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# 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

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ABSTRACT

The Punakaiki Coastal Restoration Project (PCRP) is a case study in partnership and collaboration, which outlines how a consultative approach to mine closure can deliver shared benefits and create new endeavors that advance conservation, knowledge of biodiversity, and a broader understanding of the role of multi-sector partnerships. In 2000, Rio Tinto acquired 114 ha of coastal land at Punakaiki on New Zealand's South Island that had been the focus of a proposed mineral sand development, culminating in pilot-scale mining and processing by Westland Ilmenite Limited (WIL, part of North Ltd.), in the early 1990s. The site had been in care and maintenance from 1994. Rio Tinto instigated a process to ensure its approach to post-closure was developed and managed to meet its goal of contributing to sustainable development. Though much of the land has been cleared for pasture, the area is of high conservation value.

The Punakaiki Coastal Restoration Project (PCRP) was established in 2009 to enhance the revegetation of the sand plain forest on land adjacent to the Nikau Scenic Reserve that had been previously mined and farmed. To develop and test the indicators of restoration success, we performed interdisciplinary research in a) floral and faunal inventories and monitoring to determine characteristics of forest and disturbed environments at the species and community level, with a focus on the transition of these characteristics during restoration; b) pedology and soil chemical analysis was completed to identify potential variables that may influence the restoration of floral and faunal communities at the site.

Seven transects were established across the site: each comprising 3 monitoring plots (mature forest, unplanted and restored). Several significant ecological indicators were identified across these three monitoring plots. The future trajectory of restoration success will be determined by canopy closure and subsequent colonisation and recruitment of additional species, with epiphytes and plant associations being particularly critical. Soil profile pits were dug in each plot (21 in total) and the soil profile was described and sampled for chemical analyses.

This monitoring and interdisciplinary research programme has informed the restoration process on its trajectory from post-mining to farmed pasture to mature forest, beyond the initial establishment of 130,000 trees for 5 years. A multi-dimensional approach linking changing soil, vegetation and faunal communities, beyond a baseline survey and onward monitoring, provides an example of the best practice in restoration ecology. Future management of this site presents an opportunity to develop ecological, educational, and recreational values which are potentially beneficial to the local community through tourism. This research signals a paradigm shift in creative conservation through integrative restoration ecology that includes the floristic, faunal, geological and pedological components. This approach is readily transferable and could constitute a new standard for the next generation of restoration projects and national parks.



## 1. Introduction

The Punakaiki Coastal Restoration Project (PCRP) site is located on the West Coast of the South Island, New Zealand adjacent to several

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ecologically important sites; the Paparoa National Park, the Westland Petrel Specially Protected Area and the Nikau Scenic reserve (Fig. 1). The significance of this site to ecological restoration is threefold. Firstly, the Nikau scenic reserve is a remnant of coastal sand plain forest and secondly, the PCRP site is proximal to the only colony for the Westland Petrel (tāiko) — a sub-species of petrel listed as vulnerable on the IUCN Red List of Threatened Species. In addition, the site also contains a large stand of nikau palms and an ecologically diverse wetland area. This diversity of ecological habitats is a key to providing mature vegetation to act as ecological refugia and a source of plant propagules and stepping stones for fauna to colonize the site and to restore the post-mining landscape. This will also enhance the protection of the Westland Petrel's breeding habitat by restoring a corridor of native vegetation from the coastal margin to the mountains within the Paparoa National Park. Post-European settlement resulted in significant change in vegetation cover and land use within New Zealand. Many parts of the sand plain at this location were cleared for timber, mining or for farming. As a result, much remaining native vegetation is fragmented.

### 1.1. The partnership approach to mine closure

In 2000, Rio Tinto acquired 114 ha of coastal land at Punakaiki on New Zealand's South Island that had been the focus of a proposed mineral sand development. Pilot-scale mining and processing by Westland Ilmenite Limited (WIL, part of North Ltd.) occurred from 1966–1991. Initial mineral exploration during this time involved the evaluation of black sand deposits containing ilmenite, titanium and gold (Braithwaite and Pirajno, 1993). A joint venture launched in 1988 proposed to extract 50,000 tonnes of ilmenite for 5 years to test a new process to produce titanium dioxide. A 40,000 t $a^{-1}$ pilot plant was constructed in 1989 and pilot scale mining was conducted in 1990, producing 130 tonnes of ilmenite concentrate. More than 90% of the ilmenite resource is located south of the Nikau Scenic Reserve, and further resource evaluation and a feasibility study in 1994 concluded the project would not be viable using available technology. The site remained in care and maintenance from 1994 until acquired by Rio Tinto in 2000 (Rhodes et al., 2013).

The Punakaiki Coastal Restoration Project (PCRP) was established in 2009 to enhance the revegetation of the sand plain forest on land adjacent to the Nikau Scenic Reserve that had been previously mined

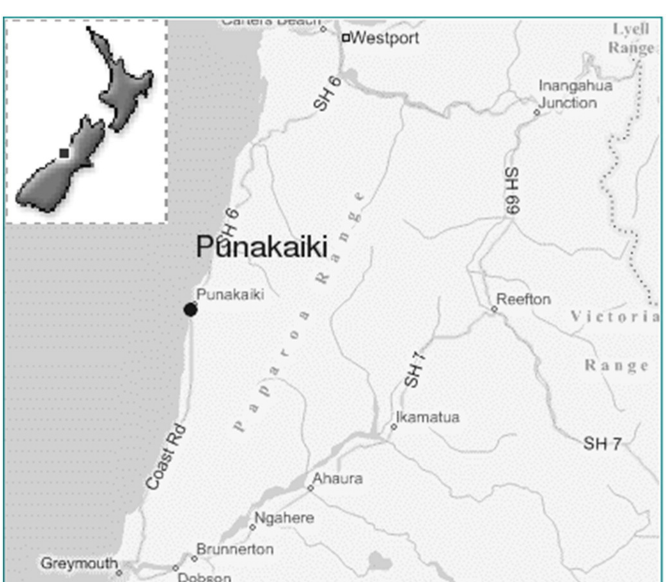


**Fig. 1.** Site location — Punakaiki, west coast of New Zealand's South Island.

and farmed. Rio Tinto instigated a process to ensure its approach to post-closure was developed and managed to meet its goal of contributing to sustainable development. A closure vision statement generated a clear set of closure objectives and an implementation plan: site decommissioning, documenting a legal partnership agreement and formal transfer of land ownership to the Department of Conservation (DOC). Additionally, the closure planning process identified unique intrinsic values (ecological and cultural) of the site. Though much of the land has been cleared for pasture, the area remains of high conservation value. The WIL land is adjacent to Nikau Scenic Reserve, located between the Paparoa National Park and the coastal dunes; contains remnant coastal forest and wetlands.

A partnership was formed between Rio Tinto, DOC, the New Zealand Department of Conservation, Conservation Volunteers (New Zealand) in 2009. The shared objectives for the project included ensuring a positive and lasting impact on the social, economic and environmental values of the location. The objectives were to restore the biodiversity of the area; develop an education and knowledge base to support species protection; strengthen community networks; build the capacity of community partners to engage with and use the site; and provide a "new heritage" of enhanced conservation land for the benefit of future generations. The Partnering Agreement provided a guiding framework. This defined the purpose and objectives for all parties; governance; use of intellectual property; financial arrangements; budget; communications; insurance; exit arrangements; planning for sustainability; independent review; dispute resolution and reporting; accountabilities and deliverables for each party. An annual Project Implementation Plan was developed, which specified the areas to be planted, the species mix, numbers of plants, plant ordering and supply from local "eco-sources", plant maintenance schedule, seed collection and propagation activities, criteria for assessment of success, and contingencies for replanting if required. The PCRP is a case study in partnership and collaboration; outlining how a consultative approach to mine closure can deliver shared benefits and create new endeavors that advance conservation, knowledge of biodiversity, and a broader understanding of the role of multi-sector partnerships.

