ARE RESTORATION PLANTINGS AN ECOLOGICAL SUCCESS?

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TESSA LOUISE ROBERTS

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Abstract

Ecological restoration is a rapidly expanding practice that has developed in response to worldwide loss of habitat and ecosystem services. However, the success of this practice in restoring a functioning and representative ecological system remains poorly studied and uncertain. This is due to several factors predominantly, restricted funds, a knowledge gap between practitioners and the developing scientific field of restoration ecology, and the length of time it takes for some ecological systems to recover. In New Zealand restoration planting has occurred in large areas since the 1980s. These have now established canopies with unassisted seedling regeneration, making predictions of successional trajectory and ecological success assessments possible.

The ecological restoration of forests is most commonly carried out through dense planting of native seedlings. This study aims to measure the ecological success of this planting method within New Zealand lowland podocarp-broadleaved forests comparing it with a 'do-nothing' control site undergoing unassisted secondary succession and a reference site of the desired target community (mature lowland forest). Restoration success was determined by the Planted Site being closer than the Spontaneous Succession Site to the Reference Site in vegetation community composition within ordinational space (principal coordinates analysis).

It was found that the vegetation community within the Spontaneous sites was more comparable to the Reference sites than the Planted sites and thus, more successful. The compositional differences between the spontaneous and planted sites were further investigated by analysing environmental and structural variables of each site sampled to find explanatory variables that may be driving the success of forest restoration (in directing the successional process towards the desired target community within a reference site). A nested multivariate analysis of the plot data and generalised linear modelling of each site was carried out to find potential explanatory variables which highly correlated to restoration success (how close a site was to its reference).

Potential explanatory variables correlating to restoration success included; a lower diversity (Shannon Wiener Index) in the restoration plantings in both species richness and within the structural and function classifications of each species; a greater diversity of vegetation tiers; a fewer number of stems at breast height per individual tree; shorter canopy heights; smaller canopy diameters uncompacted soil; a greater diversity in microtopography; and a greater coverage of ground ferns.

These explanatory variables were then modelled using Akaike's Information Criterion to identify both descriptive and driving parameters. The Akaike models identified 16 different parameters as related

to the compositional differences when plotted in ordination space. High diversity within all three measured attributes (composition, structure and function) and presence of ferns are clearly descriptors of the success of Spontaneous succession here, while lessor soil compaction and diversity in microtopography at the site could be drivers. This success is demonstrated by soil compaction and a diversity in each of the species attribute classifications of structure, function and composition.

In conclusion spontaneous succession was found to be more successful. This is likely due to uncompacted soils, a greater microsite variation, a higher diversity of species, functional groups and structural characters. Further, the secondary successional dependence on functioning soils is confirmed here, as well as the presence of indicator species such as ground ferns. Management implications of these findings suggest passive restoration methods should firstly be considered in forest restoration. If in addition, planting is also considered necessary, accelerating and directing secondary succession requires more attention to pre-planting preparation of sites and of species selection.

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Chapter 1:

General Introduction

"We need to consider, and experiment with, novel approaches to ecosystem management that focus on desired outcomes or trajectories, rather than simply taking preventative or therapeutic measures"

(Seastedt, Hobbs, & Suding, 2008, pg 1)

INTRODUCTION

General rules of ecological theory apply to successful restoration implementation. These predominantly involve the ecological fields of ecosystem dynamics, disturbance ecology and community assemblage (Stanturf, Schoenholtz, Schweitzer, & Shepard, 2001). As restoration requires an ecosystem shift from damaged, degraded or destroyed towards functioning and representative, knowledge of ecological succession or ecosystem dynamics is vital to appropriately guide this transition. Restoration practitioners must assist the natural process of succession towards the target reference system with activities that either restart, quicken, or redirect (or some combination of the three) the successional trajectory in the right direction (Holl et al., 2009).

Succession is defined as “a sequence of species that successively invade a site” (Clements, 1916). Forest succession is the process from which new substrate, bereft of any life is colonised and develops into a mature forest (in the case of Primary Succession), or when a disturbance occurs to a vegetation community that takes it back to an earlier sequence of species (Secondary Succession). The process of succession "heals" a damaged site or fills a vacant space in nature. However, this process is shaped through the unique constraints depending on site location, time of disturbance, and the wider environment. It is this process which humans attempt to mimic and even accelerate in the context of restoration plantings.

While primary succession, is reasonably well documented, few studies have been made of the initial phases of secondary succession and even less of secondary succession following an anthropogenic disturbance. Secondary succession is directed at two spatial scales through the wider-landscape, by variables associated with propagule dispersal into a site, and through within-site variables, associated with how amenable the site is to arriving propagules in terms of their survival, establishment and growth. Forest restoration is a form of assisted secondary succession, which contains an additional directive, the people carrying out restoration. Restorationists further direct the process of secondary succession through actions that either add desirable species, remove undesirable (pest) species and manipulate the amenability of the site through actions such as tilling the ground, fertilisation or irrigation.

Forest restoration is largely carried out through the addition of species, by planting tree seedlings. This method of restoration, while having many social benefits, is extremely resource intensive and has a poor success rate. With advances in restoration ecology theory, the necessity of such widespread use of planting in restoration has recently been called into question. Other methods which concentrate on removing undesirable species and/or creating a more amenable site have been proposed as suitable, or even preferable to planting within certain environments.

The Society of Ecological Restoration (SER) defines restoration as “assisting the recovery of an ecosystem which has been degraded, damaged or destroyed”. Recovery is said to be achieved when the restored site is comparable to a reference sites in its structure, function and resilience to natural disturbance regimes (SER, 2004). This definition has somewhat evolved since the beginning of restoration, which focused on restoring the “biotic communities that were formerly present at a particular place and time” (Atkinson, 1988). It is now recognised that restoration of this original state is unattainable and potentially un-sustainable in the context of the current environment.

Of all restoration efforts currently employed, the majority of these involve forests, with the objective of reducing the loss of biodiversity and increasing both carbon stocks and ecosystem resilience. Large scale international commitments in forest restoration have been made, including the Bonn Challenge, the New York Declaration on Forests, the Latin American Initiative 20×20, and the African FLR Initiative (Chazdon, 2013) – all intending to restore over a billion hectares of forest worldwide. In addition to increasing scale, restoration projects are becoming more complex with the growing pressure of global warming, invasive species, anthropogenic pollution and fragmentation. Given these facts, there is a rising need to find both effective and efficient restoration methods in order to achieve the aforementioned benefits (Keenlyside, et al., 2012).

Forest restoration is achieved, both historically and currently, largely through direct planting (Holl & Aide, 2011). While numerous social benefits no doubt result from this method (Buchan, 2007), ecological planting is a resource intensive option (Carswell, et al., 2012) with ecological success, in terms of restoring a self-sustaining ecosystem of representative structure and function, poorly studied (Ruiz-Jaen & Aide, 2005) and therefore largely unknown. The consequence is that, to date many restoration projects are *ad hoc* and undertaken using practices unfounded in ecological science and more akin to the practice of gardening (Hobbs, 2007; Jordan, 1997) or silviculture (Holl & Aide, 2011).

Planting seedlings is a method of active restoration. Material or organisms are added to the restoration site, generally planting late seral tree seedlings aiming to bypass the earlier scrub phase (Palmer et al., 1997), and accelerate the successional process toward the desired stable mature forest system. This practise began in New Zealand on offshore islands in the 1960’s, followed by mainland projects a decade later (Atkinson, 1988), although an extensive indigenous planting in the Manawatu was first established in 1954 by Mr Michael Greenwood, (Greenwood) which is still monitored today.

In contrast, passive or spontaneous restoration or natural recovery involves removing the disturbance from the area that is preventing the spontaneous or natural process of ecological succession, for example removing grazing or pest species from the site. Which strategy is needed in a restoration project, active or passive, or a mixture of both, depends on the harshness of the site, with the need for active means increasing with the severity of the barrier to spontaneous succession.

Assessment of ecological restoration success is important to both justify resources spent, improve on current restoration practice and to feedback any learnings into restoration ecology theory. However assessing the ecological success of forest restoration plantings has in the past been limited (Ruiz-Jaen & Mitchell Aide, 2005; Temperton, et al., 2013). This is likely due to the immaturity of restored systems, which need time to develop ecological structure and processes, in conjunction with the relative immaturity of the theoretical field of restoration ecology which arose in the late 1980's (Choi, 2004), as well as lack of scientific initiatives and funding.

Despite restoration ecology being a rapidly expanding field with models and frameworks to direct effective restoration, the application of successional theory is slow (Halle, 2007; Walker et al, 2006) and there is still a perceived and very real gap between the best practice theory seen in the literature and what is applied on the ground (Clewell & Aronson, 2013; Falk, Palmer, Zedler, & Society for Ecological Restoration International, 2006; Halle, 2007; Temperton, Hobbs, Nuttle, & Halle, 2013). Now with increasing understanding of ecosystem dynamics and processes there is a worldwide trend toward a more contemporary and functional objective of restoring working ecosystems.

AIMS

This research aims to evaluate restoration success in the context of lowland podocarp broadleaved forest in New Zealand, both the most widespread and the most widely restored forest system. The issue is how to test for success, and the approach taken here is to compare restoration plantings with nearby spontaneously succeeding sites, both with respect to the planting goal, the creation of normal, fully-functioning forest. Tools will be compositional studies along with aspects of system functioning. From these studies conclusions re the role of succession in restoration will be drawn.

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Chapter 2:

Is restoration planting an ecological success?

A vegetational evaluation

"Our job is to sharpen our tools and make them cut the right way… [T]he sole measure of our success is the effect which they have on the forest."

(*Aldo Leopold, 1913)*

ABSTRACT

Ecological restoration is a rapidly growing worldwide movement, aimed at combating the decline of ecosystems and the services they provide. Ecological Restoration involves assisting, through purposeful manipulation, the process of ecological succession. Recovery is achieved when the restored site is comparable to predefined reference sites in biological composition, structure, function, and resilience to natural disturbance regimes. Restoration of forest systems is most commonly carried out by planting seedlings. However, this is a highly resource-intensive method, with a high failure rate and little known about its long-term ecological success. This study investigates the ecological success of eleven restoration plantings in podocarp forests throughout lowland New Zealand. The success of each restoration planting is defined by similarity to a reference site of mature forest and compared to a 'do-nothing" counterpart of a nearby area undergoing unmanaged spontaneous succession, and of a comparable age. The success in restoration plantings was limited in comparison to their spontaneous counterpart, in measures of structure, composition and function. Analysis involved assessing differences in comparative composition using ordination. Spontaneous treatments were closer to the reference vegetation than planted treatments, dominated by *Kunzea ericoides*, *Leptospermum scoparium*, *Myoporum laetum*, *Podocarpus totara* and *Pittosporum tenuifolium*. The shrub layer of planted treatments had half the cover of spontaneous treatments, and ferns were an order of magnitude more common in spontaneous treatments. Spontaneous treatments were closer to their reference in terms of soil characteristics, tree growth, ground cover types, species' cover, seedling richness and Specific Leaf Area. Managers of future restoration projects are encouraged to first assess the potential of utilising natural recovery processes (spontaneous succession), proposing the use of reconstruction (planting) approaches only when extreme barriers to natural succession indicate it might be necessary.

Keywords: Ecological Restoration, Forest Restoration, Succession, Reconstruction, Spontaneous Succession, Temperate Forest

INTRODUCTION

Ecological restoration is defined as assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER, 2004). In response to ecological destruction, the practice of ecological restoration has grown rapidly. Currently, over 100 billion USD per annum is spent on forest restoration groups around the world (Jones et al., 2018a; Mansourian, Stanturf, Derkyi, & Engel, 2017).

Forest restoration, both historically and currently, is predominantly achieved through the direct planting of seedlings (Shoo & Catterall, 2013; Young, Petersen, & Clary, 2005). This method is also referred to in the literature as reconstruction (Hobbs, 2007) or active restoration (Holl & Aide, 2011). Recently, the effectiveness of restoration planting has been called into question (Hobbs, 2007). Concerns include the preponderance of mass planting of a low diversity of species and associated lack of structural heterogeneity (Meli et al., 2017; Prach & Hobbs, 2008). Resource-intensive management regimes are then needed to undertake and maintain the plantings (Andel & Aronson, 2006). Once planted the successional trajectory may be unpredictable because the novel and incomplete nature of these systems have yet to be adequately studied (Suding, 2011). Finally plantings seem to result in a lack of similarity to the reference sites where this has been examined (Meli et al., 2017; Morrison & Lindell, 2011; Prach & del Moral, 2015; Prach & Hobbs, 2008).

Assessment of ecological restoration success is needed in order to justify resources spent, improve on current restoration techniques, and to test the developing scientific body of restoration ecology theory (Menz, Dixon, & Hobbs, 2013; Stanturf, Schoenholtz, Schweitzer, & Shepard, 2001; Wortley, Hero, & Howes, 2013). However, the successful accomplishment of restoration methods remains poorly studied and largely isolated to reconstruction of vegetation communities and forest structure while excluding assessments of ecosystem function (Ruiz-Jaen & Mitchell Aide, 2005). Many studies of restoration success have addressed site-specific problems with little applicability to other sites or input into the general scientific theories of restoration ecology (Jones et al., 2018a). Reasons for the absence of measurements of success is likely a result of several different reasons: firstly ecological restoration is a relatively new field of science (Choi, 2007; Clewell & Aronson, 2013); secondly restoration activities on the ground are generally carried out not by restoration ecologists (Temperton, Hobbs, Nuttle, & Halle, 2013); Finally the ecological systems being restored need time to develop ecological functions and structure before any conclusions of success can be made with surety (L. R. Walker, J. Walker, & R. J. Hobbs, 2007; Wortley et al., 2013).

A successful recovery is said to be achieved when the restored site is comparable to predefined reference sites in aspects of composition, structure, function (Allen, Covington, & Falk, 1997; A. D.

Bradshaw, 1993). Therefore measures of success must include all of these aspects, not just measures of vegetation composition and structure, but measures of processes such as ecological services (water and nutrient cycling) and self-sustainability (resilience and recruitment) (Ruiz-Jaen & Mitchell Aide, 2005). While composition and structure can be manipulated directly within a restoration site (through placing or encouraging certain species), function emerges as an indirect property from interactions between both biotic and abiotic entities within the ecosystem (Andel & Aronson, 2006; Cortina et al., 2006; Fukami et al., 2010). As a result function is generally measured indirectly through proxy measures such as Specific Leaf Area, the presence of different functional groups (traits) and biodiversity measures (Laughlin, 2014; Ruiz-Jaén & Aide, 2006).

However past assessments of success tend to focus on recovery of compositional aspects, with structure and functional measurements being left out (Ruiz-Jaén & Aide, 2006; Suding, 2011; Wortley et al., 2013). New Zealand measures of restoration success show no difference in this regard (Berger, 2001; Clout, 2001; Norton, Young, & Clarkson, 2016; Stevenson & Smale, 2005).

In New Zealand, many past forest restoration plantings have developed to the stage of closed canopies with unassisted regeneration appearing beneath. Simultaneously, pockets of abandoned pasture are also found throughout the country undergoing spontaneous succession, providing an accessible comparison of restoration approaches. Furthermore, New Zealand has a relatively short history of human disturbance (McGlone, 1989) and as a result contains reasonable reference sites (Clout, 2001). These factors make New Zealand an ideal location to assess the effectiveness of restoration by comparing a restoration planting site within a reference study site.

This study asks: is ecological restoration by direct planting successful in assisting the recovery of an ecosystem? Successfulness is assessed for eleven restoration sites by comparing their function and structure with both a comparable site undergoing spontaneous succession and a reference site of mature forest.

METHODS

Site selection

Study sites were selected to cover the natural extent of New Zealand lowland podocarp broadleaf forest (Leathwick, 2001) (Figure 1; Appendix 1). Each study site has three treatment areas: a "Planted" area which has been restored with planted native seedlings that are mature enough to have developed a closed canopy, and with unassisted regeneration beneath; a "Spontaneous" area which has undergone secondary succession from a similar starting time as the Planted area; and a Reference area of mature healthy forest which has been subject to little anthropogenic disturbance.

The treatment areas were initially identified through discussion with restorationists involved at each site and through recent aerial photographs, planting plans, management plans and studies associated with the site. The treatment areas were then verified with a walk-through of each. All treatments within a site were selected to be comparable in regard to slope, aspect, and mammalian pest management. In addition to this, the Spontaneous and Planted areas had to be comparable in both their land use history and distance to the nearest seed source.

From April to August 2014, 20m x 20m plots were haphazardly staked out within each treatment area within each site, at least 10m from the edge of that vegetation type. Two replicate plots were set within each treatment area, except for Te Rere Reserve, Quail Island, Fensham Reserve and Morgan’s Reserve, where the shape and smaller size prevented this. One additional planted site was examined on Mana Island, and two of each of Kent Road, and Tiri Tiri Matangi to better summarise the variety in planted vegetation.

Figure 1: Location of the 11 study sites measured across New Zealand.

Treatment plots

Brief descriptions were compiled including past land use, site management and the state of the forested landscape. Within the centre of each 20m x 20m plot a GPS reading was taken using a Trimble Juno® SA (Trimble Inc., Sunnyvale, California) handheld device to define latitude and longitude. Aspect was taken from the centre of each plot. Soil depth was measured, using a 50cm soil probe to 0.8 mm wide, physically pushed into the substrate as far as possible. Soil compaction (unconfined compressive strength) was measured in MPa using a Humboldt H-4195 soil Penetrometer, with adapter foot, following user manual (H-4195 man 0414, Product Manual PDF). Both depth and the compaction of the soil were taken as an average of three measurements from the eastern-most and western-most edges of the plot and from the plot centre. Heights of the tallest tree and of the canopy were measured with a tape measure for species up to 5m, and with a clinometer for taller species. Slope was measured along the line of maximum slope within each plot with a clinometer. A suite of relevant explanatory variables was collated for each plot containing information on environment, composition, structure, function and diversity.

To describe ground cover, the percentage cover of bare ground, coarse woody debris, litter, rock, angiosperms, lichen and fern was visually assessed to collectively account for 100% coverage of the floor of the 20m x 20m plot. Cover was taken as the vertical projection of all material onto a horizontal surface, effectively recording the area of the shadow of that material under solar zenith. Coarse woody debris on the ground was defined as logs over 2.5cm in diameter, with anything under this threshold being classified as litter. All vascular species within the plot were identified to species' level according to Ngā Tipu Whakaoranga (Landcare Research, manaaki whenua, n.d.) and the overall cover of each was visually estimated as above. In addition, each species' occupancy within each of six vertical tier classes of <0.2m, 0.2-1m, 1.1-5m, 5.1-10m, 10.1-25m and >25m was recorded to explore forest structure. Cover values for vascular species did not necessarily total 100%, due to species' overlap. The estimated percentage of "gap" within the canopy was also recorded for the total plot area, with a gap being identified as an area where the maximum height of the vegetation over an area of >1m^2 is less than half of the maximum canopy height.

For the five most common canopy species in terms of their percentage covers within each plot Specific Leaf Area (SLA) measurements were taken of five mature leaves from five individuals, where possible and from different areas of the plot. A leaf is defined as a single photosynthetic unit and measurements are based on average size as described in the Flora of NZ (Webb, Sykes, Given, & Garnock-Jones, 1988), and employing the "small leaf" threshold of <2cm length (Wilson & Galloway, 1993). Leaves were haphazardly collected from the outer-most part of each plant (i.e., with greatest exposure to sunlight). Fresh leaves fallen from the canopy in the plot were collected in the instances where the trees were too tall to reach. All leaves were pressed, and the surface area measured using a LI-COR leaf area metre (https://www.licor.com/ model no. 3100C), then dried for 72 hours at a temperature of 60°C and weighed. Specific Leaf Area was then calculated as the ratio of leaf area to leaf dry mass.

Seedling diversity and density

For the five most dominant canopy tree species, as above, 6 – 12, seedling quadrats were measured beneath each, starting with the canopy tree nearest to the centre of the plot on a randomised compass bearing. Each subsequent canopy tree was randomly selected in this manner, using the previous tree as a starting point. In the instance that fewer than six canopy trees of the chosen species were within the 20m x 20m plot, a second random seedling quadrat was measured beneath a tree already sampled, excluding the portion previously sampled. For each selected canopy tree, the height, canopy radius from the edge of the trunk at ground level to the edge of the canopy, diameter at 1.35m above the ground (DBH), and number of stems over 2.5cm DBH at 1.35m were measured. A further 6-10 1m^2 seedling quadrats were also measured beneath gaps in the canopy.

Seedlings were sampled within a quadrat shaped as a circle-segment extending from the edge of the trunk to the dripline of that tree's canopy (Figure 2). The area of the segment differed in accordance to the radius of the canopy. Where a canopy radius of less than 0.5m was recorded, the seedling plot covered the total area of the canopy for that tree and was therefore circular – in this instance sampling area included the base of the truck. For a canopy radius of 0.5m to 1m the seedling quadrat covered half the total area of the canopy for that tree (a 180° circle-segment). For a canopy radius of 1m to 2m, the seedling quadrat covered one quarter of the total area of the canopy for that tree (a 90° circle-segment), and for greater radii a 45° circle-segment was used. Within each quadrat the number of seedlings (less than 50 cm tall) of each woody species was recorded, along with a measure of topography as the percentage of the quadrat indented below the surface of the plain defined by the three "corners" of the pie-slice. The area of each quadrat was then found using the radius of the circle and the angle but ignoring the DBH of the tree as this introduced minimal error, and data presented per square metre.

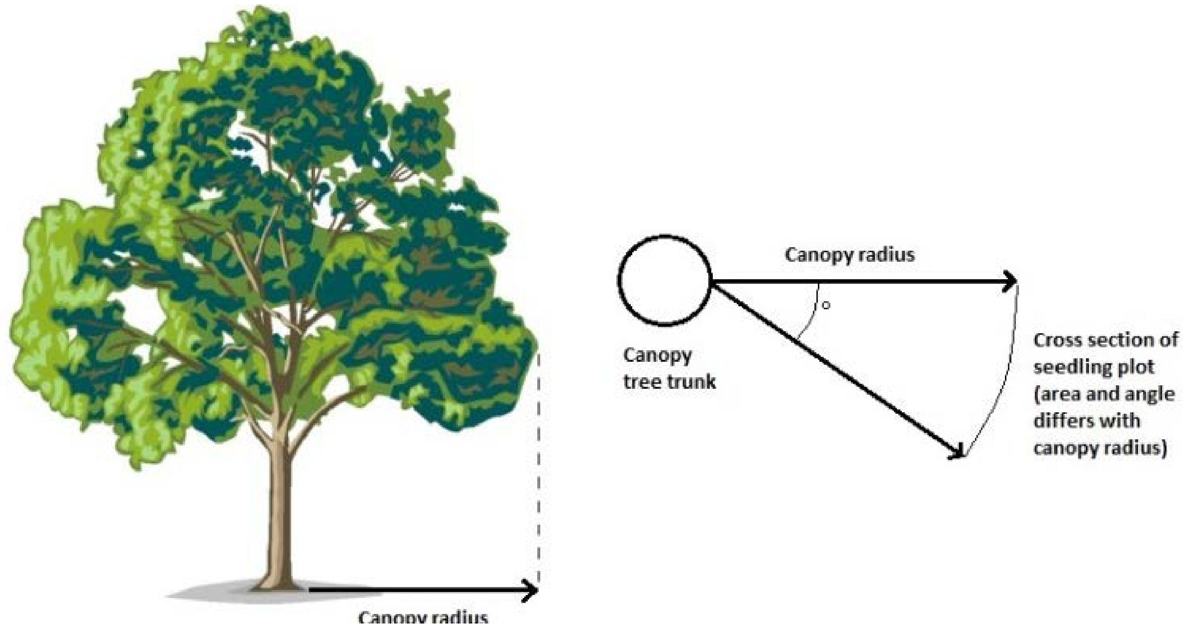

Figure 2: Diagram of a seedling plot's layout, looking at the cross section from the side (left) and above (right). The canopy radius extended to tree's dripline and the segment is taken from the trunk.

Analysis

Due to study sites spanning across a known longitudinal gradient of differing species' distribution (Wardle, 1991), it may be uninformative to compare species' composition across study sites. Therefore, in addition to the species' level used above, species were further grouped into two life-form classifications, growth form and phylogenetic class. The growth form classification relates to the typical physical structure of the plant in terms of its average height at maturity and its leaf size, while the phylogenetic class relates to the broader taxonomic grouping of the species as a reflection of its resource use and life history strategies. Refer to Table 1 of each classification for descriptions of life forms, phylogenetic forms and examples of a species fitting into both classifications simultaneously. See Appendix 2 for the species' assignment to each class.

Classifying plant species to broader lifeform and phylogenetic (taxonomic) classes allows for meta-assessment of restoration beyond the scale of a site, to that of ecosystems and landscapes (Woodward and Diament 1991; Keddy 1992; Körner 1993). The use of traits within ecological restoration (Funk, Cleland, Suding, & Zavaleta, 2008; Laughlin, 2014; Sonnier, Shipley, & Navas, 2010; Zirbel, Bassett, Grman, & Brudvig, 2017).

Table 1: Two life form classifications, of growth form and phylogeny, with examples of species fitting both classifications.		
Growthform classification (description)	**Phylogenetic classification** (adapted from NZPCN species' descriptions)	**Species' example** (fitting both classifications)
Herb – tufted *Generally <1m in height, tufted, and growing out of a central point.*	Herbaceous monocot	*Thelymitra longifolia*
Herb – large-leaved *Generally growing to reach no more than 1m in height, which is non-tufted with leaves over 2cm in length.*	Filmy fern	*Cardiomanes reniforme*
Herb – small-leaved *Generally growing to reach no more than 1m in height, which is non-tufted with leaves under 2cm in length.*	Lycophyte	*Lycopodium scariosum*
Shrub - small-leaved *Generally growing to reach <5m in height, with leaves under 2cm long.*	Woody dicot	*Streblus heterophyllus*
Shrub - large-leaved *Generally growing to reach no more than 5m in height, with leaves over 2cm long.*	Herbaceous-dicot	*Solanum laciniatum*
Tree - small-leaved *Generally growing to >5m in height, with leaves under 2cm long.*	Woody gymnosperm	*Dacrydium cupressinum*
Tree - large-leaved *Generally growing to >5m in height, with leaves over 2cm long.*	Fern	*Cyathea dealbata*
Climbing *Grows vertically using other plants as support.*	Woody monocot	*Freycinetia banksii*

Assessing the success of the differing restoration treatments is compounded by the nested experiment design (of the three treatments within each of the 11 study sites), and the inevitable latitudinal differences in species' composition between study sites. The approach was to analyse the differences in vegetational composition (distance in two-dimensional nMDS ordination space) between treatments with respect to the Reference plots within each site. For example, a Planted plot is considered more successful when closer in composition and therefore ordination space to the Reference plot than the associated Spontaneous plot. An unconstrained ordination was performed in Primer using non-metric multi-dimensional scaling (nMDS) with Euclidean dissimilarity via the square-root-transformed species' cover data (with species in multiple tiers summed), which metric retains more subtle information than Bray-Curtis (Clarke & Gorley, 2015). The same ordination was coded for treatments to show differences between them and the inverse ordination of the species was displayed.

A two-way Nested ANOSIM of treatments within sites was then performed on the cover data to determine if the treatments were significantly different, and a similarity percentage analysis (SIMPER) used to identify the average percentage contribution of each species to the overall similarity/dissimilarity of the treatments.

To explain the differing distances between treatments, each of the replicated plot variates was averaged, and estimated covers were square-root-transformed. To enable age to be analysed as a variable the Reference area was given an arbitrary age of 1000 years, while aspects were converted into radians for analysis. Specific Leaf Area was left untransformed. The list of potential explanatory variables was supplemented by calculated variates. Diversity measures were calculated using the Shannon Weiner Diversity Index (SWDI) of the square-rooted cover data for the species and for the lifeform and phylogenetic classifications. SWDI values were also derived for seedling species' abundance measures and for cover in forest community tiers using the combined cover of all species present within each tier.

RESULTS

Patterns in sites

The study sites ranged the length of New Zealand, from the far south-west (Deep Cove) to north-east (Tiri Tiri Matangi) and from 2-305 m in altitude. This geographic separation can be seen in the nMDS ordination of the vegetation composition within the sites (Figure 3), where the two southernmost plots (Deep Cove and Te Rere) are positioned at the top of the graph, with the remaining sites from the warmer eastern South Island and the North Island intermixed in the space below.

