coprosma</i>
<i>Austrocidaria gobiata</i>					X		X		X		<i>Coprosma</i>
<i>Austrocidaria similata</i>						X	X	X	X	X	<i>Coprosma</i>
<i>Chalastra perlargata</i>				X						X	Ferns
<i>Chloroclystis filata</i>					X				X		flowers
<i>Chloroclystis inductata</i>	X					X	X		X	X	flowers
<i>Chloroclystis testulata*</i>						X				X	flowers
<i>Cleora scriptaria</i>					X	X			X	X	polyphagous on trees/ shrubs
<i>Declana floccosa</i>					X	X			X	X	polyphagous on trees
<i>Declana leptomera</i>					X	X	X		X	X	polyphagous on trees

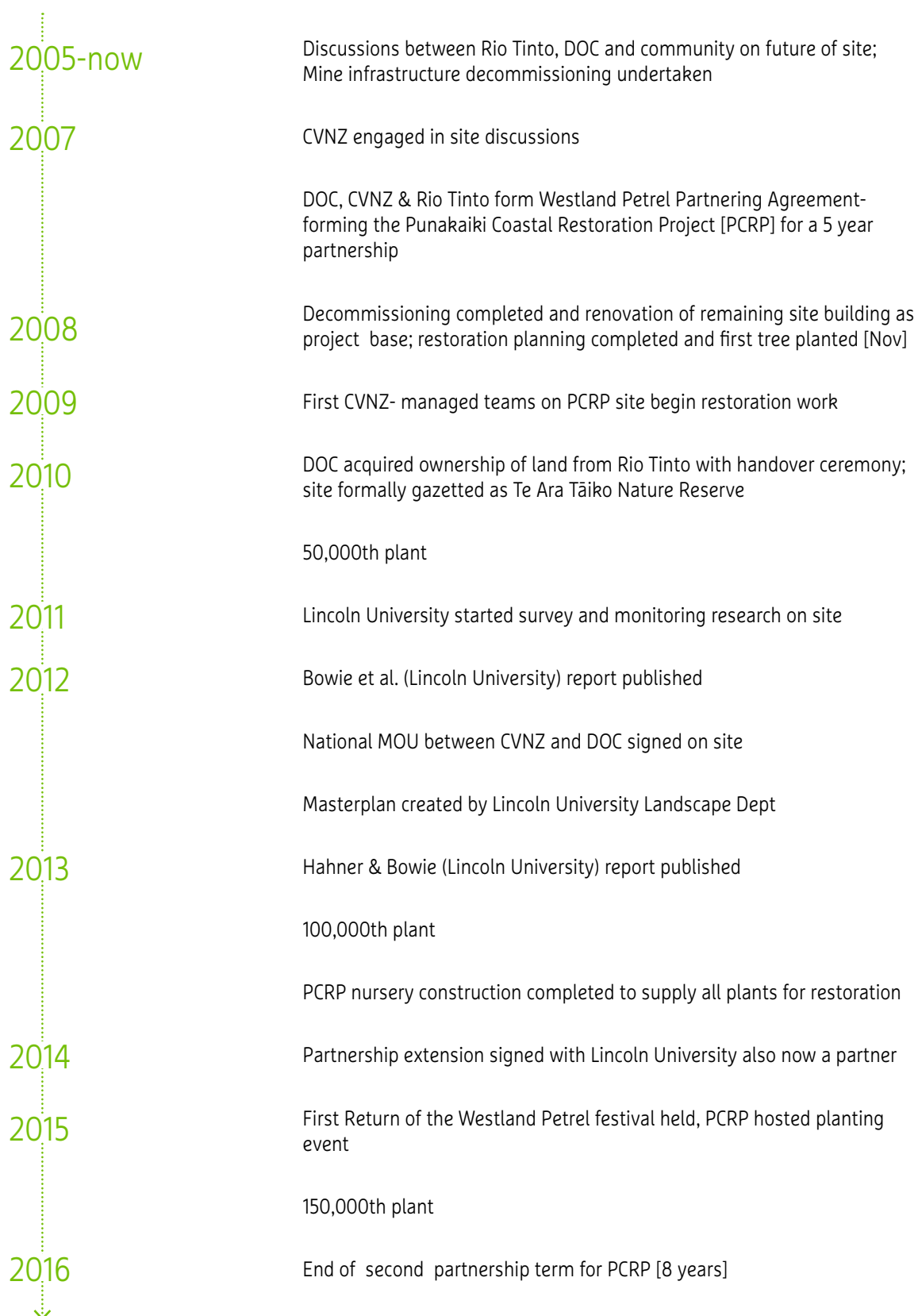
<i>Declana niveata</i>						X	X	X	X	polyphagous on trees
<i>Elvia glaucata</i>					X				X	<i>Rubus</i>
<i>Epiphyrne verriculata</i>					X	X	X	X	X	<i>Cordyline</i>
<i>Epyaxa lucidata</i>			X						X	polyphagous on herbs
<i>Epyaxa rosearia</i>		X		X	X	X	X	X	X	herbs
<i>Gellonia dejectaria</i>	X				X				X	polyphagous on trees/ lianes
<i>Helastia corcularia</i>				X	X			X	X	herbs and mosses
<i>Homodotis megaspilata</i>				X	X			X	X	leaf litter
<i>Hydriomena rixata</i>		X						X		<i>Geranium</i> sp.
<i>Ischalis variabilis</i>					X		X		X	ferns
<i>Microdes epicryptis</i>				X				X		<i>Juncus</i>
<i>Orthocylydon praefecta</i>						X		X		<i>Phormium tenax</i>
<i>Pasiphila fumipalpata</i>				X				X		<i>Hebe</i>
<i>Pasiphila muscosata</i>						X	X	X	X	?
<i>Pasiphila sandycias</i>				X	X			X	X	<i>Coprosma</i> spp.
<i>Phrissogonus laticostatus</i>					X				X	flowers
<i>Poecilasthena pulchra</i>				X				X		<i>Cyathodes</i>
<i>Pseudocoremia fenerata</i>					X				X	on podocarps
<i>Pseudocoremia leucelaea</i>					X				X	on podocarps
<i>Pseudocoremia productata</i>					X				X	polyphagous on trees
<i>Pseudocoremia suavis</i>				X	X		X	X	X	on podocarps
<i>Sarisa flexata</i>						X	X	X	X	ferns
<i>Sarisa muriferata</i>							X		X	ferns
<i>Sestra flexata</i>					X				X	ferns
<i>Sestra humeraria</i>						X	X	X	X	ferns?
<i>Tatosoma tipulata</i>						X	X	X	X	foliage/shoots?
" <i>Xanthorhoe</i> ' <i>oculta</i>	X				X				X	excellent find; herb leaves
<i>Xyridacma alectoraria</i>					X				X	<i>Pseudopanax</i> species
<i>Xyridacma ustaria</i>					X				X	<i>Pittosporum</i> species
<i>Xyridacma veronicae</i>						X	X	X	X	foliage including <i>Hebe</i>
<b>Glyphipterigidae</b>										
<i>Glyphipterix</i> species					X				X	mine monocots
<b>Gracillariidae</b>										
<i>Dialectica scalariella</i> *						X	X	X	X	
<b>Hepialidae</b>										
<i>Wiseana copularis</i>	X		X	X	X			X	X	subterranean larvae on roots
<i>Wiseana umbraculata</i>		X						X		foliage, shoots, bryophytes
<b>Noctuidae</b>										

<i>Feredayia graminosa</i>			X		X	X	X	X	X	<i>Melicytus ramiflorus</i>
<i>Graphania insignis</i>		X		X		X	X	X	X	herbs
<i>Graphania mutans</i>		X		X	X	X		X	X	herbs
<i>Graphania ustistriga</i>		X		X	X	X		X	X	arboreal on shrubs
<i>Persectania aversa</i>						X		X		grasses
<i>Rhapsa scotoscialis</i>				X	X			X	X	litter
<i>Rictonis comma</i>					X	X		X	X	herbs
<i>Tmetolophota atristriga</i>				X	X			X	X	grasses
<i>Tmetolophota purdii</i>					X				X	<i>Astelia fragrans</i>
<i>Tmetolophota semivittata</i>						X		X		<i>Carex</i>
<i>Tmetolophota steropastis</i>						X		X		<i>Phormium tenax</i>
<i>Tmetolophota sulcana</i>							X		X	<i>Carex</i>
Indet. noctuid		X						X		?
<b>Oecophoridae</b>										
<i>Barea exarcha</i>	X							X		dead wood
<i>Gymnobathra calliploca</i>					X				X	litter
<i>Gymnobathra flavidella</i>						X		X		dead wood
<i>Gymnobathra tholodella</i>					X				X	litter
<i>Izanthia heroica</i>						X		X		dead wood
<i>Izatha huttoni</i>					X				X	dead wood
<i>Izatha peroneanella</i>						X	X	X	X	dead wood?
<i>Leptocroca</i> sp.		X							X	dying stem, roots, leaves
<i>Phaeosaces compsotypa</i>					X				X	lichens
<i>Tingena</i> sp.		X							X	Leaf litter
indet sp.		X					?		X	?
<b>Psychidae</b>										
<i>Liothula ?omnivora</i>										Polyphagous; cocoon
<b>Pterophoridae</b>										
<i>Aciptilia monospilalis</i>			X						X	<i>Schefflera</i> & <i>Pseudopanax</i>
<i>Platyptilia repletalis</i>	X	X		X	X			X	X	plumemoth; <i>Plantago</i>
<b>Pyralidae</b>										
<i>Patagoniodes farinaria</i>		X		X		X		X		<i>Senecio</i> stems/Ragwort
<i>Stericta carbonalis</i> *			X						X	Eucalyptus seeds
<b>Thyrididae</b>										
<i>Morova subfasciata</i>					X				X	swellings on <i>Muehlenbeckia</i>
<b>Tineidae</b>										
<i>Archyala paraglypta</i>							X		X	litter?