In this paper we will report on two aspects of restoration: the development and testing of bio-indicators of restoration (informed by the results from a baseline survey of the ecology and soils); the value of collaborative partnerships in bringing about sustainable post-mining land use. We also explore concepts for engaging the wider community in active conservation activities, with a view to take sustainable restoration to a new level.

### 1.2. 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 (Fig. 2). 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 tectonic uplift (Braithwaite and Pirajno, 1993; Suggate, 1989). The prograding coastal sand plain has thus evolved

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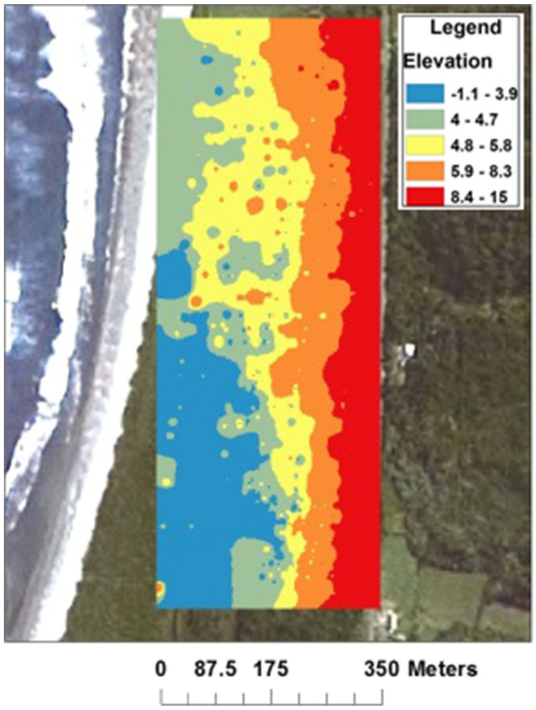


**Fig. 2.** Digital elevation model of the restoration area (m.a.s.l.). Alluvial fans are more prevalent in the northern part of the site (top portion), where the surface is more elevated.

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 (Eger et al., 2011; Hewitt, 1998; Wilms, 1985). At PCRP, soils are developed on a range of surfaces, of variable age and are summarized in Table 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.

## 2. Methodology

### 2.1. Baseline ecological survey

While restoration back to the original (pristine) landscape is often not possible, the broad aim for restoration practices must be in reestablishing fundamental ecological functions (Samways, 1999). In addition to scientific and technological aspects of restoration, it is also important to consider cultural aspects of landscape use. Sustainable public interest in a restoration project incorporating cultural aspects will foster long-term community engagement, sources of funding and provide educational opportunities. Effective monitoring programmes aim to select those species (indicators) that can act as a surrogate to represent the majority of flora and fauna. In turn, these indicators must reflect the quality of the habitat and its environment; reflecting both environmental stressors and conditions. Species diversity, vegetation structure and ecological processes are the most frequently selected indicators to determine restoration success (Ruiz-Jaen and Aide, 2005). The development of baseline information and monitoring procedures to be used for long term tracking of the restoration programme at PCRP focused on the key criteria that defined the restoration effort and also the indicators of its success. The aim was to provide an index of ecosystem functioning representative of a mature sand plain forest ecosystem. A baseline survey was conducted during 2012 and early 2013 to include the summer season (Hahner and Bowie, 2013).

A series of transects (Fig. 3) were established in 2011. Each transect consisted of three plots (M — located in mature forest, R — restoration areas planted, and U — unplanted/abandoned farmland). It was intended that each plot within a transect be located on the same land surface in order to minimize confounding variables such as soil age and soil type. Faunal inventory and monitoring was used to determine characteristics of forest and disturbed environments at the species and community level, with a focus on the transition of these characteristics during restoration. Restoration planting commenced at PCRP in 2009. Since then, in excess of 130,000 plants have been planted using 34 native species (see Hahner and Bowie, 2013) dominated by *Phormium tenax*, *Coprosma robusta*, *Coprosma propinqua* and *Aristotelia serrata*. The establishment of ground cover and the rapid trajectory towards canopy closure is evident in Fig. 4.

Baseline faunal ecological data was collected from each plot. Data was collected from surface dwelling invertebrates using two methods. Firstly, pitfall traps during two periods: 18 July–20 August 2012 (total

**Table 1**
Soil landscape relationships for the coastal sand plain system, PCRP.

| 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[a] | Orthic recent | Udipsamment | Recent soil with a weakly developed A horizon over C horizon |
| Young soils — less developed than Karoro | | | |
| 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[a] (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 ilminite 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 | Udiflurent | 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[a] (peat, with slight additions of alluvium) | Mesic organic | Haplohemist | Saturated weakly/strongly decomposed organic matter over sand |

[a] Soil series not present in Transects 1–7.

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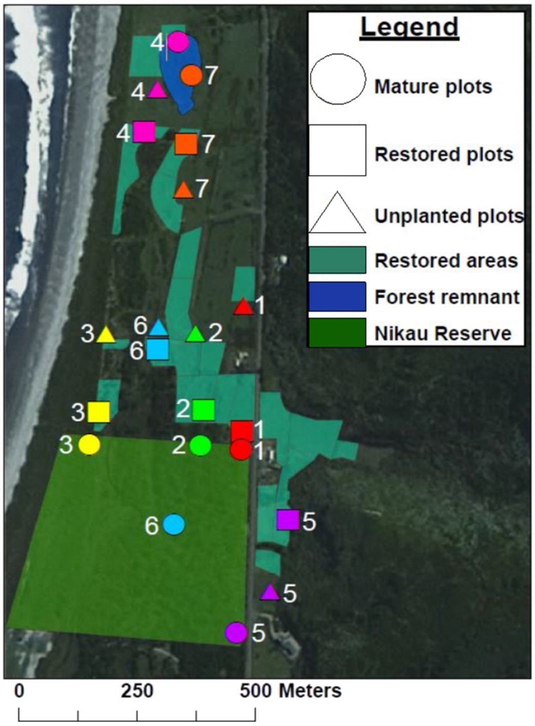


