Assessing the role of revegetation in achieving restoration goals on Tiritiri Matangi Island

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Abstract: The ecological restoration of Tiritiri Matangi Island is a community-driven initiative that has captured the interest of the international conservation movement. Ecological restoration commonly focuses on the establishment and maintenance of functioning indigenous ecosystems through the control or eradication of invasive weeds and animal pests, indigenous species translocations, and habitat enhancement, including revegetation. Revegetation of indigenous plant communities provides an opportunity to kick-start natural processes and facilitate succession towards a diverse ecosystem. However, revegetation initiatives are often conducted in an ad-hoc manner, without clear objectives or monitoring to assess the effectiveness of the chosen approach. The objective of this study was to determine whether aspects of the revegetation of Tiritiri Matangi are meeting the restoration goals by providing habitat for indigenous diversity, particularly birds. To this end, we investigated forest structure, plant regeneration and bird numbers and species richness in three different densities of pohutukawa planting, specifically a) densely planted pohutukawa, b) thinned pohutukawa stands, and c) mixed species plantings. The Point Centered Quarter and Presence of Seedlings Along a Transect methods were used to collect data on forest structure and regeneration. Five-minute bird counts were used to gather data on bird conspicuousness and species richness. Vegetation analysis showed there were low levels of regeneration in dense pohutukawa. Similarly, results showed low bird numbers and species richness in dense pohutukawa compared with the two other vegetation types. This suggests that dense pohutukawa plantings are inhibiting vegetation diversity and regeneration, and richness and relative abundance of indigenous birds, contrary to the objectives of the Tiritiri Matangi restoration. It appears that thinning dense pohutukawa stands on Tiritiri Matangi will encourage species diversity and better meet the restoration objectives. However, this may lower landscape heterogeneity overall and have negative effects on specialist species that rely on pohutukawa habitat, including invertebrates and insectivorous, ground-dwelling birds such as the kiwi.

Keywords: Tiritiri Matangi; revegetation; ecological restoration; planted pohutukawa; PCQ; five-minute bird counts

Introduction

The ecological restoration of Tiritiri Matangi (Tiritiri) Island is a community-driven initiative that has captured the interest of the international conservation movement (Hawley 1997; Rimmer 2004), and helped seed a number of other large-scale community-based restoration initiatives in New Zealand and abroad (Parker 2008). As of 2007, there were more than 3000 New Zealand community-based restoration initiatives nationally, with projects centered on habitat restoration, native revegetation, pest management and threatened species conservation. These efforts now play a critical role in halting biodiversity loss and facilitating the recovery of indigenous ecosystems and species. Furthermore, research undertaken as part of the ecological restoration on Tiritiri has continued to inform and improve the effectiveness of other restoration initiatives across the country (Parker 2008).

Ecological restoration has been defined as active intervention to restore biotic communities to some former state, with definitions often including words such as representativeness and rarity (Atkinson 1988; Norton & Miller 2000). More recently, ecological restoration has focused on returning ecosystems to functioning and dynamic systems which *largely* represent what is *known* of the original system; where success can be viewed as successful establishment of self-sustaining, functioning, natural systems (Simberloff 1990; Hobbs & Norton 1996; Reay & Norton 1999; Mitchell & Craig 2000; SER 2004, Ruiz-Jaen & Aide 2005). Offshore islands provide a unique opportunity for restoration, because introduced pests and weeds are often absent or can be eradicated. Therefore, in many instances, islands offer the most certain and cost-effective way of maintaining viable populations of many of our native species (Craig 1990; Towns et al. 1990). Additional components of ecological restoration include control of other animal pests and weeds, reintroduction of indigenous species, habitat enhancement, and native revegetation.