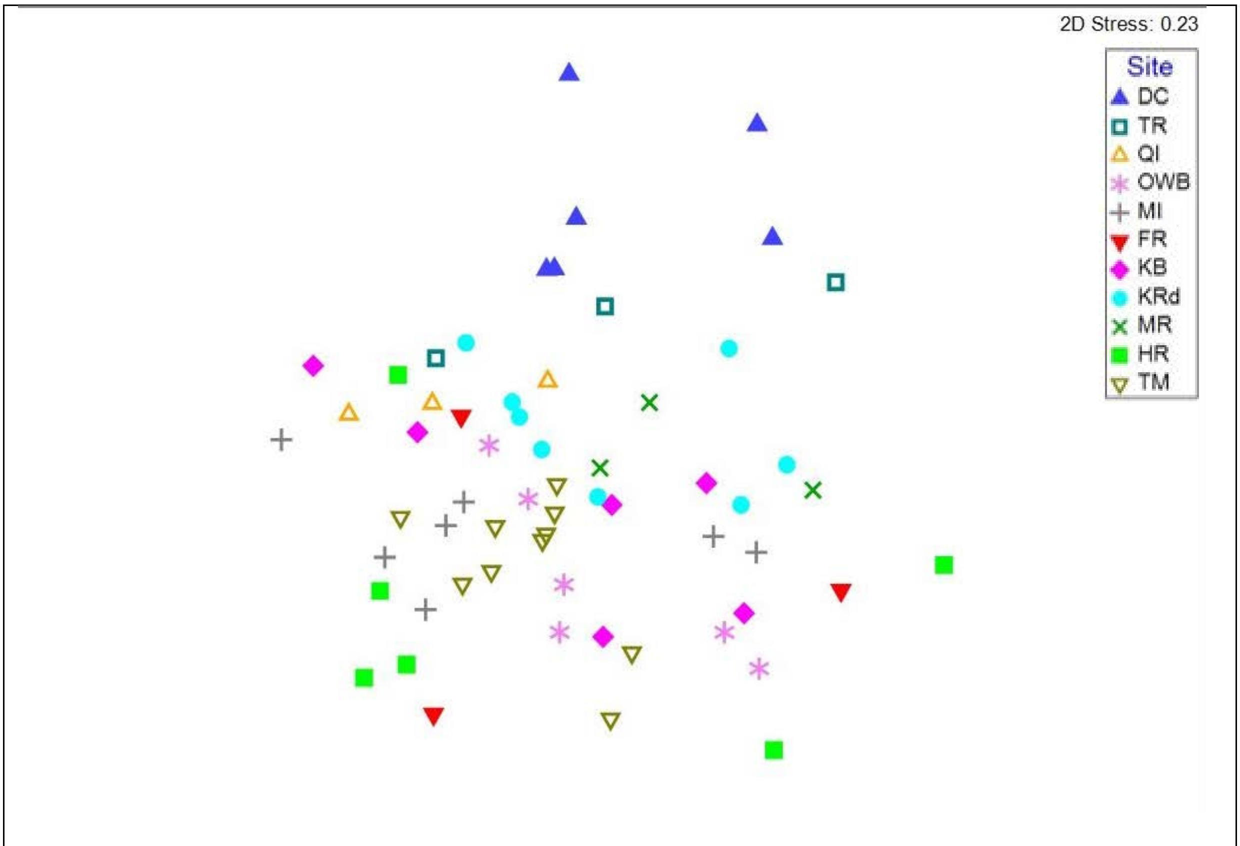

Figure 3: Two-dimensional non-parametric multi-dimensional scaling (nMDS) ordination, using Euclidean resemblance of square-root transformed data of species' cover for all plots and treatments at each site. DC = Deep Cove, TR = Te Rere, QI = Quail Island, OWB = Otari Wiltons Bush, MI = Mana Island, FR = Fensham Reserve, KB = Keeble's Bush, KRd = Kent Road, MR = Morgan Reserve, HR = Hunua Ranges, TM = Tiri tiri Matangi.

The site descriptors (Table 2) show that sites vary in soil characteristics (i.e., soil compaction and soil depth). Soil compaction is highest at Fensham Reserve and soil depth is highest at Te Rere. The canopy height is greatest for Deep Cove, Kent Road and Keeble's Bush. Stem count per tree was particularly high at Tiri Tiri Matangi Island, while canopy species' richness was highest at Otari-Wiltons Bush.

Native cover was greatest at Hunua Ranges and lowest at Quail Island (Table 2). Shannon Wiener Diversity Index was greatest at Fensham Reserve and Otari-Wiltons Bush, and lowest at Mana Island, where Specific Leaf Area was greatest. Seedling density was particularly high on Keeble's Bush and Tiri Tiri Matangi Island.

Table 2: Averaged environmental and compositional parameters of the 11 sites sampled from 3 treatments replicated 1-2 times. MPa = Megapascals. % = estimated percent cover of shadow at solar zenith. Bryo = bryophytes. SLA = Mean Specific Leaf Area of 5 leaves of each of 5 canopy species.

Site	**Deep Cove (DC)**	**Fensham Reserve (FR)**	**Hunua Ranges (HR)**	**Keeble's Bush (KB)**	**Kent Rd (KR)**	**Mana Island (MI)**	**Morgan Reserve (MR)**	**Otari-Wiltons Bush (OWB)**	**Quail Island (QI)**	**Tiri Tiri Matangi Island (TM)**	**Te Rere (TR)**	**Mean**
Altitude (m)	8	122	147	37	132	79	135	94	130	64	18	88
Aspect (cosine in radians)	0.6	0.7	0.6	0.6	0.8	0.7	0.7	0.9	1.0	0.5	0.7	0.7
Slope (^{0})	4.0	4.7	3.7	2.2	8.4	6.6	3.3	12.5	4.3	6.1	4.3	5.5
Age of regeneration (yr)	340	346	352	371	353	352	343	355	355	352	352	352
Soil compaction (PSI)	87.5	242.8	95.3	85.8	108.2	70.5	190.6	81.4	110.0	142.8	182.2	127.0
Soil depth (cm)	28.3	32.3	25.7	36.0	23.7	27.3	25.7	28.7	10.3	32.3	36.3	27.9
Height of tallest tree (m)	18.4	15.0	10.2	16.1	17.0	7.6	14.1	15.2	5.9	8.3	9.3	12.5
Canopy height (m)	9.0	7.2	7.2	10.1	12.5	5.9	8.8	7.8	3.8	5.9	6.0	7.7
Radius of canopy trees (m)	3.2	2.7	2.5	2.7	2.4	2.8	2.8	2.4	2.3	3.3	2.0	2.6
DBH (cm)	33.1	32.2	29.1	30.5	30.3	26.5	27.8	28.4	14.5	25.5	20.3	27.1
Stem count per tree at 1.35m	1.2	1.7	1.0	1.3	1.6	1.1	0.8	1.5	1.7	1.8	1.4	1.4
Canopy (%)	73	65	68	74	78	69	70	74	55	70	70	70
Canopy gap >1m² in area (%)	3	4	5	5	4	5	4	2	5	6	11	5
Canopy species richness	4.8	10.0	8.5	4.2	8.1	10.0	13.3	17.2	10.3	4.6	11.7	9.3
Bare ground (%)	6	1	1	1	1	2	1	2	2	1	1	1.6
Litter (%)	53	88	83	80	80	79	85	75	72	84	87	78.6
Woody debris (%)	9	2	3	3	2	5	2	2	3	3	3	3.3
Rock (%)	7	0	0	0	1	1	0	1	3	0	0	1.2
Lichen (%)	2	0	0	1	0	1	2	0	2	1	1	0.9
Bryo - Ground (%)	21	1	1	1	1	0	0	1	0	1	1	2.6
Bryo - Epiphytic (%)	9	2	1	1	1	1	1	1	0	1	1	1.7
Fern – Ground (%)	10	10	5	9	6	8	5	5	12	7	9	7
Fern – Total (%)	25	27	28	5	12	10	18	18	4	6	34	17
Woody spp. (%)	60	57	69	56	54	30	62	81	44	38	76	57.0
Native cover (%)	150	164	172	102	131	114	139	118	79	88	136	126.6
Exotic cover (%)	9	3	4	36	4	10	8	9	31	4	2	11.0
Total cover (%)	160	175	179	153	141	130	160	162	121	115	139	148.5
Species richness	34.3	41.0	37.0	30.2	30.7	24.0	45.3	32.5	32.3	17.8	45.3	33.7
Shannon Weiner Diversity Index	7.4	9.8	8.8	8.8	8.8	6.9	7.4	9.8	8.8	8.8	8.8	8.6
SLA ($cm^2 g^{-1}$)	137.9	148.0	127.0	124.8	119.9	161.8	137.9	148.0	127.0	124.8	119.9	134.3
Seedling richness (m^{-2})	3.8	4.1	4.5	4.2	4.6	2.8	3.8	4.1	4.5	4.2	4.6	4.1
Density of seedlings (m^{-2})	4.8	6.0	7.7	12.2	6.9	4.9	4.8	6.0	7.7	12.2	6.9	7.3

The nMDS of species within each plot (Figure 4) shows that species positioned outward on the ordination tend to be those similarly found to be common dominant species within treatment plots as seen in Table 2. The emergent podocarps *Dacrydium cupressinum* (DACcup) and *Prumnopitys ferruginea* (PRUfer) are closely associated with the understory-shrub *Hedycarya arborea* (HEDarb) and canopy tree *Beilschmiedia tawa* (BELtaw). These correspond closely to the dominant species in the Reference Plots, and the other small tree species visible in the ordination correspond to the dominant species in the Spontaneous and Planted Plots. In particular, *Melicytus ramiflorus* (MELram), found to the far left of the graph, is ubiquitous throughout the plots, generally with a high percentage of cover.

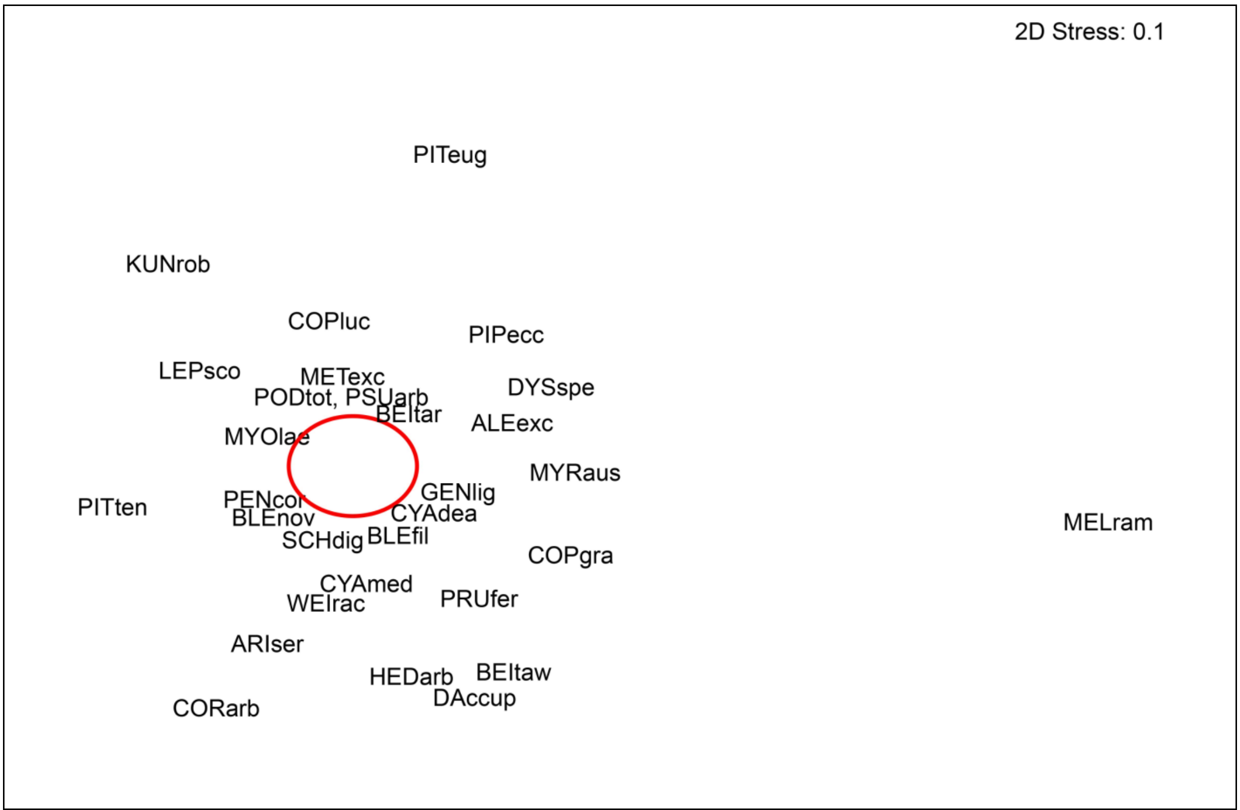

Figure 4: Two-dimensional presentation of non-parametric multi-dimensional scaling (nMDS) ordination of each species, using Euclidean distances of square-root transformed species cover data. The area of the red circle contains all remaining species. The full names for the species' coded as the first 3 letters of the genus and the first three of the species are in Appendix 2.

The predominance of certain species within each treatment can be seen with *Dacrydium cupressinum* commonly appearing in seven of the eleven reference areas, *Melicytus ramiflorus* commonly appearing in five of the eleven Spontaneous areas and *Pittosporum tenuifolium* commonly appearing in seven of the eleven Planted areas.

Differences between treatments

When coded according to treatment (Figure 5), the nMDS of species shows the Planted plots in a tight group to the centre left, the Spontaneous Plots spread vertically to the right of these and the Reference Plots, also vertically spread, to the centre right. The reference plots cover a 190% greater area and Spontaneous plots 112% greater area of ordination space than the planted plots.

One site that does not follow the general trend of the treatments is Quail Island, with the Reference Plot "misplaced" to the left of the Spontaneous Plot. This can most likely be attributed to the fact that this reference site was found to be highly disturbed by pest animals, past fire events and historic grazing, and as such, is not likely representative of the true reference community for the restoration site.

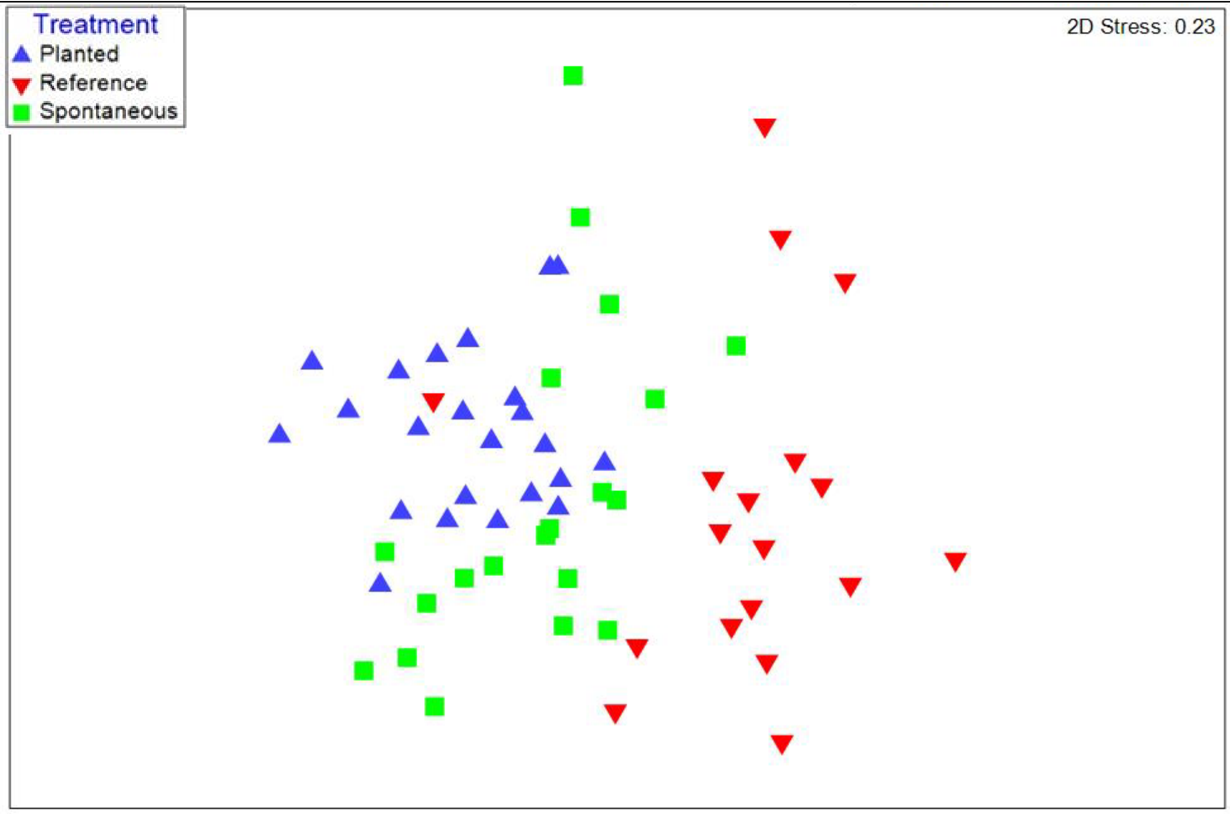

Figure 5: The nMDS ordination graph from Figure 3 coded for treatments.

To assess the significance of differences between treatments, the square-rooted cover data was analysed using a two-way nested ANOSIM. This showed that the plots were significantly different ($P < 0.001$) in terms of their community composition, with Reference Plots showing a greater similarity to the Spontaneous Plots ($r = 0.346$) than to Planted Plots ($r = 0.573$), where an r value of 0 represents identical communities, and the higher the r value from 0 the greater the dissimilarity in communities.

In terms of the differences in composition between the treatments, the Spontaneous treatments have 12 species with a high cover value, compared with 7 for the Planted treatments, and 8 for the Reference treatments (Table 3). Those species include *Leptospermum scoparium*, *Melicytus ramiflorus*, *Myrsine australis* and *Kunzea robusta* with 6% greater cover in the Spontaneous plots than the planted.

By contrast species with most cover in the Planted plots are *Aristotelia serrata*, *Coprosma robusta*, *Pittosporum eugenioides* and *Pittosporum tenuifolium*, which have 8% greater cover than the spontaneous plots. Species which are particularly low in cover in the Planted plots are *Alectryon excelsus*, *Cyathea* spp., *Lophozonia menziesii*, *Pseudowintera colorata* and *Weinmannia racemosa* with a mean of 2.4% less cover. *Myoporum laetum* and *Podocarpus totara* are the only two species which are less common (by 1.8 % cover) in the Spontaneous than Planted treatments. Species which are particularly poorly represented in the two successional treatments compared with the Reference plots are the two *Beilschmiedia* spp., *Dacrydium cupressinum*, *Dacrycarpus dacrydioides*, *Dysoxylum spectabile*, the climber *Ripogonum scandens* (at a mean of 5.1% cover), and the ferns *Blechnum fileforme* and *Cyathea medullaris* (3.1 % cover).

The phylogenetic classification indicates that herbaceous monocots are over-represented in Planted treatments compared with Spontaneous treatments (*Figure 6*), generally these species are pasture grasses from pasture abandonment. Simultaneously, ferns are under-represented as are lycophytes within Planted treatments.

Table 3: Mean percent cover of the 53 most native common species (>2% cover in total) in the three treatments. Values that are particularly high for any one species are larger in bold, and low values smaller in italics.

Spp	Planted	Reference	Spontaneous
Alectryon excelsus subsp. excelsus	*1.36*	5.54	4.46
Aristotelia serrata	**5.21**	0.47	2.12
Asplenium bulbiferum	0.47	1.03	1.92
Beilschmiedia tarairi	0.00	4.98	0.00
Beilschmiedia tawa	1.74	**10.19**	3.20
Blechnum discolor	0.20	1.88	1.11
Blechnum filiforme	0.42	**5.51**	0.96
Blechnum novae-zelandiae	1.28	0.00	**2.31**
Brachyglottis repanda	0.06	0.42	**1.87**
Carpodetus serratus	1.09	*0.21*	1.70
Collospermum hastatum	0.48	*1.94*	0.05
Coprosma grandifolia	5.11	*1.76*	5.86
Coprosma lucida	1.14	0.82	**3.42**
Coprosma robusta	**6.68**	0.03	0.46
Coriaria arborea var. *arbore*a	6.05	*0.00*	1.87
Cyathea dealbata	*0.46*	**5.04**	2.55
Cyathea medullaris	*0.94*	3.27	4.89
Cyathea smithii	*0.07*	1.67	2.10
Dacrycarpus dacrydioides	0.23	**2.28**	0.01
Dacrydium cupressinum	1.18	**15.06**	0.84
Dicksonia squarrosa	0.21	1.35	**3.37**
Dysoxylum spectabile	0.11	**6.65**	2.59
Fuchsia excorticata	0.83	0.70	3.70
Geniostoma ligustrifolium var. *ligustrifolium*	1.31	2.21	**4.43**
Griselinia littoralis	1.26	1.35	0.88
Hedycarya arborea	*2.82*	7.17	5.67
Knightia excelsa	**2.83**	1.09	1.49
Kunzea robusta	2.36	0.26	**7.60**
Leptospermum scoparium var. *scoparium*	1.89	0.14	**6.71**
Lophozonia menziesii	*0.00*	1.17	1.17
Melicytus ramiflorus	7.52	5.65	**17.11**
Metrosideros diffusa	0.04	1.76	1.66
Microsorum pustulatum subsp. *pustulatum*	0.26	0.40	**1.34**
Myoporum laetum	1.29	4.69	*0.00*
Myrsine australis	3.99	2.73	**7.09**
Pennantia corymbosa	2.08	0.70	0.84
*Phyllocladus trichomanoide*s	1.39	0.99	0.45
Piper excelsum subsp. *excelsum*	1.85	3.60	**5.10**
Pittosporum eugenioides	**13.51**	0.32	0.29
Pittosporum tenuifolium	**12.73**	2.08	1.65
Plagianthus regius subsp. *regius*	**2.33**	1.06	0.41
Podocarpus totara var. *totar*a	3.09	2.15	*0.83*
Prumnopitys ferruginea	1.29	10.40	0.42
Prumnopitys taxifolia	1.72	3.57	0.06
Pseudopanax arboreus	**3.23**	1.90	1.30
Pseudowintera colorata	*0.00*	1.67	1.53
Rhopalostylis sapida	0.11	1.90	0.40
Ripogonum scandens	0.15	**2.45**	0.90
Schefflera digitata	0.96	1.98	2.88
Sophora microphylla	0.74	3.23	0.05
Urtica ferox	0.34	0.07	**1.86**
Weinmannia racemosa	*1.30*	6.31	4.14

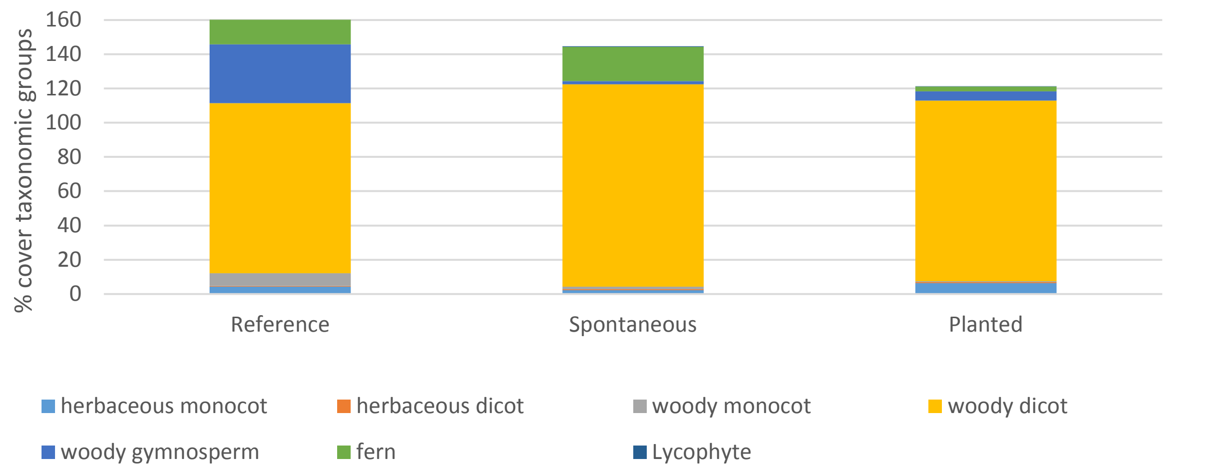

Figure 6: Mean percentage cover of species within each treatment for each of the groups in the phylogenetic classification.

Small-leaved trees and small-leaved herbs are under-represented in both early successional treatments compared with the reference treatments, and partially replaced by large-leaved shrubs (Figure 7).

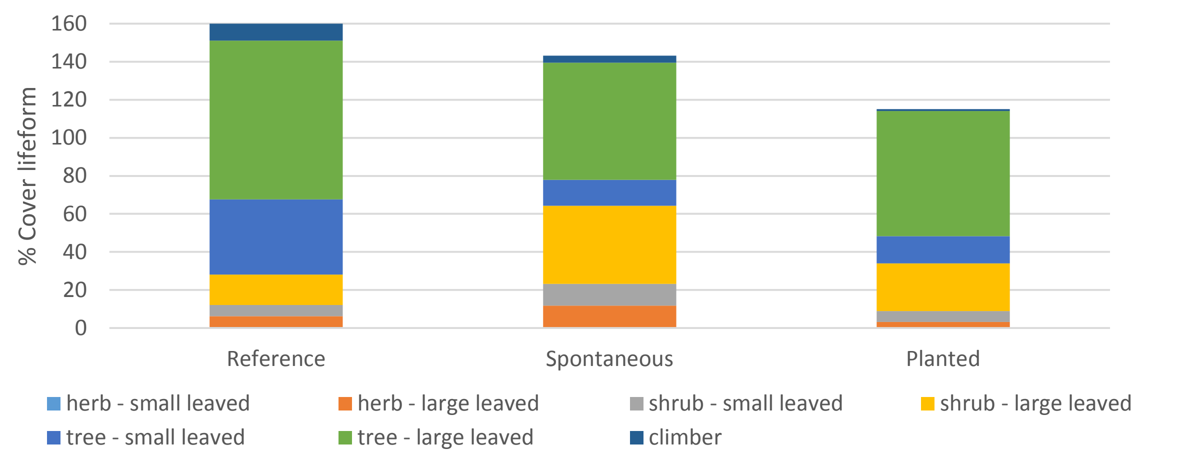

Figure 7: Mean percentage cover of species within the taxonomic classes for each of the treatments over all the sites.

In terms of tier structure within the sites, Spontaneous treatments appear to host higher tiers more than planted treatments (Figure 8), as well as nearly 70% more cover in the lowest tier (<0.2m). Small shrubs to <1m are only half as common in the planted sites to those undergoing spontaneous regeneration.

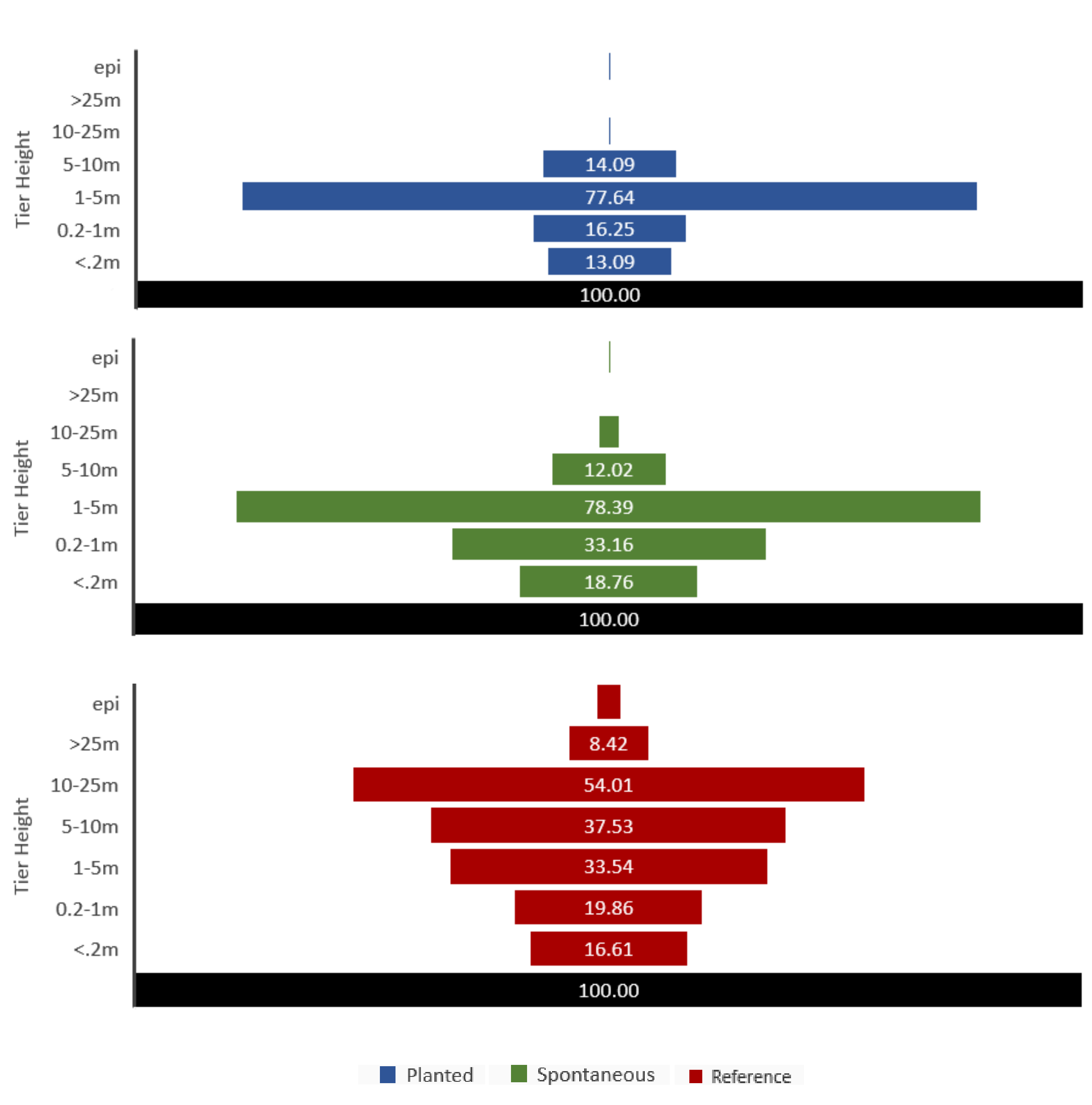

Figure 8: Difference in mean percentage cover of each vegetation tier, for treatments at each site.