**Fig. 3.** Transect plot locations at the PCRP by colour. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

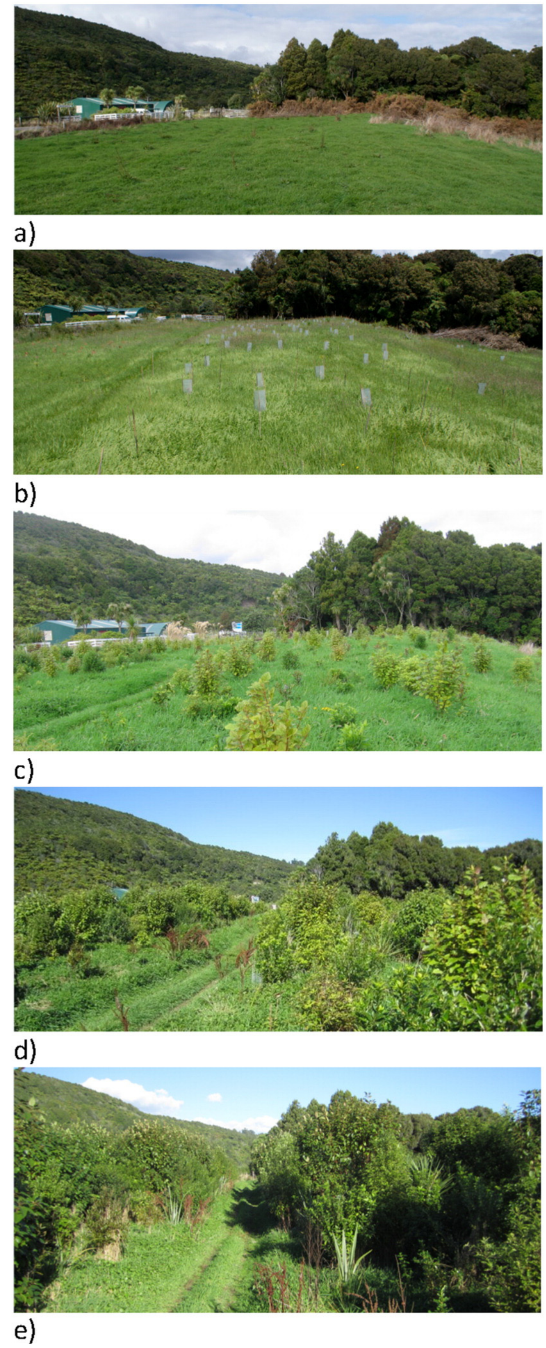


**Fig. 4.** Transect 1 looking south showing replanting of R1 a) April 2009, b) April 2010, c) March 2011, d) April 2012 and e) May 2013. Photo taken photo-point station 9 showing the Nikau Scenic Reserve in distance and CV(NZ) buildings adjacent to State Highway 6 far left. Transect 1 is located on the post-mid-Holocene sand dune.
Photos by James Washer.

of 33 days) and 17 December–9 January 2013 (23 days). Secondly, artificial habitats including wooden discs (Bowie and Frampton, 2004), tree mounted insect refuges (Bowie et al., 2014), corrugated lizard monitoring devices and synthetic bark tree wraps. Data was collected from these habitats on 19–20 July 2012 and 20–22 February, 2013. Leaf litter from each plot was collected using frames (placed using a statistically random location) and invertebrates were extracted in Tullgren funnels according to standard procedures. Native and exotic earthworms were collected in each plot by digging and careful hand sorting. Sampling occurred in August and September 2012 and January 2013. Samples of earthworm tissue were taken for DNA barcoding analyses in order to construct a phylogenetic tree, determine species boundaries and estimate the number of species present. Earthworm sampling data (abundance and biomass) was pooled for each transect and analysed using ANOVA and TUKEY tests with R software. Data on herbivorous insects within the vicinity of each mature and restored plot was collected using light traps at night between 12 February 2013 and 10 March 2013. Paired mature and restored plots were trapped simultaneously to remove environmental conditions. Moths were preserved and identified according to standard procedures. Five minute bird counts were completed in each mature and restored plot, following a modified method of Dawson and Bull (1975) (Hahner and Bowie, 2013).

Aquatic invertebrates were sampled from two sites within the PCRP. The first site was located where surface water flows out of naturally regenerating forest and the second site was located in a stream within the Nikau Scenic Reserve. Samples were collected using a D-shaped aquatic kick net, with the samples collected being subsequently sorted and stored in ethanol for identification. Fish trapping using 15 G-Minnow style live traps were carried out during 11–12 December 2012 within a drainage creek that flowed through mature, restored and unplanted plots. Fish caught were counted, photographed, measured for length and then released. Data on mammalian pests (brushtail possums, mice, rats and stoats) were also collected during November 2012 and 2, 3 April, 2013. Tracking tunnel transects were used; each transect consisted of 10 tracking tunnels spaced at 50 m intervals. Five transects were located in the PCRP; Nikau Scenic Reserve, the band of coastal vegetation and the elevated surfaces east of State Highway 6. These transects crossed through mature, revegetated and unplanted plots. Sampling methods were based on standard DOC operating procedures. Single sampling events occurred for arboreal geckos in the Nikau Scenic Reserve (February 2013) and for skinks within the western edge of the coastal band of vegetation (October 2012). A photographic record of fungi observed during the baseline monitoring period was compiled on NatureWatch NZ (www.naturewatch.org/) (date, location and species) (Hahner and Bowie, 2013). Data from these single sampling events are not included here.

A fundamental component of assessing the progress of a restoration programme is the comparison with a benchmark plant community. The Nikau Scenic Reserve provides a point of reference for soils, floral and faunal communities and will inform site management strategies encompassing plantings, and creating habitats to encourage invertebrate and avian biodiversity. The results of these vegetation surveys are detailed in Hahner and Bowie (2013).

*2.2. Soil profile description*

Soil pits measuring approximately 1 $m^2$ 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 (Milne et al., 1995). 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 (Blakemore et al., 1987). Sub-samples were oven-dried and subsequently microwave digested in a solution of 5 M $HNO_3$ and $H_2O_2$. 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 faunal communities at the site.

*2.3. Landscape design concept plan: "Punakaiki Living Lab"*

Formally gazetted in 1987, the Paparoa National Park (adjacent to the PCRP), is one of New Zealand's newest national parks. It is also one of the fastest growing in terms of visitors; recording similar numbers to Aoraki Mount Cook National Park. The Paparoa NP is notable for the wild coastlines, tropical palm trees, limestone formations and unspoilt forests. Research has shown that it is an integral component of the 3 day West Coast tourist experience. Yet despite its high destination appeal, café and accommodation structure, there are minimal concessionaire-based activities on offer. Commercial activities are thin, revolving around walks, self-catered meals and campervans. The tourist/visitor season is short — resulting in significant over capacity from April to November. The drive for national parks evolved from the 19th Century desires for scenery preservation to the 20th Centaury egalitarianism and values of outdoor education for all. However, current activities on conservation lands (walking, sightseeing, camping) no longer match the conservation-based benefits people value — such as protecting the plants, animals and the country's clean green image. Thus, a key challenge for national parks in the 21st century is how to support the experiences and activities that directly engage people with the action's that contribute to current conservation values and benefits (Abbott, 2014).

There is an opportunity for the long-term sustainability of the PCRP restoration programme to be enhanced by incorporating opportunities for long-term community engagement. An educational dimension to the PCRP could include the opportunity to experience environmental protection and restoration of biodiversity; facilitated and achieved through the active involvement of citizens and visitors. However in New Zealand, opportunities to become involved in conservation projects often involve passive participation (interpretative board walks) or longer term volunteer conservation projects. The PCRP offers the opportunity for active 'hands on' engagement for the local or international visitor on a short-term basis through participative activities such as planting, species monitoring, weed control and citizen science.

By actively engaging with conservation issues, visitors can leave both a positive impact on the environment, but can also take home not just pictures but knowledge, skills and ownership. This posits that "more-people-visiting-a-site" can be good for the environment. As an extension of the multidisciplinary research at the PCRP, landscape architects at Lincoln University created a concept plan for the "Punakaiki Living Lab". The concept plan incorporated active conservation activities within an interpretative boardwalk framework; allowing the opportunity for visitors and the local community to contribute to scientific conservation (Abbott, 2014).