<i>Erechthias</i> species						X				X	dead wood?
<i>Opogona omoscopa</i>		X	X	X		X	X		X	X	perched litter
<b>Tortricidae</b>											
<i>Apoctena flavescens</i>					X	X			X	X	polyphagous
<i>Apoctena orthropis</i>				X		X				X	?
<i>Bactra noteraula</i>	X				X	X			X	X	monocots
<i>Capua intractana</i>						X	X		X	X	litter
<i>Catamacta gavisana</i>					X	X			X	X	polyphagous
<i>"Cnephasia" jactatana</i>				X	X	X			X	X	polyphagous
<i>Cryptaspasma querula</i>						X				X	fruits
<i>Ctenopseustis obliquana</i>				X	X	X	X	X	X	X	polyphagous
<i>Cydia succedana</i> *	X		X	X	X	X			X	X	gorse biological control
<i>Epalxiphora axenana</i>							X	X	X	X	?
<i>Epiphyas postvittana</i> *	X					X		X	X	X	polyphagous
<i>Merophyas leucaniana</i>			X	X	X	X	X		X	X	grasses
<i>Planotortrix excessana</i>						X				X	polyphagous
<i>Pyrgotis arcuata</i>						X				X	kahikatea
<b>Total native species</b>	11	8	21	14	40	61	47	28	83	110	
<b>% of Restored site species common with Mature site species</b>	<b>13</b>		<b>38</b>		<b>46</b>		<b>71</b>				

# 14. The Punakaiki Living lab

## 14.1 Project timeline





## context

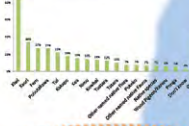
### 1 WHY ARE OUR COASTAL LANDS SO FERTILE?



For millions of years the coastal ranges of Aotearoa New Zealand were the nesting home for millions of burrowing seabirds. Each winter awaiting their would-be in with food to sustain them and their chicks through the nesting and fledging stages. Each evening the forest would receive a daily dose of phosphorus in the form of guano.

The value of our seabirds is largely unnoted. It is still our forest species that New Zealanders explicitly connect with.

Phosphorus and nitrogen are essential for life.



Forest clearances for pasture removed most mammalian burrows, while cats and mustelids targeted the eggs in any that remained. The result is isolated Aotearoa New Zealand is no longer the safe haven for its ocean-bird endemic seabirds, and phosphorus from above the forest is now great machinery.

But what of the long-term health of our coastal forests, whose health comes not from its native animal and plant life, but its soil?

### 2 PROCELLARIA WESTLANDICA'S ONLY HOME



The world's largest penguin (procellaria westlandica) is mainland New Zealand's rarest seabird. Found only in a 20 square kilometre zone just south of Punakaiki, it breeds on the forested ranges that meet the coast and Bayneson Flats sandspit. Only 2000-3000 breeding pairs remain, living in remote forest areas, that surround privately owned, logged and farmed sites.

Each April mature adults return to clean their burrows and lay a single egg. In late spring the chicks spend several weeks trying to fly, with finally on their first successful flight they take off for the ocean. It's five years before they'll make landfall again, which renews, and eventually, is at the exact same rocky they left from.

While Nikau are the region's notable plant species, it's the Westland Flats that is Papatua National Park's iconic bird, and the bell weather indicator of the health of its ecosystems.

### 3 HISTORY WALKS ALONG PAKIROA BEACH



Papatua has long been found on the beaches south of Punakaiki, with Pakiroa beach an enduring travelling route for Maori. It is along this beach, and in walking through this area, or inland through major rivers near here that this precious stone has been carried to places throughout Aotearoa.

It's also where, in the 1930s, thousands of east Maori moved in search of better. Later it was the turn of loggers, cattle and dairy farmers. And then along the Bayneson Flats in the site of industrial rivers waiting to extract minerals used to produce titanium.

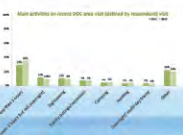
In 1976 a large scale pilot mining operation was developed on a 277 ha site also south of Punakaiki, at the northern end of the Bayneson Flats. However evaluation showed commercial production not viable. In 2000 Rio Tinto acquired the company, and a decision was made to restore as the site that would reconnect the Nikau Reserve with the National Park. In 2010 the land was gifted to Department of Conservation (DOC), with Conservation Volunteers NZ engaged in an intensive reforestation programme. With the project well underway there is now an opportunity to engage a wider community with the possibilities this project brings.

### 4 A NEW TYPE OF NATIONAL PARK

The drive for national parks came out of nineteenth century desires for scenery preservation and twentieth century aspirations and values of outdoor recreation for all.

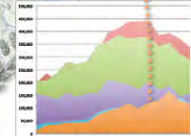
However current activities on conservation lands, which emphasize walking, camping and lightening no longer match the spectrum of conservation-based benefits people value, such as protecting the environment, plants and animals and also the country's clean green image.

A key challenge for national parks this century is how to support experiences and activities that directly engage people with actions that contribute to current conservation values and benefits.



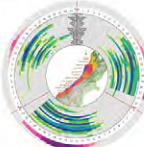
### PUNAKAIKI COASTAL RESTORATION PROJECT LIVING LAB DEVELOPMENT

### 5 NEW TOURISM OPPORTUNITIES



Formally gazetted in 1982, Papatua National Park is one of the country's newest national parks. It's also one of the fastest growing in terms of visitors, with similar numbers to Aoraki Mount Cook National Park.

Papatua National Park is famed for its wild coastlines, tropical palms, limestone formations and unique beaches. Research shows it is an integral component of a standard's day West Coast experience. Not despite its high destination appeal, and safe and accommodation infrastructure, there are limited conservation-based activities on offer.



Despite the strong appeal of the West Coast as a tourism destination, the coast has yet to realize the potential of this industry. Commercial activities are thin, with the region more a place for walks, self-catered meals, and campers. It is mainly accommodation providers and visitors who benefit. Compared to national parks, the season is too short - making for lumpy use and significant over capacity from April to November.

### 6 PUNAKAIKI COASTAL RESTORATION PROJECT



In 2014 new partners have been brought to the project, and including ecologists and researchers from Lincoln University. A key challenge in the next 3 years is how to restore the project with the Papatua National Park, West Coast tourism opportunities, and the desires of many people to be part of making a positive difference to the environment.

From this context the following proposal has been developed - a proposal that begins here, on the edge of the coast and the edge of Papatua National Park, beside a suspension forest remnant on Pakiroa Beach.



**Punakaiki** is well known to both New Zealanders and visitors alike - renowned of course for the 'Pancake Rocks', but also for the outstanding beauty of the limestone-walled river valleys that dissect the densely forested foothills of the Paparoa Range.

The **Punakaiki Living Lab** site sits some three kilometres south of Punakaiki Village - a few minutes' drive - or a short bike ride for those so inclined. Here, the changing values of multiple generations - first of Maori and then European - are revealed in the changing land use - from food provision, through timber extraction, farming, mining and now environmental restoration and education - a story repeated throughout the West Coast.

**It's these stories** - complemented by those of the many volunteers who have contributed to the project - that underpin the ecological values of the Living Lab initiative. This page identifies some of the key values and interpretive opportunities of the site, as well as how the project supports and enhances visitor expectations and experiences.

**= opportunity**

# master plan

## PUNAKAIKI COASTAL RESTORATION PROJECT LIVING LAB DEVELOPMENT

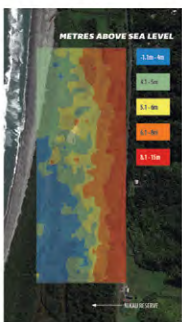


**The Punakaiki Living Lab** offers a new set of National Park –type experiences, where instead of just walking and sightseeing, opportunities for seed-raising, planting, species monitoring, pest-control, citizen science and volunteering are offered. This project will initiate a shift from the current ‘take only pictures, leave only footprints’ policy of National Parks toward an ‘hands on’ engagement of local communities and visitors in the conservation of NZ environment. Through these participative experiences, visitors will leave a positive mark on the natural environment and take home not only pictures, but also knowledge, skills and ownership.

**The initial development** of the Living Lab will focus on the western side of the site - creating a series of linked [staged] walkways and boardwalks that will provide visitors with a range of recreational and educational opportunities. The walkways will showcase the restoration activities and processes as well as leading people into one of the few remaining areas of sand-plain forest on the West Coast .

**Interpretation material** on the site will be innovative and world-class-setting a new standard for natural area interpretation within National Park ‘gateways’