Comparison of treatments by sites

Compositional differences between the study sites and their treatments are described below. Details of the sites' locations are available in Appendix 1, species' classifications in Appendix 2, site x treatment means for environmental and compositional variates in Appendix 3, and site x treatment x species means for cover in Appendix 4. Descriptions of the treatment differences at each site are provided below.

1. Deep Cove (DC)

All three treatments are located within Deep Cove, Fiordland National Park, on a flat river terrace within the valley of the Lyvia River. The study site is surrounded by steep slopes covered in podocarp-beech-broadleaved forest. Management of the wider valley (West Arm) involves pest control using DOC200 traps (CMI Springs & Department of Conservation (DOC), Auckland) which are serviced by volunteers.

The Reference area is a mature, mixed podocarp-beach forest on an un-logged river terrace, consisting of emergent *Dacrydium cupressinum, Metrosideros umbellata* and *Lophozonia menziesii* over a canopy of *Weinmannia racemosa* (Table 4). The understory contains a large variety of shrub species (18 species) with *Pseudowintera colorata* being the most prevalent at an average of 19% cover. The soil is deep (average 48 cm) and damp as indicated by the ground-layer coverage of fern species (40%) and moss (4%). There is also a large amount of coarse woody debris (10%) on the forest floor.

Both the Planted and the Spontaneous areas are adjacent to the Reference area on land reclaimed by 2002 with the spoil from excavation of the two tailrace tunnels of the Manapouri Power Station. This area is rocky (5-15 % ground cover), with thin soil (average 18cm deep). The Planted area is found predominantly to the eastern end of the site and borders a walking track. The Planted area contains a variety of small trees and shrubs that were planted; however, it also spontaneously contained *Aristotelia serrata* and *Coriaria arborea.* The Spontaneous area is found inland from the walking track. The Spontaneous area predominantly contained *Aristotelia serrata* and *Coriaria arborea,* in large quantities (25% and 65% cover respectively). The ground layer on both sites is sparse and mostly consists of exotic grass species, with the fern *Microsorum pustulatum* found in shadier areas, and a medium density of seedlings (5.5 m^{-2}).

Table 4: Comparison of vegetation structure using the common species (above 10% cover) of each treatment within each site, and the history and age of the Spontaneous and Planted treatments. Vegetation classification follows that of (Atkinson, 2012). Where average species' cover within the plots is greater than 81%, then that species is doubly underlined; where cover is between 51-80% that species is singly underlined; where cover is between 21-50% that species is not underlined and where cover is between 10-19% that species is within parentheses. The forward slash (/) denotes a change in tier, where the species at the beginning of the description occupies the higher tier relative to others following the slash. Ferns are in green, podocarps in blue and exotic species in red.

Site	Reference	Spontaneous	Planted
Deep Cove	*Lophozonia menziesii – (Metrosideros umbellata) / Weinmannia racemosa (Cyathea medullaris) – (Cyathea smithii) / Pseudowintera colorata - (Schefflera digitata) / (Metrosideros diffusa)*	Land reclaimed from fill in 2002 *Coriaria arborea - Aristotelia serrata / (Hedycarya arborea)*	Planted in ground-fill in 2002 *Coriaria arborea - Aristotelia serrata / Hebe salicifolia*
Te Rere	*(Dacrydium cupressinum) – (Prumnopitys ferruginea) / Weinmannia racemosa – (Dicksonia squarrosa) / (Hedycarya arborea) / (Blechnum discolor)*	Pasture fenced and retired in 1987 *Dicksonia squarrosa - Fuchsia excorticata – (Cyathea smithii)*	Planted in retired pasture in 1992 *Pittosporum tenuifolium*
Quail Island	*Sophora microphylla – (Alectryon excelsus* subsp. *excelsus) – (Myoporum laetum) – (Melicytus ramiflorus) – (Plagianthus regius* subsp. *regius)*	Slip site from 2009 *Melicytus ramiflorus - Urtica ferox – (Fuchsia excorticata) – (Coriaria arborea* var. *arborea)*	Planted in retired pasture in 1998 *(Kunzea robusta) – (Pittosporum tenuifolium) Coprosma robusta / (Agrostis stolonifera)*
Otari-Wiltons Bush	*Dacrydium cupressinum - Dysoxylum spectabile - Cyathea dealbata – (Blechnum filiforme) – (Prumnopitys ferruginea) – (Beilschmiedia tawa) – (Melicytus ramiflorus) – (Knightia excelsa)*	Retired from pasture the 1960's *Melicytus ramiflorus - Piper excelsum* subsp. *excelsum – (Dysoxylum spectabile) – (Brachyglottis repanda) – (Myrsine australis)*	Planted in retired pasture 2001 *Melicytus ramiflorus - Pittosporum eugenioides - Pittosporum tenuifolium - (Pseudopanax arboreus)*
Mana Island	*Beilschmiedia tawa – (Dysoxylum spectabile)*	Fenced in 1986 *Kunzea robusta / Asplenium oblongifolium / (Carex raoulii)*	Planted in retired pasture 1987 *Myoporum laetum – Melicytus ramiflorus (Coprosma robusta) – (Pittosporum tenuifolium) / Agrostis stolonifera*
Fensham Reserve	*Dacrycarpus dacrydioides - Dacrydium cupressinum - (Prumnopitys taxifolia) / (Beilschmiedia tawa) / (Alectryon excelsus) – (Cyathea dealbata) / (Myrsine australis) – (Ripogonum scandens) - Blechnum filiforme*	Recovery from pine harvest in 1998 *Leptospermum scoparium* var. *scoparium – (Cyathea medullaris) – (Pseudopanax arboreus) – (Knightia excelsa) – (Melicytus ramiflorus)*	Planted in retired pasture 2001 *Pseudopanax arboreus - Coprosma robusta – (Plagianthus regius* subsp. *regius) – (Pittosporum tenuifolium) – (Pittosporum eugenioides)*
Keebles' Bush	*Prumnopitys ferruginea – (Dacrydium cupressinum) / Alectryon excelsus / Piper excelsum - (Streblus heterophyllus)*	Wind throw 1934 *Alectryon excelsus – (Melicytus ramiflorus) – (Hedycarya arborea) / Piper excelsum*	Planted in retired pasture 1970 *(Myoporum laetum) – (Hoheria sexstylosa) / Piper excelsum / (Holcus lanatus) – (Dactylis glomerata)*
Kent Road	*Dacrydium cupressinum / Beilschmiedia tawa - Podocarpus totara* var. *totara / (Alectryon excelsus* subsp. *excelsus)*	Fenced 1995 *Weinmannia racemosa / Coprosma grandifolia - (Cyathea medullaris) – (Cyathea cunninghamii) / (Hedycarya arborea)*	Planted in retired pasture 2002 *Pittosporum eugenioides - Pennantia corymbosa / Coprosma grandifolia*
Morgan Reserve	*Prumnopitys ferruginea - Dacrydium cupressinum / Beilschmiedia tawa / Hedycarya arborea– (Cyathea dealbata) – (Blechnum filiforme)*	Fenced in 1997 *Myrsine australis - Melicytus ramiflorus – (Hedycarya arborea) – (Aristotelia serrata) – (Carpodetus serratus) – (Geniostoma ligustrifolium* var. *ligustrifolium) – (Coriaria arborea)*	Planted in retired pasture 1996 *(Podocarpus totara* var. *totara) - (Knightia excelsa) - (Melicytus ramiflorus) – (Pittosporum tenuifolium)*
Hunua Ranges	*Dacrydium cupressinum - Lygodium articulatum - Beilschmiedia tawa - Prumnopitys ferruginea – (Beilschmiedia tarairi) – (Cyathea medullaris)*	Retired from farming in the 1960's *Kunzea ericoides* var. *ericoides / (Myrsine australis) – (Hedycarya arborea) (Geniostoma ligustrifolium) / (Blechnum novae-zelandiae)*	Planted on excavated slope in 1967 *Pittosporum eugenioides - Myrsine australis - Pittsoporum tenufolium*
Tiritiri Matangi	*Dysoxylum spectabile – (Vitex lucens) - Beilschmiedia tarairi / Rhopalostylis sapida*	Retired from farming 1972 *Kunzea robusta / Coprosma lucida / (Blechnum chambersii)*	Planted in retired pasture 1988 *Melicytus ramiflorus + Metrosideros excelsum + Leptospermum scoparium*

2. Te Rere (TR)

Te Rere Penguin Reserve on the Catlins' coast is 67 hectares of mature, restored and regenerating podocarp-broadleaved forest. The Catlins Forest Park is 2.5 km to the east of the reserve, with immediate surroundings of sheep- and beef-farmland and patches of scrub scattered in the gullies and steeper wetter slopes. Te Rere has been managed by Forest and Bird (NZ conservation non-governmental organisation) since the reserve's gazetting in 1981. Management involves fencing the area from stock, servicing DOC200 trap-lines and planting over 25 000 locally sourced plants.

The Reference area surrounds a waterfall at the inland-most extent of the reserve. This consists of emergent podocarps up to 24 m high of *Dacrydium cupressinum, Metrosideros umbellata,* and *Prumnopitys ferruginea* over a 15m-high canopy of *Weinmannia racemosa* (Table 3). The understory is fairly dry and open due to past stock access and the more accessible edges were logged in the 1960's. The two dominant understory species are *Hedycarya arborea* (19%) and *Dicksonia squarrosa* (10%). The forest floor coverage consists of 20% ground fern, predominantly *Blechnum discolor* (10%), and supports a large community of regenerating woody seedlings (37 species recorded within the plot) at an average density of 5.7 seedlings m^{-2}.

The Spontaneous area is in the eastern section of the reserve which was devoid of woody vegetation, but a few tree ferns likely persisted in this location that had recovered from grazed pasture. The canopy cover is dominated by tree ferns *Dicksonia squarrosa* (32%) and *Cyathea dealbata* (12%) and *Fuchsia excorticata* (20%). The forest floor contains a high cover of ferns (25%) and density of seedlings (5.6 m^{-2}).

The Planted area is located to the southeast of the mature forest behind a planted sward of *Phormium tenax* and *Austroderia richardii*, protecting the inland planting from the coastal winds and salt spray. The canopy is low at 3.5m, but is dense with a high canopy cover (90%). The diversity within the site is low, predominantly of *Pittosporum tenuifolium* (80%). The understory is bare and dry, but with many seedlings (on average 9.3 seedling m^{-2}).

3. Quail Island (QI)

Quail Island is a recreation reserve, 81 ha in size in Lyttelton Harbour, Christchurch. It is predator-free and isolated except at a very low tide. The island is managed by DOC and Friends of Quail Island (a volunteer organisation). Prior to restoration efforts the island was farmed and almost completely devoid of native woody vegetation (Burrows & Wilson, 2010). Planting on the island began in 1998, and today vegetation consists of a 3m high canopy of predominantly *Coprosma robusta* (46%), *Kunzea robusta* (15%) and *Pittosporum tenuifolium* (10%) (Table 2, 3). Seedlings within the understory were common (on average 15 seedlings m^{-2}) with woody seedling regeneration even noted outside the protection of the planted canopy and along the grass tracks.

The nearest intact remaining native vegetation reference to this site is found 2km south of Quail Island on the mainland. The Reference area was located in Buckley's Bay Scenic Reserve, and consisted of a mixed canopy of *Sophora microphylla* (35% cover), *Alectryon excelsus* (17%), *Myoporum laetum* (14%), *Melicytus ramiflorus* (12%) and *Plagianthus regius* (12%), with a dry open understory containing *Myrsine australis* and a variety of small-leaved divaricate shrubs. The ground layer appeared grazed with only a few seedlings present and some ground fern (6% cover). At time of sampling, possum and rabbit presence was noted, with no management of these pests currently operating due to earthquake risks associated with the 2011 swarm of earthquakes in Canterbury.

The Spontaneous area adjoined the Reference area on the rocky toe (5% cover) of a slip which occurred in 2010. Soil depth was irregular (3-16cm). Spontaneous vegetation was for the most part untouched by browse due to a dense sward of *Urtica ferox* on the exposed edges. The 1.8 metre canopy within the plots consisted of young *Melicytus ramiflorus* (20%), *Fuchsia excorticata* (18%), *Coriaria arborea* (10%) and the exotic shrub *Solanum chenopodioides* (7%). Both a high density (40 seedlings m^{-2}) and a high diversity of seedlings were recorded regenerating within the Spontaneous plots (on average 5 species m^{-2} at an average density of 14.3 seedlings m^{-2}).

4. Otari-Wiltons Bush (OWB)

This seven-hectare area is the last large podocarp-broadleaved remnant within Wellington City (Figure 9). The remnant forest is found within a steep gully, running north to south, and opening out at the Kaiwharawhara Stream. It is surrounded by a 93ha of regenerating and planted native forest and together these form Otari-Wiltons Bush Reserve. The reserve is managed by Wellington City Council staff with the help of volunteers. Management includes servicing bait and trap-lines, weed control and restoration planting.

The Reference area includes large emergent trees (up to 30m tall) of *Dacrydium cupressinum* and *Prumnopitys taxifolia* with a mixed canopy of *Dysoxylum spectabile*, *Beilschmiedia tawa* and *Elaeocarpus dentatus*. The undergrowth is dense and is dominated by tree ferns (25% cover) and broadleaved shrubs (42%). The ground floor contains many terrestrial ferns (35%) as well as some fallen logs. There is a mild coastal influence in places which are protected from frosts, with *Myoporum laetum*, *Rhopalostylis sapida* and *Piper excelsum* as well as *Dysoxylum spectabile* present to varying degrees.

Figure 9: Otari-Wiltons Bush, Wellington. In the foreground is the canopy of planted Pittosporum (lighter coloured foliage), with the Reference area (dark vegetation) to the centre of the picture and Spontaneous succession occurring up the slope behind this.

Otari-Wiltons Bush Trust began restoration planting at the Planted area in 2001, adjacent to the Reference area alongside the walking track on the southern side of the Kaiwharawhara Stream. The canopy of this site is 4.3 m tall, with 90% cover, and primarily consists of *Melicytus ramiflorus*, *Pittosporum eugenioides*, *Pittosporum tenuifolium* and *Pseudopanax arboreus.* There is little undergrowth and little regeneration with an average of 4.1 seedlings m^{-2} of 2.5 species m^{-2}.

The Spontaneous area is found 20m in altitude above the Reference area and 40m above the Planted area. It was retired from farming in the 1960's and left to regenerate naturally from pasture through gorse to what is now a native community of early seral species. Only a fraction of the once widespread gorse now remains, due to overtopping by natives. This community (4m tall) is on average dominated by *Melicytus ramiflorus* (65% cover), *Piper excelsum* (15%), *Myrsine australis* (15%), *Brachyglottis repanda* (14%) and *Dysoxylum spectabile* (10%). The understory is high in cover with broadleaved shrubs such as *Piper excelsum* (14%) *Coprosma grandifolia* (7%) and *Geniostoma ligustrifolium* (7%). The forest floor is dry and contains approximately 20% cover of ferns.

5. Mana Island (MIs)

Mana is a 217-hectare predator-free island that lies 2.5 km from the west coast of Wellington. It is a remnant of uplifted marine terrace. It was farmed until the last of the stock was removed in 1986, by which time all mature forest had been cleared and only some native scrub remained. Mice were eradicated in 1990 making the island free of introduced mammals. Management includes monitoring for predator incursions and caring for planted trees which includes infill plantings, enrichment planting, and weed control. Planting into pasture began in 1987 and continued until 2009 by when approximately half the island was planted. Planting occurred in blocks after blanket-spraying of exotic pasture grass. The dominant species planted differed from year to year but predominantly consisted of small trees *Pittosporum tenuifolium* (40%) and *Myoporum laetum* (40%), *Melicytus ramiflorus* (10%), *Pseudopanax arborea* (9%) and *Myrsine australis* (6%).

The Spontaneous area on Mana Island is found within a north-eastern gully where the soil is thin (18 cm). On its steeper coastal edge the area contains two remnant specimens of *Streblus banksii* and the area has regenerated since sheep were fenced out in 1986. The canopy is dominated by *Kunzea robusta* (45%), while the understory of saplings predominantly consists of *Melicope ternata* (6%), *Melicytus ramiflorus* (8%), *Piper excelsum* (6%) and *Streblus banksii* (4%). Ferns are common on the ground layer *Asplenium oblongifolium* (15%) along with woody seedlings with a density of 6 m^{-2}.

The Reference area for Mana Island is found 22km north, on Kapiti Island a 1,965-hectare predator-free DOC-managed conservation reserve. Like Mana Island, part of this island was cleared and farmed, although some original vegetation remains intact. The Reference area was located within a remnant gully system draining into Rangatira Bay. This site is dominated by *Prumnopitys taxifolia* (5%), *Metrosideros robusta* (6%), *Beilschmiedia tawa* (50%) and *Dysoxylum spectabile* (20%). The understory is dense with regenerating *Rhopalostylis sapida* palms (10%), woody seedlings (density of 5.2 seedlings m^{-2}), and ground ferns (15% cover).

6. Fensham Reserve (FR)

This 48-hectare reserve is located near Carterton in the Wairarapa (Figure 10). The reserve is owned and managed by Forest and Bird. Management consists of regular tree planting and weeding of plantings, as well as mammalian pest control. The Reference area consists of 9 hectares of remnant podocarp-broadleaved forest on the lower slopes containing tall (30-40m) *Dacrycarpus dacrydioides* with *Dacrydium cupressinum* (22%), *Prumnopitys taxifolia* (11 %) and *Prumnopitys ferruginea* (6%) emerging above a canopy of *Beilschmiedia tawa* (16%) and *Laurelia novae-zelandiae* (4%). The understory consists of *Cyathea dealbata* (10%), *Hedycarya arborea* (9%), *Myrsine australis* (15%) and

Melicytus ramiflorus (5%), along with many vines and epiphytes, ferns, filmy ferns and mosses. For seedlings, 7.6 species and 11 seedlings were found per square metre.

Figure 10: Fensham Reserve, Carterton. The Planted area is the low canopy to the right of the foreground. The Reference area is the taller canopy on the foothill and the Spontaneous area is on the slope above.

On the gentle slopes above the remnant forest is the Spontaneous area, a community that has spontaneously regenerated under *Leptospermum scoparium* (56%) following felling of a *Pinus radiata* plantation. The vegetative cover is high (199% total cover) and diverse (43 species recorded), with many different species of broadleaves, and with *Knightia excelsa* (11%) emerging above the canopy at points. Seedling density is 3.0 m^{-2}.

Restoration for the Planted area on the lower slope below the podocarp remnant began in 2001 in an area of retired pasture. Species planted consisted of small tree species, low growing and multi-stemmed and predominantly are *Pseudopanax arboreus* (21% canopy cover), *Coprosma robusta* (20%), *Plagianthus regius* (15%), *Pittosporum tenuifolium* (10%) and *Pittosporum eugenioides* (10%). The understory is sparse with few seedlings (on average 2.5 species m^{-2} and a density of 4.3 seedlings m^{-2}).

7. Keeble's Bush (KB)

Keeble's Bush is a 23-hectare protected complex on a river terrace near Palmerston North, owned and/or managed by the C.T. Keeble Memorial Forest Trust for scientific purposes, and thus not open to the public. Management of the reserve includes buffer planting, linkage planting and both weed and mammalian pest control.

The Reference area is a 17-hectare remnant of podocarp-broadleaved forest of emergent *Dacrydium cupressinum* (21% cover), *Dacrycarpus dacrydioides* (3%) over a canopy of 13% A*lectryon excelsus* and a little *Beilschmiedia tawa* on a marine terrace. The sub-canopy is predominantly woody (ground ferns only 10%) with a diverse range of small trees, saplings and shrubs (46 species in total found within the two replicates).

The site is surrounded by farmland. The only area undergoing spontaneous succession was a section of remnant forest within the Bush proper which succumbed to wind-fall in a gale in 1936 (Esler A. E., 1962). Here there is a canopy of *Alectryon excelsus* (45% of total cover) with a dense understory of *Melicytus ramiflorus* (18%), *Piper excelsum* (39%) and *Hedycarya arborea* (14%), and a ground layer of *Asplenium oblongifolium*. Woody debris, from the large logs of the original windthrown forest, are also scattered throughout this area.

Restoration occurred in this area largely in two discreet time periods, in a 2-ha block in the 1970s (called the Greenwood Planting) and in a 1 ha block in the 2000s (the Link). The Planted area borders the Mungatungaroa Stream which runs from the remnant along the base of a terrace to the Kahutarawa River. A replicate plot was placed in each of these. Planted species consist of *Podocarpus totara* (5%), *Plagianthus regius* (6%), *Melicytus ramiflorus* (16%) and *Pittosporum tenuifolium* (34%). Apart from exotic grass (22% cover), the understory is sparse and predominantly consists of *Muehlenbeckia australis* (4%), *Myrsine australis* (3%) and *Hedycarya arborea* (2%).

8. Kent Rd (KRd)

Kent Road site is within a landscape of dairy pasture with vegetated gullies, draining from Mount Taranaki to the coast northwest of New Plymouth. The Kent Rd Planted area is located on private property on heavily compacted retired dairy pasture. The area has been planted in blocks of differing species, resulting in low species diversity (Table 2). Trees are mostly of the same stature, low growing, multi-stemmed and in groups of *Melicytus ramiflorus* (7%) and *Myrsine australis* (3%) or *Pittosporum eugenioides* (28%) and *Pennantia corymbosa* (20%) or of just *Hebe stricta* (3%). There is a prevalence of weed species, and DOC200s are serviced in the area. Seedlings occur at a density of 9.3 m^{-2}, of 3.4 species m^{-2}.

Situated between the Reference area, and adjoining it on a flat terrace, the Spontaneous area was fenced off and retired in 1995. This community comprises a canopy of *Melicytus ramiflorus* (10%), with a dense sapling layer of *Melicytus ramiflorus*, *Knightia excelsa* (2%) and *Alectryon excelsus* (3%), and with shrub species of *Geniostoma ligustrifolium* (7%), *Coprosma grandifolia* (3%) and *Piper excelsum* (1%), and a sparse ground layer of *Asplenium oblongifolium* and *Microsorum pustulatum*.

Five kilometres downstream of the Planted area located on a raised river terrace is the Reference area, at Araheke, a DOC-managed reserve containing a podocarp-broadleaved remnant of emergent *Prumnopitys taxifolia* (16%), *Podocarpus totara* (16%), and *Dacrydium cupressinum* (17%), over a canopy of *Beilschmiedia tawa* (27%). There were 5.7 seedlings m^{-2} .

9. Morgan's Reserve (MR)

This 13-hectare podocarp-kauri-broadleaved reserve is found at Waikino at the southern end of the Coromandel Ranges, within dairy pasture 500 m from the Coromandel Forest Park (Table 2). The reserve is managed by Forest and Bird who carry out fencing, and pest- and weed-control.

The Reference area consists of a tall canopy of *Dacrydium cupressinum* (22% cover), *Prumnopitys ferruginea* (27%) and *Beilschmiedia tawa* (37%; Table 3). There is also a kauri stand nearby on the drier north-facing slope. The understory is predominantly woody, of *Hedycarya arborea* (26%) and *Myrsine australis* (2%), with the ground layer well-covered with *Blechnum flilforme* (12%) and ground fern species of *Asplenium* and *Polystichum*.

The Spontaneous area is a recently fenced section of retired pasture, 500m to the west of the planting and adjoining a remnant within a gully system. The canopy is a mix of the exotic shrubs *Ulex europaeus*, *Cytisus scoparius* and *Lonicera japonica*. The understory cover is high (74%), due to 21% cover of *Melicytus ramiflorus* and contains many woody seedlings, including *Dacrydium cupressinum* seedlings. The forest floor contains a high cover of ferns, and 5.5 seedlings m^{-2}.

The Planted area surrounds the north and western edges of the Reference area and was initiated in 1996. Species planted primarily consisted of *Podocarpus totara* (16%), *Knightia excelsa* (16%), *Melicytus ramiflorus* (15%) and *Pittosporum tenuifolium* (12%). The understory is dry and sparse with no ferns.

10. Hunua Ranges (HR)

The Hunua Ranges is the largest Forest Park in the Auckland region and the primary water catchment for Auckland City containing four large water-supply dams (Figure 11). The areas surrounding the dams were planted in the 1980s as mitigation for dam construction. The species planted consisted of

Pittosporum eugenioides (89% cover in one plot), *Myrsine australis* (22%), *Pittosporum tenuifolium* (an average of 10%) and *Sophora microphylla* (10%).

Figure 11: Hunua Ranges, Auckland, with the bright green broadleaved trees of the Planted area in the foreground, and the Spontaneous area dominated by kanuka in the background.

The Reference area within the Hunua Ranges consists of an area which has previously escaped logging. This contains large specimens of emergent *Dacrydium cupressinum* (22%) and *Prumnopitys ferruginea* (11%) over a canopy of *Beilschmiedia tarairi* (26%) and *Beilschmiedia tawa* (21%). The ground fern layer is dense (60% cover) and the undergrowth is diverse.

The Spontaneous area is located within an area where farming activities have been carried out in the past, but poor soil (26 cm deep) and large areas of steep terrain saw the area abandoned in the 1960's. Much of the area has thinning *Kunzea robusta* canopy (on average 33% cover), regenerating vegetation cover is high with a ground floor covered in ferns. In this area, podocarp seedlings have already established amongst the young *Kunzea robusta* as well as a variety of seedlings of broad-leaved species (14.3species m^{-2}).

11. Tiritiri Matangi (TM)

Tiritiri Matangi Island is a 220-hectare reserve managed to be predator-free by DOC which is 3.5km offshore from the Whangaparaoa Peninsula, Northland (Table 4; Figure 12). It was farmed up until 1971, and once it became apparent that the island in its current state would not naturally regenerate, the decision was made to plant it as a community-focused education project (Rimmer, 2004). The planned approach to this restoration was to bypass the woody scrub sere and plant desired climax and mid-successional species. Restoration planting was carried out on the island from 1984 to 1994.

Figure 12: Tiritiri Matangi Island, Auckland. The Spontaneous area is in the foreground and the Planted area (darker, even canopy) is in the upper slopes of the background.

In the Planted area, initially *Metrosideros excelsa* (15% cover) was the main species planted, which, to further increase diversity, was followed by *Sophora microphylla* (5%), *Coprosma robusta* (7%), *Pseudopanax arborea* (1%) *Pittosporum crassifolium* (3%) and *Melicytus ramiflorus* (16%) and *Cordyline australis* (1%).

Two Spontaneous areas were measured in duplicate – one area succeeding through the native *Leptospermum scoparium* and the other through the exotic *Chamaecytisus palmensis*. The *Chamaecytisus palmensis* site occurred in a sheltered gully to the South and the *Kunzea robusta* site within an exposed gully. The canopy consisted o*f Dysoxylum spectabile*, *Kunzea robusta* and *Leptospermum scoparium* (all 8-9% cover), over *Melicytus ramiflorus* (38%), with a shrub layer of *Myrsine australis* (6%), *Coprosma lucida* (14%), *Coprosma rhamnoides* (6%), with a fern layer dominated by *Blechnum chambersii* (5%). Seedling density was 11.0 m^{-2} of 4.2 species m^{-2}.

The Reference area to Tiritiri Matangi is located within Wenderholm Regional Park, Waiwera, Northland, 14 km to the west. It is a remnant coastal forest, consisting of large canopy forming *Vitex lucens* (8%), *Dysoxylum spectabile* (41%) and *Rhopalostylis sapida* (11%), with an understory full of young *Rhopalostylis sapida*, *Piper excelsum* and fern species. Although not considered predator-free, pest control is carried out by both baiting and possum trapping. For seedlings, density was 21.7 m^{-2} represented by 6.2 species m^{-2}.

Analysis of site x treatment interactions

Table 5 shows the mean distance in ordination space between treatment plots within each site (of coordinates from Figure 3), averaged over all sites. Spontaneous sites are 1.9 times closer to the Reference sites than are the Planted sites. The same differences are shown for each of the 33 explanatory variables. Of the variables, 71% show a closer similarity (smaller distance) between spontaneous plots and their reference sites. However, the planted site was closer to the reference site in eight measured variables of altitude, canopy species richness, percentage of gap, percentage of course woody debris ground cover, percentage of rock ground cover and percentage cover of native vegetation.