## 3. Results and discussion

*3.1. Baseline ecological survey*

While ecological indicators will signal the overall trajectory of restoration success for the PCRP, canopy closure will be the precursor to the establishment and the recruitment of species. Implicit in canopy closure is the increase in both the amount of vegetation and the species composition, as well as an increase in surfaces available for invertebrate colonization. As the restored areas mature, changes in species composition occurred as a result of physical change within the vegetation composition and canopy and/or chemical changes in the soils. Certain species/communities typical of mature forest systems were detected in the restored plots, suggesting that not only could certain species be utilized as bio-indicators, but also that the mature forest areas act as valuable refugia for flora and fauna.

*3.1.1. Invertebrates*

The dung beetles *Saphobius edwardsi* and *Saphobius lesnei* were the most common beetle species trapped during the collection period; all three sampling dates showed significantly higher number in the mature sites (Fig. 5). The mature remnant containing M4 and M7 caught 79.7% of the total beetles and this imbalance is shown by the large standard errors (Fig. 4). It is very likely that the higher abundance of beetles in this remnant is a result of manure from cows using the trees for shelter. Orthopteran insects called weta were caught in pitfall traps consisted of one cave weta species (*Talitropsis sediloti*) and two ground weta species (*Hemiandrus* n. sp. and *Pleioplectron* n. sp. "black face"; Peter Johns, pers. comm.). All weta apart from a single specimen were caught in mature sites and therefore show significantly higher weta abundance over three sampling periods (Fig. 6). Leaf litter extracts yielded approximately 35 species (Recognisable Taxonomic Units) of mites, dominantly Oribatidae. Seven species were found to be largely in the mature forest leaf litter (Fig. 7). Two Oribatidae (RTUs 4 & 6) and two Uropodina (RTUs 7 & 16) look to be the most reliable two indicators due to their presence in mature sites for more than 60% of the time on average.

*3.1.2. Earthworms*

Based on DNA barcoding analyses, a total of 10 native and four exotic species were collected from the study area (Fig. 8). Exotic species were *Dendrobaena octaedra*, *Lumbricus rubellus*, *Amynthas corticis* and *Octolasion cyaneum*. Native earthworms were mostly undescribed

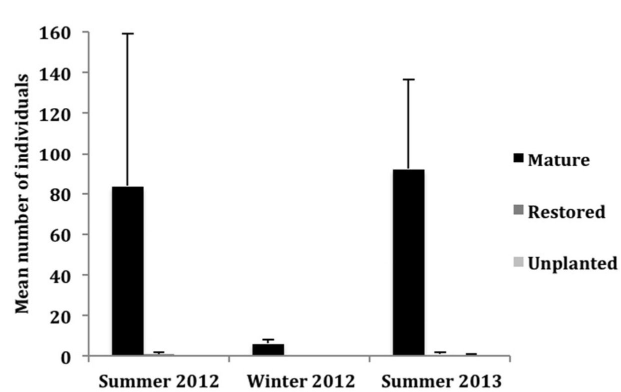


**Fig. 5.** Mean dung beetle abundance from pitfall traps in transects sampled on three occasions (±s.e.).

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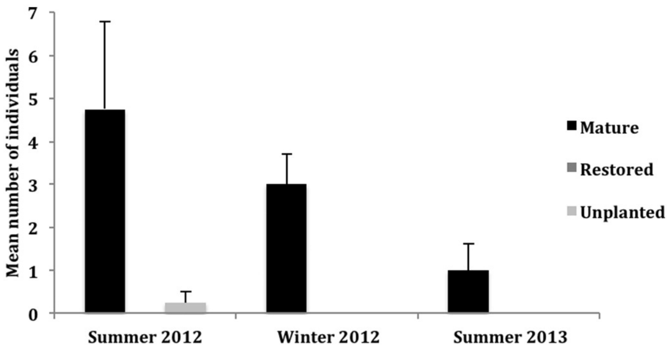


**Fig. 6.** Mean weta abundance from pitfall traps sampled on three occasions (±s.e.).

species. There was significantly less earthworms (mean total abundance) in the mature sites than in both restored ($P < 0.001$) and unplanted sites ($P < 0.001$). Exotic earthworms were more abundant in unplanted and restored sites compared to mature sites ($P < 0.001$). Differences between earthworm abundance in restored and unplanted sites were not significant ($P > 0.05$). Similar trends were observed for earthworm biomass except that Restored areas had higher biomass than Unplanted areas with marginally significant difference ($P = 0.09$) (Fig. 8). It is possible that higher earthworm biomass may lead to higher ecosystem services provided by the earthworm community (organic matter decomposition, topsoil formation, soil mixing, increase of soil fertility and provision of food source for predators (Boyer and Wratten, 2010)).

The proportion of native versus exotic earthworms between the three plots varied in both abundance and biomass ($P < 0.001$), with significantly higher proportions of natives in mature sites than in restored and unplanted sites ($P < 0.001$) (Fig. 8). Although initial results indicated an intermediate level of natives in restored sites (Bowie et al., 2012), here we find no differences in the proportion of natives in restored and unplanted sites (abundance: $P = 0.75$, biomass: $P = 0.88$). However, when taking into account the time elapsed since commencement of restoration, there is an increase of the proportion of native earthworms with time. Earthworm communities and particularly the proportion of endemic earthworms, could be a valuable indicator of restoration success; however the increase in native earthworms is only visible after 3–4 years of restoration.

### 3.1.3. Herbivorous insects

Moths caught from light traps were used as the measure of herbivorous insects present in mature and restored sites with a total of 42 moth species identified. Greater numbers and species diversity were collected in the restored areas (Fig. 9); this could possibly be a reflection of the

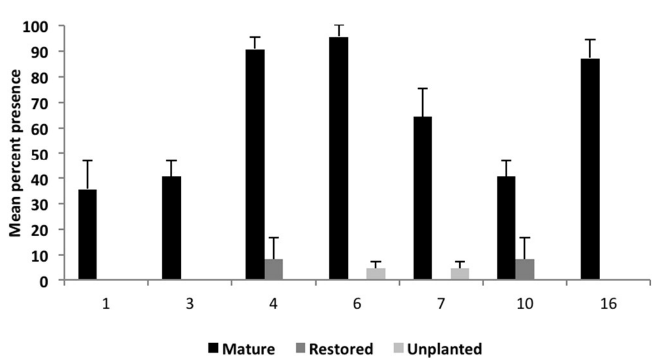


**Fig. 7.** Mean presence of mites identified as indicator species over three litter samples across mature, restored and unplanted transects (±s.e.). Mites are identified according to the Recognisable Taxonomic Unit (RTU) where RTU 1 is Oribatida; RTU 3 is Parasitengone Velvet mite; RTU 4 is Box Oribatida; RTU 6 is Oribatida; RTU 7 is Trachytidae Uropodina; RTU 10 is Uropodina and RTU 16 is Uropodina.

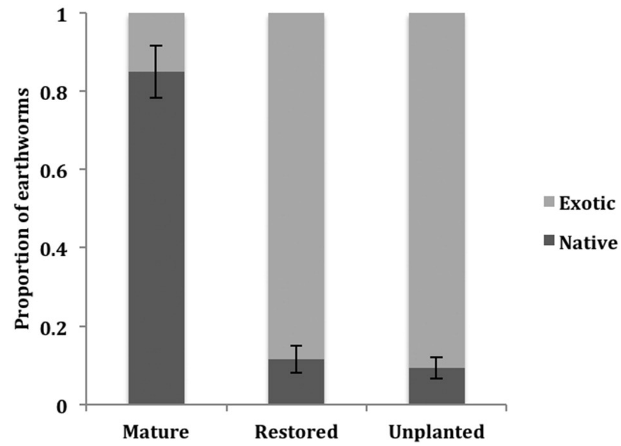


**Fig. 8.** Proportion of exotic or native earthworms in mature, restored and unplanted areas (mean ± s.e.). Data were pooled per transect i.e. three soil samples.

openness of these sites compared to the denser and darker mature sites (which would experience reduced light ingress).