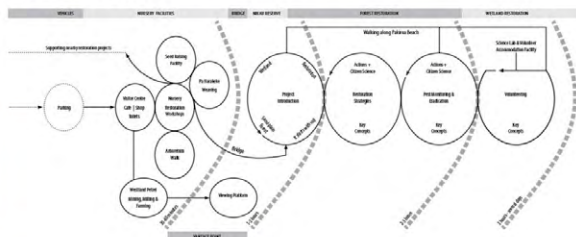
### ELEVATION



### SOILS

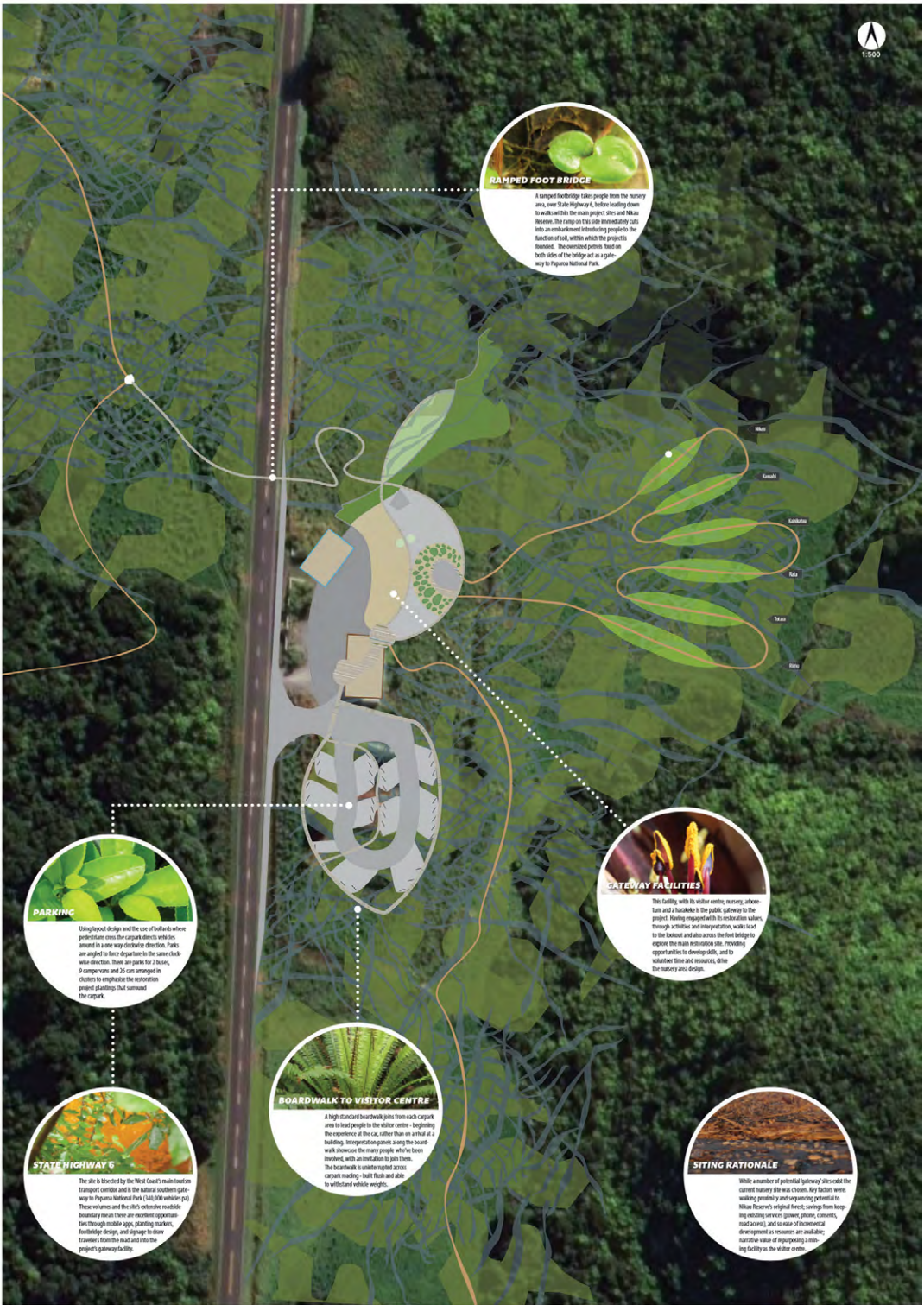


### EXPERIENCE MAP



# a gateway facility to ...

**PUNAKAIKI COASTAL RESTORATION PROJECT**  
LIVING LAB DEVELOPMENT



The **second phase** of the development of the Living Lab initiative will see the development of a Visitor Centre - this will utilise the existing building and provide a range of amenities - and of course - information on the activities and opportunities provided within the Living Lab experience.

The **current site nursery** which grows all the plants for the on-going restoration work will be expanded and re-modelled to allow and encourage easy interaction with visitors. Here we can tell another 'story' - that of the life-cycle of plants - in particular, those naturally occurring on the site.

A **key objective** of the second phase is to engage visitors upon arrival—to provide visual, sensory and physical opportunities for interaction and connection with the site commencing upon arrival.

**Importantly** from both an experiential and public safety perspective, visitors will park on this side and will gain access to the western side via a tunnel. [not over-bridge as pictured] This will provide a unique interpretive opportunity - telling the important story of soil development and soil-ecosystems.

## LEADING PEOPLE FROM THE ROAD AND INTO THE PROJECT GATEWAY FACILITY

**MARKER**  
A simple, sleek, minimalist design made from the site's native and local materials. It's a subtle guide that points to the project's location and provides information on the project's location and provides information on the project's location.

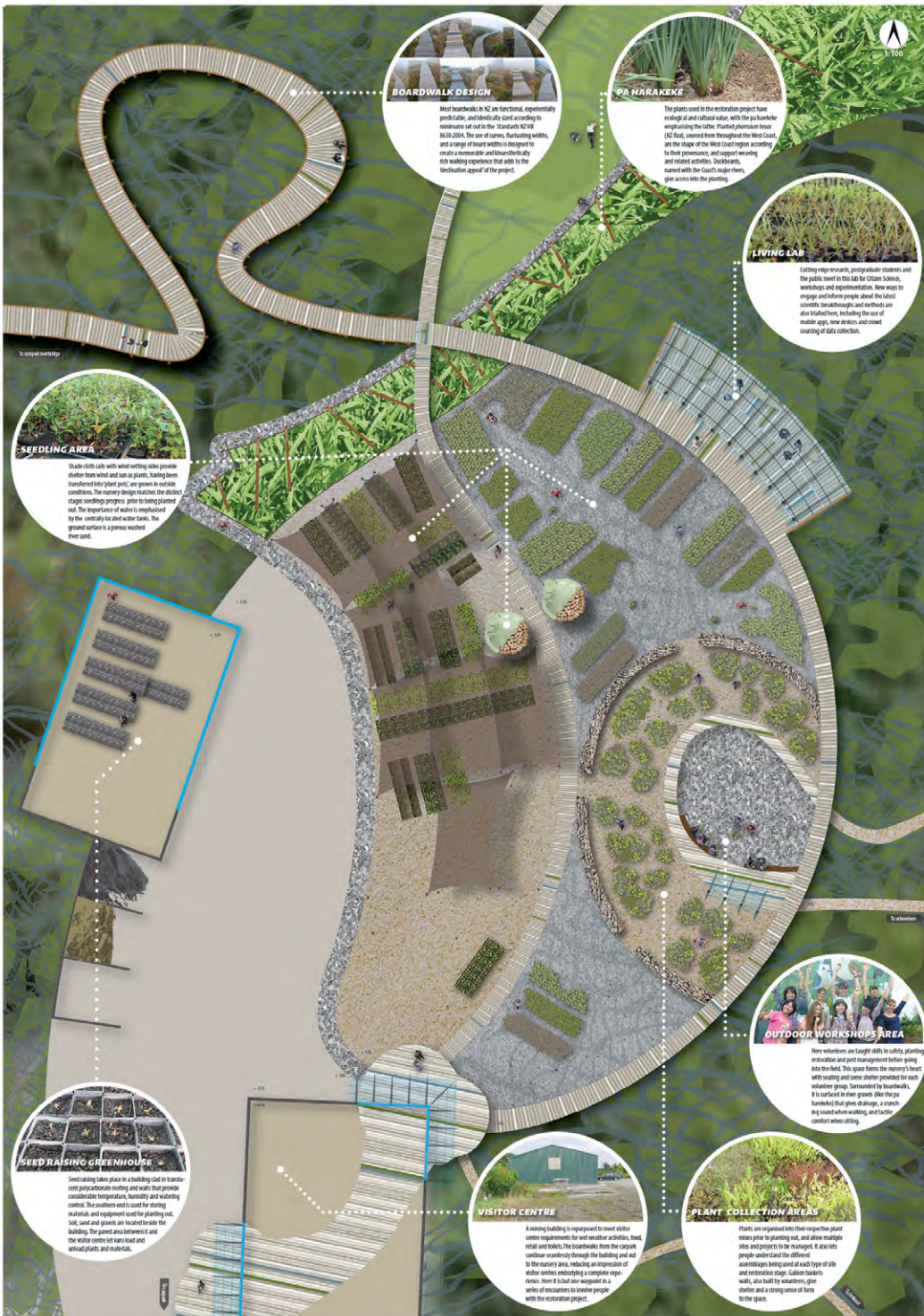
**APP**  
This new app makes it easier to navigate the site and provides information on the project's location and provides information on the project's location.

**OVERBRIDGE**  
A giant wooden bridge spans the site, providing a unique view of the project's location and provides information on the project's location.

**WHAT'S ON**  
A vertical board listing various activities and events, including 'PUNAKAIKI COASTAL RESTORATION PROJECT' and 'LIVING LAB DEVELOPMENT'.

# living lab & plant nursery

**PUNAKAIKI COASTAL RESTORATION PROJECT**  
LIVING LAB DEVELOPMENT



The site nursery currently provides all the plant stock for the on-going restoration process-providing skill-based learning opportunities for volunteers and students alike.

The Living Lab will enhance both the nursery itself-and the educational opportunities provided through allowing more open access and engagement with the nursery components.

Visitors will be drawn through the area on arrival - immediately being engaged with the restoration processes. The nursery layout will be designed to allow for simple interpretive experiences including plant identification, and key species.

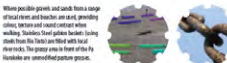
Plants will be available to purchase - to take away or to support the restoration process - the latter particularly aimed at travellers who may wish to 'off-set' their carbon footprint. For the more 'hands-on visitor, they will be able to both purchase and plant - and then use an app to photograph and 'track' their trees.