Revegetation provides an opportunity to initiate natural processes and facilitate succession towards a diverse ecosystem. Some landscapes left to recover via natural succession alone may take many years to regenerate, e.g. because suppression of successional processes by bracken (*Pteridium esculentum*) communities after fire (Mitchell 1985). In some cases forest never recovers, and instead of reverting, the vegetation shifts to ecosystems dominated by exotic species e.g. kikuyu dominated pastures (West 1980). Consequently, revegetation is often a critical component of ecological restoration and a method of achieving intended biodiversity outcomes (Norton & Miller 2000). Several studies have shown that revegetation has led to an increase in biodiversity, particularly of birds (Kanowski et al. 2005; Munro et al. 2008), while recent reviews of the revegetation literature in Australia found that revegetated sites supported an increase in the number and diversity of indigenous birds, invertebrates, reptiles and some marsupials (Kanowski et al. 2005; Munro et al.2008; Munro et al.2010). Generally, increasing plant diversity leads to an overall increase in biodiversity and carrying capacity (Reay & Norton 1999; Verberk et al.2006). In addition, revegetation provides ecosystem services such as water filtration, erosion control and nutrient recycling; processes which in turn lead to ecosystem resilience (Holling 1986; Daily & Ellison 2002; O'Connor 2003). However, revegetation projects are often ad-hoc, not following a systematic process or aiming for a defined goal. Choice of plant species, planting methodology, and post-planting management are all-crucial in achieving desired outcomes.

The revegetation of Tiritiri was planned in the late 1970s when there were few models for restoration of northern indigenous coastal forest (Mitchell 1985). Thus, revegetation of the island served as a working experiment that provided insight into the successes and failures of island restoration techniques, as well as unique opportunities for research and monitoring. The Tiritiri revegetation programme began in 1982 with the aim of restoring the island to its pre-European condition. It was hoped this would provide habitat for indigenous biodiversity, including nationally threatened species (Mitchell 1985; Craig 1990). With few existing revegetation projects to serve as reference sites, several options including both natural regeneration and active restoration were considered. Natural regeneration was ruled out because it was determined that succession might not occur or at least take a very long time in the dense rank grass and bracken habitats (West 1980) which dominated the island. Moreover, a key objective of the restoration initiative was to provide habitat for indigenous birds in as short a timeframe as possible. Given the above, earlier successional stages were by-passed and the aim of the revegetation programme became to plant "climax" species (Mitchell 1985; Atkinson 1990; Hawley 1997). As a result, the majority of trees planted were late successional species, e.g. kohekohe (*Dysoxylum spectabile*), rewarewa (*Knightia excelsa*), pohutukawa (*Metrosideros excelsa*) and some taraire (*Beilschmiedia tarairi*). Shrub species were interspersed to provide food for birds; a move often criticized, as many see restoration for birds and bird translocations specifically as ad hoc since it suggests that minimal thought has been given to other existing animal and plant communities (Atkinson 1990; Craig & Veitch 1990; Meurk & Blaschke 1990). Revegetation of the majority of the island was completed by 1995, with 250,000 trees and shrubs planted in total (Cashmore 1995). A portion of the northwestern end of the island was left to regenerate naturally.

Problems with some species used in the revegetation became apparent early on. Survival rates by 1995 were estimated to be as low as 37% (Cashmore 1995). The early successional species including pohutukawa, ngaio (*Myoporum laetum*), cabbage tree (*Cordyline australis*), karo (*Pittosporum crassifolium*) and taupata (*Coprosma repens*) were the most successful. Late canopy species such as kohekohe, taraire, karaka (*Corynocarpus laevigatus*), tawapou (*Planchonella costata*) and rewarewa, showed poor growth and survival, presumably because they were planted in inappropriate or suboptimal environments. Planting primary shrub species initially for revegetation shades out grass and weeds, and quickly provides shelter to foster the regeneration of canopy species (Cashmore 1995). In addition, where primary successional species are used, mistakes can be addressed in the short term, whereas those made with canopy plantings may take many years to recognise and rectify (Cashmore 1995). This aspect was particularly relevant in relation to the pohutukawa plantings on Tiritiri. Concern about salt spray led to dense plantings of pohutukawa on the east coast of the island. Seventy-thousand trees were closely planted to provide shade and shelter for future canopy species. Survival was better than expected (60–80%) resulting in a pohutukawa-dominated forest with almost no regeneration of other species. This was possibly due to low light levels coupled with poor seed dispersal by birds, as suggested by Clout and Craig (1998). In addition, in many of these areas of planted pohutukawa trees have never flowered. Pohutukawa flowers usually provide an important source of nectar between December and February (May 2000) for nectivorous birds, invertebrates and lizards (Wotherspoon 1993; Eifler 1995; Anderson 1997; Anderson 2003; Bergin & Hosking 2006). It is possible the lack of flowering is due to the poor development of the crown as a result of the high density of planting (Bergin & Hosking 2006). Consequently, successional processes via both natural regeneration and pollination are severely limited, and a gap in food resources exists for a range of nectivorous fauna.