Table 5: Mean distance between each treatment pair (Reference to Planted (R - P), Reference to Spontaneous (R - S), and Spontaneous to Planted (S - P) in compositional ordination space, and the mean difference between the values of each of the potential explanatory variables. See appendix 3 for averaged potential explanatory variables for each treatment within sites. Bolded values are the pair with the smallest difference for each variate, ie., the two treatments which are the most alike.			
Explanatory variate	**R - P**	**R- S**	**S - P**
Compositional distance	7.22	**3.73**	3.49
Altitude (m)	**0.02**	0.04	-0.02
Aspect (cosine in radians)	978.38	**966.23**	12.15
Slope (^{O})	2.51	**1.57**	0.94
Regeneration age (yrs)	-173.42	**-89.39**	-84.03
Soil compaction (MPa)	18.75	**16.70**	2.05
Soil depth (cm)	18.01	**16.64**	1.37
Height of highest tree (m)	7.95	**6.86**	-0.91
Canopy height (m)	1.88	**1.58**	0.30
Radius of canopy (m)	32.54	**29.76**	2.78
Stem diameter at 1.35m (cm)	-1.10	**-0.48**	-0.63
Stem count at 1.35m	-10.15	**0.91**	-11.06
Structural tiers (of 7)	2.96	**2.31**	0.65
Canopy cover (%)	-12.58	**-1.64**	-10.95
Canopy species richness	**0.90**	-3.84	4.75
Canopy gap (over 1m² in area) (%)	**-0.77**	-4.45	3.68
Area of raised ground (%)	6.44	**3.98**	2.45
Ground cover - bare (%)	-6.43	**-1.80**	-4.64
Ground cover - litter (%)	3.67	**0.59**	3.08
Ground cover - woody debris (%)	**-0.13**	-0.66	0.53
Ground cover - fern (%)	23	**6**	17
Ground cover - rock (%)	**0.20**	-0.53	0.73
Ground cover - lichen (%)	1.13	**0.59**	0.54
Ground cover - bryophytes (%)	2.29	**1.67**	0.62
Epiphytic bryophytes (%)	-6.18	**5.47**	-11.65
Woody species (% cover)	51.21	**38.01**	13.20
Native species (% cover)	**0.38**	-1.06	1.44
Exotic species (% cover)	48.84	**24.56**	24.28
Total species cover (% cover)	7.36	**5.05**	2.32
Species richness	4.57	**3.90**	0.67
SWDI – species cover	5.05	**4.38**	0.67
Specific Leaf Area of canopy species (cm² g^{-1})	2.80	**1.26**	1.54
Seedling richness (m^{-2})	5.12	**0.05**	5.07
Seedling density (m^{-2})	7.22	**3.73**	3.49

Some of the differences between treatments can be seen in Figure 13, with the Planted plots containing small tree species which, due to open growing conditions, have developed multi-stemmed trunks and form a dense canopy cover, with the forest floor beneath covered in leaf litter. The Spontaneous plots show vegetation (green) throughout the understorey, with a variety of mostly single-stemmed trees, and a relatively open canopy. Lastly, the Reference plots show defined vegetation layers with a large proportion of terrestrial fern species, along with a range of other species, ages and lifeforms.

Figure 13: Treatment photos of each treatment: (upper) Planted (centre) Spontaneous and (lower) Reference plots, within two sites Fensham Reserve (left) and Mana Island (right).

DISCUSSION

This study found that at most sites, restoration planting was not as successful as the do-nothing control (spontaneous succession) in assisting the recovery of a system comparable to a reference site. While the Planted Plots in comparison to their spontaneous counterparts, were on average closer to the reference on two accounts, a higher ratio of native: exotic cover and higher canopy richness. The Planted Plots were further from the reference in all other 31 measured variables of structure and function.

The Spontaneous Plots in comparison to reference sites, showed higher functioning measures and a more complex (diverse) structure than those of the Planted Plots. This result concurs with the current literature, where meta-studies have shown a greater success in passive restoration strategies, in comparison to active forest restoration (Jones et al., 2018b; Meli et al., 2017). This advantage of spontaneous succession does not appear to be restricted to forest ecosystems, with similar results appearing in drylands (Birch et al., 2010), wetlands (Moreno-Mateos, Meli, Vara-Rodríguez, & Aronson, 2015) and stream ecosystems (Kauffman, Beschta, Otting, & Lytjen, 2011).

Furthermore, the lack of seedling abundance and diversity within the planted treatments in comparison to the Spontaneous plots is an indicator that the successional development will continue to be slower and less diverse in planted communities. This concurs with similar studies which have found that restoration planting within retired agriculture has led to a slower successional process than unfarmed land (Cramer, Hobbs, & Standish, 2008), and in some studies this has even impeded the successional process (Sampaio, Holl, & Scariot, 2007).

Of the compositional data, species richness and the Shannon Weiner index of species cover were found to be indicators of restoration success within the plots, with a high species diversity in the Spontaneous flora compared with the Planted ones. The planted sites were comparatively low in diversity and in particular, were found to have a preponderance of Pittosporum tenuifolium, Kunzea robusta and Leptospermum scoparium.

The Shannon Wiener Diversity Index proved a significant indicator of success, not only when used as a measure of species diversity, but as a measure of diversity within the function and structural classifications of each species. Both diversity and abundance of species affect functioning, as all species at the very least have a metabolism in addition to other ecological services they provide, such as filtration, pollination, dispersal, and so on. This reiterates that idea that biodiversity measures in themselves, are a good proxy measurement for ecosystem functioning (Hooper et al., 2005).

Of the structural attributes measured, micro-topography, stem count at 1.35m, diversity of growth-forms, and diversity in tier-cover, were found to be indicators of restoration success within the plots. Of the functional attributes measured, phylogenetic class was found to be an indicator of restoration success. A higher diversity of phylogenetic class was also measured in the Spontaneous plots compared to the Planted plots. Of note, there was a greater abundance of fern-cover in the Spontaneous plots, compared with the Planted plots.

The planted treatments did not only show a higher dissimilarity to their reference in comparison to the spontaneous treatments, they also showed little variation within the planting treatment in vegetation composition in comparison to their geographic spread. This shows that Planted sites throughout New Zealand are similar in both the species planted and their relative proportions and therefore out of context with the locally native plant communities. This, along with difference in structural and functional variables, indicates that planted sites are a novel, or non-analog ecosystem (Williams & Jackson, 2007).

Due to high maintenance costs, restoration plantings tend to focus on species that are easy to collect, germinate and are hardy and fast growing once planted, often with the aim of growing a canopy to shade out the weeds and nurse natural regeneration (Morrison & Lindell, 2011). Species with these traits are generally a select few species of woody early successional stage, shown in this New Zealand study to be *Melicytus ramiflorus, Pittosporum eugenioides, Pittosporum tenuifolium*, *Pseudopanax arboreus, Coprosma robusta* and *Kunzea robusta*. Planting solely this structural class, results in a structural monoculture and while this does achieve weed suppression, there appears to also be a suppression of a native seedling community and lowering of function.

In this study a difference in soil compaction was noted between two sites which presented reclaimed land as part of hydro-dam schemes Deep Cove and Hunua Ranges, and the remaining sites which were recovering from past land use of pastural farming. Soil compaction was shown to be greater and microtopography less variable at previously pastoral sites. Highly compacted soils have been shown to result in lower growth rates and seedling establishment in New Zealand (Bassett, Simcock, & Mitchell, 2005). Therefore, higher soil compaction will have a negative influence on seedling community and subsequently the successional process.

This study did assume no inherent differences between the Planted and Spontaneous treatments in terms of general environmental variables. While an effort was made to select comparable treatments, the majority of the Spontaneous treatments were abandoned farmland, indicating they were perhaps poor, either due to steep or difficult terrain, or low-quality pasture. In comparison, the majority of the Planted treatments, while broadly similar to the Spontaneous treatments, were selected for restoration in part because of their ease of access, usually meaning they were located on less steep, less difficult terrain. However, no significant correlations were found between the vegetation communities and environmental variables at these sites, with the exception of soil compaction. Spontaneous sites exhibited lower soil compaction, perhaps due to these sites being farmed less intensively.

It was assumed that the age difference between the Spontaneous and Reference treatments doesn't account for the difference in restoration success. The Spontaneous treatments were, on average, older than the Planted treatments. However, the variable of age was tested in correlation to restoration success and was not found to be a significant factor in determining success.

It was assumed that wider landscape variables were similar within each site. This is because all plots were within vegetation contiguous to mature remnant forest, meaning the distance to the nearest seed source was similar between all plots within sites. The two exceptions to this were Quail Island and Mana Island, with the nearest seed source being the mainland and therefore not contiguous. The reference site for Quail Island was considered a poor example of the desired target ecosystems and therefore this is not investigated further and the two planted and spontaneous treatments of Mana Island, although not contiguous with a reference site, were similar in their distance to the nearest outside seed source.

Some variables of potential importance were not tested. These include humidity, temperature, and sunlight. These variables have been shown to be important to the growth and establishment of species (Bassett, Simcock, & Mitchell, 2005). and incorporating these measures as potential explanatory variables in future studies could improve our understanding of successful restoration methods.

Chronological studies could provide more accurate measures of restoration success. Succession is a dynamic process in which species composition and environmental variables change over time. Time series measurements would further refine its accuracy of predicting the successional trajectory. This would provide insight into best practices for restoration efforts moving forward, allowing for the refinement and improvement of on-the-ground restoration techniques, which would, in turn, improve our understanding of how these systems respond to human disturbance and manipulation.

Sites which are examined individually cannot reveal broader patterns and trends regarding restoration methods. Meta-analysis of restoration sites, across environmental gradients and encompassing different strategies of active and passive methods would overcome this single site constraint and further aid in the development of restoration and the successional process as a scientific field of study.

Furthermore, the environmental variables shown to be indicators of success need to be integrated into a predictive model. This would make it possible to predict if a restoration site is following the desired successional trajectory and intervene with remedial works if necessary.

In conclusion, passive restoration strategies were more successful than active planting strategies in terms of similarity to a reference site. Further work is needed to understand species assemblage in a novel environment and the mechanisms of succession in restoration plantings. This will allow us to more successfully restore environments into the future.

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Chapter 3:

What variables relate to restoration success?

Modelling the successional trajectory

"In short, as an instrument for the control of the entire range of human uses of vegetation and the land, succession is wholly unrivalled"

(Clements, 1949)

ABSTRACT

To justify the growing resources dedicated to forest restoration and to improve on current techniques we need to ensure the practice is successful in its goal; that is to restart and or guide the successional trajectory towards a desired target community that is comparable to a reference site in compositional, structural and functional attributes. To further understand how the successional process is shaped, especially within the restoration context of novel disturbances and management regimes, we need to find patterns between the degree of restoration success (in how far restoration has progressed toward its reference) and changes in abiotic and biotic variables across differing environments.

This study aims to achieve this, through a meta-analysis of eleven restoration sites throughout New Zealand within lowland podocarp forest. Restoration success was measured within each site, as the similarity of vegetation composition of the restoration treatment to that of the reference treatment, when compared with a treatment of spontaneous secondary succession. The variables reflecting success were identified by Akaike model selection and their parameters estimated.

The success of these models was then determined using an independent data set of a direct seeded restoration site at McGregor's Reserve in Northland. Of the three models tested, the variables that most corelated to success were a decrease in soil compaction, and increases in diversity indices of species structural, functional and compositional classes, and tier diversity.

This showed that legacy effects from past disturbances influence the successional success in terms of highly compacted soil from past pasture management and restoration success can be accurately assessed through measures of species structural, functional and compositional diversity.

Keywords: Ecological restoration, direct seeding, Akaike, ecological restoration success.

INTRODUCTION

An ecosystem is said to have been restored when it is comparable in structure and function to the desired preconceived target (reference site), self-sustaining with resilience against natural disturbance regimes and follows a desired successional trajectory without needing assistance (SER, 2004). If the Reference Site is the end goal or aim of restoration activities, then the process of recovery that restoration assists, through restarting or manipulation, is that of ecological succession, specifically secondary succession (Walker, Walker, & Hobbs, 2007). Succession is a fundamental scientific concept in restoration ecology ((Bradshaw, 1993; Temperton, Hobbs, Nuttle, & Halle, 2013; Walker et al., 2007; Young, Petersen, & Clary, 2005), such that it has been remarked that the only difference between the vegetation development of succession and restoration is that restoration also includes the involvement of people (Aronson & Alexander, 2013).

Restoration planting aims to speed up the natural successional process by 'skipping steps' of forest succession (Walker & del Moral, 2009), generally, the early scrub stage. This is approached by planting later successional tree species into low growing vegetation (often into pasture grass species), to reach the desired mature target ecosystem earlier (Rodrigues, 2015). However, there is increasing concern in the literature that restoration planting, or active restoration is not always as successful as has been assumed (Hobbs, 2007; Jones & Dudley, 2005; Meli et al., 2017).

The variates that influence succession of restoration plantings are poorly known (Walker et al., 2007). However the indicators of success in previous studies suggest that surrounding seed dispersal (Hobbs, 2007), heterogeneity of the site (Saldaña, Parra, Flores-Bavestrello, Corcuera, & Bravo, 2014), age since disturbance (Cortina et al., 2006) and Land use history (Zirbel, Bassett, Grman, & Brudvig, 2017) to be of importance in the successional process.

The investigations in Chapter 2 have indicated that many variates might be important, including stem polypodiality and ground fern cover which have not previously been implicated in restoration success. Here I use modelling procedures to clarify the role of various variates. I then test the models so derived against an independent data set from McGregor's Reserve, in Northland.

27 years' spontaneous succession. | 34 years' spontaneous succession. | 70 years’ spontaneous succession | 117 years’ spontaneous succession | Reference site

1 year direct seeding | 4 years' direct seeding | 10 years' direct seeding | 24 years' direct seeding. | Reference site

Figure 14: McGregors Reserve, Top row: areas recovering from disturbance through spontaneous succession. Bottom row: restoration from a known disturbance through direct seeding.

METHODS

Data was obtained from eleven sites within lowland podocarp forest located throughout New Zealand. Within each site three treatments within a comparable environment were measured; a reference site of mature forest, a site undergoing unassisted succession (spontaneous), and a restoration site. At least two replicate samples were taken within each treatment. Restoration success was measured for each site, as the similarity of vegetation composition of the restoration treatment to that of the reference treatment, when compared with a treatment of spontaneous secondary succession.

Refer to Chapter 2 for methods of raw data collection multivariate analyses of sites.

Analysis

The interrelationships between the variables (found in Chapter 2) were investigated using the Pearson dissimilarity coefficient. Where correlation between two variables was found to be high (above 0.8), one variable was removed from later analysis (see Appendix 3).

For the remaining variables, to find those corelated to restoration success the differences were tabulated for each variable between each pair of the three treatments, Reference to Planted, Reference to Spontaneous and Spontaneous to Planted. For each variable, this matrix was compared with the plot pairs' distances apart in ordination space using Pearson's correlations ($P<0.05$; $r>0.08$) in a Mantel test via the "Relate" procedure in Primer7, and significant variables identified.

Model creation

The variables which were significant were then presented to a forward stepwise linear regression in SYSTAT 8 (Systat Software, 1998) for each site. SYSTAT finds the best single variate, then adds the second best, and so on to determine the best candidate model to predict restoration success per site. Each candidate model from SYSTAT was tested using Akaike's Information Theorem (Akaike, 1992) with the programme R (R Development Core Team, 2015) using software packages AICcmodavg_2.1-0 (Mazerolle, 2016) and MuMIn_1.15.6 (Bartoń, 2016). This uses the candidate model, and all different configurations of its component variables to find the most parsimonious fit, i.e., as those with the lowest AIC value. However, increases in the number of component variables result in a significant increase in fit, so the most minimal model is sought. Larger combinations of variables or relationships other than linear could not be investigated with the size of the database available.

The sites with un-replicated plots (TR, QI, FR, MR) did not yield significant results in Akaike modelling. However, the compositional distances between each treatment pair were assessed using linear regression in Systat, against each predictive parameter involved in the parsimonious model of each of the other sites to generate coefficients for the models. This and the Aikaike tests generated a table of the parameters which successfully predict compositional distances between treatments within sites and reports their actual values.

Common explanatory variables (i.e., those found within parsimonious models of more than three sites) were selected to assess three different models. Model accuracy was then tested on non-training data (data collected throught the same not used to make the model).

These common variables were then tested for their ability to predict the compositional differences in vegetation between treatments for an independent site (namely, McGregor's Reserve), determined from distances in 2 dimensions of nMDS space.

McGregor's Reserve

The Professor W.R. McGregor Memorial Reserve is a 343 hectare reserve on the southern edge of Waipoua Forest, owned and managed by the Waipoua Forest Trust (Figure 2). The first section of this land was purchased in 1985 and restoration efforts of the past dairy farm back into native forest began in 1990. The soils within the reserve are considered low to moderate fertility (Sutherland et la, 1980). The climate of the area is mild (with a minimum daily average temperature 8°C and maximum daily average temperature of 18.5°C) and wet (total annual rainfall average is 1584mm, with few dry periods). The vegetation within the site consists of Kauri forest in the lower altitudes and podocarp above (Burns, 1992). Management of the area by the Trust includes enrichment planting and pest control.

Planting occurred by direct seeding of the nurse shrub *Leptospermum scoparium* onto recently cleared sites via a bulldozer, which intermittently peals back the grass sward and topsoil in a brick like pattern across the landscape. Four different seeded sites of 1, 5, 10 and 15 years of age were used. The four spontaneous succession sites were also of a known age, recovering from a variety of disturbance events: through exotic shrubland after pasture was abandoned in 1980; through native scrub *(Leptospermum scoparium*) after pasture abandonment in 1987; from clearcut logging in 1944; and from a fire in 1897. Reference sites of mature forest within the Reserve were also sampled (Figure 2). Sampling was as for Chapter 2.

Figure 2:Plot locations within Professor McGregor reserve and the wider Waipoua Forest Park, all located between State Highway 12 and Malbourgh Road.

RESULTS

Derivation of predicter variables from study sites

The parameters able to best predict the similarity of vegetation composition to the reference site differed between each site (Table 1). Of the 30 explanatory variables tested, 25 matrices showed a significant correlation to the distances between the compositional data. The most common of the correlations is the Shannon Wiener Diversity Index of tier cover (SWDI Tier) which is significantly correlated to 5 of the 11 sites. Also, commonly correlated is the Shannon Wiener index of phylogeny classes and average soil compaction which are significantly correlated to 4 of the 11 sites.

Tier diversity (Sum of the Shannon Wiener Diversity Index for vegetation cover within each tier), was the most common predictor of ordination distance between plots. This predictor occurred within the Deep Cove, Hunua Ranges, and Keebles' Bush sites. Tier diversity is positively correlated to compositional similarity, where the higher the tier diversity, the greater the similarity of composition between plots.

The differences in age of each vegetation community within each plot appeared to have an overall small impact on the ordination distances between Plots. Two sites showed age as a predictive parameter. One was Deep Cove, where the age of the Planted Plots was the same as the Spontaneous Plots. The other site where age was a predictive parameter, is Otari-Wiltons Bush, which predicts that as the age of the vegetation community increases, the ordination distance between plots decreases. In the instance of the Otari-Wiltons Bush Site, the difference in age between the Spontaneous Plots and the Planted Plots was large (40 years, Figure 11), here the age of succession at the Spontaneous Plot was a conservative estimate from when the land was retired from farming in this area.

Table 6: Cophenetic correlation coefficient values (Rho) between the similarity matrices of species' composition and each explanatory variable for all plots within each site. The higher the correlation coefficient the higher the correlation between the two matrices. An unshaded cell denotes a Rho significant at P <0.05 by Mantel test using Pearson's dissimilarity coefficient.

Significant variable	DC	FR	HR	KB	KRd	MR	OWB	MIs	QI	TM	TR
Age	0.956	0.556	0.390	0.007	0.313	0.976	0.695	0.401	-0.149	0.226	-0.225
Canopy cover	0.444	-0.115	0.713	0.227	0.218	-0.833	0.605	0.013	-0.534	0.018	0.959
Canopy height	0.970	0.339	-0.027	0.221	0.291	0.999	0.485	0.359	-0.585	0.310	-0.234
Ground bryophytes	-0.139	-0.397	-0.339	-0.206	-0.117	0.976	0.381	0.285	-0.778	-0.018	-0.087
Ground fern	0.781	-0.912	0.600	-0.055	0.291	0.901	0.666	-0.271	0.461	0.366	0.232
Micro-topography	0.102	-0.699	-0.229	0.719	0.018	0.860	-0.205	-0.265	0.833	0.328	0.879
Ground woody debris	-0.364	-0.607	0.301	0.026	0.166	-0.861	0.688	0.157	0.635	0.043	0.630
Native species	-0.244	-0.982	-0.186	0.063	0.183	-0.906	0.169	0.582	0.703	-0.114	-0.276
Radius of canopy	0.857	0.687	0.499	0.026	0.277	0.827	0.194	-0.291	-0.234	-0.084	0.095
Seedling density	-0.142	0.706	-0.445	0.500	0.242	-0.801	0.615	0.017	-0.193	-0.008	0.023
Seedling richness	-0.255	0.635	0.123	0.245	0.239	-0.063	0.612	0.170	0.055	-0.016	0.486
Soil compaction	0.135	0.127	-0.173	0.005	0.467	0.719	0.579	0.681	0.958	0.419	0.900
Species richness	0.831	-0.866	0.632	-0.076	0.544	0.423	0.080	-0.058	-0.360	0.405	0.459
Specific leaf area of canopy species	0.252	-1.000	0.755	-0.348	0.043	-0.562	-0.031	-0.019	-0.284	-0.121	-0.715
Stem count at 1.35m	0.679	0.828	-0.136	-0.052	-0.250	-0.694	-0.025	0.702	0.888	0.193	-0.959
Stem diameter at 1.35m	0.765	0.571	0.075	-0.116	0.328	0.998	0.619	0.151	-0.095	-0.109	-0.639
Structural tiers	0.726	0.301	0.113	0.120	0.233	0.993	0.716	0.138	0.360	0.296	0.725
SWDI – lifeform cover	0.319	-0.535	0.768	0.033	0.469	0.934	0.700	-0.141	-0.968	-0.013	0.995
SWDI – seeding abundance	0.074	0.596	0.240	0.542	0.195	-0.868	0.453	0.077	0.905	0.008	0.959
SWDI – species cover	0.878	-0.737	0.786	0.080	0.555	0.872	0.642	0.162	0.996	0.280	0.978
SWDI – taxa cover	0.219	-0.536	0.844	-0.132	0.548	0.486	0.636	-0.048	-0.014	0.338	0.986
SWDI – tier cover	0.806	-0.425	0.429	0.655	0.353	0.840	0.566	0.267	0.969	0.240	0.785
SWDI species cover /canopy cover	0.891	0.076	0.768	0.154	0.462	-0.239	0.605	0.152	-0.975	0.146	0.974
Woody species	-0.227	0.215	0.818	0.116	0.160	-0.881	0.440	0.199	0.923	0.159	0.991

Akaike models of treatment differences between sites

The Akaike selection procedure identified a total of 16 variables as predictive parameters of vegetation composition across each of the sites. Of these, tier diversity, canopy density, soil compaction and micro-topography were the most common predictor of distance between sites, each occurring in more than 3 of the most parsimonious models (Table 6).

Table 7: Akaike model selection using significantly correlated variables to species composition from Table 5. All candidate models with a delta AICc of < 10 are shown, unless only one model is <10, in which case the first two most parsimonious models are shown. Site codes are given in the text.

Site	Model	df	LogLiK	AICc	delta AICc	w
*DC	Gfern+Radius+StemBH+SWTier	7	245.606	-461.2	0	0.987
DC	CanHgt+Gfern+Radius+StemBH	7	239.824	-449.6	11.56	0.003
OWB	Rich+SoilCompA+SWspp+SWtaxa+SWtier	7	216.455	-402.9	0	0.454
OWB	Rich+SoilCompA+SWlife+SWtaxa+SWtier	7	216.427	-402.9	0.06	0.441
OWB	Rich+SWlife+SWspp+SWtaxa+SWtier	7	214.985	-400	2.94	0.104
MIs	NatCov+SoilCompA	4	-64.549	141.1	0	0.381
MIs	NatCov+SoilCompA+StemBH	5	-62.659	142	0.89	0.245
MIs	SoilCompA+StemBH	4	-65.073	142.1	1.05	0.226
MIs	NatCov	3	-67.967	144.1	3.02	0.084
MIs	StemBH	3	-68.795	145.8	4.67	0.037
MIs	NatCov+StemBH	4	-67.597	147.2	6.1	0.018
HR	Radius+Rich+SLA+SWtaxa+WoodySpp	7	239.997	-450	0	1
HR	Radius+Rich+SLA+SWtier+WoodySpp	7	224.954	-419.9	30.09	0
*KB	Raised+SdDen+SWsd+Swtier	6	-46.855	116.2	0	0.548
KB	Raised+SWsd+Swtier	5	-50.049	116.8	0.55	0.416
KB	SdDen+SWsd+Swtier	5	-52.793	122.3	6.04	0.027
KB	Raised+Swtier	4	-56.919	125.8	9.63	0.004
KRd	Rich+SoilCompA+SWlife+SWspp+SWtaxa	7	-75.23	170.1	0	0.85
KRd	Rich+SoilCompA+SWlife+SWspp+SWtaxa+SWtier	8	-74.978	173.5	3.47	0.15
TM	Rich+SoilcompA+SWlife+SWspp+SWtaxa+SWtier	8	324.533	-621.1	0	1
TM	Rich+SoilcompA +SWspp+SWtaxa+SWtier	7	-63.059	148.7	769.8	0

*Models chosen to test using independent data

Deep Cove

Two models, were found to be equally the most parsimonious in explaining the ordination distance in composition between the treatment sites at Deep Cove. Variables within the first model were ground fern cover, canopy radius, number of stems per individual at breast height and the Shannon Weiner Tier diversity. The second model also included ground fern cover, canopy radius and number of stems per individual at breast height, with the addition of canopy height.

Otari-Wiltons Bush (OWB)

The model best predicting compositional distances in ordination space in Otari-Wiltons Bush uses five variables. They are age of vegetation, soil compaction, number of structural tiers present, ground fern cover, and diversity of lifeforms. Here a greater distance in ordination space between plots is predicted through a decrease in age and woody debris cover, and an increase in structural tiers and DBH.

Mana Island (MI)

The model best predicting ordination distance in Mana Island uses average soil compaction and stem count at 1.35m. Here a greater distance in ordination space between plots is predicted through an increase in both soil compaction and stem count.

Keebles' Bush (KB)

There are two models best predicting ordination distance in Keebles' Bush. One is area of raised ground plus seedling density plus seedling diversity plus tier diversity. The other is area of raised ground plus seedling diversity plus tier diversity. In both models a greater distance in ordination space between plots is predicted through an increase in variables except for tier diversity.

Kent Rd (KRd)

The model best predicting ordination distance in Kent Road uses one variable. It is species diversity. Here a greater distance in ordination space between plots is predicted through an increase in species diversity.

Hunua Ranges (HR)

The model best predicting ordination distance in the Hunua Ranges uses three variables. They are radius of canopy tree, SLA of canopy species, and tier diversity. A greater distance in ordination space between plots is predicted through an increase in radius of the canopy tree and a decrease in tier diversity and SLA.

Tiritiri Matangi (TM)

The model best predicting ordination distance in Tiritiri Matangi uses six variables. They are species richness, soil compaction, and the Shannon wiener diversity index of lifeforms, species, taxanomic class and tier coverage. A greater distance in ordination space between plots is predicted through an increase in soil compaction, number of structural tiers, area raised, canopy height, and a decrease in diversity of taxa present.

Table 8: The constant and the coefficients of each of the explanatory variables (as found in the GLM analysis by SYSTAT) in the 1 or 2 most parsimonious models for each site (AICc <2).

Model Parameters	**DC**	**OWB**	**FR(s)**	**MIs**	**MIs**	**MIs**	**KB**	**KB**	**KRd**	**HR**	**TM**
Constant	0.00		0.00	8.74	14.03	13.11	-0.01	0.51	2.967	0.00	3.23
Ground fern %	6.39		0.322								
Soil compaction (MPa)		-0.220	-0.031	-0.08	-0.383	-0.352			0.012		0.139
Native Cover			0.909	-1.295	0.248						
StemBH	24.41				-76.509	-67.308					
Radius of tree canopy (m)	70.15									26.968	
Seedling density M2			4.062				0.354				
SLA of Canopy spp			-0.119							1.592	
Area raised (%)			3.17				-0.093	0.379			
Canopy height (m)			6.067								
Woody species(% cover)										-91.454	
SWDI - seedling							1.272	1.078			
SWDI - taxa cover		61.357	11.403						13.605	-232.535	-108.434
SWDI - tier cover	-46.54	44.977	10.391				-2.036	-1.583			23.696
SWDI - lifeform cover		6.84	32.547						-28.780		
SWDI- species cover			38.806						6.317		
Species richness		0.0572	0.935						0.015	7.493	2.115

Model testing

Refer to Chapter 2 for overview of eleven study sites. In this chapter I include the addition of a test site: Professor W.R. McGregor Memorial Reserve. The nMDS analysis of McGregor's Reserve shows (Figure 3) that the Spontaneous sites are on average a distance of 12.9 from the reference sites, compared with 16.1 for the Planted sites.