## MATERIALS PALETTE

### SURFACE ELEMENTS



### COLLECTION DEVICES



### RECLAD VISITOR CENTRE



### SEATING / BOLLARDS



### PA HARAKEKE DUCKBOARDS



### WATER TANK



### BOARD WALK

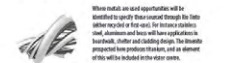


### BUMPER STOPS



## MADE for VOLUNTEERS by VOLUNTEERS and SUPPORTERS

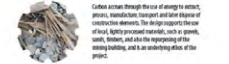
### SHELTERS



### VOLUNTEERTECH



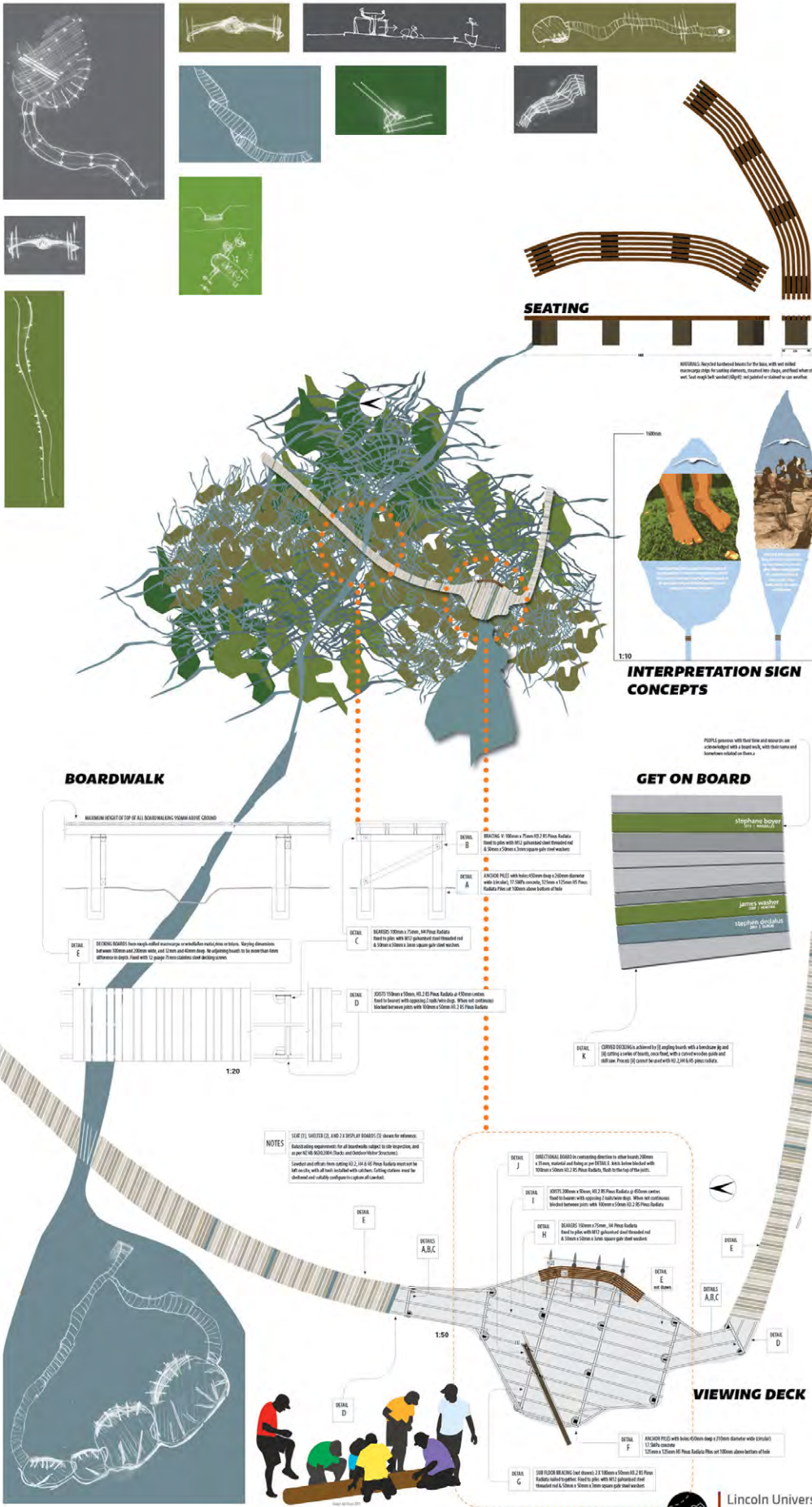
### PALETTE OF FOUND/LOW CARBON MATERIALS



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# design details

**PUNAKAIKI COASTAL RESTORATION PROJECT**  
LIVING LAB DEVELOPMENT

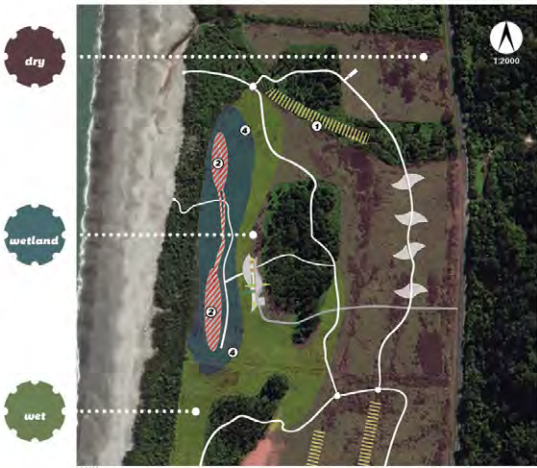


Design of facilities and paths are all directed at creating an experientially rich activity.

Many of the facilities are specified in such a way as to encourage volunteer involvement in their construction.

# planting strategy

**PUNAKAIKI COASTAL RESTORATION PROJECT**  
LIVING LAB DEVELOPMENT



## WETLAND RESTORATION AREA



When farming was established on this site low lying wetland areas were drained by digging a series of lateral drains. However some moderate size trees in the lowest areas filling with surface water. Wetlands will be re-established at the lowest areas of the site's northern end with the following proposed:

- 1 Reducing the speed of flow MUMBERS Creek has to the sea. This involves stepping clearing of branches, roots and stanching that has been undertaken in the past. Also, where practical, large rocks are to be arranged into the water channel to impede flow. This will foster seepage into the wetland restoration area, especially during periods of extended rainfall.
- 2 Removing grass and creating off soil cover to a depth of 200mm in the lowest parts of the wetland restoration area to ensure surface water remains year round.
- 3 Use this soil cover as fill for closing existing lateral drains. This will ensure previously drained water will return to the wetland restoration area.
- 4 Undertake restoration planting of the area with mixes of wetland and wet soil nursery species.



A neighbouring site has been selected to locate the lab and volunteer accommodation facility due to its elevated nature, visibility from the road and proximity to the beach. This site also allows tracks related to broader volunteer and visitor activities to be routed so as not to interfere with the functions of this facility. As well as lab and volunteer accommodation, other functions can be readily incorporated including the Discovery Centre being considered by Wetland District Council. Planting around the facility will be according to the wider restoration project, other than two planned plantings with a range of native plants:

A neighbouring nikau (*Phormium tenax*) grove, in a matching shape also pointing west. This palm stands in its juvenile form for 40-50 years until it first obstructs traffic sight lines and is emblematic of the patience, effort and timeframes involved in successful restoration projects.

## ZONE BASED ECOLOGICAL RESTORATION PLANTING STRATEGY

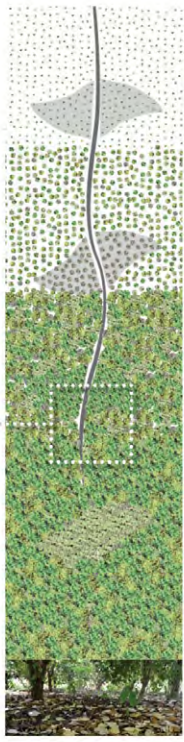
### PROPOGATION

Collect seed from local sources  
Wetland plant species are collected from local sources  
Raise seeds in controlled conditions  
Use seed trays to raise seedlings  
Transfer to individual seedling pots  
When required, transfer seedlings to PPS  
Count out plants for specific sites and collect for hardening



### PLANTING

Suppress existing grass and weed cover  
Use weed mats to ensure weeds are suppressed  
Plant out using micro shelters  
Use bird perches to encourage bird based seed distribution



### YEAR 1

**Harakake** → NZ Flax → *Phormium tenax* 50%  
Pencil palm → *Xylocarpus* 50%



### YEAR 2

**Mahoe** → whitebait → *Melicope ramiflora*  
**Horeaka** → lancewood → *Pseudopanax crassifolius*

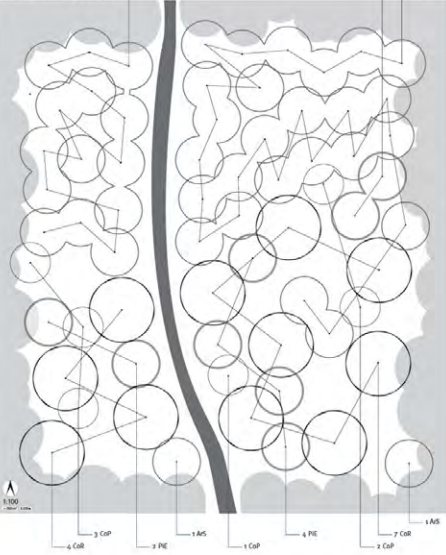


### YEAR 4

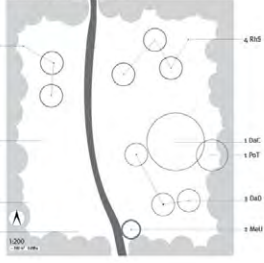
**Tatara** → podocarpus tatara  
**Nikau** → *Phormium tenax*  
**Kahikatea** → *Decaspermum decurcoides*  
**Rimu** → *Dacrydium cupressinum*  
**Rata** → *Metrosideros umbellata*  
**Kanuhū** → *Wellingtonia regularis*