The results indicated suitable bio indicator moth species (indicative of open grassland habitats) included the following: *Cydia succedana* (gorse pod moth), grass larval moth species *Orocrambus flexuosellus* and *Orocrambus ramosellus*, and pasture pests known as Porina (*Wiseana copularis* and *Wiseana umbraculata*). From the five species above 55 moths were recorded from the restored sites compared with only a single moth in the mature sites. Species considered to be good indicators of mature sites would include moth species which larvae feed specifically on natives found in bush and would include the following: *Aciptilia monospilalis*, *Anisoplaca achyrota*, *Chalastra perlargata*, *Cnephasia jactatana*, and *Feredayi graminosa*. All of these species were found in the mature sites.

### 3.1.4. Bird counts

Six and seven native species were recorded in the restoration plantings and mature sites respectively. The weka and the shining cuckoo were the two species found in the mature sites but not in the restoration sites during the counts; however weka are often seen in all parts of PCRP sites. Moreover, kereru were recorded in five minute bird counts in restoration plantings but not in mature sites, even though they are regularly seen and heard in most areas. These results are most likely to be indicative of a lack of monitoring sessions to pick up the more common species. Seasonal bird surveys reveal that native bird species prefer mature forest plant communities, while exotic bird species prefer the restored habitats (Fig. 10). This difference could be due to the contrast of floral communities between open and non-mature planting areas compared to mature native New Zealand forests. Many of the exotic bird species originate from Europe and have evolved with the European plant

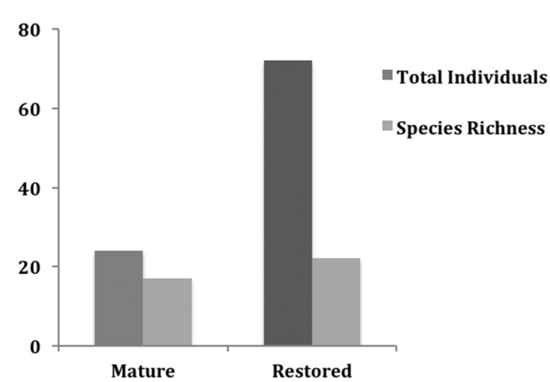


**Fig. 9.** Light trap results from 14 locations.

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species where they feed on seeds found in the abandoned pastures. Likewise, native New Zealand bird species would have evolved with native New Zealand plant species found within mature New Zealand forests. Specific dietary and habitat requirements define each species preferred habitat type. However, this does not mean that birds will not frequent a different habitat type. With the maturing of the restoration plantings, these areas will begin to develop more of the attributes of a native mature forested habitat. This process has already started with more native birds been attracted.

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

### 3.1.5. Aquatic invertebrates

Indicators based on mayflies, stoneflies and caddis flies in sample (%EPT) reveal differences in water quality between altered and natural streams. Aquatic invertebrate indices indicated degraded stream conditions within the restoration area. Samples taken from the Restoration area sampling sites produced a greater number of individuals yet a lower species richness was found. This can be mostly attributed to large numbers of molluscs such as snails as well as dragonfly and damsel fly larvae sampled within the Restoration area sites. The Macroinvertebrate Community Index (QMCI) (Stark, 1985) was developed to assess the health of New Zealand's streams through the use of a quantified system of aquatic invertebrate indicators based on tolerance to water and habitat quality. The most sensitive taxa are given an index score of 10 and taxa that can survive in the poorest quality water are given a score of 1. The Restoration Planting sampling site scored a lower QMCI rating than the other two sampling sites. This was due to the larger number of snails (scored 3–4) sampled in this location. An aquatic health index based on the percent of mayflies, stoneflies and caddis flies in sample (%EPT) also reveal differences in water quality between the altered and natural streams (Fig. 11). These species are sensitive to water quality and a high abundance of individuals indicates a healthy system.

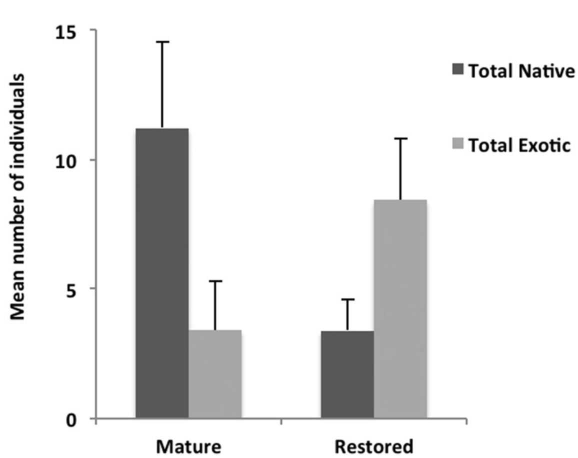


**Fig. 10.** Means of eight bird observation sampling events at six sites over 3 seasons (± s.e.).

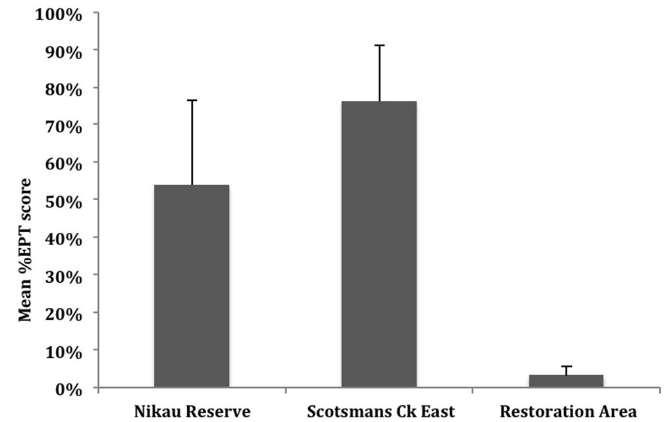


**Fig. 11.** %EPT taxa for aquatic invertebrates (± s.e.).

### 3.1.6. Fish diversity

Within the restored and unplanted trapping locations, similarities in fish species abundance and richness were seen. Here, the majority of the fish caught were Inanga (*Galaxias maculatus*) with one Shortfinned eel (*Anguilla australis*) caught within the unplanted area. Fish trapping within the mature forested area revealed a change in individual abundance and species composition with a greater abundance of Banded kokopu (*Galaxias fasciatus*) as well as a Giant kokopo (*Galaxias argenteus*). Some Inanga were still caught.

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

## 3.2. 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 1.

Soils for this area of the West coast have been described by Mew (1980), Laffan (1980) and Wilms (1985). Mew (1980) identified two soil series 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.