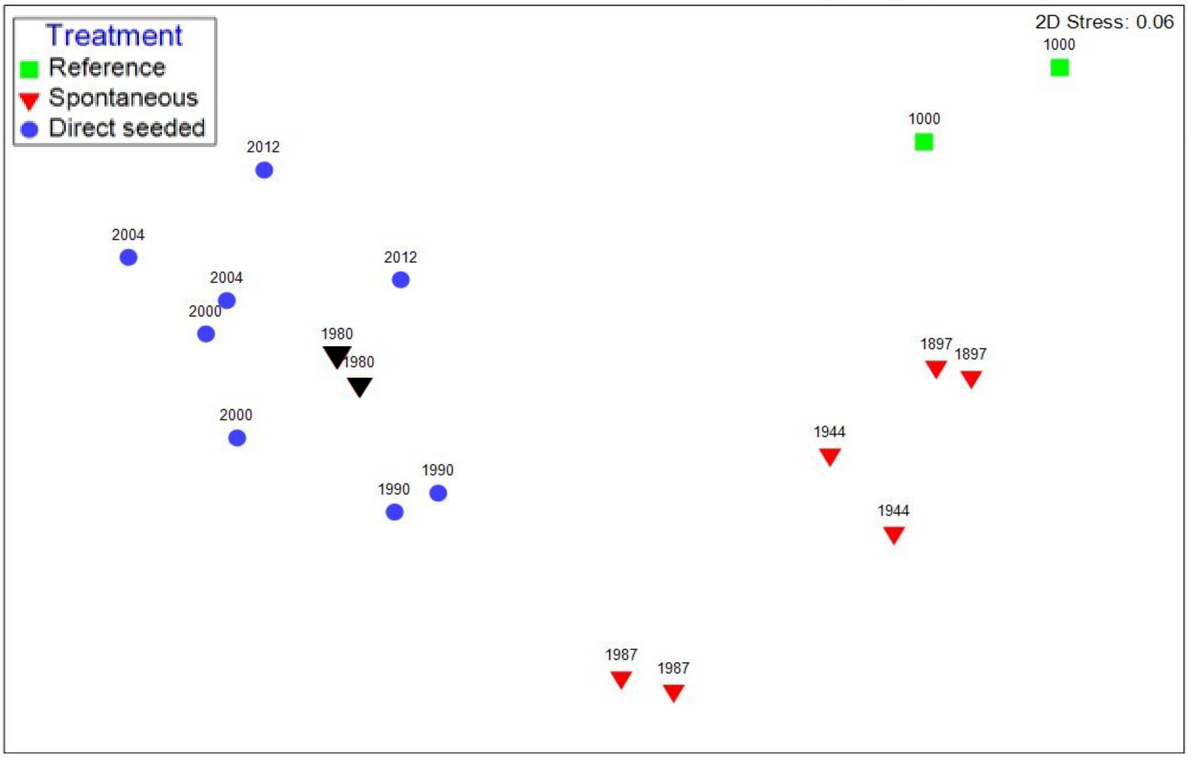

Figure 3: nMDS of the square root of vegetation cover, within each plot showing age and treatment of each plot within Professor McGregor Reserve in Waipoua. Note, the 1990 sites with the two black triangles follow spontaneous succession through exotic shrubs and pasture, while the red triangles all follow a successional trajectory from primarily native community.

The 3 different models, their variables and parameters from the 11 references sites which were selected for testing were:

Model 1

= raised*10.248 + SdDen*0.377+SWtaxa*-0.0404+WDspp*-4.633+ (C= 8.303)

Model 2

= gfern*0.23 + radius*-0.533 + StemBH*-8.429+SWTier*9.567 + C =2.057)

Model 3

= rich*1.797 + SoilComp*0.085 + SWlife*-11.061 + SWspp*26.478+SWtaxa*-15.663 + sWtier*37.756 + (C = 1.943)

The models and their parameters were then tested using differences of each corresponding variable in distance of ordinational space between the Reference to the Planted and Reference to the Spontaneous sites within McGregor's Reserve. The resulting number gives a prediction as to the success of the restoration, in regard to the similarity of the species compositions between the Planted and spontaneous sites to the Reference.

Figure 4, shows the difference between the predictions of each of the tested models to the actual dissimilarity of composition between the two corresponding treatments. Here Model 1 is seen to underestimate and Model 2 overestimates success. Model 3, is the most successful at predicting similarity in species composition to the reference site to both the restoration and spontaneous succession sites.

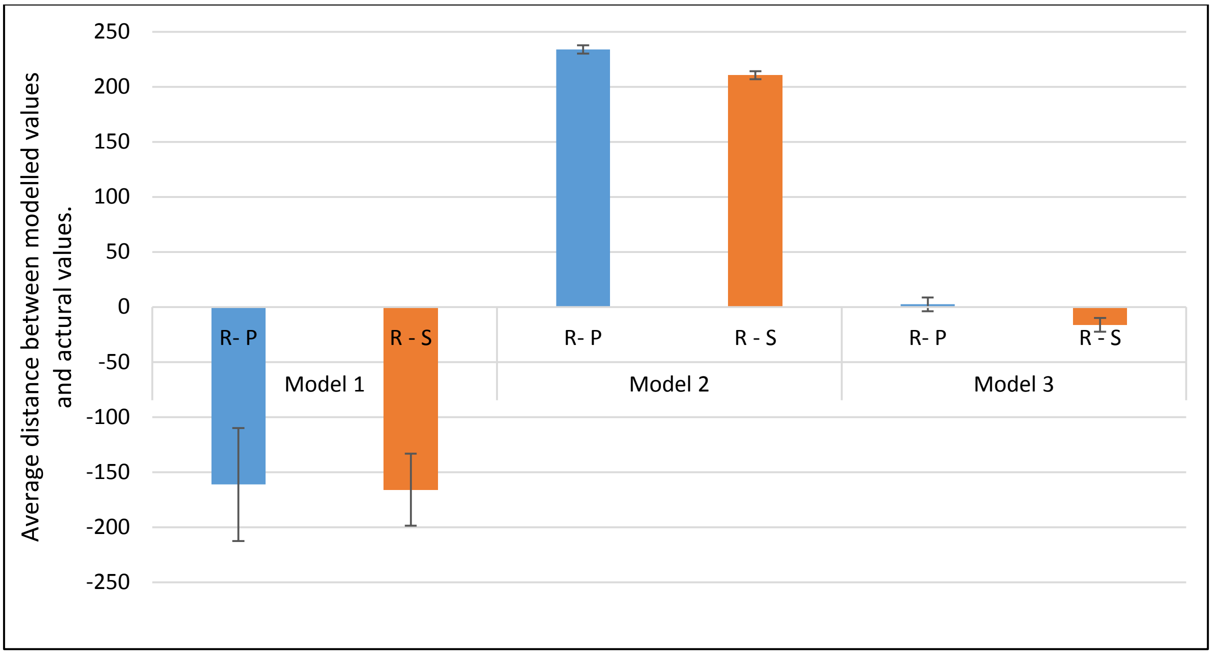

Figure 15: Fit of predicted restoration success models from Table 8 to the ordinational distance between variables from McGregor's reserve between the reference treatment (R) to both the restoration treatment (P) and the spontaneous treatment (S). Values are the differences found between the model predicted values and the actual values of compositional similarity to the reference.

DISCUSSION

The common explanatory variables predicting greater restoration success within the most parsimonious Akaike models were: a higher percentage of ground fern cover, shorter radius of canopy tree, lower number of stems at 1.35m, higher percentage of raised ground, lower soil compaction, higher seedling density, lower percentage of woody species, higher species richness and a higher Shannon Wiener diversity indies of tier diversity all three species classifications of phylogeny, lifeform, Tier structure, life form classification, and species diversity. These explanatory variables when further tested on an independent site showed the variables most effective at predicting restoration success were a combination of soil compaction, species richness and diversity indices of all three species attributes, composition, structure and function. Within these models the explanatory variables within the most parsimonious models differed between sites showing that there is some degree of influence by site.

Due to the unique and somewhat new characteristics of novel ecosystems, little information exists on their structure and functioning (Seastedt, Hobbs, & Suding, 2008). It is unknown what trajectory these communities will follow, whether it be convergent or divergent to the trajectory towards a reference system. However, they exhibit less diversity and ecological functioning, traits which have been attributed to of lower resilience to disturbance (Dudley, 2005) and a slower progression through successional stages to mature forest (Hobbs, Higgs, & Harris, 2009).on

In a forest system, multiple tiers are a sign of patterns of resource allocation of light and a form of niche partitioning within the forest.-Due to the different growth pattern in different species, canopy crowns overlap in diverse forests, creating an increase in structural complexity. A denser, more plastic, canopy in mixed stands may increase light interception, stand density, productivity and resilience (Forrester, 2014). This study showed that canopy species diversity was not an indicator of restoration success, but diversity in species structures and functions was.

Plants show architectural plasticity in response to differing physical environments. Here I found that plants in restoration sites, which are often planted in open areas, responded to this by growing several stems which spread outward. This is in comparison to spontaneous sites, which often grow in a light competitive environment through scrub and need to put more resources into fewer but higher stems. Differing architectural morphology is shown to affect functioning of stem hydraulics and growth, with the potential greater effect on carbon and water content at the ecosystem level (T. M. Bleby, I. J. Colquhoun, & M. A. Adams, 2009). So in terms of speeding up succession for restoration, fewer stems is shown to be more favourable.

All measures of diversity were found to be lacking in the restoration plantings, in comparison to the spontaneous succession, with diversity strongly lacking in planted sites. Both diversity in plant species and in structure (lifeform) and in functional groups (taxa) were affected by planting. Higher diversity has been shown to relate to higher ecosystem resilience (ref) and higher ecosystem functioning (Zirbel et al., 2017) . Active restoration was much lower in overall diversity.

Seedling establishment and survival is strongly dependent on canopy cover, microtopography and species already present. Seedling establishment and survival is also found to be dependent in New Zealand on competition with exotic grass species (Stevenson & Smale, 2005).

The failure in restoration success implies that the early scrub or shrub phase may be more important than has been assumed, and this was the phase added by direct seeding at McGregor's. The seed supply was entirely of *Leptospermum scoparium*, a small Myrtaceous tree to 5m, which is generally seen as a pioneer in natural successions after disturbances (ERF). Thus, direct seeding here is equivalent to deliberate generation of the "early scrub sere" and appears to be critical in the development of forest.

Soil compaction was another common predictor of compositional similarity which was always lowest in the Reference Plots. Soil compaction is an attribute often associated with grazed pastures (Sparling G. & Schipper L, 2004). The two sites that did not have a past land use of grazing were those associated with dam construction, Deep Cove and Hunua Ranges. Again, at Deep Cove the Planted and Spontaneous Plots occurred in the same area, therefore any difference seen between these is not a result of past land use. The Hunua Ranges however, showed the Spontaneous Plots to have higher compaction than The Planted Area, this is the only study site where the past land use differed between the Planted and the Spontaneous Plots, where the Planted Plots were on newly reclaimed land due to dam construction and the Spontaneous Plots were within retired pasture. This indicates that the difference in soil compaction is most likely a legacy of past land use.

In conclusion, variables showed that legacy effects from past disturbances influence the successional success in terms of highly compacted soil from past pasture management and restoration success can be most accurately assessed through measures of species structural, functional and compositional diversity

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SYNTHESIS

This thesis provides an assessment of the ecological success of forest restoration planting, currently the most common system restored. The practice of restoration is a reaction to habitat loss, the main cause of biodiversity loss (Temperton, Hobbs, Nuttle, & Halle, 2013) and a significant factor in anthropogenic climate change (Hall, 2001). (Sampaio, Holl, & Scariot, 2007). Restoration projects are currently increasing in scale, frequency and complexity, along with the resources needed to implement them. Success measures are needed to ensure intended environmental benefits, further advancements in restoration ecology theory and to justify resources spent.

Ecological restoration through restoration planting does have benefits with regards to community engagement, as well as being the preferred strategy in some extreme circumstances where seed sources are lacking entirely, or the site conditions are unsupportive of life and there is no chance for spontaneous succession to ever occur. However, the widespread success of restoration planting has been questioned (Hobbs, 2007; Prach & Hobbs, 2008).

Chapter 2 measures ecological success of forest restoration planting, in terms of restoring a comparable system of species composition, structure and functioning, in comparison to that of a mature forest reference. Further comparisons were made to that of a similar aged, similar environment site spontaneously undergoing the natural process of secondary succession. It was found that passive restoration or spontaneous succession was more successful that planted sites in recovery of a site comparable in function, structure and composition to a reference system.

Chapter 3, builds on the explanatory variables found in Chapter 2 to predict success, through modelling, the restoration planting successional trajectories. A scientific framework of succession needs to underpin and give explanation success of restoration methods. Ecological restoration through direct planting, traditionally this has led to some unknown successional trajectories and in some circumstances slowed down or supressed or suspended the successional process. This provides a framework in which to evaluate and predict the effects of these changes on altered rates or pathways of successional trajectories and losses of ecosystem services.

Ecological restoration is still predominantly pursued through planting despite numerous examples worldwide of how such efforts may actually inhibit ecosystem recovery (Chambers, Brown, & Williams, 1994; de Souza & Batista, 2004; Hodačová & Prach, 2003; Holl & Aide, 2011). In contrast, the success of passive restoration within the scientific literature has been well established (Meli et al., 2017; Prach & del Moral, 2015). Future ecological restoration methods must be tailored to suit the unique needs of the restoration site and be underpinned by ecological theory.

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APPENDIX 1: SITE AND PLOT LOCATION

GSP locations of each sample Plot in Transverse Mercator projection (NZTM2000) based on the NZGD2000 datum using the GRS80 reference ellipsoid.

Plot	Latitude	Longitude
DC_P1	4948723	1144029
DC_P2	4948538	1144059
DC_R1	4948284	1144068
DC_R2	4948005	1144286
DC_S1	4948942	1143237
DC_S2	4948872	1143331
TR_P	4827022	1310807
TR_R	4827426	1309950
TR_S	4827168	1310895
Q.Is_P	5169242	1575429
Q.Is_R	5171993	1578271
Q.Is_S	5172009	1578168
OWB_P1	5429493	1746534
OWB_P2	5429362	1746249
OWB_R1	5429654	1746304
OWB_R2	5429698	1746527
OWB_S1	5429830	1746729
OWB_S2	5430075	1746524
M.Is_P1	5449599	1749527
M.Is_P2	5449611	1749950
M.Is_P3	5449636	1749894
M.Is_R1	5476603	1762567
M.Is_R2	5476543	1762601
M.Is_S1	5450431	1750091
M.Is_S2	5450519	1750094
FR_P1	5458977	1810480
FR_R1	5458850	1810511
FR_S1	5458744	1810765

Plot	Latitude	Longitude
KB_P1	5524679	1820214
KB_P2	5524944	1820042
KB_R1	5524580	1820485
KB_R2	5524555	1820420
KB_S1	5524388	1820482
KB_S2	5524437	1820489
KRd_P1	5665108	1694812
KRd_P2	5665293	1694661
KRd_P3	5665034	1694635
KRd_P4	5665075	1694594
KRd_R1	5671479	1697076
KRd_R2	5671546	1696288
KRd_S1	5665125	1694593
KRd_S2	5671314	1696859
MR_P	5858504	1846286
MR_R	5858471	1846343
MR_S	5858088	1846013
HR_P1	5893189	1791972
HR_P2	5891611	1788820
HR_R1	5896017	1787507
HR_R2	5895704	1786306
HR_S1	5892891	1791575
HR_S2	5891195	1788847
TM_P1	5948040	1768441
TM_P2	5947224	1769167
TM_P3	5947198	1769035
TM_P4	5947511	1769478
TM_R1	5955046	1753052
TM_R2	5954940	1752841
TM_S1	5948209	1768652

APPENDIX 2: CLASSIFICATION OF SPECIES INTO LIFEFORM AND TAXONOMIC CLASSES.

Species	Common name	Status	Lifeform Class	Phylogeny class
Abelia xgrandiflora	Abelia	Exotic	shrub - large leaved	woody dicot
Acaena anserinifolia	Bidibid, hutiwai, piripiri	Native	herb - small	herbaceous dicot
Adiantum formosum	Giant maidenhair, Plumed maiden-hair	Native	herb - small	fern
Adiantum fulvum	Maidenhair	Native	herb - small	fern
Adiantum viridescens	Maidenhair	Native	herb - small	fern
Agathis australis	kauri, kauri pine	Native	tree - large leaved	woody gymno-sperm
Agrostis capillaris	browntop	Exotic	herb - tufted	herbaceous monocot
Agrostis stolonifera	Creeping bent	Exotic	herb - small	herbaceous monocot
Alectryon excelsus subsp. excelsus	New Zealand ash, titoki	Native	tree - large leaved	woody dicot
Alseuosmia quercifolia	oak-leaved toropapa, toropapa, karapapa	Native	shrub - large leaved	woody dicot
Anagallis arvensis subsp. arvensis var arvensis	pimpernel	Exotic	herb - small	herbaceous dicot
Anthosachne solandri	Native Wheatgrass, Blue Wheatgrass	Native	herb - tufted	herbaceous monocot
Anthoxanthum odoratum	sweet vernal	Exotic	herb - tufted	herbaceous monocot
Aristotelia serrata	Makomako, wineberry	Native	tree - large leaved	woody dicot
Ascarina lucida var. lucida	Hutu	Native	tree - large leaved	woody dicot
Asplenium appendiculatum subsp. appendiculatum	Ground Spleenwort	Native	herb - tufted	fern
Asplenium bulbiferum	Hen and chicken fern, pikopiko, mother spleenwort	Native	herb - tufted	fern
Asplenium flabellifolium	butterfly fern, walking fern, necklace fern	Native	herb - tufted	fern
Asplenium flaccidum	Drooping spleenwort, hanging spleenwort	Native	herb - tufted	fern
Asplenium hookerianum var. hookerianum	Hookers spleenwort	Native	herb - tufted	fern
Asplenium oblongifolium	Shining Spleenwort	Native	herb - tufted	fern
Astelia fragrans	Bush flax, bush lilly, kakaha	Native	herb - tufted	herbaceous monocot
Astelia trinervia	Kauri grass	Native	herb - tufted	herbaceous monocot
Austroderia fulvida	Toetoe	Native	herb - tufted	herbaceous monocot
Austroderia richardii	Toetoe	Native	herb - tufted	herbaceous monocot
Austroderia splendens	Toetoe	Native	herb - tufted	herbaceous monocot
Austroderia toetoe	Toetoe	Native	herb - tufted	herbaceous monocot
Beilschmiedia tarairi	Taraire	Native	tree - large leaved	woody dicot
Beilschmiedia Belischmiedia tawa	*Belischmiedia tawa*	Native	tree - large	woody dicot

Species	Common name	Status	Lifeform Class	Phylogeny class
			leaved	
Berberis darwinii	Darwins barberry	Exotic	shrub - small leaved	woody dicot
Berberis glaucocarpa	barberry	Exotic	shrub - small leaved	woody dicot
Blechnum chambersii	Lance fern, nini, rereti	Native	herb - tufted	fern
Blechnum colensoi	Colensos hard fern, peretao, petako	Native	herb - small	fern
Blechnum discolor	Crown fern, petipeti, piupiu	Native	herb - tufted	fern
Blechnum filiforme	Thread fern, climbing hard fern	Native	climbing	fern
Blechnum fluviatile	Kiwikiwi, kiwakiwa, creek ferm	Native	herb - tufted	fern
Blechnum fraseri		Native	herb - small	fern
Blechnum novae-zelandiae	kiokio, horokio, palm leaf fern	Native	herb - tufted	fern
Blechnum penna-marina subsp. alpina	little hard fern, alpine hard fern	Native	herb - small	fern
Blechnum procerum	small kiokio	Native	herb - tufted	fern
Blechnum vulcanicum	korokio, mountain hard fern	Native	herb - tufted	fern
Brachyglottis buchananii		Native	shrub - large leaved	woody dicot
Brachyglottis kirkii var. angustior	Kohurangi, Kirk's Tree Daisy	Native	shrub - large leaved	woody dicot
Brachyglottis repanda	Rangiora, bushmans toilet paper	Native	shrub - large leaved	woody dicot
Calystegia tuguriorum	Climbing convolvulus, NZ bindweed	Native	climbing	herbaceous dicot
Cardamine corymbosa		Native	herb - small	herbaceous dicot
Cardamine debilis agg.	NZ bitter cress	Native	herb - small	herbaceous dicot
Cardiomanes reniforme	Kidney fern, Konehu, Kopakopa, Rau-renga	Native	herb - small	herbaceous dicot
Carex dissita	Forest Sedge	Native	herb - tufted	herbaceous monocot
Carex flagellifera	Glen Murray tussock, Trip Me Up	Native	herb - tufted	herbaceous monocot
Carex lambertiana	Forest sedge	Native	herb - tufted	herbaceous monocot
Carex raoulii	Coastal forest sedge, Raoul's sedge	Native	herb - tufted	herbaceous monocot
Carex solandri	Forest Sedge, Solander's Sedge	Native	herb - tufted	herbaceous monocot
Carmichaelia australis	Common Broom	Native	shrub - small leaved	woody dicot
Carpodetus serratus	Putaputaweta, marbleleaf	Native	tree - large leaved	woody dicot
Centella uniflora	Centella	Native	herb - small	herbaceous dicot
Chamaecytisus palmensis	Tree lucerne	Exotic	shrub - small leaved	woody dicot
Chenopodium allanii		Native	herb - small	herbaceous dicot
Cirsium arvense	Californian thistle	Exotic	herb - erect	herbaceous monocot
Cirsium vulgare	Scotch thistle	Exotic	herb - erect	herbaceous dicot
Clematis afoliata	Leafless clematis	Native	climbing	woody dicot

Species	Common name	Status	Lifeform Class	Phylogeny class
Clematis forsteri	Small white clematis	Native	climbing	woody dicot
Clematis paniculata	White clematis, puawananga	Native	climbing	woody dicot
Collospermum hastatum		Native	herb - tufted	herbaceous monocot
Collospermum microspermum		Native	herb - tufted	herbaceous monocot
Conyza sumatrensis	broad-leaved flea-bane	Native	herb - erect	herbaceous dicot
Coprosma arborea	Mamangi, tree coprosma	Native	shrub - small leaved	woody dicot
Coprosma areolata	Thin-leaved coprosma	Native	shrub - small leaved	woody dicot
Coprosma ciliata		Native	shrub - small leaved	woody dicot
Coprosma cuneata		Native	shrub - small leaved	woody dicot
Coprosma foetidissima	Stinkwood	Native	shrub - small leaved	woody dicot
Coprosma grandifolia	Kanono, manono, large-leaved coprosma, raurekau	Native	shrub - large leaved	woody dicot
Coprosma linariifolia	Mikimiki, yellow wood	Native	shrub - small leaved	woody dicot
Coprosma lucida	Karamu, shining karamu	Native	shrub - large leaved	woody dicot
Coprosma microcarpa	Small seeded coprosma	Native	shrub - small leaved	woody dicot
Coprosma propinqua Hybrid	Mingimingi	Native	shrub - small leaved	woody dicot
Coprosma propinqua var. propinqua	Mingimingi	Native	shrub - small leaved	woody dicot
Coprosma pseudocuneata		Native	shrub - small leaved	woody dicot
Coprosma repens	Taupata, looking glass plant, mirror plant	Native	shrub - large leaved	woody dicot
Coprosma rhamnoides		Native	shrub - small leaved	woody dicot
Coprosma rigida		Native	shrub - small leaved	woody dicot
Coprosma robusta	Karamu, glossy karamu	Native	shrub - large leaved	woody dicot
Coprosma robusta X	Karamu, glossy karamu	Native	shrub - large leaved	woody dicot
Coprosma rotundifolia		Native	shrub - small leaved	woody dicot
Coprosma spathulata subsp. spathulata		Native	shrub - small leaved	woody dicot
Coprosma tayloriae		Native	shrub - small leaved	woody dicot
Coprosma tenuicaulis	Swamp coprosma, hukihuki	Native	shrub - small leaved	woody dicot
Cordyline australis	Cabbage tree, ti, ti kouka, palm lily	Native	tree - large leaved	woody monocot
Coriaria arborea var. arborea	Tutu, tree tutu	Native	shrub - large leaved	woody dicot
Corokia cotoneaster	Korokio, wire-nettting bush	Native	shrub - small leaved	woody dicot
Corynocarpus laevigatus	Karaka, kopi	Native	shrub - large leaved	woody dicot

Species	Common name	Status	Lifeform Class	Phylogeny class
Crocosmia x crocosmiiflora	montbretia	Exotic	herb - tufted	herbaceous monocot
Cyathea cunninghamii	Gully tree fern, Slender tree fern, Ponga	Native	tree - large leaved	fern
Cyathea dealbata	Silver fern, Ponga	Native	tree - large leaved	fern
Cyathea medullaris	Black tree fern, Mamaku, Black mamaku	Native	tree - large leaved	fern
Cyathea smithii	Katote, Smiths tree fern, Soft tree fern	Native	tree - large leaved	fern
Dacrycarpus dacrydioides	Kahikatea, white pine	Native	tree - small leaved	woody gymnosperm
Dacrydium cupressinum	Rimu, red pine	Native	tree - small leaved	woody gymnosperm
Dactylis glomerata	Cocksfoot	Exotic	herb - tufted	herbaceous monocot
Daucus carota	wild carrot	Exotic	herb - erect	herbaceous dicot
Dianella nigra	Turutu, NZ blueberry, Ink berry	Native	herb - tufted	herbaceous monocot
Dichelachne crinita	Long-hair plume grass	Native	herb - tufted	herbaceous monocot
Dichondra repens	Mercury Bay weed, dichondra	Native	tree - large leaved	herbaceous dicot
Dicksonia fibrosa	Wheki-ponga, wheki-kohoonga, golden tree fern, kuripaka	Native	tree - large leaved	fern
Dicksonia squarrosa	Rough tree fern, Harsh tree fern, Wheki	Native	tree - large leaved	fern
Digitalis purpurea	Foxglove	Exotic	herb - erect	herbaceous dicot
Discaria toumatou	Matagouri, Wild Irishman	Native	shrub - small leaved	woody dicot
Dodonaea viscosa	Akeake	Native	tree - large leaved	woody dicot
Dysoxylum spectabile	*Dysoxylum spectabile* , New Zealand mahogany	Native	tree - large leaved	woody dicot
Elaeocarpus dentatus var. dentatus	Hinau	Native	tree - large leaved	woody dicot
Elaeocarpus hookerianus	Pokaka	Native	tree - large leaved	woody dicot
Entelea arborescens	Whau	Native	shrub - large leaved	woody dicot
Ephiphyte Earina autumnalis	Easter orchid, raupeka	Native	epiphyte	herbaceous monocot
Epilobium nerteroides	Epilobium	Native	herb - erect	herbaceous dicot
Epiphyte Earina muc	Bamboo orchid, peka-a-waka, spring earina	Native	epiphyte	herbaceous monocot
Epiphytic Hebe elliptica	Kokomuka, shore hebe, shore koromiko	Native	shrub - small leaved	woody dicot
Euphorbia pleplus	milkweed	Native	herb - erect	herbaceous dicot
Freycinetia banksii	Kiekie	Native	climbing	woody monocot
Fuchsia excorticata	Kotukutuku, Tree fuchsia	Native	tree - large leaved	woody dicot
Gahnia setifolia	Mapere, Gahnia, Giant Gahnia, Razor Sedge	Native	herb - tufted	herbaceous monocot
Galium aparine	cleavers	Exotic	herb - small	herbaceous