The purpose of this study was to quantify aspects of biodiversity in revegetated habitats on Tiritiri to determine whether differences exist and to examine the causes of those differences. Specifically, we examined whether aspects of indigenous vegetation communities (plant species richness, relative abundance and regeneration dynamics), and richness and relative conspicuousness of indigenous bird communities, differed among various revegetated habitats. These included a) dense single-species pohutukawa plantings, b) thinned pohutukawa (where pohutukawa had been thinned to create light gaps), and c) mixed species plantings with minimal pohutukawa.

Little is known about regeneration and plant species diversity in pohutukawa forest and almost nothing is known about successional pathways in planted pohutukawa. It was expected that areas planted in only pohutukawa would exhibit little evidence of succession and have low bird use compared with thinned pohutukawa areas and mixed species plantings. Thinning planted pohutukawa was expected to increase biodiversity, as diversity in natural systems is often facilitated by disturbance (Ogden et al. 1997; Hardy 2002; Esler 2006). The findings of this study have implications for the future management of the dense pohutukawa stands on Tiritiri Matangi and they will also be useful in the wider context for restoration managers elsewhere. The results of this study also demonstrate to conservation managers the risks associated with planting strategies. Some plantings may require substantial management in the future, thus resulting in additional costs to stakeholders involved in such projects.

Methods

Study area

Tiritiri Matangi lies 3.5 km off the Whangaparaoa Peninsula north of Auckland (Mitchell 1985). The island is classified as a Scientific Reserve under the Reserves Act 1977. It is owned by the Crown and administered by the Department of Conservation (Tiritiri Matangi Working Plan Hawley 1997). The 220-ha island rises to 80 m asl (Cashmore 1995), the main north-south ridge has numerous secondary ridges which slope gently to the coast on either side. (Mitchell 1985). The east coast of the island is rocky with steep cliffs, whereas the western side has several sandy beaches. Tiritiri Matangi is composed of greywacke overlain with soils derived from the upper strata Waitemata Series silty-sandstones and siltstones. These soils are free draining and of quite high natural fertility (Mitchell 1985; Cashmore 1995). The temperature is generally mild throughout the year and the island has a moderate rainfall, although summer droughts can occur (Mitchell 1985). The island's history of farming until 1971 led to much of the forest cover being removed (Mitchell 1985; Anderson 1997). In 1975, grassland covered 52% of the island, fernland and bracken 27%, with the remainder in regenerating forest and scrub. Broadleaf coastal forest survived in several gullies along with a fringe of coastal pohutukawa, mature in places. In total, 339 vascular plant species and varieties have been recorded, 186 of them natives (Esler 1978). Before restoration began, at least 30 species of bird (19 native and 11 exotic) were breeding on the island (West 1980). A number of seabirds were also regular visitors (Mitchell 1985), and grey face petrels *(Pterodroma macroptera)* were breeding on the south side of the island. The only introduced predatory mammal present on Tiritiri Matangi was the Pacific rat (*Rattus exulans*) since eradicated in 1993 (Rimmer 2004).