**Table 2**
Soil series present in each plot, per transect.

| 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 |

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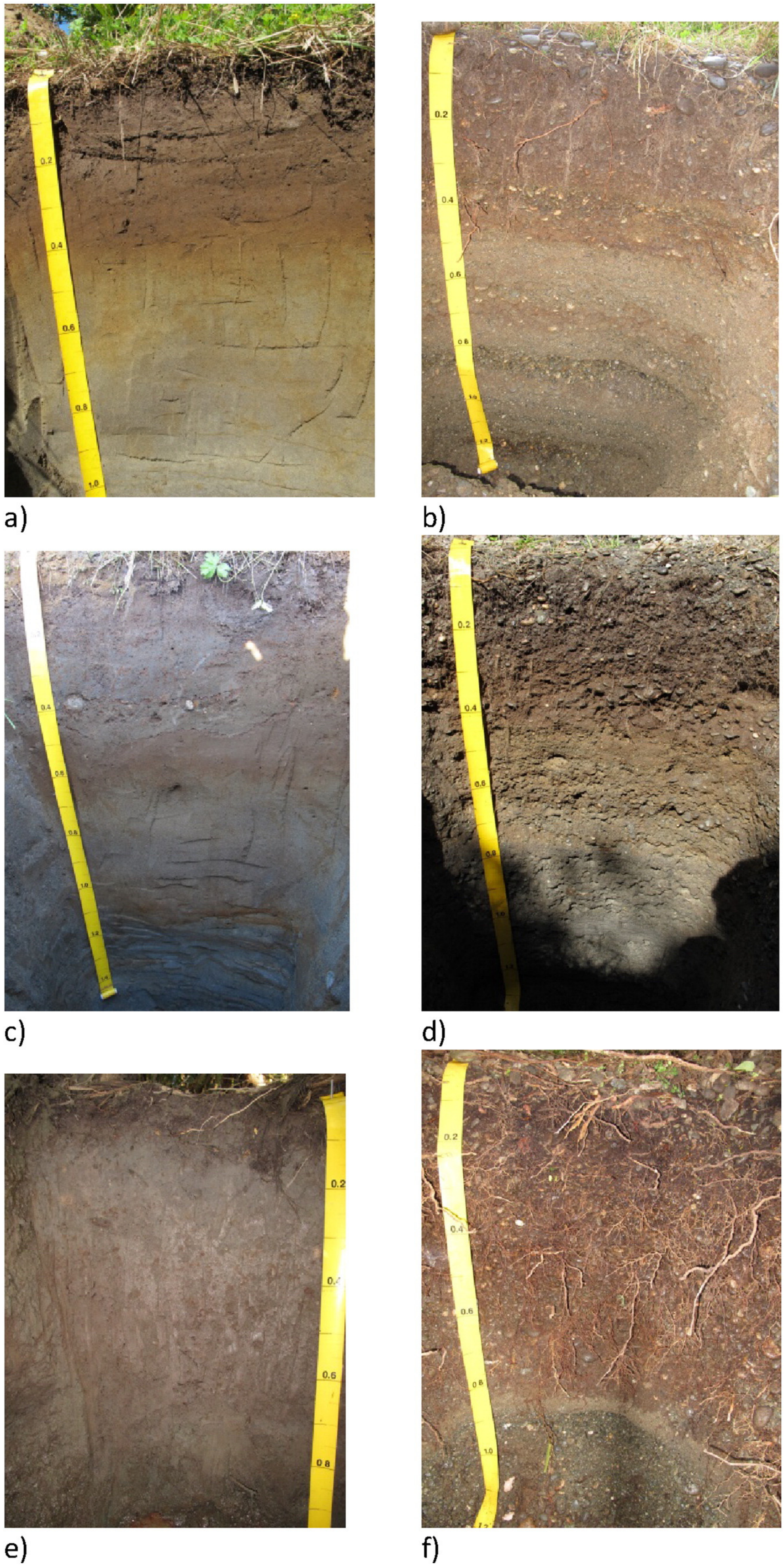


**Fig. 12.** a) to e): Soil profiles from treatment plots on chronosequence of Transect 1 (oldest sand dune shoreline — Mahinapua soil series) and Transect 3 (youngest gravel ridge — Karoro soil series). a) Restored 1, b) Restored 3, c) Unplanted 1, d) Unplanted 3, e) Mature 1, and f) Mature 3.

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Laffan (1980) identified three soil series defining a 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 iron pan developed below the A horizon). Wilms (1985) sought to combine these differing interpretations and these are incorporated in Table 1. Furthermore, Wilms (1985) identified that Karoro was the dominant soil series developed on the coastal sands (in the vicinity of the PCRP). He noted that inclusions of Okari could 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 2.

#### 3.2.1. 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 (Fig. 12a, 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 organic matter from U3, to R3 and to M3. As with M1, the deepest B horizon exists in the M sites (Fig. 12b, d, f).

#### 3.2.2. 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.

#### 3.2.3. 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.

#### 3.2.4. 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 including large clasts or cobbles. Regular flooding events from the creeks depositing alluvium will also bury existing land surfaces. Buried soils are evident at 25, 58 and 83 cm depth in profile U2.

### 3.3. 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; Fig. 12). Data from the Ah and Bw horizons of Transects 1 and 3 are presented in Table 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

**Table 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).

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

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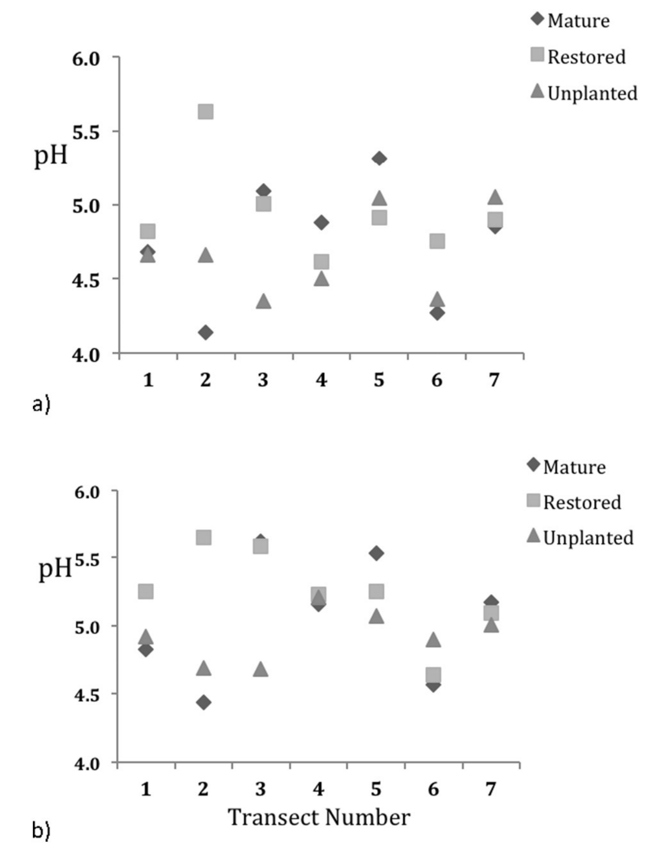


**Fig. 13.** Soil pH in a) upper (Ah) and b) lower (Bw) horizons, across the 7 transects in mature, restored and unplanted plots. a) Ah horizon and b) Bw horizon. Refer to Table 2 for transect soil details.