Species	Common name	Status	Lifeform Class	Phylogeny class
				dicot
Galium propinquum		Native	herb - small	herbaceous dicot
Geniostoma ligustrifolium var. ligustrifolium	Hangehange	Native	shrub - large leaved	woody dicot
Geranium homeanum	geranium	Native	herb - small	herbaceous dicot
Griselinia littoralis	Broadleaf, kapuka, papauma	Native	shrub - large leaved	woody dicot
Griselinia lucida	Puka	Native	shrub - large leaved	woody dicot
Haloragis erecta subsp. erecta	Toatoa, fire weed, shrubby haloragis	Native	herb - small	herbaceous dicot
Hebe salicifolia	Koromiko	Native	shrub - large leaved	woody dicot
Hebe stricta var. stricta	Koromiko	Native	shrub - large leaved	woody dicot
Hedera helix subsp. helix	ivy	Exotic	climbing	woody dicot
Hedycarya arborea	Porokaiwhiri, Pigeonwood	Native	tree - large leaved	woody dicot
Helichrysum lanceolatum		Native	shrub - small leaved	woody dicot
Histiopteris incisa	Histiopteris, water fern, mata, Bat's wing fern	Native	herb - small	fern
Hoheria angustifolia	Narrow-leaved Houhere	Native	tree - large leaved	woody dicot
Hoheria populnea	Lacebark, houhere, ribbonwood	Native	tree - large leaved	woody dicot
Hoheria sexstylosa	Houhere, lacebark	Native	tree - large leaved	woody dicot
Holcus lanatus	yorkshire fog	Exotic	herb - small	herbaceous monocot
Hydrocotyle heteromeria	Waxweed, waxweed pennywort	Native	herb - small	herbaceous dicot
Hydrocotyle moschata		Native	herb - small	herbaceous dicot
Hymenophyllum armstrongii		Native	epiphyte	flimy fern
Hymenophyllum demissum	Drooping filmy fern, Irirangi, Piripiri	Native	herb - small	flimy fern
Hymenophyllum dilatatum	Filmy fern, Matua mauku	Native	epiphyte	flimy fern
Hymenophyllum flabellatum	filmy fern	Native	epiphyte	flimy fern
Hymenophyllum multifidum	Much-divided filmy fern	Native	herb - small	flimy fern
Hymenophyllum pulcherrimum	filmy fern, tufted filmy fern	Native	epiphyte	flimy fern
Hymenophyllum rarum	Filmy fern	Native	herb - small	flimy fern
Hymenophyllum revolutum	Filmy fern	Native	epiphyte	flimy fern
Hymenophyllum sanguinolentum	Filmy fern, Piripiri	Native	herb - small	flimy fern
Hymenophyllum scabrum	filmy fern, rough filmy fern	Native	herb - small	flimy fern
Hypolepis ambigua		Native	herb - small	fern
Ichthyostomum pygmaeum	Pygmy tree orchid, Bulbophyllum	Native	herb - small	herbaceous monocot
Knightia excelsa	Rewarewa, NZ honeysuckle	Native	tree - large leaved	woody dicot
Kunzea ericoides var. ericoides	Manuoea, Titira, Atitira, Manuka-Rauriki, Kanuka	Native	tree - small leaved	woody dicot
Lastreopsis glabella	Smooth shield fern	Native	herb - tufted	fern
Lastreopsis hispida	Hairy fern	Native	herb - tufted	fern

Species	Common name	Status	Lifeform Class	Phylogeny class
Laurelia novae-zelandiae	Pukatea	Native	tree - large leaved	woody dicot
Lepidothamnus intermedius	Yellow silver pine	Native	tree - small leaved	woody gymno-sperm
Leptopteris hymenophylloides	Crape fern, Single crape fern, Heruhe-ru	Native	herb - tufted	fern
Leptopteris superba	Heruheru, Crape fern, Prince of Wales feathers	Native	herb - tufted	fern
Leptospermum scoparium var. scoparium	Manuka, tea tree, kahikatoa	Native	shrub - small leaved	woody dicot
Leucopogon fasciculatus	Mingimingi, tall mingimingi	Native	shrub - small leaved	woody dicot
Libertia ixioides	Mikoikoi, NZ iris	Native	herb - tufted	herbaceous monocot
Libocedrus plumosa	Kawaka, kaikawaka, NZ cedar	Native	tree - small leaved	woody gymno-sperm
Ligustrum lucidum	tree privet	Exotic	shrub - small leaved	woody dicot
Ligustrum sinense	chinese privet	Native	shrub - large leaved	woody dicot
Litsea calicaris	Mangeao, tangeao	Native	tree - large leaved	woody dicot
Lobelia angulata	Pratia	Native	herb - small	herbaceous dicot
Lolium perenne	perennial rye grass	Exotic	herb - small	herbaceous monocot
Lonicera japonica	Japanese honeysuckle	Exotic	climbing	woody dicot
Lophomyrtus bullata	Ramarama, bubble leaf	Native	shrub - small leaved	woody dicot
Lotus corniculatus	lotus	Exotic	herb - small	herbaceous dicot
Lotus pedunculatus	yellow lupin	Native	herb - small	woody dicot
Lotus suaveolens		Native	herb - small	herbaceous dicot
Lupinus aboreus		Exotic	tree - small leaved	woody dicot
Lycium ferocissimum	boxthorn	Exotic	shrub - small leaved	woody dicot
Lycopodium volubile	Climbing clubmoss, Waewaekoukou	Native	climbing	Lycophyte
Lygodium articulatum		Native	climbing	fern
Melicope simplex	Poataniwha	Native	shrub - small leaved	woody dicot
Melicope ternata	Wharangi	Native	tree - large leaved	woody dicot
Melicytus lanceolatus	Narrow-leaved mahoe, mahoe-wao	Native	tree - large leaved	woody dicot
Melicytus macrophyllus	Large-leaved mahoe	Native	tree - large leaved	woody dicot
Melicytus ramiflorus	mahoe, whitey wood	Native	tree - large leaved	woody dicot
Metrosideros diffusa	white rata	Native	climbing	woody dicot
Metrosideros excelsa	Pohutukawa, New Zealand Christmas tree	Native	tree - large leaved	woody dicot
Metrosideros fulgens	rata	Native	climbing	woody dicot
Metrosideros perforata	white rata, akatea	Native	climbing	woody dicot
Metrosideros robusta	Northern rata	Native	tree - large	woody dicot

Species	Common name	Status	Lifeform Class	Phylogeny class
			leaved	
Metrosideros umbellata	Southern rata	Native	tree - large leaved	woody dicot
Microlaena avenacea	Bush rice grass, oat grass	Native	herb - tufted	herbaceous monocot
Microlaena polynoda	bamboo grass, bamboo	Native	herb - tufted	herbaceous monocot
Microlaena stipoides	Meadow rice grass, slender rice grass	Native	herb - tufted	herbaceous monocot
Microsorum pustulatum subsp. pustulatum	Hounds tongue, Kowaowao, Para-haraha	Native	herb - small	fern
Microsorum scandens	Fragrant fern, Mokimoki	Native	climbing	fern
Muehlenbeckia australis	Pohuehue, large-leaved muehlen-beckia	Native	climbing	woody dicot
Muehlenbeckia complexa	Small-leaved pohuehue, scrub po-huehue, wire vine	Native	climbing	woody dicot
Myoporum laetum	Ngaio	Native	tree - large leaved	woody dicot
Myrsine australis	Red mapou, red matipo, mapau, red maple	Native	shrub - large leaved	woody dicot
Myrsine salicina	Toro	Native	tree - large leaved	woody dicot
Nertera depressa	Nertera, bead plant, fruiting duck-weed	Native	herb - small	herbaceous dicot
Nestegis cunninghamii	Black maire	Native	tree - large leaved	woody dicot
Nestegis lanceolata	White maire	Native	tree - large leaved	woody dicot
Nestegis montana	Narrow-leaved maire	Native	tree - large leaved	woody dicot
Nothofagus menziesii	Silver beech	Native	tree - small leaved	woody dicot
Notogrammitis billardierei	Common strap fern	Native	climbing	fern
Olearia ilicifolia	Mountain holly	Native	shrub - large leaved	woody dicot
Olearia paniculata	Akiraho, golden akeake	Native	shrub - small leaved	woody dicot
Olearia rani var. colorata	Heketara	Native	shrub - large leaved	woody dicot
Olearia solandri	Coastal tree daisy	Native	shrub - small leaved	woody dicot
Oxalis exilis	Creeping oxalis, yellow oxalis	Native	climbing	herbaceous dicot
Paesia scaberula	Lace fern, Ring fern, Scented fern	Native	herb - tufted	fern
Paraserianthes lophantha	brush wattle	Exotic	tree - small leaved	woody dicot
Parsonsia capsularis var. capsu-laris	New Zealand jasmine, small flowered jasmine	Native	climbing	woody dicot
Parsonsia heterophylla	New Zealand jasmine	Native	climbing	woody dicot
Passiflora tetrandra	Kohia, NZ passionflower, NZ passion-fruit	Native	climbing	woody dicot
Pennantia corymbosa	Kaikomako	Native	tree - large leaved	woody dicot
Phormium tenax	Flax, Harakeke, Korari (maori name for inflorescence).	Native	herb - tufted	herbaceous monocot
Phyllocladus trichomanoides	Tanekaha, celery pine	Native	tree - small leaved	woody gymno-sperm

Species	**Common name**	**Status**	**Lifeform Class**	**Phylogeny class**
Phytolacca octandra	inkweed	Exotic	shrub - large leaved	woody dicot
Pinus radiata	radiata pine, P Rad	Exotic	tree - small leaved	woody gymno-sperm
Piper excelsum subsp. excelsum	kawakawa, pepper tree	Native	shrub - large leaved	woody dicot
Pittosporum colensoi	pittosporum	Native	tree - large leaved	woody dicot
Pittosporum crassifolium	Karo	Native	tree - large leaved	woody dicot
Pittosporum eugenioides	Tarata, lemonwood	Native	tree - large leaved	woody dicot
Pittosporum tenuifolium	Kohukohu, black matipo	Native	tree - large leaved	woody dicot
Plagianthus regius subsp. regius	Manatu, ribbonwood, lowland rib-bonwood	Native	tree - large leaved	woody dicot
Plantago lanceolata	narrow-leaved plantain	Exotic	herb - erect	herbaceous dicot
Pneumatopteris pennigera	Gully fern, Feather fern, Piupiu	Native	herb - tufted	fern
Poa cita	Silver tussock	Native	herb - tufted	herbaceous monocot
Podocarpus cunninghamii	Mountain totara, Hall's totara, thin-barked totara, totara-kiri-kotukutuku	Native	tree - small leaved	woody gymno-sperm
Podocarpus totara var. totara	Totara	Native	tree - small leaved	woody gymno-sperm
Polystichum neozelandicum subsp. zerophyllum	shield fern	Native	herb - tufted	fern
Polystichum vestitum	Punui, prickly shield fern	Native	herb - tufted	fern
Prumnopitys ferruginea	Miro, brown pine	Native	tree - small leaved	woody gymno-sperm
Prumnopitys taxifolia	Matai, black pine	Native	tree - small leaved	woody gymno-sperm
Prunella vulgaris	Self heal	Exotic	herb - erect	woody dicot
Pseudopanax arboreus	Fivefinger, five finger, whau-whaupaku	Native	tree - small leaved	woody dicot
Pseudopanax arboreus X crassifo-lius	Fivefinger, five finger, whau-whaupaku	Native	tree - small leaved	woody dicot
Pseudopanax colensoi var. colensoi	Mountain five-finger, three finger	Native	tree - small leaved	woody dicot
Pseudopanax crassifolius	Horoeka, lancewood	Native	tree - small leaved	woody dicot
Pseudowintera colorata	Red horopito, mountain horopito, alpine peppertree	Native	shrub - small leaved	woody dicot
Pteridium esculentum	bracken, rarauhe, bracken fern	Native	herb - small	fern
Pteris macilenta	Sweet fern	Native	herb - small	fern
Pteris tremula	Shaking or tender brake, Australian bracken	Native	herb - small	fern
Pyrrosia eleagnifolia	Leather-leaf fern, Pyrrosia	Native	climbing	fern
Ranunculus repens	buttercup	Exotic	herb - small	herbaceous dicot
Raukaua simplex		Native	tree - large leaved	woody dicot
Rhabdothamnus solandri	New Zealand gloxinia, taurepo, kaikaiatua, mata, matata, waiuatua	Native	shrub - small leaved	woody dicot
Rhopalostylis sapida	*Rhopalostylis sapida* palm	Native	tree - large leaved	woody monocot

Species	Common name	Status	Lifeform Class	Phylogeny class
Ripogonum scandens	Supplejack, kareao	Native	climbing	woody monocot
Rubus australis	Tataramoa, bush lawyer, swamp lawyer	Native	climbing	woody dicot
Rubus cissoides	Tataramoa, bush lawyer	Native	climbing	woody dicot
Rubus fruticosus agg.	blackberry	Exotic	shrub - large leaved	woody dicot
Rubus schmidelioides var. schmidelioides	Tataramoa, bush lawyer, white-leaved lawyer	Native	climbing	woody dicot
Rumex acetosella		Native	herb - erect	herbaceous dicot
Rumex obtusifolius	broad-leaved dock	Exotic	herb - erect	herbaceous dicot
Rytidosperma gracile	Dainty bristle grass	Native	herb - tufted	herbaceous monocot
Sambucus nigra	elder, elderflower, elderberry	Exotic	tree - large leaved	woody dicot
Schefflera digitata	Patete, pate, seven-finger	Native	tree - large leaved	woody dicot
Selaginella kraussiana	Selaginella	Exotic	herb - small	Lycophyte
Senecio minimus	Fireweed	Native	herb - erect	herbaceous dicot
Solanum chenopodioides	Velvety nightshade	Exotic	herb - erect	herbaceous dicot
Solanum laciniatum	Poroporo	Native	shrub - large leaved	woody dicot
Solanum nigrum	Black nightshade	Exotic	herb - erect	herbaceous dicot
Solanum pseudocapsicum	Jerusalem cherry	Exotic	shrub - small leaved	woody dicot
Sophora chathamica	Kowhai, coastal kowhai	Native	tree - small leaved	woody dicot
Sophora microphylla	Kowhai, weeping kowhai, small-leaved kowhai	Native	tree - small leaved	woody dicot
Stellaria media subsp. media	chickweed	Exotic	herb - small	herbaceous dicot
Stellaria parviflora	New Zealand chickweed	Native	herb - small	herbaceous dicot
Stenotaphrum secundatum	buffalo grass	Exotic	herb - small	herbaceous monocot
Streblus banksii	Large-leaved milk tree, turepo	Native	tree - large leaved	woody dicot
Streblus heterophyllus	small-leaved milk tree, turepo	Native	shrub - small leaved	woody dicot
Syzygium maire	swamp maire, maire *Belischmiedia tawa*ke, waiwaka	Native	tree - large leaved	woody dicot
Tmesipteris lanceolata	Fork Fern	Native	herb - small	fern
Tmesipteris tannensis	Fork Fern	Native	herb - small	fern
Tradescantia fluminensis	wandering Jew	Exotic	herb - small	herbaceous monocot
Trifolium pratense	red clover	Exotic	herb - small	herbaceous dicot
Trifolium repens	white clover	Exotic	herb - small	herbaceous dicot
Ulex europaeus	gorse	Exotic	shrub - small leaved	woody dicot
Uncinia banksii	Fine-leaved Bastard Grass	Exotic	herb - tufted	herbaceous monocot

Species	Common name	Status	Lifeform Class	Phylogeny class
Uncinia uncinata	Bastard grass, Hook sedge, Kamu, Matau-a-Maui	Native	herb - tufted	herbaceous monocot
Urtica ferox	Ongaonga, tree nettle	Native	shrub - large leaved	woody dicot
Vicia sativa	Vetch	Exotic	herb - small	herbaceous dicot
Vitex lucens	puriri	Native	tree - large leaved	woody dicot
Weinmannia racemosa	kamahi	Native	tree - large leaved	woody dicot
Weinmannia silvicola	towai, tawhero	Native	tree - large leaved	woody dicot
Winika cunninghamii	Winika, Pekapeka, Christmas Orchid, Bamboo Orchid	Native	herb - small	herbaceous monocot

APPENDIX 3: EXPLANATORY VARIABLES AVERAGED FOR EACH TREATMENT WITHIN EACH SITE.

Site		Deep Cove			Fensham Reserve			Hunua Ranges			Keebles' Bush			Kent Rd			Mana Island			Morgan Reserve			Otari-Wiltons Bush			Quail Island			Tiri Tiri Matangi Island			Te Rere		
Treatment	**ANALYSIS CODE**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**
Sample size (#plots)		2	2	2	2	2	2	4	2	4	2	2	2	2	2	2	4	2	2	2	2	2	2	2	2	1	1	1	6	2	4	2	2	2
altitude (m.a.s.l)	ALT	2.5	5	15.5	114	134	119	163	135.5	141.5	37.5	37.5	37	203.3	90	104	22.33	146.5	67	139	144	121	68	95	118.5	54	157	178	109.5	33	48	12	27	14
Aspect (cosine in radians)	ASP	0.864	0.689	0.343	0.766	0.259	0.998	0.601	0.381	0.826	0.323	0.965	0.66	0.643	0.853	0.766	0.515	0.791	0.804	0.998	0.899	0.342	0.819	0.997	0.946	0.996	0.993	0.985	0.498	0.405	0.452	0.857	0.857	0.5
Slope (degrees)	SLOPE	5	3	4	4	4	6	2.5	5.5	3	2	2.5	2	5.25	15.5	4.5	4.667	9	6	3	2	5	10.5	16	11	3	5	5	4.5	7.5	6.25	3	5	5
Age of regeneration (years)	AGE	12	1000	12	13	1000	26	29.5	1000	25	32.5	1000	79	24.5	1000	35	22.33	1000	33	15	1000	15	10.5	1000	53	31	1000	33	23.5	1000	31	27	1000	30
Average soil compaction (MPa)	SolCompA	190	4.167	68.33	400	45	283.3	43.33	25.83	216.7	115	50.83	91.67	257.1	35	32.5	105.6	6.667	99.17	295	61.67	215	96.67	18.33	129.2	178.3	51.67	100	256.7	35.83	135.8	403.3	98.33	45
Average soil depth (cm)	SoilDA	16.67	48	20.33	17.33	48.67	31	15.17	35.5	26.33	33.83	42	32.17	22.58	32.17	16	16.67	46	18.67	21.67	36.33	19.33	21.83	43.33	20.5	18	10	3.167	23.17	47.17	26.58	23.33	47.33	38.67
Highest tree (m)	Hgt	5.65	32	17.5	7	30	8	6.5	17.5	6.5	10	31	7.25	6.125	39	5.75	3.9	12.5	6.5	7	29	6.3	6.25	33.5	5.75	3.2	12	2.4	4.475	13.5	7	5.8	14	8
average canopy height (m)	CanHgt	4.5	17	5.5	6	12	3.5	7	10	4.5	12.5	12	5.75	5.25	27.5	4.75	4.5	8	5.25	5	18	3.5	4.25	15	4	4	3	4.5	4.025	8	5.75	5	8	5
Average Radius of canopy tree (m)	Radius	2.692	4.71	2.155	1.74	5.08	1.31	1.898	3.207	2.387	2.19	3.36	2.447	1.618	3.977	1.62	2.12	2.657	3.642	1.473	4.587	2.32	1.653	3.49	1.977	1.853	3.42	1.713	2.612	4.273	3.132	1.296	3.039	1.73
average DBH (cm)	DBH	12.53	64.9	21.77	15.43	64.7	16.57	22.11	44.33	20.77	23.16	45.73	22.5	14.29	56.33	20.43	18.98	31.66	28.76	14.2	59.53	9.691	14.39	57.02	13.82	0	29.89	13.64	19.14	33.57	23.87	14.53	39	7.481
average stem count at BH	StemBH	1.25	1	1.25	2.2	1	1.76	1.02	0.75	1.325	1.478	0.75	1.467	2.919	0.75	1.091	1.8	0.642	0.93	1.12	0.6	0.84	1.875	0.85	1.65	1.95	1.32	1.75	3.038	0.895	1.483	2.7	0.643	0.92
Canopy cover (%)	CanCov	82.5	62.5	72.5	65	75	55	77.5	62.5	65	75	65	82.5	77.5	85	72.5	66.67	67.5	72.5	85	65	60	90	52.5	80	50	75	40	85	62.5	62.5	90	60	60

Site		Deep Cove			Fensham Reserve			Hunua Ranges			Keebles' Bush			Kent Rd			Mana Island			Morgan Reserve			Otari-Wiltons Bush			Quail Island			Tiri Tiri Matangi Island			Te Rere		
Treatment	**ANALYSIS CODE**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**
Canopy Gap (over 1m²)(%)	CanG	3	5	0.75	1	6	5	5	3	8	12.5	1	1	6.75	1.5	3	3.333	6	7	4	1	7	0.5	4	1	4	4	6	1.5	1.5	16.25	1	2	30
Canopy Species richness	CanRich	4.5	4.5	5.5	16	11	3	3.5	8.5	13.5	3	7.5	2	4.75	9	10.5	9	5.5	15.5	2	11	27	18	13	20.5	18	2	11	4.25	4.5	5	9	7	19
Bare (% cover)	Bare	5.5	7.5	5	0.1	0.5	1	0.5	0.75	0.25	1	0.25	1.5	1.275	0.5	1	1.7	2.5	3	1	1	1	3.5	0.5	0.75	1	4	2	0.375	0.5	0.775	1	2	0.5
Litter (% cover)	Litter	45	37.5	75	98	90	75	87.5	87.5	75	60	96.5	82.5	81.25	75	85	91	77.5	67.5	95	80	80	77.5	62.5	85	80	70	65	94.5	77.5	78.75	95	80	85
woody debris (% cover)	Debris	4	10	12.5	0.1	5	2	1.05	2.5	5.5	1.75	3	3	1.525	3.5	1	1.333	10	5	0.1	1	4	0.3	5	0.75	0.5	3	5	0	3.5	4.25	0.5	5	2
Rock (% cover)	Rock	7.5	4.5	9	0	0	0	0	0	0.05	0	0	0	0.25	0.5	2	0.033	0.55	1	0	0	0	3.5	0.05	0.3	0.1	5	5	0.15	0	0	0.5	0	0.5
lichen (% cover)	Lich	1	1.75	3.5	0	0	0.5	0	0.05	0.3	1	0.5	0.3	0.4	0	0.3	0.5	0.1	1.25	0	5	2	0.75	0.3	0.25	0.1	0.5	4	0.4	0.1	1.275	2	0.1	0.5
Bryos Ground (% cover)	BryroG	20	20	22.5	0	1	0.5	0.05	1.05	1.75	0.05	2.25	0.05	1.025	1.25	1.05	0.367	0.5	0.5	0.1	1	0.1	0.25	3	0.1	0.5	0.5	0.1	0.15	1.5	1.4	0.1	3	0.5
Bryos Epiphytic (% cover)	BryroE	6.5	12.5	9	0.1	4	0.5	0.5	1.75	1.05	0.05	3	0.75	0.3	3	0.1	0.367	1.5	1.5	0.1	3	0.5	0.05	2.25	0.3	0.1	0.1	0.1	0.05	0.3	1.15	0.1	2	0.1
Woody spp (% cover)	Wdspp	87.7	47.5	43.45	70	63.7	36.8	78.05	70.15	60.25	81.85	49.55	36.6	60.65	33.4	69.2	22.4	29.4	39.65	45.5	66.7	74.7	61.3	117.8	62.75	70.2	22.2	38.9	20.5	59.65	33.63	94.1	64.3	68.2
Native cover (% cover)	NatCov	121.1	162.4	166	119.3	198.4	174.1	137.3	201.1	178.3	91.5	124.3	89.2	111.1	161.1	120.6	87.63	143.6	110.9	107.8	166	143.6	93.6	177.5	81.55	108.2	79.7	49.7	72.03	120.2	71.38	107.1	185.7	116.6
Exotic cover (% cover)	ExoCov	4	22	0.5	1.2	1.8	5.5	2.1	6.8	3.5	43.55	24.7	40.45	7.225	1.25	2.35	18.42	1.45	11.6	10.4	0.2	14.4	5.55	8	14.45	17.4	41.2	34	0.2	10.85	1.525	4.1	0.1	1.7
Total Cover (% cover)	TotCov	126.7	185.7	167.1	122.6	209.3	191.8	139.4	211.3	187.1	151.2	161	147.7	125.3	164.5	133.5	113	145.2	130.8	133.5	166.9	178.6	123.7	199.2	161.8	125.6	133.1	104.2	92.78	139.7	111.2	111.3	186.6	118.4
Species Richness	SppRich	28.5	45.5	29	33	47	43	23	50.5	37.5	35.5	30	25	22	38	32	16	30	26	58	32	46	32	37.5	28	31	32	34	13	25.5	15	43	48	45

Site		Deep Cove			Fensham Reserve			Hunua Ranges			Keebles' Bush			Kent Rd			Mana Island			Morgan Reserve			Otari-Wiltons Bush			Quail Island			Tiri Tiri Matangi Island			Te Rere		
Treatment	**ANALYSIS CODE**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**	**Planted**	**Reference**	**Spontaneous**
Shannon Wiener Diversity Index	SWDI	5.496	10.91	5.709	8.041	12.62	8.875	5.997	12.46	7.872	7.365	11.23	7.865	6.708	11.75	8.032	4.269	10.52	5.858	10.21	9.323	8.704	7.11	12.01	6.925	6.111	10.66	6.855	5.189	10.83	5.113	6.475	10.92	8.508
average specific leaf area of canopy species	SLA	172.1	89.32	152.2	212.6	122.6	108.8	115	121.8	144.2	124.5	110.2	139.7	161.8	100.2	97.78	152.6	178.3	154.4	67.51	100.1	210.3	178.6	134.8	204.5	147.9	187.8	257.9	115.6	158.5	173.5	204.1	124.3	246.5
Average seedling richness per seedling plot	SdRich	1.064	4.956	5.175	2.52	7.6	2.24	2.38	6.05	4.95	2.244	6.15	4.2	3.388	6.825	3.553	2.089	3.492	2.925	1.72	2.6	2.56	0.55	2.8	1.475	4.2	6	7.15	0	0	0	1	5.429	3.84
Average density of Seedl/ing/m2	SdDen	2.535	6.461	5.488	4.083	10.96	3.011	3.715	5.142	14.34	3.919	21.7	10.99	9.33	5.65	5.619	3.345	5.249	6.225	2.816	3.74	4.515	0.514	6.886	2.6	14.81	24.32	40.19	5.771	4.393	7.782	1.77	14.42	7.62

APPENDIX 4: CORRELATION OF EXPLANATORY VARIABLES PER SITE

Peach coloured cells show highly correlated variables.