Site selection

Three main vegetation types were selected for the study; dense pohutukawa, mixed-species vegetation and thinned pohutukawa. Dense pohutukawa and mixed vegetation sites were selected for vegetation type, vegetation age, size, topography and aspect. The choice of thinned pohutukawa sites was already determined, as thinning had been carried out before this study began. At these sites densely planted 20-year old pohutukawa stands had been selectively thinned by Department of Conservation staff three years previously. Where possible, sites were chosen with a north-easterly or easterly aspect, on slopes varying from 5° to 9°. The locations of the study sites are shown in Figure 1. All of the study sites were located on the east coast of the island in either the Emergency Landing or Fisherman's Bay areas. The thinned sites were areas where some pohutukawa trees had been removed from densely-planted stands, creating light gaps. The criteria for the selection as dense pohutukawa sites were that they must be areas where pohutukawa existed as a monoculture with few, or no other planted species. Mixed vegetation sites were selected based on their greater diversity of planted species. Nine sites were selected overall, three in each vegetation type.

Data collection

Vegetation sampling

<u>Point-Centered-Quarter method</u>

Two vegetation sampling methods were used in this study, the Point-Centered-Quarter (PCQ) technique and Sampling at Known Intersects Along a Transect. The PCQ technique is

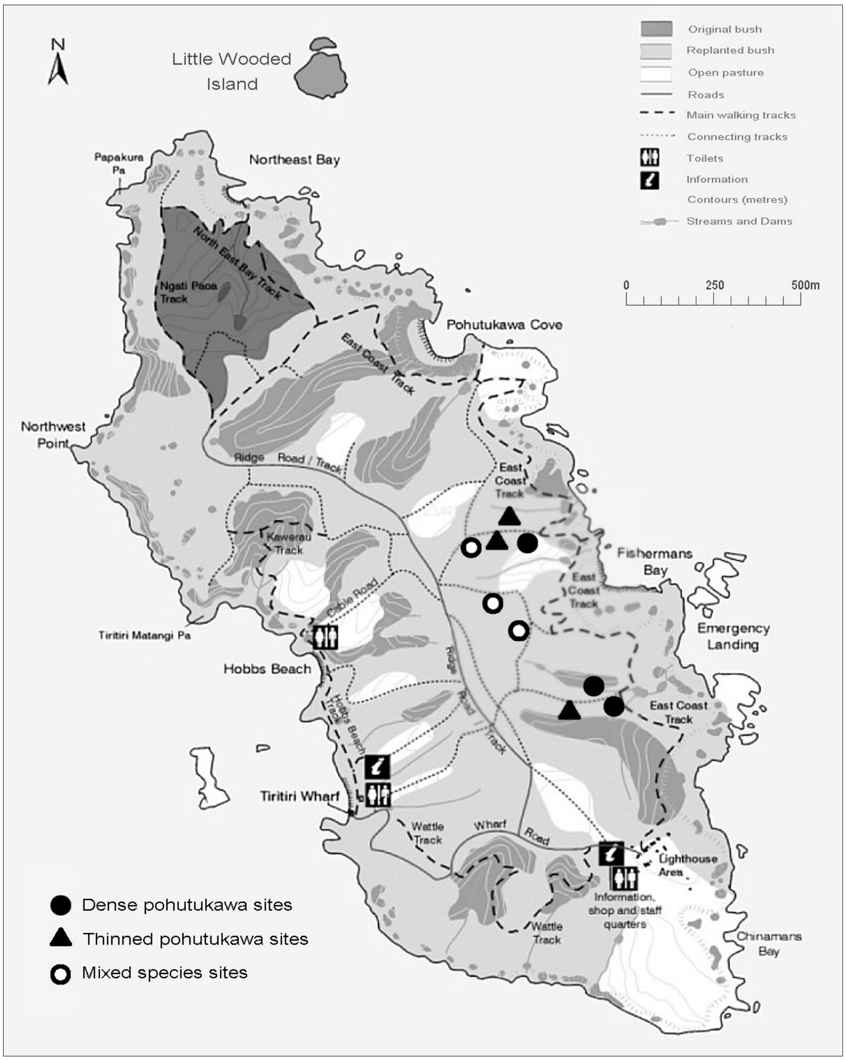

Figure 1. Location of study sites on Tiritiri Matangi Island. (Base map sourced from the Department of Conservation 2006.)