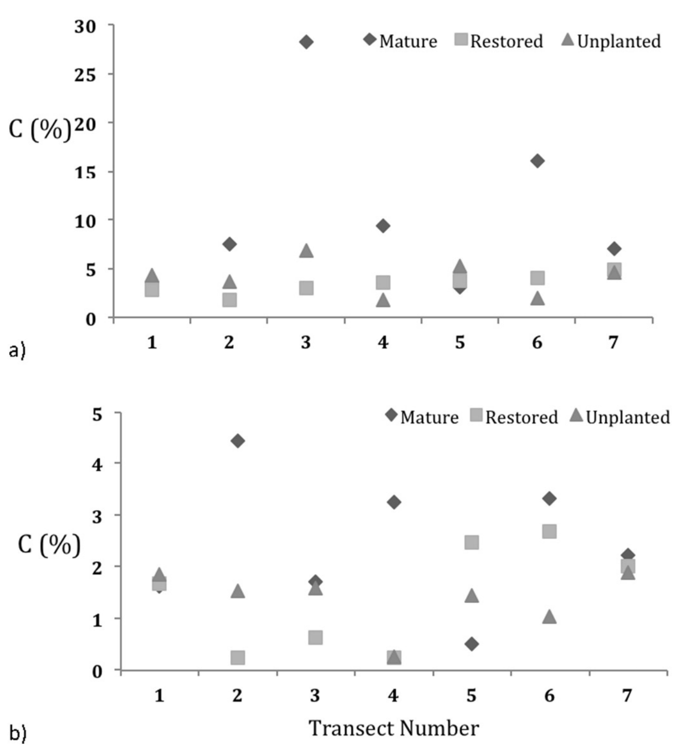


**Fig. 14.** Total carbon concentrations in a) upper (Ah) and b) lower (Bw) soil horizons, across the 7 transects in mature, restored and unplanted plots. Refer to Table 2 for transect soil details.

contrast, potassium and magnesium concentrations were lower in Transect 1.

When we examine the soil chemistry data from all transects, the soil variability across the PCRP site tends to outweigh the three treatment variables within each of the seven transects. The values for soil pH (Fig. 13) 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 (Fig. 3).

Total soil carbon concentrations (Fig. 14) 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 (Fig. 15a and 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 (Fig. 15c).

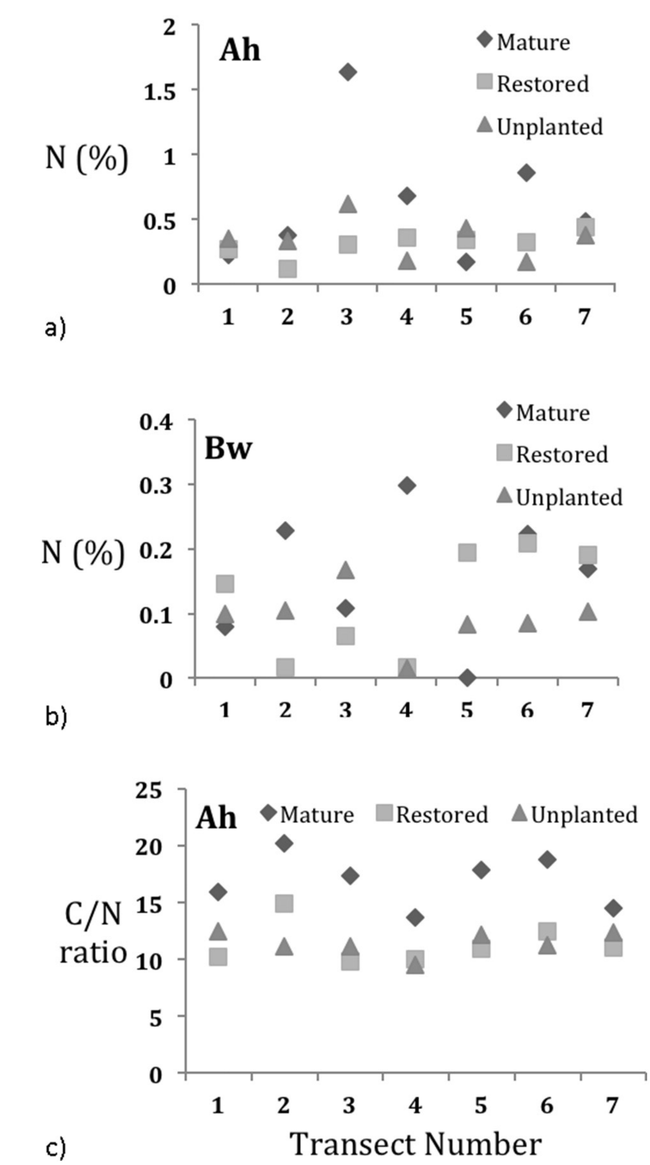


**Fig. 15.** Total nitrogen concentrations in a) upper (Ah), b) lower (Bw) soil horizons, and c) soil C/N ratios (Ah only) across the 7 transects in mature, restored and unplanted plots. Refer to Table 2 for transect soil details.

Lower concentrations of P in mature plots, were only evident in plots on eastern side of the Nikau Scenic Reserve (Fig. 16c). 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 (Fig. 16a, 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.

A number of other patterns of dispersion of soil chemistry data are evident across the site. Sodium (Fig. 16f) 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 (Fig. 17).