	AGE	TIERNO	CANCOV	CANRICH	TOTRICH	TREEHT	CANHT	STRATCOV	TOTDCAN	SEEDCANC	SEEDCANW	DIVDCAN	SEEDCANR	SWCOV	SWLIFE	SWTAXA	SWTIER	SWSEED	SEEDRPP
AGE	1.0000																		
TIERNO	0.8800	1.0000																	
CANCOV	-0.2603	-0.2272	1.0000																
CANRICH	-0.0747	-0.1563	-0.2522	1.0000															
TOTRICH	0.3671	0.3718	-0.2176	0.2770	1.0000														
TREEHT	0.8920	0.8758	-0.1947	-0.0192	0.4405	1.0000													
CANHT	0.7599	0.7638	-0.1645	-0.0548	0.3394	0.8876	1.0000												
STRATCOV	-0.0613	-0.1979	-0.0646	0.1567	-0.3644	-0.1755	-0.1540	1.0000											
TOTDCAN	0.1139	0.0182	-0.8498	0.2873	-0.0325	0.0081	0.0184	0.5182	1.0000										
SEEDCANC	0.0924	0.0790	-0.4337	0.0785	0.0633	0.0108	-0.0120	0.1015	0.4886	1.0000									
SEEDCANW	0.4275	0.4801	-0.5531	-0.0744	0.2540	0.3804	0.3298	-0.2212	0.3526	0.4908	1.0000								
DIVDCAN	0.3809	0.3528	-0.8075	0.3605	0.6293	0.3669	0.2939	-0.1298	0.6189	0.4042	0.5322	1.0000							
SEEDCANR	0.2447	0.3237	0.0675	-0.4362	0.2546	0.2008	0.1227	-0.4258	-0.2658	0.2035	0.2213	0.1103	1.0000						
SWCOV	0.4276	0.4271	-0.3981	0.3008	0.8151	0.4549	0.3474	-0.2978	0.1586	0.1665	0.3667	0.8372	0.2717	1.0000					
SWLIFE	0.2602	0.3711	-0.3623	0.1870	0.5828	0.3947	0.2999	-0.4200	0.0685	0.2585	0.4674	0.6829	0.3355	0.7955	1.0000				
SWTAXA	0.6821	0.7455	-0.3171	0.0720	0.6506	0.7747	0.6648	-0.2467	0.0651	0.0886	0.4066	0.5677	0.1370	0.6854	0.6427	1.0000			
SWTIER	0.7935	0.8879	-0.2843	-0.1250	0.3898	0.7890	0.6499	-0.2518	0.0344	0.1483	0.5930	0.4351	0.3148	0.5078	0.4732	0.7665	1.0000		
SWSEED	0.5005	0.5847	-0.2559	-0.2094	0.2001	0.4757	0.4283	-0.2723	0.0431	0.3263	0.8687	0.3149	0.3637	0.3274	0.4951	0.4691	0.6904	1.0000	
SEEDRPP	0.4601	0.5330	-0.2024	0.0651	0.4937	0.4727	0.4259	-0.5340	-0.0813	0.4544	0.5410	0.4122	0.5899	0.4831	0.5602	0.5239	0.5157	0.6291	1.0000
SEEDEN	0.1514	0.1460	-0.2950	0.0045	0.0185	0.0769	0.0046	0.0491	0.3166	0.9430	0.4566	0.2903	0.3346	0.1454	0.2980	0.1012	0.2079	0.4063	0.5086

	SEEDEN	AGEDHT	BRYOSCOV	FERNCOV	BASALAX	AVLAX	STEMCT	SLA	RADIUS	DEBRIS	WOODY	NATIVECV	SOILPSI	CVSOILPSI	SPDEBRIS	SPBRYOS	SPFERNS	SPRAISED	SPSDR	SPSDDEN
AGEDHT	0.8466	0.6330	-0.2469	-0.1473	0.1980	0.5438	0.4040	0.1060	0.1835	0.1192	0.3297	0.2922	0.2813	0.3067	0.0633	0.4060	0.5881	0.3683	0.2814	
BRYOSCOV	0.0809	0.1444	-0.0597	-0.1530	0.1237	0.0822	0.1310	-0.4501	-0.1737	-0.0867	0.2883	0.0452	0.1335	0.0539	0.1628	0.1032	0.1757	0.2470	0.1719	
FERNCOV	0.4001	0.4855	-0.2563	0.1511	0.2938	0.4866	0.3627	-0.1592	0.1022	-0.0241	0.3393	0.3849	-0.0643	0.3452	0.4320	0.4757	0.4914	0.3749	0.1935	
BASALAX	0.7034	0.6050	-0.1106	-0.0178	0.2522	0.6344	0.5490	-0.0656	0.0260	-0.0429	0.2012	0.2580	0.0349	0.3347	0.0612	0.4602	0.5429	0.2227	0.1961	
AVLAX	0.8457	0.8532	-0.2322	-0.1048	0.3260	0.8954	0.8229	-0.1601	0.0513	0.0349	0.4001	0.3314	0.1986	0.3738	0.4042	0.7123	0.7611	0.5108	0.4524	
STEMCT	-0.3784	-0.3635	0.2249	-0.1649	-0.0553	-0.4234	-0.4061	0.0888	-0.1253	-0.0774	-0.2807	-0.1923	-0.0409	-0.1337	-0.1857	-0.2929	-0.3461	-0.3567	-0.3149	
SLA	-0.2489	-0.3798	-0.0489	0.2178	-0.1500	-0.3581	-0.4020	0.2778	0.2096	0.2328	-0.0215	-0.0083	-0.0891	-0.0820	-0.1415	-0.3331	-0.3010	-0.1420	-0.1781	
RADIUS	0.6801	0.6517	-0.2467	-0.0838	0.1374	0.7003	0.6149	0.0033	0.1393	0.0156	0.4422	0.2479	0.0731	0.2504	0.3057	0.5455	0.6542	0.4736	0.2137	
DEBRIS	0.3706	0.3414	-0.4460	0.0216	0.2866	0.3016	0.2731	-0.2862	0.1946	0.2066	0.5421	0.4486	0.2146	0.3872	0.4551	0.3852	0.4593	0.4968	0.4003	
WOODY	0.0746	0.1254	-0.1533	0.2686	0.3810	0.2038	0.1051	-0.2539	0.0373	-0.0532	-0.0367	0.3182	-0.1000	0.3308	0.1661	0.2105	0.1335	-0.1923	0.0638	
NATIVECV	0.1370	0.0603	0.0740	0.0000	-0.2434	0.0336	0.0304	0.2049	0.0435	-0.0661	0.0098	-0.1792	-0.3115	-0.2399	-0.2580	-0.1931	-0.0241	-0.0131	-0.2249	
SOILPSI	-0.6048	-0.6257	0.2870	-0.0295	-0.1485	-0.5240	-0.4640	0.1290	-0.1584	-0.0820	-0.3307	-0.3235	-0.1825	-0.2990	-0.2419	-0.4709	-0.5923	-0.3459	-0.3593	
CVSOILPSI	0.6933	0.6782	-0.2287	-0.0564	0.3410	0.6202	0.5584	-0.1937	0.0233	-0.0194	0.3750	0.3232	0.2003	0.3713	0.2317	0.4953	0.6263	0.4274	0.3756	
SPDEBRIS	0.4053	0.3110	-0.1072	-0.0605	0.1342	0.3469	0.2161	-0.0359	0.0288	0.0336	0.3433	0.1087	-0.0420	0.1273	0.0979	0.2252	0.4180	0.3195	0.0951	
SPBRYOS	0.4080	0.4147	-0.1330	-0.0238	0.2473	0.3725	0.2626	-0.2298	-0.0596	-0.0788	0.2329	0.1886	0.2156	0.2560	0.2891	0.3639	0.4636	0.2652	0.2199	
SPFERNS	0.4906	0.4884	-0.1139	0.1253	0.1144	0.4995	0.4606	0.1221	0.0981	0.1537	0.3298	0.1208	-0.0007	0.1087	0.1399	0.3805	0.5187	0.3736	0.2138	
SPRAISED	0.3430	0.4012	-0.0309	-0.1013	0.1777	0.3347	0.2685	-0.2183	-0.1125	0.0560	0.3387	0.0611	0.2180	0.1129	0.0319	0.1333	0.4254	0.3227	0.2660	
SPSDR	0.5168	0.5345	-0.4164	-0.0290	0.1401	0.4660	0.3914	-0.0544	0.2210	0.2606	0.4936	0.3386	0.0630	0.2546	0.2676	0.4798	0.6070	0.4866	0.3033	
SPSDDEN	0.2298	0.1938	-0.2636	0.0161	0.1118	0.0553	0.0765	-0.0661	0.1548	0.3419	0.3279	0.2598	0.1580	0.1957	0.1590	0.1669	0.2335	0.3176	0.3278	

	SEEDEN	AGEDHT	BRYOSCOV	FERNCOV	BASALAX	AVLAX	STEMCT	SLA	RADIUS	DEBRIS	WOODY	NATIVECV	SOILPSI	CVSOILPSI	SPDEBRIS	SPBRYOS	SPFERNS	SPRAISED	SPSDR	SPSDDEN
SEEDEN	1.0000																			
AGEDHT	0.1681	1.0000																		
BRYOSCOV	-0.1110	-0.0064	1.0000																	
FERNCOV	-0.0084	0.1568	0.2059	1.0000																
BASALAX	-0.0298	0.5929	0.0572	0.2499	1.0000															
AVLAX	0.0988	0.5396	0.1195	0.5255	0.5579	1.0000														
STEMCT	-0.1027	-0.1934	-0.0495	-0.2366	-0.4139	-0.4054	1.0000													
SLA	0.1426	-0.0216	-0.0403	-0.3219	-0.0626	-0.4608	0.0803	1.0000												
RADIUS	0.0586	0.4792	0.1828	0.3718	0.4344	0.7703	-0.3615	-0.2395	1.0000											
DEBRIS	0.1936	0.3591	0.5410	0.2427	0.2046	0.4002	-0.1148	0.0447	0.3941	1.0000										
WOODY	-0.0948	-0.0740	0.0615	0.0387	0.2277	0.0764	0.0138	-0.0441	0.0024	0.0304	1.0000									
NATIVECV	-0.0494	0.1314	0.0626	0.1233	0.1487	0.1006	0.1753	-0.0520	0.0973	0.0928	-0.1223	1.0000								
SOILPSI	-0.0686	-0.5256	-0.1764	-0.2381	-0.4473	-0.6000	0.2987	0.2282	-0.5002	-0.4573	-0.0531	-0.0540	1.0000							
CVSOILPSI	-0.0149	0.6006	0.2436	0.3146	0.4989	0.6261	-0.2615	-0.1921	0.4327	0.3753	0.0945	-0.0022	-0.6624	1.0000						
SPDEBRIS	0.0826	0.3736	0.0891	0.2092	0.2506	0.3923	0.0268	-0.1598	0.5301	0.3788	0.1286	0.3185	-0.2512	0.1930	1.0000					
SPBRYOS	-0.0134	0.3238	0.3795	0.2679	0.1983	0.4290	-0.2374	-0.2119	0.5265	0.4397	0.1801	0.0092	-0.4202	0.3302	0.5229	1.0000				
SPFERNS	0.1884	0.3474	0.1233	0.4646	0.1777	0.5088	-0.2641	-0.1866	0.4543	0.3165	-0.0721	0.1291	-0.3924	0.3664	0.3603	0.4532	1.0000			
SPRAISED	0.1125	0.2450	0.3215	0.1136	0.3257	0.2735	-0.0971	-0.0970	0.3810	0.3499	0.2837	0.2465	-0.1217	0.1941	0.4910	0.3992	0.2714	1.0000		
SPSDR	0.3095	0.4113	0.1914	0.3021	0.3370	0.5316	-0.2159	-0.0677	0.3599	0.5578	0.1090	0.0383	-0.3244	0.4609	0.2828	0.3689	0.4172	0.3093	1.0000	
SPSDDEN	0.3424	0.3853	0.1583	0.1109	0.1575	0.1466	-0.0261	0.1070	0.0529	0.4923	-0.0430	0.0499	-0.1575	0.3673	0.0818	0.2263	0.1756	0.2095	0.5811	1.0000

APPENDIX 5: DIFFERENCES BETWEEN PLOT POINTS AND EXPLANATORY VARIABLES

Site	treatment distance	distance between x and y	Average soil compaction (PSI)	Bryos Ground (% cover)	Canopy cover (%)	CV Soil compaction (PSI)	Ground fern	Native (% cover)	No of structual tiers	Radius of tree canopy (m)	seedling density M2	Seedling richness	SLA of Canopy spp	Square root of age of regeneration (years)	Square root of area raised (% cover)	Square root of average canopy height (m)	Square root of average DBH (cm)	Square root of woody debris (% cover)	Square root of woody spp (% cover)	Stem count of tree at BH	SWDI - lifeform cover	SWDI - seedling	SWDI - taxa cover	SWDI - tier cover	SWDI- species cover	Total diversity/canopy cover	Total Species Richness
Site	Treat.	dist.	soilpA	bryo	CanCov	SoilCV	Gfern	NatCov	Tier	Radius	SdDen	SdRich	SLA	Age	Raised	CanHgt	DBH	Debris	WdSpp	StemBH	SWlife	SWsd	SWtaxa	SWtier	SWspp	DivCan Cov	Rich
DC	P1-P2	5.448	83.333	5	-5	-0.205	-3.969	-0.010	1	0.163	2.340	1.570	-28.950	0.334	0.977	-0.139	-0.250	-0.504	-0.310	0.832	-0.161	0.505	-0.126	-0.041	-0.307	-0.002	5
DC	P1-S1	-21.194	181.667	5	10	-0.481	-13.580	5.538	-1	0.500	-9.450	-2.950	50.733	-0.154	2.583	0.151	-2.154	-1.430	2.493	0.816	-0.476	-0.232	-0.623	-0.188	-0.284	-0.007	-1
DC	P1-R1	-33.014	228.333	-5	15	-1.613	-31.196	2.792	-3	-2.527	-10.986	-2.379	71.527	-28.461	-1.184	-2.740	-5.032	-1.732	2.390	1.941	-0.747	-0.865	-0.631	-0.822	-1.322	-0.025	-14
DC	P1-R2	-32.356	226.667	-5	20	-0.881	-41.774	3.465	-3	-1.347	-5.224	-1.083	65.160	-28.461	2.347	-2.958	-4.237	-1.096	2.244	1.941	-0.610	-0.269	-0.904	-0.503	-1.056	-0.025	-15
DC	P1-S2	2.067	145.000	-20	5	-0.141	-12.258	8.190	0	0.738	-6.555	-1.300	-39.750	-0.302	2.033	0.000	-0.132	-2.141	2.743	0.831	-0.383	-0.298	-0.338	-0.113	-0.226	-0.004	5
DC	P2-S1	-26.642	98.333	0	15	-0.276	-9.611	5.548	-2	0.337	-11.790	-4.520	79.683	-0.488	1.606	0.290	-1.904	-0.926	2.803	-0.016	-0.315	-0.737	-0.496	-0.147	0.022	-0.005	-6
DC	P2-S2	-3.381	61.667	-25	10	0.064	-8.289	8.200	-1	0.574	-8.895	-2.870	-10.800	-0.636	1.056	0.139	0.118	-1.637	3.053	-0.002	-0.221	-0.803	-0.212	-0.072	0.080	-0.002	0
DC	P2-R1	-38.462	145.000	-10	20	-1.408	-27.226	2.802	-4	-2.690	-13.326	-3.949	100.477	-28.794	-2.161	-2.601	-4.781	-1.228	2.699	1.109	-0.586	-1.370	-0.504	-0.781	-1.016	-0.023	-19
DC	P2-R2	-37.804	143.333	-10	25	-0.676	-37.805	3.475	-4	-1.510	-7.563	-2.653	94.110	-28.794	1.369	-2.820	-3.986	-0.592	2.554	1.109	-0.449	-0.774	-0.777	-0.462	-0.749	-0.022	-20
DC	R1-R2	0.658	-1.667	0	5	0.732	-10.578	0.673	0	1.180	5.762	1.295	-6.367	0.000	3.530	-0.218	0.795	0.636	-0.145	0.000	0.137	0.596	-0.273	0.319	0.267	0.001	-1
DC	R1-S1	11.820	-46.667	10	-5	1.132	17.616	2.746	2	3.027	1.536	-0.571	-20.793	28.306	3.766	2.891	2.878	0.302	0.103	-1.125	0.271	0.633	0.008	0.634	1.038	0.018	13
DC	R1-S2	35.081	-83.333	-15	-10	1.472	18.938	5.398	3	3.264	4.431	1.079	-111.277	28.159	3.217	2.740	4.900	-0.409	0.354	-1.110	0.365	0.567	0.293	0.709	1.096	0.021	19
DC	R2-S1	11.162	-45.000	10	-10	0.400	28.194	2.074	2	1.847	-4.227	-1.867	-14.427	28.306	0.236	3.109	2.083	-0.334	0.249	-1.125	0.134	0.037	0.281	0.315	0.772	0.018	14
DC	R2-S2	34.423	-81.667	-15	-15	0.740	29.516	4.725	3	2.084	-1.332	-0.217	-104.910	28.159	-0.313	2.958	4.105	-1.045	0.499	-1.110	0.228	-0.029	0.566	0.390	0.830	0.020	20
DC	S1-S2	23.261	-36.667	-25	-5	0.340	1.322	2.652	1	0.238	2.895	1.650	-90.483	-0.147	-0.550	-0.151	2.022	-0.711	0.250	0.015	0.094	-0.066	0.285	0.075	0.058	0.003	6
FR	P1-S1	-11.283	116.667	-0.5	30	-0.039	-38.241	-13.764	-1	0.430	-2.910	-0.690	103.780	-1.493	-2.500	-0.365	-0.143	-1.098	2.300	-0.464	-0.340	0.000	-0.608	-0.612	-0.211	-0.020	-10
FR	S1-R1	-1.157	238.333	-0.5	-20	-0.312	12.957	3.227	-3	-3.770	-0.023	0.000	-13.830	-26.524	-1.593	-1.228	-3.973	-0.822	-1.915	0.714	0.178	-1.374	-0.506	-0.591	-0.124	0.012	-4
FR	R1-P1	12.440	-355.000	1	-10	0.351	25.283	10.537	4	3.340	2.934	0.690	-89.950	28.017	4.093	1.593	4.116	1.920	-0.385	-0.250	0.163	1.374	1.115	1.203	0.336	0.009	14
HR	P1-P2	64.058	50.000	-0.1	15	-0.121	-18.496	14.140	-1	-0.655	2.817	0.440	-73.523	-0.276	2.646	0.379	0.482	-1.098	1.574	-0.909	-0.993	0.045	-0.813	-0.343	-1.731	-0.027	-12
HR	P1-S1	29.280	-185.000	-0.5	20	0.042	-15.159	11.293	0	-1.270	-3.349	-1.543	-66.511	0.292	0.576	0.592	-0.173	-1.416	1.984	0.004	-0.876	-0.679	-0.658	-0.449	-1.652	-0.029	-15
HR	P1-R1	22.580	45.000	-0.1	20	-0.457	-43.289	1.312	-3	-1.737	1.401	-1.200	-52.364	-26.331	-0.579	0.592	-1.559	-1.098	1.274	0.750	-0.879	-1.113	-1.294	-0.950	-1.852	-0.032	-33

Site	treatment distance	distance between x and y	Average soil compaction (PSI)	Bryos Ground (% cover)	Canopy cover (%)	CV Soil compaction (PSI)	Ground fern	Native (% cover)	No of structual tiers	Radius of tree canopy (m)	seedling density M2	Seedling richness	SLA of Canopy spp	Square root of age of regeneration (years)	Square root of area raised (% cover)	Square root of average canopy height (m)	Square root of average DBH (cm)	Square root of woody debris (% cover)	Square root of woody spp (% cover)	Stem count of tree at BH	SWDI - lifeform cover	SWDI - seedling	SWDI - taxa cover	SWDI - tier cover	SWDI- species cover	Total diversity/canopy cover	Total Species Richness
Site	Treat.	dist.	soilpA	bryo	CanCov	SoilCV	Gfern	NatCov	Tier	Radius	SdDen	SdRich	SLA	Age	Raised	CanHgt	DBH	Debris	WdSpp	StemBH	SWlife	SWsd	SWtaxa	SWtier	SWspp	DivCan Cov	Rich
HR	P1-R2	30.694	40.000	-2	25	-0.500	-16.960	0.018	-3	-1.537	0.062	-2.350	-34.711	-26.331	0.196	-1.414	-1.880	-1.416	1.148	1.150	-0.948	-1.150	-1.091	-0.864	-2.115	-0.040	-34
HR	P1-S2	48.097	-111.667	-3	20	-0.124	-26.330	1.524	1	-0.363	-15.383	-2.900	-65.424	0.292	0.987	0.828	1.008	-2.512	1.668	-0.015	-0.936	-0.758	-0.549	-0.064	-1.930	-0.033	-26
HR	P2-S1	-34.777	-235.000	-0.4	5	0.163	3.338	-2.847	1	-0.615	-6.166	-1.983	7.012	0.568	-2.070	0.213	-0.654	-0.318	0.410	0.913	0.117	-0.724	0.155	-0.106	0.079	-0.002	-3
HR	P2-S2	-15.960	-161.667	-2.9	5	-0.003	-7.833	-12.616	2	0.292	-18.200	-3.340	8.098	0.568	-1.658	0.449	0.526	-1.414	0.094	0.894	0.057	-0.803	0.264	0.279	-0.199	-0.006	-14
HR	P2-R1	-41.478	-5.000	0	5	-0.336	-24.793	-12.828	-2	-1.082	-1.416	-1.640	21.158	-26.055	-3.225	0.213	-2.041	0.000	-0.300	1.659	0.114	-1.158	-0.481	-0.608	-0.121	-0.005	-21
HR	P2-R2	-33.363	-10.000	-1.9	10	-0.379	1.536	-14.122	-2	-0.882	-2.756	-2.790	38.812	-26.055	-2.449	-1.793	-2.361	-0.318	-0.426	2.059	0.045	-1.196	-0.278	-0.522	-0.384	-0.013	-22
HR	R1-R2	8.114	-5.000	-1.9	5	-0.043	26.329	-1.293	0	0.200	-1.339	-1.150	17.653	0.000	0.775	-2.007	-0.320	-0.318	-0.125	0.400	-0.069	-0.037	0.203	0.086	-0.263	-0.008	-1
HR	R1-S1	6.700	-230.000	-0.4	0	0.499	28.131	9.982	3	0.467	-4.750	-0.343	-14.147	26.623	1.155	0.000	1.387	-0.318	0.710	-0.746	0.003	0.434	0.636	0.502	0.200	0.003	18
HR	R1-S2	25.517	-156.667	-2.9	0	0.333	16.960	0.212	4	1.373	-16.784	-1.700	-13.060	26.623	1.567	0.236	2.567	-1.414	0.394	-0.765	-0.057	0.355	0.745	0.887	-0.077	-0.001	7
HR	R2-S1	-1.414	-225.000	1.5	-5	0.542	1.801	11.275	3	0.267	-3.410	0.807	-31.800	26.623	0.379	2.007	1.707	0.000	0.835	-1.146	0.072	0.471	0.433	0.416	0.463	0.011	19
HR	R2-S2	17.403	-151.667	-1	-5	0.376	-9.370	1.505	4	1.173	-15.444	-0.550	-30.713	26.623	0.791	2.243	2.888	-1.096	0.520	-1.165	0.012	0.392	0.542	0.801	0.185	0.007	8
HR	S1-S2	18.817	73.333	-2.5	0	-0.166	-11.171	-9.770	1	0.907	-12.034	-1.357	1.087	0.000	0.412	0.236	1.181	-1.096	-0.316	-0.019	-0.060	-0.079	0.109	0.385	-0.278	-0.004	-11
KB	P1-P2	-10.250	173.333	-0.1	-30	-0.160	1.245	-32.174	0	0.534	2.690	1.289	-5.906	-3.816	0.471	0.646	0.549	1.025	1.169	-0.150	0.623	0.517	0.543	0.291	0.435	0.019	19
KB	P1-S1	-0.253	140.000	-0.1	-25	0.143	-1.379	-32.901	-1	-0.123	-2.015	-1.311	6.106	-5.424	-2.691	0.196	0.233	-0.504	2.634	-0.158	0.453	-0.584	0.566	-0.334	0.483	0.018	16
KB	P1-R1	45.515	113.333	-0.5	-10	0.107	-10.028	-37.127	-3	-1.230	-1.057	-4.161	3.592	-28.159	-2.029	-0.818	-2.053	0.318	1.669	0.509	-0.003	-0.479	-0.254	-0.526	0.020	0.006	18
KB	P1-R2	11.094	188.333	-4	0	-0.911	-15.952	-34.360	-2	-0.576	0.440	-3.411	19.072	-28.159	-1.927	-0.818	-1.293	-0.268	3.612	0.576	0.357	-1.085	0.127	-0.367	0.151	0.003	12
KB	P1-S2	8.333	80.000	0	-20	0.314	-0.234	-26.163	-1	0.144	1.190	-0.391	-42.281	-5.424	-2.321	0.301	0.441	0.732	4.663	0.909	0.652	-0.419	0.726	-0.317	0.542	0.017	24
KB	P2-S1	9.997	-33.333	0	5	0.302	-2.624	-0.727	-1	-0.657	-4.705	-2.600	12.011	-1.608	-3.162	-0.449	-0.317	-1.529	1.465	-0.008	-0.171	-1.101	0.024	-0.625	0.048	-0.001	-3
KB	P2-S2	18.583	-93.333	0.1	10	0.474	-1.479	6.010	-1	-0.390	-1.500	-1.680	-36.375	-1.608	-2.793	-0.345	-0.108	-0.293	3.494	1.059	0.028	-0.937	0.184	-0.609	0.106	-0.002	5
KB	P2-R1	55.765	-60.000	-0.4	20	0.267	-11.273	-4.953	-3	-1.764	-3.747	-5.450	9.498	-24.343	-2.500	-1.464	-2.603	-0.707	0.500	0.659	-0.626	-0.996	-0.796	-0.817	-0.415	-0.012	-1
KB	P2-R2	21.344	15.000	-3.9	30	-0.752	-17.197	-2.186	-2	-1.110	-2.250	-4.700	24.978	-24.343	-2.398	-1.464	-1.842	-1.293	2.444	0.725	-0.266	-1.602	-0.415	-0.659	-0.285	-0.016	-7
KB	R1-R2	-34.422	75.000	-3.5	10	-1.018	-5.924	2.767	1	0.653	1.497	0.750	15.480	0.000	0.102	0.000	0.760	-0.586	1.944	0.067	0.360	-0.606	0.381	0.158	0.130	-0.004	-6
KB	R1-S1	-45.768	26.667	0.4	-15	0.036	8.649	4.226	2	1.107	-0.958	2.850	2.513	22.735	-0.662	1.015	2.286	-0.822	0.965	-0.667	0.455	-0.105	0.820	0.192	0.462	0.012	-2
KB	R1-S2	-37.182	-33.333	0.5	-10	0.207	9.794	10.963	2	1.373	2.247	3.770	-45.873	22.735	-0.293	1.119	2.494	0.414	2.994	0.400	0.655	0.059	0.980	0.208	0.521	0.011	6
KB	R2-S1	-11.347	-48.333	3.9	-25	1.054	14.573	1.459	1	0.453	-2.455	2.100	-12.967	22.735	-0.764	1.015	1.525	-0.236	-0.979	-0.733	0.096	0.501	0.439	0.034	0.332	0.015	4
KB	R2-S2	-2.761	-108.333	4	-20	1.226	15.718	8.196	1	0.720	0.750	3.020	-61.353	22.735	-0.395	1.119	1.734	1.000	1.050	0.333	0.295	0.665	0.599	0.050	0.391	0.015	12

Site	treatment distance	distance between x and y	Average soil compaction (PSI)	Bryos Ground (% cover)	Canopy cover (%)	CV Soil compaction (PSI)	Ground fern	Native (% cover)	No of structual tiers	Radius of tree canopy (m)	seedling density M2	Seedling richness	SLA of Canopy spp	Square root of age of regeneration (years)	Square root of area raised (% cover)	Square root of average canopy height (m)	Square root of average DBH (cm)	Square root of woody debris (% cover)	Square root of woody spp (% cover)	Stem count of tree at BH	SWDI - lifeform cover	SWDI - seedling	SWDI - taxa cover	SWDI - tier cover	SWDI- species cover	Total diversity/canopy cover	Total Species Richness
Site	Treat.	dist.	soilpA	bryo	CanCov	SoilCV	Gfern	NatCov	Tier	Radius	SdDen	SdRich	SLA	Age	Raised	CanHgt	DBH	Debris	WdSpp	StemBH	SWlife	SWsd	SWtaxa	SWtier	SWspp	DivCan Cov	Rich
KB	S1-S2	8.586	-60.000	0.1	5	0.171	1.145	6.738	0	0.267	3.205	0.920	-48.387	0.000	0.369	0.104	0.209	1.236	2.029	1.067	0.199	0.165	0.160	0.016	0.059	-0.001	8
KRd	P1-P2	54.540	165.000	1.9	0	-0.004	-1.537	5.284	1	-0.573	-2.337	0.050	50.805	0.303	1.400	0.236	-0.893	0.000	-1.613	-1.000	-0.708	0.164	-0.762	-0.068	-1.678	-0.022	-20
KRd	P1-P3	48.748	115.000	1	5	-0.016	-1.705	5.247	1	0.000	0.000	0.000	0.000	0.303	0.000	-0.213	0.000	0.000	1.156	-2.000	-0.506	0.000	-0.386	0.079	-1.612	-0.024	-25
KRd	P1-P4	7.853	91.667	1	-15	0.127	-1.098	8.944	1	-0.030	-4.133	-0.600	7.789	0.000	0.066	-0.213	-0.124	1.098	-3.397	0.617	-0.220	-0.134	-0.377	0.111	-0.342	-0.002	1
KRd	P1-R1	12.617	303.333	0	-5	-0.659	-26.571	4.631	-2	-2.440	4.007	0.650	67.293	-26.524	0.808	-3.241	-3.994	0.000	0.137	0.750	-0.670	-0.949	-1.138	-0.624	-1.485	-0.018	-23
KRd	P1-R2	20.666	326.667	1.5	-15	-0.455	-11.372	6.344	-2	-2.580	4.956	0.690	85.133	-26.524	2.076	-2.764	-4.003	-0.822	1.673	-0.250	-0.829	-0.839	-1.242	-0.655	-1.631	-0.016	-31
KRd	P1-S1	26.136	343.333	0	5	-0.946	-22.012	21.561	-1	-0.363	2.945	-0.700	51.467	-0.817	1.937	0.000	-0.599	1.414	-2.067	-0.015	-0.323	-0.153	-0.733	-0.386	-1.406	-0.021	-22
KRd	P1-S2	62.798	291.667	1.9	0	-0.146	-9.227	4.932	0	0.057	0.468	-0.550	105.860	-0.817	2.394	0.115	-1.392	0.000	-1.285	-0.583	-0.516	-0.397	-0.486	-0.286	-1.433	-0.019	-20
KRd	P2-P3	-5.792	-50.000	-0.9	5	-0.012	-0.167	-0.037	0	0.573	2.337	-0.050	-50.805	0.000	-1.400	-0.449	0.893	0.000	2.769	-1.000	0.203	-0.164	0.376	0.147	0.066	-0.002	-5
KRd	P2-P4	-46.687	-73.333	-0.9	-15	0.131	0.439	3.659	0	0.543	-1.796	-0.650	-43.016	-0.303	-1.333	-0.449	0.770	1.098	-1.784	1.617	0.489	-0.298	0.385	0.179	1.336	0.021	21
KRd	P2-R1	-41.923	138.333	-1.9	-5	-0.655	-25.034	-0.654	-3	-1.867	6.344	0.600	16.488	-26.827	-0.592	-3.477	-3.101	0.000	1.750	1.750	0.038	-1.114	-0.376	-0.556	0.193	0.005	-3
KRd	P2-R2	-33.874	161.667	-0.4	-15	-0.451	-9.835	1.060	-3	-2.007	7.292	0.640	34.328	-26.827	0.676	-3.000	-3.109	-0.822	3.286	0.750	-0.121	-1.003	-0.480	-0.587	0.048	0.007	-11
KRd	P2-S1	-28.404	178.333	-1.9	5	-0.942	-20.474	16.277	-2	0.210	5.282	-0.750	0.662	-1.120	0.537	-0.236	0.294	1.414	-0.454	0.985	0.385	-0.318	0.029	-0.318	0.272	0.001	-2
KRd	P2-S2	8.259	126.667	0	0	-0.142	-7.689	-0.352	-1	0.630	2.805	-0.600	55.055	-1.120	0.994	-0.121	-0.498	0.000	0.328	0.417	0.192	-0.561	0.277	-0.218	0.246	0.003	0
KRd	P3-P4	-40.895	-23.333	0	-20	0.143	0.607	3.696	0	-0.030	-4.133	-0.600	7.789	-0.303	0.066	0.000	-0.124	1.098	-4.553	2.617	0.286	-0.134	0.009	0.032	1.270	0.022	26
KRd	P3-R1	-36.131	188.333	-1	-10	-0.643	-24.866	-0.616	-3	-2.440	4.007	0.650	67.293	-26.827	0.808	-3.028	-3.994	0.000	-1.019	2.750	-0.164	-0.949	-0.752	-0.703	0.127	0.006	2
KRd	P3-R2	-28.082	211.667	0.5	-20	-0.439	-9.668	1.097	-3	-2.580	4.956	0.690	85.133	-26.827	2.076	-2.551	-4.003	-0.822	0.517	1.750	-0.323	-0.839	-0.856	-0.733	-0.019	0.008	-6
KRd	P3-S1	-22.612	228.333	-1	0	-0.930	-20.307	16.314	-2	-0.363	2.945	-0.700	51.467	-1.120	1.937	0.213	-0.599	1.414	-3.223	1.985	0.183	-0.153	-0.347	-0.464	0.206	0.003	3
KRd	P3-S2	14.050	176.667	0.9	-5	-0.130	-7.522	-0.315	-1	0.057	0.468	-0.550	105.860	-1.120	2.394	0.328	-1.392	0.000	-2.441	1.417	-0.010	-0.397	-0.100	-0.364	0.179	0.005	5
KRd	P4-R1	4.763	211.667	-1	10	-0.786	-25.473	-4.313	-3	-2.410	8.140	1.250	59.505	-26.524	0.742	-3.028	-3.870	-1.098	3.534	0.133	-0.451	-0.815	-0.761	-0.735	-1.143	-0.016	-24
KRd	P4-R2	12.812	235.000	0.5	0	-0.581	-10.274	-2.599	-3	-2.550	9.089	1.290	77.345	-26.524	2.010	-2.551	-3.879	-1.920	5.070	-0.867	-0.609	-0.705	-0.865	-0.766	-1.288	-0.014	-32
KRd	P4-S1	18.283	251.667	-1	20	-1.072	-20.914	12.618	-2	-0.333	7.078	-0.100	43.678	-0.817	1.871	0.213	-0.475	0.316	1.329	-0.631	-0.104	-0.019	-0.356	-0.496	-1.064	-0.020	-23
KRd	P4-S2	54.945	200.000	0.9	15	-0.273	-8.129	-4.011	-1	0.087	4.601	0.050	98.071	-0.817	2.327	0.328	-1.268	-1.098	2.112	-1.200	-0.297	-0.263	-0.108	-0.396	-1.090	-0.018	-21
KRd	R1-R2	8.049	23.333	1.5	-10	0.205	15.199	1.714	0	-0.140	0.949	0.040	17.840	0.000	1.268	0.477	-0.009	-0.822	1.536	-1.000	-0.159	0.111	-0.104	-0.031	-0.146	0.002	-8
KRd	R1-S1	13.520	40.000	0	10	-0.286	4.559	16.930	1	2.077	-1.061	-1.350	-15.827	25.707	1.129	3.241	3.395	1.414	-2.204	-0.765	0.347	0.796	0.405	0.239	0.079	-0.003	1
KRd	R1-S2	50.182	-11.667	1.9	5	0.513	17.344	0.302	2	2.497	-3.539	-1.200	38.567	25.707	1.586	3.356	2.602	0.000	-1.422	-1.333	0.154	0.553	0.653	0.339	0.052	-0.001	3