### YEAR 1 PLANTING DIAGRAM



### YEAR 4 PLANTING DIAGRAM



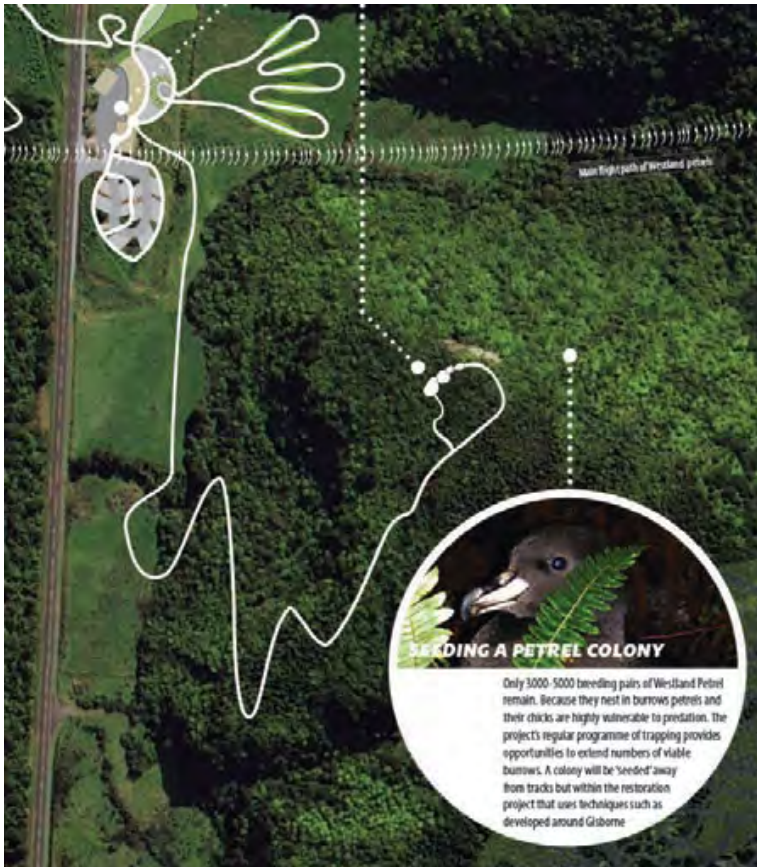
### PLANTING SCHEDULE

ID	QTY	BOTANICAL NAME	COMMON NAME(S)	SIZE	YEAR
AS	41	<i>Antrodia serrata</i>	makomako / whiteberry	Pat 1	
CoP	4	<i>Coprosma grandifolia</i>	karamea	PE3 2	
CoP	6	<i>Coprosma propinqua</i>	mitikingi	Pat 1	
CoP	11	<i>Coprosma robusta</i>	karamea	Pat 1	
DaD	3	<i>Decaspermum decurcoides</i>	kahikatea	PE3 4	
DaC	2	<i>Decaspermum crassifolius</i>	horeaka	PE3 4	
MaH	4	<i>Melicope ramiflora</i>	whitebait	PE3 2	
MaH	2	<i>Melicope ramiflora</i>	whitebait	PE2 4	
PE	8	<i>Pseudopanax crassifolius</i>	horeaka / lancewood	Pat 1	
PE	2	<i>Podocarpus latara</i>	tatara	Pat 4	
PE	4	<i>Podocarpus latara</i>	tatara	Pat 4	
PE	4	<i>Podocarpus latara</i>	tatara	Pat 4	
PE	7	<i>Phormium tenax</i>	nikau	Pat 4	
PE	4	<i>Phormium tenax</i>	nikau	Pat 4	

Note: all plants are to be grown at the site nursery using seeds sourced from within the restoration project.

The planting strategy underpins the public involvement in an active project of ecological restoration.

Species are selected on their value as nurse crops such that large canopy species are established as per those found in the regenerating Nikau Reserve.

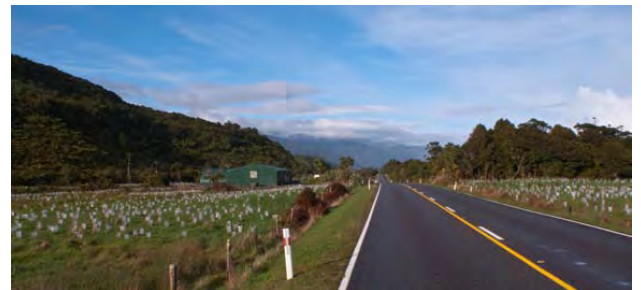


**The Westland Petrel [tāiko]** is endemic to the precipitously steep foothills that abut the eastern edge of the project site. Here, they return annually to breed in burrows scattered throughout the densely forested slopes. The site itself is a Scientific Reserve monitored by Te Papa. Current estimates suggest some 4,000 breeding pairs in a population of some 20,000 birds.

Every winter - commencing in late April, the petrels return to the site to mate. Every evening, thousands of birds wheel in circles over the ocean just beyond the project site before heading along a well-defined flight path to their burrows.

The Draft Master Plan provides for a truly unique visitor experience with the creation of a viewing platform to the rear of the nursery area. A twenty minute walk up an old farm track will allow visitors to watch these magnificent birds from close-up as they home in on their burrows in the hills beyond.

Given the uniqueness of the colony, the viewing platform component of the master plan will be subject to specific consents and impact studies, and will proceed only on the basis of no negative impact on the viability of the colony.



**The 'Punakaiki Living Lab'** will provide a genuinely unique range of learning experiences - and the master plan provides for longer term engagement with the site to capitalise on these through the building of the 'Discovery Centre Lodge'.

This multi-purpose building will provide accommodation for school and university groups as well as volunteers. The low-impact design will include open ecology lab space and will feature the latest technology in off-grid power and water reticulation systems. Open Days will allow the building[s] to showcase to visitors and West Coast residents the benefits of 'green technology' in developing a more sustainable use of natural resources.

Both the 'Discovery Centre Lodge' and the 'Living Lab' as a whole linking will link closely with the proposed Discovery Centre development in Greymouth.

# The Bigger Picture...

## Tourism on the West Coast and the local economy

**Punakaiki Tourism plays an increasingly significant role on the West Coast**, where the on-going and increasingly rapid decline in extractive industries is being supplanted by a steady growth in visitor numbers and spending.

The value of tourism to the West Coast is highlighted in the Tourism 2014 Election Manifesto; the \$288 million a year that international and domestic visitors spend on the West Coast is equivalent to 20.4% of the region's gross domestic product.

"This highlights that tourism is a significant and valuable part of the region's economy. But both the Tourism Election Manifesto and Tourism 2025, the industry-led growth framework, show there is plenty of potential to grow tourism even more," TIA Chief Executive Chris Roberts says.

The longer-term outlook for tourism on the West Coast is for continuing growth - [New Zealand's Tourism Sector Forecasts for 2012-2018, MBIE. 2012] "A rising tide of middle income earners in emerging markets, who are relatively young and from large markets, is a source of many potential visitors."

**The local Punakaiki economy** is heavily reliant [almost wholly] dependent upon visitor spend. But whilst increased visitation provides overall economic benefits, it highlights a number of underlying issues. The 'PUNAKAIKI ISSUES AND OPTIONS REPORT' 2007 prepared by NZ Tourism Recreation Research and Education Centre, Lincoln University for Development West Coast notes the following issues - and the related opportunities:

### Issues

- Peak crowding can reduce the quality of the visitor experience.
- Lack of access to recreation opportunities due to private and public ownership of land.

### Opportunity

- Provide increased activities (e.g. short walks) that encourage visitors to disperse rather than focus on Pancake Rocks.
- Develop an attraction based on viewing on the Black Petrel.

Punakaiki has over 400,000 visitors to the Blowholes Track each year, and approximately 50% of these visitors enter the DOC Visitor Centre. Only 31,000 (7.8%) stay overnight. Current evidence suggests that visitor stays are actually reducing – so it is more short walks and high levels of engagement that will play a significant role in maintaining and building 'visitor nights'—the key economic driver for the local Punakaiki economy

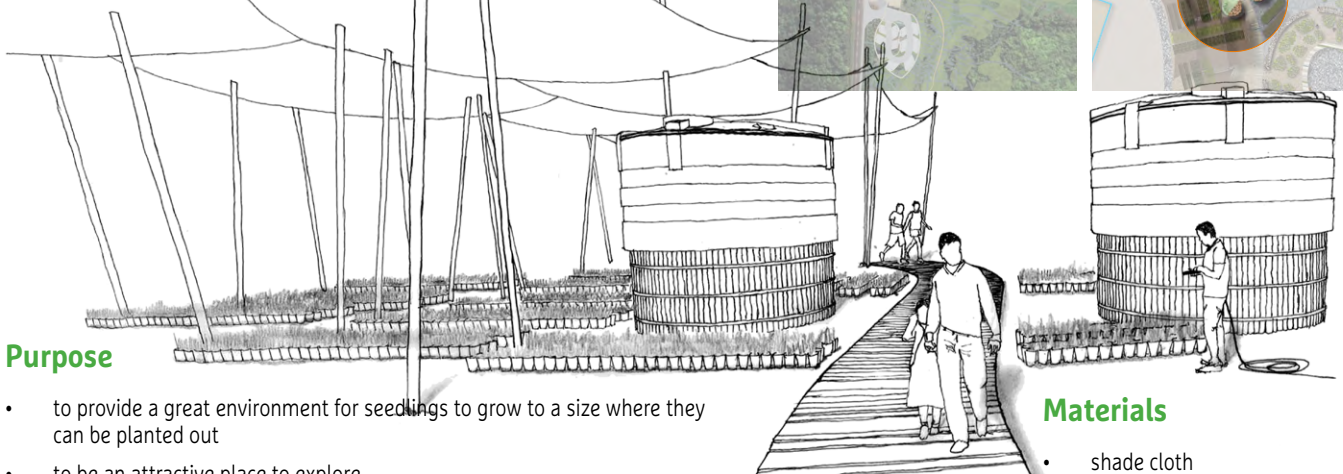
In 2014/15 visitor season Punakaiki had the highest visitor numbers for the West Coast –but the great majority stayed for no more than 3 hours.

"The [petrel] viewing experience is quite spectacular... This is strategically important to Punakaiki as although it is unlikely to drive mass visitation, it would produce a new visitor attraction in the off-peak season and because of the evening timing, is highly likely to generate overnight stays. It is in keeping with the conservation values of the area and will be simple to market to niche audiences through established and new birding marketing networks... The experience could also be extended to include hands-on conservation work such as planting, weed and predator control, to provide a deeper engagement and sense of contribution for the visitor "



## 14.3 Project Componentets

### 14.3.1 Shade Nursery



#### Purpose

- to provide a great environment for seedlings to grow to a size where they can be planted out
- to be an attractive place to explore

#### Specification Summary

- Shade cloth and poles anchored with guy-wires and suitable inground fixing
- poles preferably made of found beach timbers, cut to length and with steel bands near ends to prevent splitting
- water tanks filled by gravity feed system from creek and raised to sufficient height for adequate water pressure
- water tanks placed on a raised 'barrel-like' structure of vertical timbers with fill inside and steel bands around the outside

#### Materials

- shade cloth
- steel rope
- local timbers
- water tanks

#### Construction

- Volunteer Group to build
- Detailed Design: DESIGNLAB [minimal input required]

### 14.3.2 Eco Lab



#### Purpose

- to showcase the science values of the project
- to provide all weather activities
- to provide discretionary activities while people wait for a tour/session

#### Specification Summary

- verandah front with aluminum sliding doors allowing it to be fully opened up or closed
- glazed along the back wall so glass can be etched with elements that augment the story of the plants and site located beyond
- ideally sponsored by a university/CRI and a corporate

#### Materials

- to be confirmed and include horizontal lapped timbers of varying lengths with slot windows
- water, power