used to assess vegetation composition and structure across the landscape and follows that described by Cottam & Curtis (1956). The PCQ is a plot-less sampling method which usually does not involve the use of a specified area such as a quadrat (Mark & Esler 1970; Causton 1988). Instead, it involves individual sampling points, located along transect lines. At each sampling point the area around that point is divided into quarters. In each quarter, the distance from the point to the nearest tree with diameter at breast height (dbh) > 5 cm, is recorded. The individual tree's size (dbh) and species is also recorded. The distance measurement provides an estimate of density. To determine patterns of regeneration, the vascular flora within a radius of 1m is recorded. As pohutukawa can be multi-stemmed near the ground, diameter measurements were taken just above ground level to provide consistency (see Clarke 2002). Canopy cover (%) and canopy height (m) were also estimated. At each of the nine sampling sites a total of four PCQs were taken, at 20-m intervals along a 60-m transect, the first at 0 m. The gap of 20 m was chosen to avoid any overlap in sampling. Transect placement was influenced by topography, slope and aspect, as we wanted these three variables to remain consistent across sites.

The PCQ method is the most widely used of the original distance methods (Causton 1988; Bryant et al. 2004). Compared with other vegetation community analysis methods, PCQ has been criticized for its biases, particularly in estimating vegetation species richness (Risser & Zedler 1968; Korb et al. 2003; Bryant et al. 2004). However, it is still accepted as an efficient and robust technique when used appropriately (Lindsey et al. 1958; Causton 1988; Brady et al. 1995; White et al. 2008; Perry et al.2010).

Sampling along a transect

To better understand regeneration between sites, we employed a second method. It also involved sampling at known intervals along a transect (Kershaw & Looney 1985). Seedling presence or absence within a 10-cm radius of a point was recorded, with points at 1-m intervals along the same 60-m transect used in the PCQ method. This method gives a clear indication of vegetation change along an environmental gradient (Kershaw & Looney 1985). This is particularly important in non-uniform sites, such as thinned pohutukawa, where changes in regeneration patterns may be patchy.

Bird counts

A five-minute count method similar to that described by Dawson & Bull (1975) was used to determine bird conspicuousness at each of the nine sites. Two sampling points were established along transects within each study site. The first point was 5 m from the beginning of the transect, the second point 5m from the end of the transect. The sampling area was within a 20-m radius of each point, with a gap of 10 m left between the two sampling areas to minimize duplication of sightings. A radius of 20 m was chosen to ensure that most birds within the type of forest being surveyed would be detected. Some sites were in low, dense scrubland, with visibility beyond 20 m difficult. The observer waited for one minute after arrival at the sampling point before starting the count (Reynolds et al. 1980), to minimize the effects of disturbance caused by the observer's arrival at the count site. Each count site was sampled twice daily in random order for three consecutive days. Sampling was carried out in hours of dawn and dusk (actual times varied during the year). This was repeated each month for five months from April to August. In total, 24 counts were carried out at each study site providing a total of 72 sets of data for each vegetation type. Methods were designed to minimize any biases that may have been introduced due to the time of day or peaks in bird activity (Dawson 1981; Alexander et al. 2007). The April to August period was chosen as the best period for sampling (Elliott 1998) as this is outside the mating and nesting season when bird conspicuousness varies. As observers differ in their ability to see, hear and identify birds (Dawson & Bull 1975), all counts were carried out by the authors. Bird conspicuousness rather than abundance was chosen as the term to describe the five-minute counts in this study because, as with most bird counting methods, five-minute counts do not necessarily detect all birds that may be presenting in the count area (Gibb 1996).