Site	treatment distance	distance between x and y	Average soil compaction (PSI)	Bryos Ground (% cover)	Canopy cover (%)	CV Soil compaction (PSI)	Ground fern	Native (% cover)	No of structual tiers	Radius of tree canopy (m)	seedling density M2	Seedling richness	SLA of Canopy spp	Square root of age of regeneration (years)	Square root of area raised (% cover)	Square root of average canopy height (m)	Square root of average DBH (cm)	Square root of woody debris (% cover)	Square root of woody spp (% cover)	Stem count of tree at BH	SWDI - lifeform cover	SWDI - seedling	SWDI - taxa cover	SWDI - tier cover	SWDI- species cover	Total diversity/canopy cover	Total Species Richness
Site	Treat.	dist.	soilpA	bryo	CanCov	SoilCV	Gfern	NatCov	Tier	Radius	SdDen	SdRich	SLA	Age	Raised	CanHgt	DBH	Debris	WdSpp	StemBH	SWlife	SWsd	SWtaxa	SWtier	SWspp	DivCan Cov	Rich
KRd	R2-S1	5.471	16.667	-1.5	20	-0.491	-10.640	15.217	1	2.217	-2.010	-1.390	-33.667	25.707	-0.139	2.764	3.404	2.236	-3.741	0.235	0.506	0.685	0.509	0.269	0.225	-0.005	9
KRd	R2-S2	42.133	-35.000	0.4	15	0.308	2.145	-1.412	2	2.637	-4.488	-1.240	20.727	25.707	0.318	2.879	2.611	0.822	-2.958	-0.333	0.313	0.442	0.756	0.369	0.198	-0.003	11
KRd	S1-S2	36.662	-51.667	1.9	-5	0.799	12.785	-16.629	1	0.420	-2.478	0.150	54.393	0.000	0.457	0.115	-0.793	-1.414	0.782	-0.569	-0.193	-0.243	0.247	0.100	-0.027	0.002	2
Mis.	P1-P2	38.166	75.000	-1	40	0.224	0.874	-24.670	0	0.880	3.302	1.333	53.340	0.200	0.000	0.236	-0.070	-1.025	-3.821	-0.900	0.142	0.501	0.554	0.410	-0.463	-0.032	3
Mis.	P1-P3	16.042	78.333	-0.1	0	-0.033	2.014	-24.230	0	0.320	3.844	1.400	12.230	0.976	0.000	0.115	-0.396	0.000	-0.222	-0.650	0.513	0.518	0.578	0.536	1.083	0.014	9
Mis.	P1-R1	20.717	150.000	-0.5	10	-1.381	-4.086	-21.937	-3	0.220	-25.350	-2.550	-14.900	-26.524	-1.000	-0.592	-1.143	-1.529	-2.213	-0.929	0.109	-0.311	-0.143	-0.593	-0.833	-0.015	-13
Mis.	P1-R2	30.705	150.000	-0.5	15	-0.081	-11.719	-20.804	-2	-0.493	-6.605	-3.750	7.160	-26.524	-2.739	-0.592	-1.702	-3.166	-2.527	-0.971	0.191	0.103	-0.215	-0.635	-0.741	-0.016	-7
Mis.	P1-S1	47.519	61.667	-0.5	15	0.122	-18.241	-21.126	-2	-1.250	-0.187	0.200	7.610	-0.646	0.000	-0.109	-0.881	-1.529	-2.738	-0.567	-0.604	0.082	-0.320	-0.193	-0.773	-0.017	-13
Mis.	P1-S2	41.110	53.333	-0.5	0	0.251	-10.181	-24.586	-1	-0.993	-8.976	-1.200	32.563	-0.646	-3.266	0.000	-1.435	-1.529	-3.718	-0.567	-0.590	0.164	0.266	0.092	-0.512	-0.006	1
Mis.	P2-P3	-22.124	3.333	0.9	-40	-0.257	1.140	0.440	0	-0.560	0.542	0.067	-41.110	0.776	0.000	-0.121	-0.326	1.025	3.599	0.250	0.371	0.017	0.024	0.127	1.546	0.045	6
Mis.	P2-R1	-17.449	75.000	0.5	-30	-1.605	-4.959	2.732	-3	-0.660	-28.652	-3.883	-68.240	-26.724	-1.000	-0.828	-1.073	-0.504	1.607	-0.029	-0.033	-0.811	-0.697	-1.003	-0.370	0.017	-16
Mis.	P2-R2	-7.461	75.000	0.5	-25	-0.306	-12.593	3.866	-2	-1.373	-9.907	-5.083	-46.180	-26.724	-2.739	-0.828	-1.632	-2.141	1.293	-0.071	0.049	-0.398	-0.769	-1.045	-0.278	0.016	-10
Mis.	P2-S1	9.353	-13.333	0.5	-25	-0.102	-19.114	3.544	-2	-2.130	-3.490	-1.133	-45.730	-0.846	0.000	-0.345	-0.811	-0.504	1.082	0.333	-0.746	-0.418	-0.874	-0.603	-0.310	0.015	-16
Mis.	P2-S2	2.943	-21.667	0.5	-40	0.027	-11.055	0.084	-1	-1.873	-12.279	-2.533	-20.777	-0.846	-3.266	-0.236	-1.365	-0.504	0.103	0.333	-0.732	-0.337	-0.288	-0.318	-0.049	0.026	-2
Mis.	P3-R1	4.675	71.667	-0.4	10	-1.347	-6.100	2.292	-3	-0.100	-29.194	-3.950	-27.130	-27.500	-1.000	-0.707	-0.747	-1.529	-1.992	-0.279	-0.404	-0.829	-0.722	-1.129	-1.916	-0.028	-22
Mis.	P3-R2	14.663	71.667	-0.4	15	-0.048	-13.733	3.426	-2	-0.813	-10.449	-5.150	-5.070	-27.500	-2.739	-0.707	-1.306	-3.166	-2.306	-0.321	-0.322	-0.415	-0.793	-1.171	-1.824	-0.030	-16
Mis.	P3-S1	31.477	-16.667	-0.4	15	0.155	-20.255	3.104	-2	-1.570	-4.031	-1.200	-4.620	-1.621	0.000	-0.224	-0.485	-1.529	-2.517	0.083	-1.117	-0.436	-0.899	-0.730	-1.856	-0.030	-22
Mis.	P3-S2	25.068	-25.000	-0.4	0	0.284	-12.195	-0.356	-1	-1.313	-12.820	-2.600	20.333	-1.621	-3.266	-0.115	-1.039	-1.529	-3.496	0.083	-1.103	-0.354	-0.313	-0.444	-1.595	-0.020	-8
Mis.	R1-R2	9.988	0.000	0	5	1.299	-7.633	1.134	1	-0.713	18.745	-1.200	22.060	0.000	-1.739	0.000	-0.559	-1.637	-0.314	-0.042	0.082	0.414	-0.071	-0.042	0.092	-0.001	6
Mis.	R1-S1	26.802	-88.333	0	5	1.503	-14.155	0.812	1	-1.470	25.162	2.750	22.510	25.878	1.000	0.483	0.262	0.000	-0.525	0.362	-0.713	0.393	-0.177	0.400	0.060	-0.002	0
Mis.	R1-S2	20.392	-96.667	0	-10	1.631	-6.095	-2.649	2	-1.213	16.373	1.350	47.463	25.878	-2.266	0.592	-0.292	0.000	-1.504	0.362	-0.699	0.475	0.409	0.685	0.321	0.008	14
Mis.	R2-S1	16.815	-88.333	0	0	0.204	-6.521	-0.322	0	-0.757	6.418	3.950	0.450	25.878	2.739	0.483	0.821	1.637	-0.211	0.404	-0.795	-0.021	-0.106	0.441	-0.032	0.000	-6
Mis.	R2-S2	10.405	-96.667	0	-15	0.332	1.538	-3.782	1	-0.500	-2.371	2.550	25.403	25.878	-0.527	0.592	0.267	1.637	-1.191	0.404	-0.781	0.061	0.480	0.727	0.229	0.010	8
Mis.	S1-S2	-6.410	-8.333	0	-15	0.129	8.060	-3.460	1	0.257	-8.789	-1.400	24.953	0.000	-3.266	0.109	-0.554	0.000	-0.980	0.000	0.014	0.082	0.586	0.285	0.261	0.010	14
MR	P1-S1	-3.230	80.000	0	25	-0.118	-5.300	14.045	1	-0.847	-4.486	-2.750	-142.787	0.000	0.054	0.365	0.655	-1.684	-1.898	1.045	-0.060	-0.780	0.344	-0.234	0.180	-0.012	12
MR	S1-R1	-7.864	153.333	-0.9	-5	-0.237	-22.291	-3.906	-4	-2.267	2.826	-1.750	110.173	-27.750	0.170	-2.372	-4.603	1.000	0.476	-0.027	0.168	0.460	-0.604	-0.665	0.606	0.013	14

Site	treatment distance	distance between x and y	Average soil compaction (PSI)	Bryos Ground (% cover)	Canopy cover (%)	CV Soil compaction (PSI)	Ground fern	Native (% cover)	No of structual tiers	Radius of tree canopy (m)	seedling density M2	Seedling richness	SLA of Canopy spp	Square root of age of regeneration (years)	Square root of area raised (% cover)	Square root of average canopy height (m)	Square root of average DBH (cm)	Square root of woody debris (% cover)	Square root of woody spp (% cover)	Stem count of tree at BH	SWDI - lifeform cover	SWDI - seedling	SWDI - taxa cover	SWDI - tier cover	SWDI- species cover	Total diversity/canopy cover	Total Species Richness
Site	Treat.	dist.	soilpA	bryo	CanCov	SoilCV	Gfern	NatCov	Tier	Radius	SdDen	SdRich	SLA	Age	Raised	CanHgt	DBH	Debris	WdSpp	StemBH	SWlife	SWsd	SWtaxa	SWtier	SWspp	DivCan Cov	Rich
MR	R1-P1	11.094	-233.333	0.9	-20	0.355	27.591	-10.140	3	3.113	1.661	4.500	32.613	27.750	-0.224	2.007	3.948	0.684	1.422	-1.017	-0.108	0.320	0.260	0.899	-0.786	-0.001	-26
OWB	P1-P2	-26.353	-23.333	-0.5	0	0.153	0.848	4.891	0	-0.667	-1.664	-0.800	61.760	0.464	-2.646	0.121	-0.118	0.391	-1.970	0.011	0.047	-0.010	-0.015	-0.153	0.137	0.002	8
OWB	P1-S1	-19.025	-48.333	-0.1	15	-0.156	-3.904	0.337	-1	-0.533	-2.472	-1.690	-56.580	-3.816	-2.490	0.121	0.145	0.000	-1.560	-0.012	-0.068	-0.429	0.024	-0.273	0.095	-0.004	8
OWB	P1-R1	-24.811	55.000	-2	35	-0.713	-38.980	-1.012	-4	-1.553	-10.424	-7.050	82.560	-28.159	-3.000	-1.343	-4.323	-1.742	-3.848	-0.029	-0.447	-0.725	-0.805	-1.141	-0.413	-0.023	-8
OWB	P1-R2	-13.306	78.333	-4	40	-0.539	-30.478	2.268	-4	-2.787	-10.061	-6.250	66.807	-28.159	-2.887	-2.121	-3.277	-1.293	-4.286	0.788	-0.315	-1.035	-0.760	-1.086	-0.434	-0.029	5
OWB	P1-S2	-10.245	-40.000	-0.1	5	-0.054	-3.709	-1.288	-1	-0.780	-2.457	-1.050	66.550	-3.816	-2.082	0.121	-0.110	-0.293	-0.694	0.010	-0.079	-0.502	-0.095	-0.514	0.103	0.000	8
OWB	P2-S1	7.328	-25.000	0.4	15	-0.309	-4.752	-4.554	-1	0.133	-0.808	-0.890	-118.340	-4.280	0.156	0.000	0.263	-0.391	0.409	-0.023	-0.115	-0.419	0.039	-0.119	-0.042	-0.005	0
OWB	P2-S2	16.108	-16.667	0.4	5	-0.207	-4.557	-6.179	-1	-0.113	-0.793	-0.250	4.790	-4.280	0.564	0.000	0.007	-0.684	1.276	-0.001	-0.126	-0.492	-0.080	-0.360	-0.034	-0.002	0
OWB	P2-R1	1.542	78.333	-1.5	35	-0.866	-39.828	-5.903	-4	-0.887	-8.760	-6.250	20.800	-28.623	-0.354	-1.464	-4.205	-2.133	-1.878	-0.040	-0.493	-0.715	-0.790	-0.988	-0.549	-0.025	-16
OWB	P2-R2	13.047	101.667	-3.5	40	-0.691	-31.326	-2.624	-4	-2.120	-8.396	-5.450	5.047	-28.623	-0.241	-2.243	-3.159	-1.684	-2.316	0.777	-0.362	-1.025	-0.745	-0.933	-0.571	-0.030	-3
OWB	R1-R2	11.505	23.333	-2	5	0.175	8.502	3.280	0	-1.233	0.364	0.800	-15.753	0.000	0.113	-0.779	1.046	0.449	-0.438	0.817	0.131	-0.310	0.045	0.055	-0.021	-0.005	13
OWB	R1-S1	5.786	-103.333	1.9	-20	0.557	35.076	1.349	3	1.020	7.952	5.360	-139.140	24.343	0.510	1.464	4.468	1.742	2.287	0.017	0.378	0.296	0.829	0.868	0.508	0.020	16
OWB	R1-S2	14.566	-95.000	1.9	-30	0.659	35.271	-0.276	3	0.773	7.967	6.000	-16.010	24.343	0.918	1.464	4.212	1.449	3.154	0.039	0.367	0.222	0.710	0.628	0.515	0.023	16
OWB	R2-S1	-5.719	-126.667	3.9	-25	0.382	26.574	-1.930	3	2.253	7.588	4.560	-123.387	24.343	0.397	2.243	3.422	1.293	2.725	-0.800	0.247	0.606	0.784	0.813	0.529	0.025	3
OWB	R2-S2	3.061	-118.333	3.9	-35	0.484	26.769	-3.556	3	2.007	7.603	5.200	-0.257	24.343	0.805	2.243	3.166	1.000	3.591	-0.778	0.236	0.533	0.665	0.573	0.536	0.028	3
OWB	S1-S2	8.780	8.333	0	-10	0.102	0.195	-1.625	0	-0.247	0.015	0.640	123.130	0.000	0.408	0.000	-0.256	-0.293	0.866	0.022	-0.011	-0.074	-0.119	-0.241	0.007	0.003	0
QI	P1-S1	9.983	78.333	0.4	10	-0.094	-1.568	-0.796	-1	0.140	-16.633	-3.717	-110.087	-0.177	-1.826	-0.121	-0.118	-1.529	2.142	-1.068	0.096	-0.877	0.037	-0.288	-0.149	-0.015	-3
QI	S1-R1	-4.299	48.333	-0.4	-35	-0.383	-2.630	-0.906	-2	-1.707	10.067	1.967	70.125	-25.878	-1.638	0.389	-1.774	0.504	1.525	0.115	-0.136	0.065	0.241	-0.168	-0.042	0.028	2
QI	R1-P1	-5.684	-126.667	0	25	0.477	4.198	1.702	3	1.567	6.566	1.750	39.962	26.055	3.464	-0.268	1.892	1.025	-3.667	0.954	0.040	0.812	-0.277	0.455	0.191	-0.013	1
TMIs	P1-P2	-14.704	-80.000	-0.5	-15	-0.079	-66.129	0.000	0	2.773	-0.840	-0.200	-19.133	-0.204	3.416	0.413	-0.285	0.000	2.436	-0.029	-0.558	-1.038	0.183	0.093	-0.415	-0.003	4
TMIs	P1-P3	12.314	-113.333	0	-10	-0.052	-7.209	1.863	0	2.540	-0.879	-1.963	-89.255	0.000	3.416	0.145	-0.068	0.000	1.262	-0.014	-0.855	-0.905	-0.417	-0.149	-1.330	-0.014	-11
TMIs	P1-P4	-9.193	-140.000	-0.1	5	0.023	0.025	0.000	1	1.880	-0.828	-1.600	-27.200	0.000	3.416	0.023	-0.372	0.000	0.160	-1.023	-0.547	-0.052	0.048	0.438	-0.933	-0.013	-5
TMIs	P1-R1	-3.820	126.667	-2	20	-0.423	-4.109	0.000	-2	0.850	-5.868	-2.200	-55.413	-26.827	0.191	-0.684	-0.512	-1.732	-1.970	0.427	-0.472	-0.951	-0.522	-0.453	-1.608	-0.029	-14
TMIs	P1-R2	10.087	148.333	-1	15	-1.157	-9.851	0.148	-2	-0.577	-1.208	-3.350	-98.313	-26.827	0.966	-0.684	-2.519	-2.000	-2.689	0.101	-0.839	-1.171	-0.553	-0.590	-1.882	-0.031	-17
TMIs	P1-S1	44.609	50.000	-3	10	-0.268	-12.169	0.401	0	0.903	0.769	-3.500	-101.953	-0.772	1.835	-0.684	-0.698	-2.449	-0.454	-0.026	-1.250	-1.370	-0.403	-0.323	-1.573	-0.023	-7
TMIs	P1-S2	18.005	75.000	-0.5	35	-0.152	-37.272	0.428	0	0.220	-1.133	-1.267	-88.770	-0.772	0.834	0.145	-0.907	-2.000	-2.165	0.248	-1.148	-0.994	-0.173	0.044	-1.755	-0.045	-10

Site	treatment distance	distance between x and y	Average soil compaction (PSI)	Bryos Ground (% cover)	Canopy cover (%)	CV Soil compaction (PSI)	Ground fern	Native (% cover)	No of structual tiers	Radius of tree canopy (m)	seedling density M2	Seedling richness	SLA of Canopy spp	Square root of age of regeneration (years)	Square root of area raised (% cover)	Square root of average canopy height (m)	Square root of average DBH (cm)	Square root of woody debris (% cover)	Square root of woody spp (% cover)	Stem count of tree at BH	SWDI - lifeform cover	SWDI - seedling	SWDI - taxa cover	SWDI - tier cover	SWDI- species cover	Total diversity/canopy cover	Total Species Richness
Site	Treat.	dist.	soilpA	bryo	CanCov	SoilCV	Gfern	NatCov	Tier	Radius	SdDen	SdRich	SLA	Age	Raised	CanHgt	DBH	Debris	WdSpp	StemBH	SWlife	SWsd	SWtaxa	SWtier	SWspp	DivCan Cov	Rich
TMIs	P2-P3	27.018	-33.333	0.5	5	0.026	58.920	1.863	0	-0.233	-0.039	-1.763	-70.123	0.204	0.000	-0.268	0.218	0.000	-1.174	0.015	-0.297	0.132	-0.600	-0.242	-0.916	-0.011	-15
TMIs	P2-P4	5.511	-60.000	0.4	20	0.102	66.154	0.000	1	-0.893	0.013	-1.400	-8.068	0.204	0.000	-0.389	-0.087	0.000	-2.275	-0.995	0.011	0.986	-0.135	0.346	-0.518	-0.010	-9
TMIs	P2-R1	10.884	206.667	-1.5	35	-0.345	62.020	0.000	-2	-1.923	-5.028	-2.000	-36.281	-26.623	-3.225	-1.096	-0.227	-1.732	-4.406	0.455	0.086	0.087	-0.705	-0.546	-1.193	-0.026	-18
TMIs	P2-R2	24.791	228.333	-0.5	30	-1.078	56.278	0.148	-2	-3.349	-0.367	-3.150	-79.181	-26.623	-2.449	-1.096	-2.234	-2.000	-5.125	0.130	-0.282	-0.133	-0.736	-0.683	-1.467	-0.027	-21
TMIs	P2-S1	59.313	130.000	-2.5	25	-0.189	53.960	0.401	0	-1.869	1.609	-3.300	-82.821	-0.568	-1.581	-1.096	-0.413	-2.449	-2.890	0.002	-0.693	-0.332	-0.586	-0.415	-1.158	-0.020	-11
TMIs	P2-S2	32.709	155.000	0	50	-0.073	28.857	0.428	0	-2.553	-0.293	-1.067	-69.638	-0.568	-2.582	-0.268	-0.622	-2.000	-4.600	0.277	-0.591	0.044	-0.356	-0.048	-1.340	-0.041	-14
TMIs	P3-P4	-21.507	-26.667	-0.1	15	0.075	7.233	-1.863	1	-0.660	0.051	0.363	62.055	0.000	0.000	-0.121	-0.305	0.000	-1.102	-1.009	0.308	0.853	0.465	0.587	0.398	0.001	6
TMIs	P3-R1	-16.134	240.000	-2	30	-0.371	3.099	-1.863	-2	-1.690	-4.989	-0.238	33.842	-26.827	-3.225	-0.828	-0.445	-1.732	-3.232	0.441	0.383	-0.045	-0.105	-0.304	-0.277	-0.015	-3
TMIs	P3-R2	-2.227	261.667	-1	25	-1.104	-2.642	-1.715	-2	-3.117	-0.329	-1.388	-9.058	-26.827	-2.449	-0.828	-2.451	-2.000	-3.952	0.115	0.016	-0.265	-0.136	-0.441	-0.552	-0.017	-6
TMIs	P3-S1	32.295	163.333	-3	20	-0.216	-4.961	-1.462	0	-1.637	1.648	-1.538	-12.698	-0.772	-1.581	-0.828	-0.631	-2.449	-1.716	-0.012	-0.395	-0.464	0.013	-0.174	-0.242	-0.009	4
TMIs	P3-S2	5.691	188.333	-0.5	45	-0.100	-30.063	-1.435	0	-2.320	-0.254	0.696	0.485	-0.772	-2.582	0.000	-0.839	-2.000	-3.427	0.262	-0.293	-0.088	0.243	0.193	-0.425	-0.031	1
TMIs	P4-R1	5.373	266.667	-1.9	15	-0.446	-4.134	0.000	-3	-1.030	-5.040	-0.600	-28.213	-26.827	-3.225	-0.707	-0.140	-1.732	-2.130	1.450	0.075	-0.899	-0.570	-0.892	-0.675	-0.016	-9
TMIs	P4-R2	19.280	288.333	-0.9	10	-1.180	-9.876	0.148	-3	-2.457	-0.380	-1.750	-71.113	-26.827	-2.449	-0.707	-2.147	-2.000	-2.850	1.124	-0.293	-1.119	-0.601	-1.028	-0.949	-0.018	-12
TMIs	P4-S1	53.802	190.000	-2.9	5	-0.291	-12.194	0.401	-1	-0.977	1.597	-1.900	-74.753	-0.772	-1.581	-0.707	-0.326	-2.449	-0.615	0.997	-0.704	-1.318	-0.451	-0.761	-0.640	-0.011	-2
TMIs	P4-S2	27.198	215.000	-0.4	30	-0.175	-37.297	0.428	-1	-1.660	-0.306	0.333	-61.570	-0.772	-2.582	0.121	-0.535	-2.000	-2.325	1.271	-0.602	-0.942	-0.221	-0.394	-0.823	-0.032	-5
TMIs	R1-R2	13.907	21.667	1	-5	-0.733	-5.742	0.148	0	-1.427	4.661	-1.150	-42.900	0.000	0.775	0.000	-2.006	-0.268	-0.719	-0.326	-0.368	-0.220	-0.031	-0.137	-0.274	-0.001	-3
TMIs	R1-S1	48.429	-76.667	-1	-10	0.155	-8.060	0.401	2	0.053	6.637	-1.300	-46.540	26.055	1.644	0.000	-0.186	-0.717	1.516	-0.453	-0.778	-0.419	0.118	0.131	0.035	0.006	7
TMIs	R1-S2	21.825	-51.667	1.5	15	0.271	-33.163	0.428	2	-0.630	4.735	0.933	-33.357	26.055	0.643	0.828	-0.394	-0.268	-0.195	-0.179	-0.677	-0.043	0.348	0.498	-0.148	-0.015	4
TMIs	R2-S1	34.522	-98.333	-2	-5	0.889	-2.318	0.253	2	1.480	1.977	-0.150	-3.640	26.055	0.868	0.000	1.821	-0.449	2.235	-0.127	-0.411	-0.199	0.150	0.267	0.309	0.007	10
TMIs	R2-S2	7.918	-73.333	0.5	20	1.005	-27.421	0.280	2	0.797	0.074	2.083	9.543	26.055	-0.133	0.828	1.612	0.000	0.525	0.147	-0.309	0.177	0.379	0.634	0.127	-0.014	7
TMIs	S1-S2	-26.604	25.000	2.5	25	0.116	-25.103	0.027	0	-0.683	-1.902	2.233	13.183	0.000	-1.001	0.828	-0.209	0.449	-1.710	0.274	0.102	0.376	0.230	0.367	-0.183	-0.021	-3
TR	P1-S1	20.371	358.333	-0.4	30	-0.242	-46.661	-0.566	-2	-0.434	-12.918	-2.550	-42.423	-0.281	-0.702	0.000	1.077	-0.707	1.442	-0.500	-0.743	0.250	-0.578	-0.619	-1.342	-0.030	-2
TR	S1-R1	-13.520	-40.000	0	-10	0.286	-4.559	-16.931	-1	-2.077	1.061	1.350	15.827	-25.707	-1.129	-3.241	-3.395	-1.414	2.204	0.765	-0.347	-0.796	-0.405	-0.239	-0.079	0.003	-1
TR	R1-P1	-12.617	-303.333	0	5	0.659	26.571	-4.631	2	2.440	-4.007	-0.650	-67.293	26.524	-0.808	3.241	3.994	0.000	-0.137	-0.750	0.670	0.949	1.138	0.624	1.485	0.018	23