#### Construction

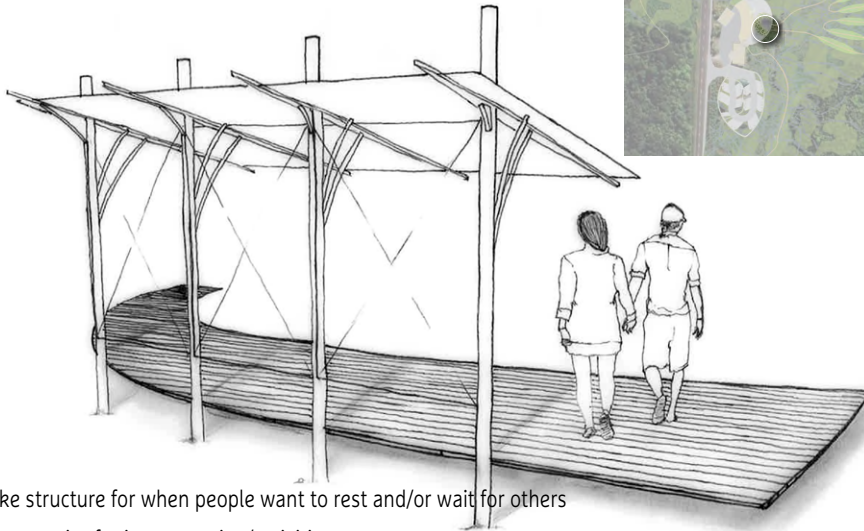
- to be confirmed

#### Detailed Design

- DESIGNLAB with partner architect
- Engineer for structural design

• NOTE image is indicative only

### 14.3.3 Verandahs



#### Purpose

- verandah-like structure for when people want to rest and/or wait for others
- to act as a focus point for interpretation/activities
- to reflect mineral industry support

#### Specification Summary

- structure cross braced with steel rope
- modular metal structure that can be used wherever verandahs/shelter is required
- roof overhangs boardwalk so rain falls off the path, and so no guttering required
- boardwalk as per listed elsewhere on schedule

#### Materials

- Rio Tinto metals
- Polycarbonate roof
- Fixings

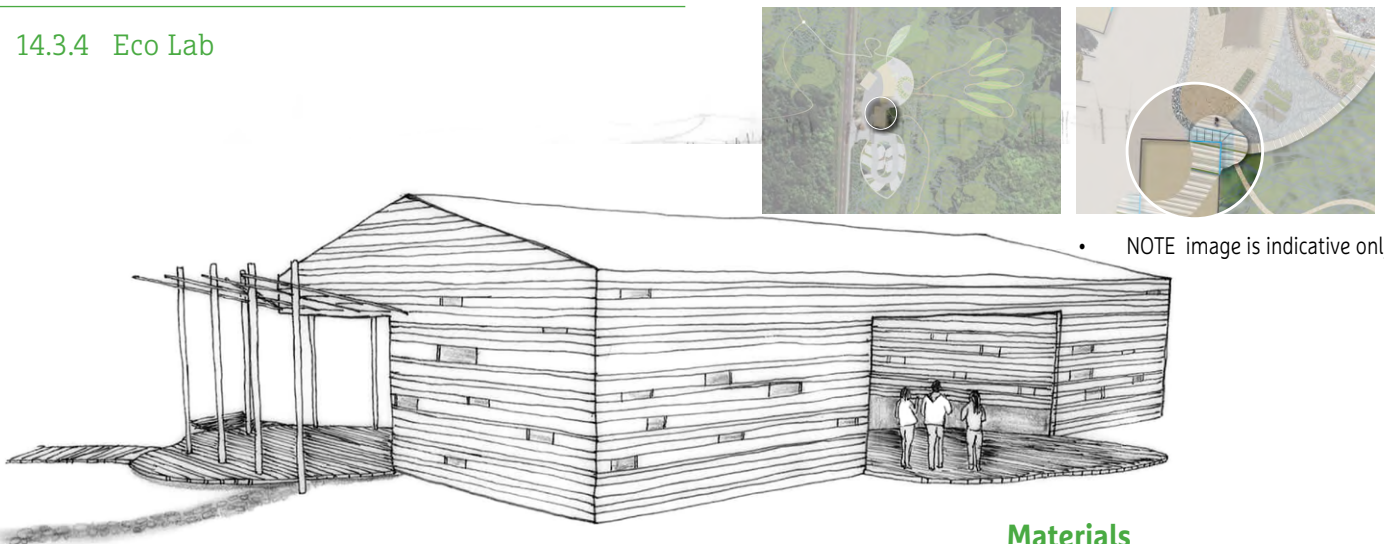
#### Construction

- Metal fabricators for modular structure
- Registered builder for installation

#### Detailed Design

- DESIGNLAB with metal fabricators

### 14.3.4 Eco Lab



#### Purpose

- to invite people to be involved in the project
- to place a boardwalk through the facility so people do not perceive it to be a destination
- to showcase a repurposed mining building that is green-tech

#### Specification Summary

- the existing building footprint and structure will be used but relined inside and out, the goal is not to require significant new consent - hence image is indicative only
- Boardwalk and verandah as per. specifications listed elsewhere on schedule

#### Materials

- to be confirmed and include horizontal lapped timbers of varying lengths with slot windows
- water, power

#### Construction

- to be confirmed

#### Detailed Design

- DESIGNLAB with partner architect
- engineer for structural design

• NOTE image is indicative only

### 14.3.5 Shade Nursery



#### Purpose

- to be a bright all weather environment for raising seedlings
- to provide volunteer activities when its raining
- to provide volunteer activities for less mobile people
- to in part screen the project from the road

#### Specification Summary

- polycarbonate roof and walls except on south side which is horizontal timbers of different widths
- sliding walls to open facility out
- slab concrete floor with drainage for easy wash out
- trestle tables and mist-irrigation provided

#### Materials

- polycarbonate roofing
- local timbers
- concrete
- water, power & drainage

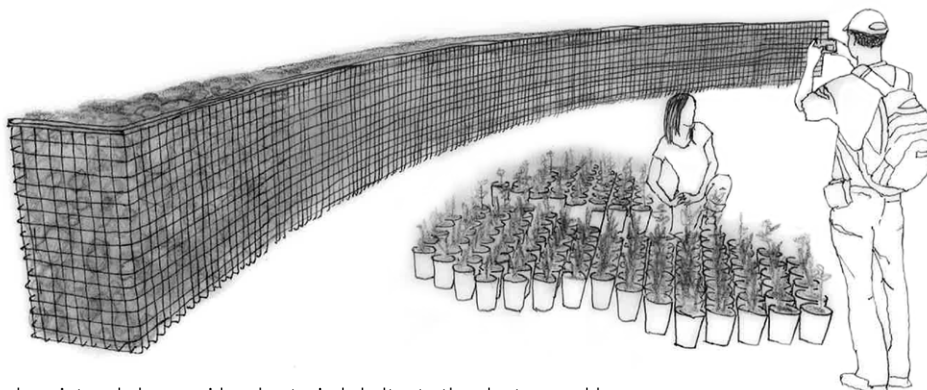
#### Construction

- Volunteer group to build

#### Detailed Design

- DESIGNLAB with partner architect

### 14.3.6 Gabion Basket Riverstone Wall



#### Purpose

- to be a focal point and also provide robust wind shelter to the plant assemblage area

#### Specification Summary

- Galvanised steel mesh filled with west coast river stones.
- height may vary
- curved through use of internal ties so baskets cant topple

#### Materials

- Galvanised steel 50mm-100mm steel mesh
- riverstones

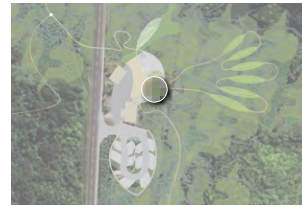
#### Construction

- Volunteers to build

#### Detailed Design

- DESIGNLAB [minimal Input required]

### 14.3.7 Plant Assemblage Area



#### Purpose

- TO ALLOW STAFF To pre-place different configurations of plants ready for planting at specific sites
- to let people understand that different plant configurations are required according to the type of site
- to provide an opportunity for discovery and interpretation

#### Specification Summary

- short timber guard wraps each assemblage made from beach timber and coded using different paint colours according to the plants being used: eg red totara, blue karamu, green kanuka etc
- this allows people to quickly look for where their favourite plants are being used

#### Materials

- local timbers
- paint

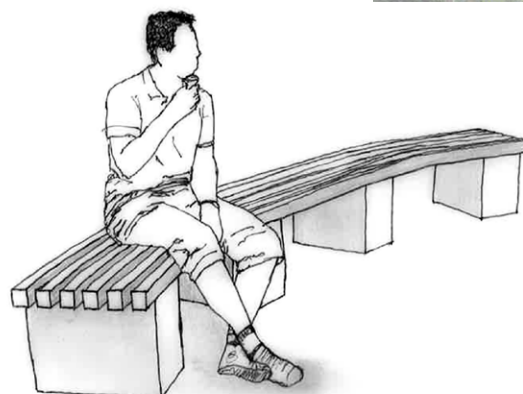
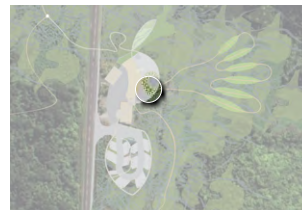
#### Construction

- Volunteer Group to build

#### Detailed Design

- N/A

### 14.3.8 Seating



- NOTE image is indicative only

#### Purpose

- to allow people to rest
- to let others catch up
- to act as allocation point for interpretation

#### Specification Summary

- slatted timber seat, curved to encourage conversation
- base large (possibly recycled bridge) timbers cut to size