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-

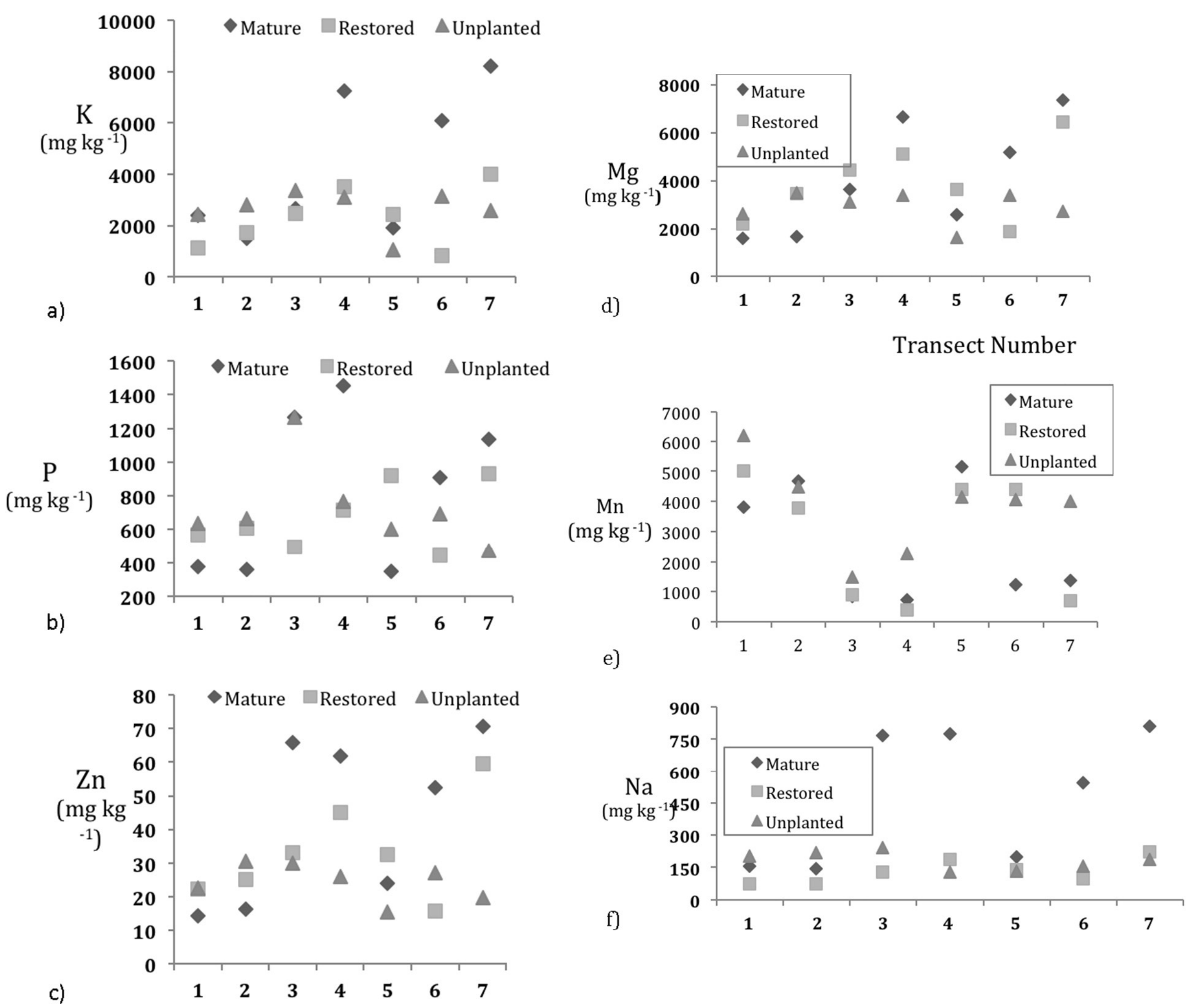


**Fig. 16.** Total concentrations for a) P, b) K, c) Zn, d) Mn, e) Mg concentrations and f) Na concentrations in upper (Ah) soil horizon, across the 7 transects in mature, restored and unplanted plots. Refer to Table 2 for transect soil details.

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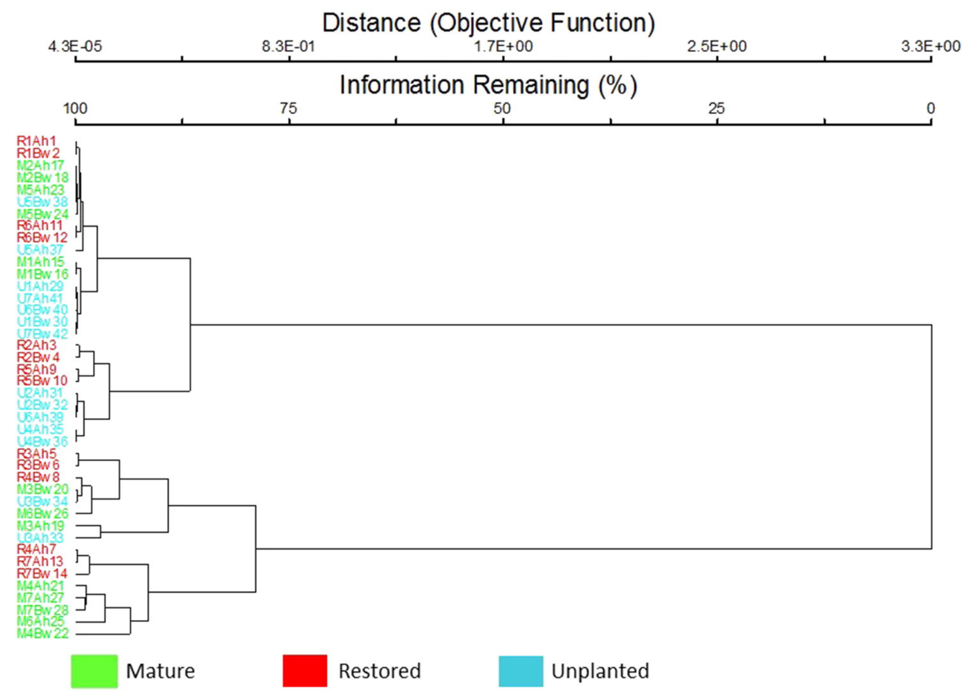


**Fig. 17.** Dendrogram using hierarchical clustering of the soil chemistry data set for the Ah and Bw soil horizons. Algorithms are used to connect objects to form clusters based on their distance; the y-axis marks the distance at which the clusters merge. R, M, and U refer to restored, mature and unplanted sites respectively.

litter invertebrates and birds. These mobile fauna can quickly become established in suitable ecological niches within the PCRP. 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 plots will 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.

### 3.4. Concept plan — "Punakaiki Living Lab"

The "Punakaiki Living Lab" encapsulates the concept of the opportunity for active visitor participation and engagement in scientific research — citizen science — alongside university research programmes.

State Highway 6, the main tourism and transport corridor for the West Coast, bisects the PCRP. It is the potential gateway to enter the PCRP, with 340,000 vehicle movements per annum. The volume of traffic and extensive roadside boundary means there are multiple opportunities for visitor engagement through signage, planting maps and mobile apps.

Gateway facilities will include a visitor centre, nursery and an arboretum. Radiating out from here, visitors can walk to the site and interpretative boardwalk via a footbridge, spanning SH6. The boardwalk will follow a series of loops through the Nikau Scenic Reserve and the different components of the PCRP. Throughout the walk, there will be opportunities for citizen science involving project information, restoration activities, pest monitoring and eradication. In this context, citizen science would involve visitors collecting and analysing data from the PCRP, thus being part of a collaborative scientific project, run by professional scientists.

The gateway facility would also lead to a track and viewing platform. This would enable the public to view the restoration of the area as well as the petrels in flight over the site as they make their way in from the sea to the colony at dusk. Nestled within the northern part of the PCRP, there would be a Discovery Lodge — offering the opportunity for smaller groups (volunteers, university students or school groups) to spend more time at the PCRP site. This would allow opportunities for night time conservation activities such as moth trapping, spotlight surveys of fish monitoring penguin activity and invertebrate monitoring walks (Abbott, 2014).

## 4. Conclusions

The future trajectory of restoration success at PCRP will be determined by canopy closure and subsequent colonization and recruitment of additional plants (particularly epiphytes) and animal (bird and invertebrate) species. Studies showed that epiphytes and plant associations are particularly critical in this regard (Hahner and Bowie, 2013). In the oldest restoration planting canopy closure, leaf litter accumulation and plant surfaces available for colonization are precursors to enhanced diversity. Elsewhere, mature stands of gorse provided a nursery resource for 23 native plant species. Indicators of restoration success identified at this stage of the process included dung beetles, weta, moths, leaf litter invertebrates, and birds: all indicative of mature forest sites. Native and exotic earthworms appear to have distinct habitat preferences, and demonstrate a transition of suitability within the restoration planting areas.

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 timeframe, or else that restoration work has been carried out in parts of the site

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that are chemically distinct. Further research is already underway to explore this further.

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.

In terms of the efficacy of a collaborative partnership approach between Rio Tinto, CVNZ, DOC and Lincoln University, the PCRP is a case study in the commitment to sustainable development through demonstrating leading practice in closure, biodiversity conservation and working with communities. This partnership brought together corporate, government and non-government organisations. There was a commitment to transparency, good governance, and appropriate resourcing. The legacy of this work is the development, protection and management of a unique biodiversity asset. It is clear that for the PCRP, benefits from the partnership approach outweighed any direct returns from options such as sale of the land. Future management of this site presents an opportunity to further this legacy by developing ecological, educational, and recreational values and potentially benefit the local community through tourism. A multi-dimensional approach linking changing soil, vegetation and faunal communities, beyond a baseline survey and onward monitoring, provides an example of best practice in restoration ecology. This research aims to demonstrate an approach to creative conservation through integrative restoration ecology that includes floristic, faunal and pedological components. We believe this approach is readily transferable and could constitute a new standard for the next generation of restoration projects.

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