#### Materials

- local timbers

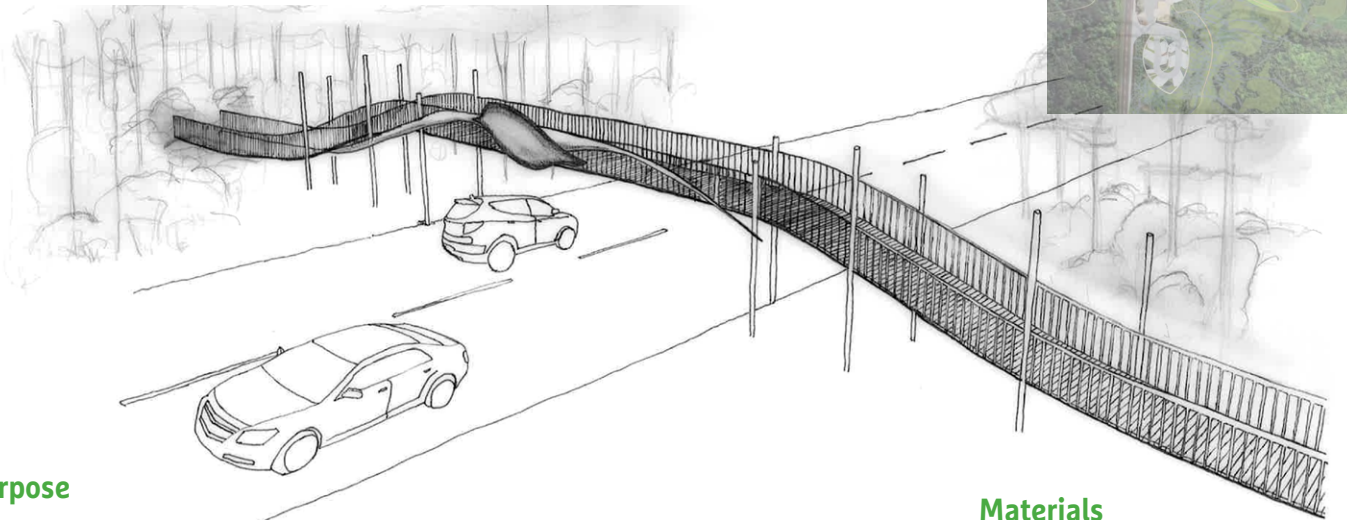
#### Construction

- Volunteers to build

#### Detailed Design

- N/A

### 14.3.9 Bridge or Tunnel



#### Purpose

- to allow people to safely get across the highway
- to create a sense of transition from the nursery to the project site
- to build a narrative that links bird flight and bird guano with the story of the soil
- to act as a billboard for the project
- to act as the de facto southern gateway to paparoa national park

#### Specification Summary

- to be confirmed if a bridge or tunnel will provide the best option in terms of cost and the requirements of oversized vehicles
- hence the image is indicative only

#### Materials

- to be confirmed

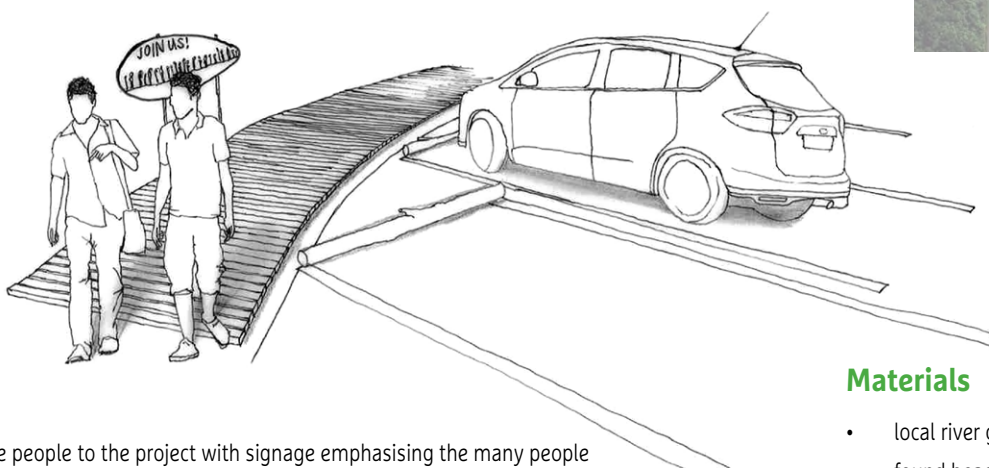
#### Construction

- to be confirmed

#### Detailed Design

- DESIGNLAB
- transport engineer for this and project access points
- engineer for structural design

### 14.3.10 Carpark welcome



#### Purpose

- To welcome people to the project with signage emphasising the many people who have already helped and a call for the new arrivals to 'join us'
- To use boardwalks to encourage people to not only walk to the visitor facility but through it and into the project

#### Specification Summary

- Gravelled carpark
- Beach timber to work as car barriers. these have bird and leaf motifs burnt on them
- Signage/interpretation as per. project template

#### Materials

- local river gravels
- found beach timber

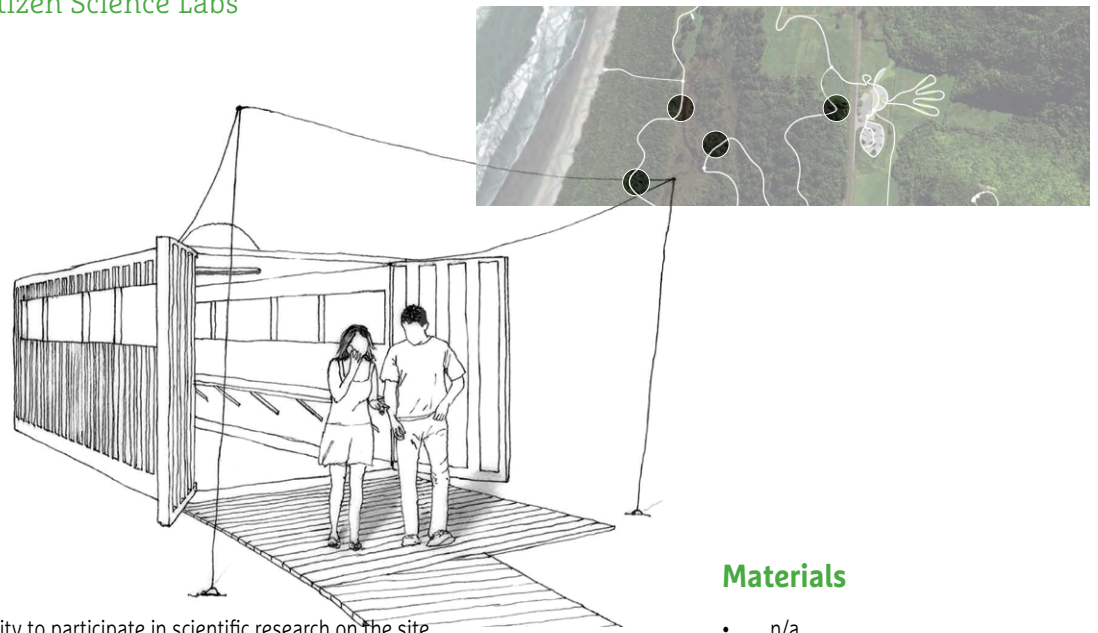
#### Construction

- volunteers for carpark and boardwalks
- Signage manufacturer

#### Detailed Design

- DESIGNLAB for final carpark layout, car barriers and motif design
- DESIGNLAB for project signage and interpretation system

### 14.3.11 Relocatable Citizen Science Labs



#### Purpose

- to give people the opportunity to participate in scientific research on the site
- to provide an all weather activity
- to develop skills that can be taken away so the citizen project can be distributed back to visitor's own locales

#### Specification Summary

- relocatable container with awnings, solar power and basic lab facilities
- Signage/interpretation as per. project template

#### Materials

- n/a

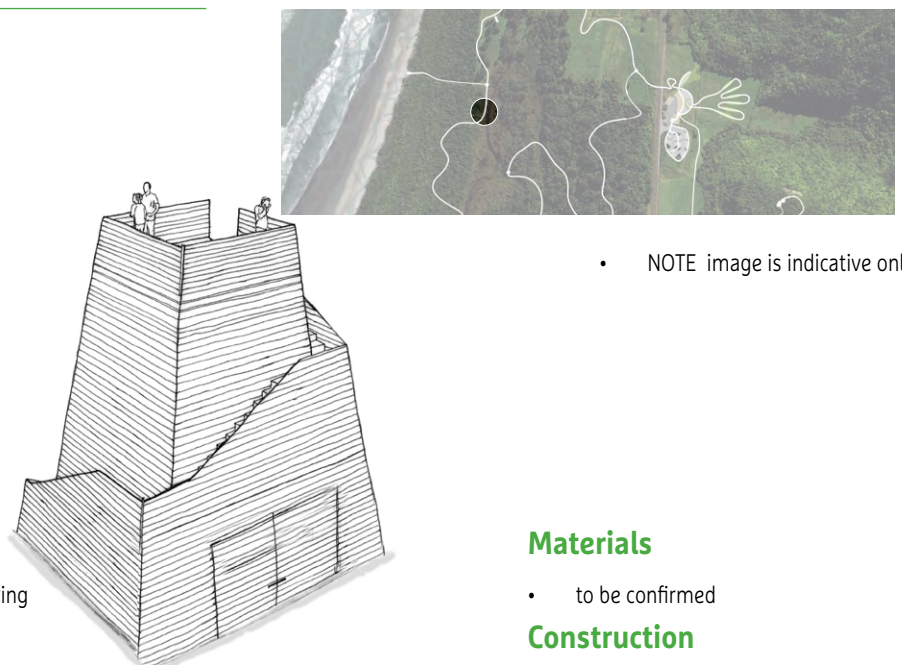
#### Construction

- N/a

#### Detailed Design

- DESIGNLAB and partner architect

### 14.3.12 Project Viewing Tower



- NOTE image is indicative only

#### Purpose

- to allow people to view the project without having to climb the hill
- to create a sense of destination
- to allow people to see the sea
- to store equipment associated with restoration

#### Specification Summary

- the exact requirements are to be determined
- hence the image is indicative only

#### Materials

- to be confirmed

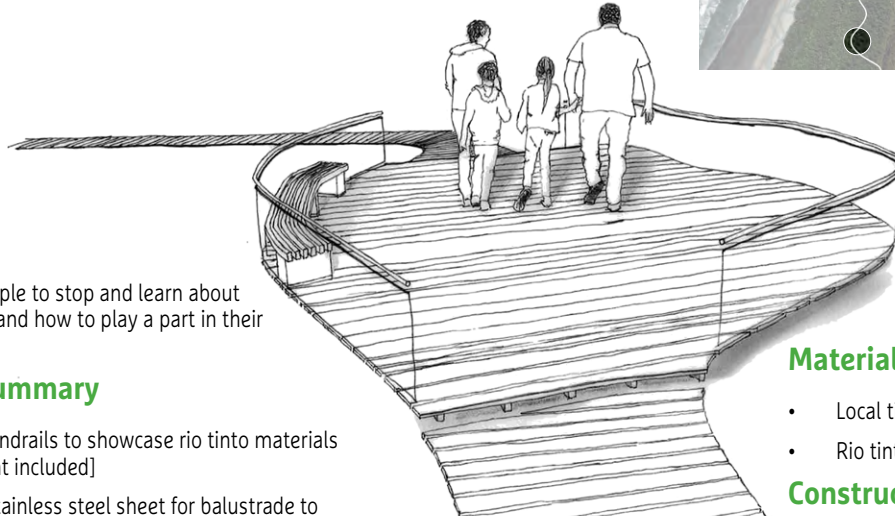
#### Construction

- to be confirmed

#### Detailed Design

- DESIGNLAB and partner architect
- engineer for structural design

### 14.3.13 Wetland Viewing Platform



#### Purpose

- to encourage people to stop and learn about wetland ecology and how to play a part in their conservation

#### Specification Summary

- Flowing metal handrails to showcase rio tinto materials [narrative element included]
- pressed curved stainless steel sheet for balustrade to showcase rio tinto materials [narrative element included]
- Deck made of varying width milled windfallen native timbers
- Deck understructure as per NZS3604, windfall totara preferred as substitute for treated pine subject to required engineer's report
- Seating and boardwalk as per. specifications listed elsewhere on schedule

#### Materials

- Local timbers
- Rio tinto metals

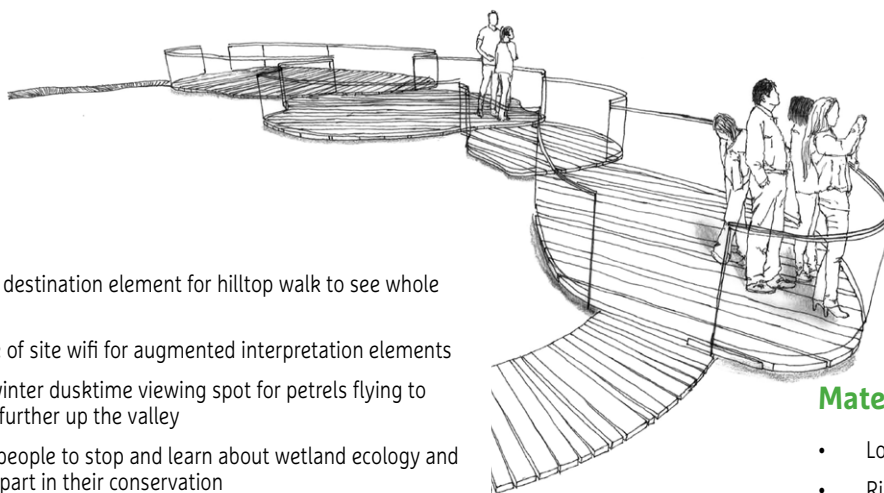
#### Construction

- Metal fabrications for balustrade/rail
- Registered building practitioner to supervise
- Local volunteer group to build

#### Detailed Design

- DESIGNLAB
- Engineer to sign off on drawings and Totara

### 14.3.14 Hilltop Viewing Platform



#### Purpose

- to be daytime destination element for hilltop walk to see whole project
- to provide line of site wifi for augmented interpretation elements
- option to be winter dusktime viewing spot for petrels flying to their burrows further up the valley
- to encourage people to stop and learn about wetland ecology and how to play a part in their conservation

#### Specification Summary

- Flowing metal handrails to showcase rio tinto materials [narrative element included]
- pressed curved stainless steel sheet For Balustrade to showcase rio tinto materials [narrative element included]
- Deck understructure as per NZS3604, windfall totara preferred as substitute for treated pine subject to required engineer's report
- DECK made of varying width milled windfallen native timbers
- boardwalk as per. specifications listed elsewhere on schedule

#### Materials

- Local timbers
- Rio Tinto metals
- Fixings

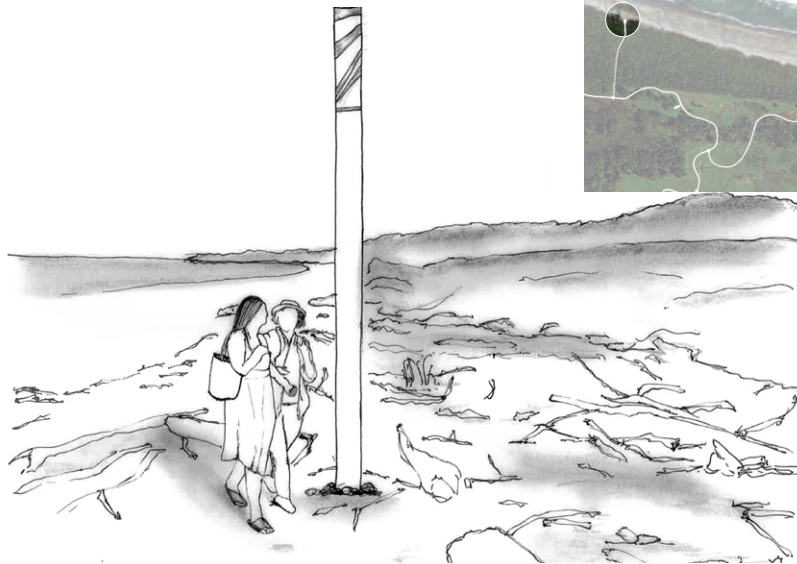
#### Construction

- Metal fabrications for balustrade/rail
- Registered building practitioner to supervise and build

#### Detailed Design

- DESIGNLAB
- Engineer to prepare substructure drawings & use of Totara as alternative solution

### 14.3.15 Coastal Track Start Marker



#### Materials

- found logs from beach cut to length
- concrete foundation to anchor log in gabion basket
- gabion basket made of galv or stainless steel 50mm mesh
- stones from local beach or river
- stainless steel bands

#### Construction

- Steel fabricators for stainless steel bands
- Registered building practitioner to supervise
- Local volunteer group to build

#### Detailed Design

- DETAILED DESIGN
- DESIGNLAB (minimal input required)

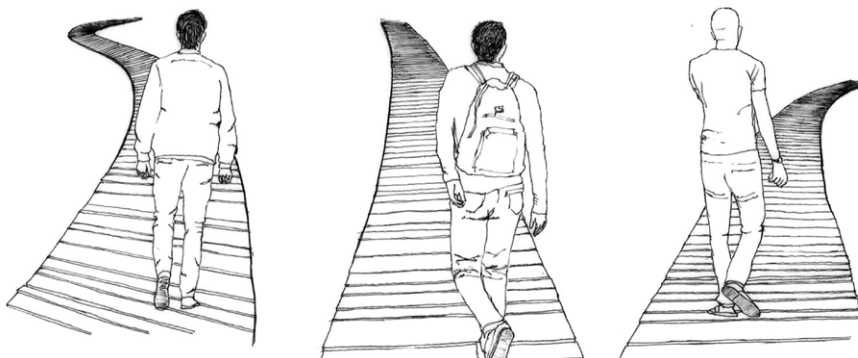
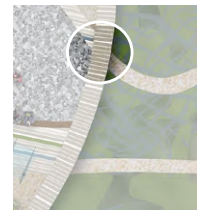
#### Purpose

- to ensure people walking on the beach can identify where the track reenters
- the stainless steel elements signals human intention to put it there ensuring people recognise it as a marker
- found low cost design allowing it to be rebuilt should major storm events require it

#### Specification Summary

- found logs from beach cut to 8m length and set in concrete block
- concrete block itself placed in a large gabion basket foundation filled with beach or river rocks
- sited just off the beach

### 14.3.16 Boardwalk



- NOTE image is indicative only

#### Purpose

- to ensure walking on boardwalks is kinaesthetically enjoyable, and encourages a sense of discovery
- let individual boards be inscribed with names of people who have significantly supported the project

#### Specification Summary

- DECKING made of varying width milled windfallen native timbers
- boardwalk understructure as per NZS3604, windfall totara preferred as substitute for treated pine subject to required engineer's report
- AVOID boardwalk being 1 metre or more in height above the ground
- as balustrading and engineer's specification required

#### Materials

- Local timbers
- Fixings

#### Construction

- Registered building practitioner to supervise

Local volunteer group to build

#### Detailed Design

- DESIGNLAB
- Engineer to sign off on drawings and Totara



## 14.4 Walking Track Implementation



**The Draft Master Plan** walks have now been 'ground-truthed' to allow for more detailed [GPS] mapping and costings. The combined Stage 1 and Stage 2 tracks cover a distance of approximately 2.5 kms, and are designed to showcase the transition from restoration plantings through to existing sand-plain forest together with the related interpretive opportunities. The tracks and structures will be built to Department of Conservation standards - with structures reflecting the high level of design consideration that underpins the whole project [see artist impressions].

There is no imperative that the stages be completed separately, but Stage 1 is designed to be a 'stand-alone' amenity should Stage 2 [and others] not progress.

**Stage 1** commences on the eastern side of the site and takes the visitor over/under SH6 on a 1.7 km loop that includes 165m of boardwalk through forested wetlands. This section wends its way through the Nikau Scenic Reserve which abuts the site to the south –here the forest includes beautiful old rata and is one of very few extant sand-plain forest remnants in the region. A short diversion provides access to the sweeping Pakihiroa Beach. [ Whilst an initial supporting opinion has been provided by DOC re. access through the Scenic Reserve, this will subject to a formal consent process].

**Stage 2** is a .8 km loop that leads the walker through two significant vegetation remnants - one a significant stand of stately Nikau palms. Throughout both stages, visitors will be encouraged to engage with the site beyond merely walking the tracks; innovative interpretive tools and citizen science stations will create a unique and memorable-visitor experience.

**Stage 3** will be linked to the development of the Discovery Centre, providing access to the Centre, Pakihiroa Beach and the proposed wetland restoration. [refer to Draft Master Plan, Page 5].

## 14.5 Continuing the restoration programme



As of August 2016, over 140,000 plants have now been established on the PCRP site. A key objective of the project has now been realized, with the 'blanket-planting' of the petrel flight-path and the re-creation of a hills-to-ocean forest. There remains however the opportunity to continue the restoration programme - planting and planting maintenance beyond the current partnership timeframe [end of 2016]. The scale of the planting programme would be dependent upon the timing of implementation of the Living Lab stages, as volunteers would alternate between track and restoration activities.



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