There are many different methods of investigating bird abundance and species composition (Dawson & Bull 1975; Scott et al. 1981; Pyke 1983; Ralph et al. 1993). Since this study only required a relative estimate of bird conspicuousness to compare between treatments the five minute method was deemed most appropriate. The aim of the bird counts was to estimate bird conspicuousness in the three vegetation types to determine whether densely planted pohutukawa was less favored habitat. Five-minute bird counts, which are quick and easily repeatable, have been used in many studies to estimate relative abundance (Clout & Gaze 1984; Ralph et al. 1993; Elliott 1998 Alexander et al. 2007). Since only a small sampling radius (20 m) was used in the counts, distance estimation (Scott et al. 1981) was unnecessary.

Analysis

Vegetation

To quantify habitat characteristics of each vegetation type, we calculated the relative density (number of individuals of a species / total number of individuals), relative dominance of all tree species (mean basal area x density of tree species), and absolute density (all species combined) of all vegetation types (see Causton 1988). The data were not normally distributed so non-parametric tests were used to test for differences between the three vegetation types. The Kruskal-Wallis test was used to test for differences in canopy height, canopy cover, sub-canopy/sapling cover and seedling cover. For indicators that showed significant differences among vegetation types, we used Mann-Whitney U tests to test for pairwise comparisons between vegetation types. Where Kruskal-Wallis tests did not detect significant differences between groups, mean and standard error values were calculated and graphed to show any significant differences between means (McArdle 1987).

Birds

Indigenous bird conspicuousness and species richness data were pooled across months and sites for comparison. Because of the small sample size (i.e. small number of site replicates), and non-normal distribution of the data, mean and standard error values were calculated and graphed to show any significant differences between means (McArdle 1987).

Results

Vegetation composition

Forest characteristics

Vegetation richness and composition differed among sites (Fig. 2). Dense pohutukawa sites had low species richness, whereas thinned pohutukawa and mixed species plantings had higher but similar species richness. Mixed plantings and thinned pohutukawa areas had similar densities.

Pohutukawa was the dominant tree species in dense and thinned pohutukawa sites (Fig. 3). Pohutukawa was also the dominant species in the mixed species sites as indicated by basal area. As relative dominance is a direct result of basal area, it essentially calculates the absolute area covered by each tree species. As a result, the proportion contributed by each tree species differs between relative density and relative dominance. This is particularly clear in mixed plantings. Absolute density of canopy trees was highest in dense pohutukawa plantings (Fig. 4).

There were clear differences in canopy cover between vegetation types (Table 1). Percent canopy cover in dense pohutukawa plantings was significantly higher compared with both thinned and mixed plantings (Kruskal-Wallis and Mann-Whitney *U* non-parametric two-tailed tests, $P < 0.05$). Canopy height, and sub-canopy/sapling cover between vegetation types showed no significant differences (Kruskal-Wallis non-parametric two-tailed tests, $P < 0.05$).

Overall, the densely planted pohutukawa sites had the highest values for pohutukawa contribution (95%) and canopy cover (85%), and the lowest values for sub-canopy/sapling (12.5%) and seedling cover (1.8%). Conversely, mixed vegetation sites had low values in pohutukawa density (19%) and canopy cover (56%) and higher values for sub-canopy/sapling (25%) and seedling cover (11%). Thinned pohutukawa sites had lower values for pohutukawa density (82%) and canopy cover (56%) than dense sites. Seedling percent cover in thinned pohutukawa was the highest of all three sites (13%). This percentage was slightly higher than that recorded for mixed vegetation.

Regeneration

Dense pohutukawa had lower numbers of seedlings compared with the other two vegetation types, which had similar numbers of seedlings. These differences in seedling occurrence between both dense and thinned sites, and dense and mixed sites, were significant (Kruskal-Wallis and Mann-Whitney *U* non-parametric two-tailed tests, $P < 0.05$) (Table 2). Dense pohutukawa sites showed much lower frequency of seedling occurrence along each transect at two out of the three sites, compared with other vegetation types, with seedlings present at only 1 and 2 points respectively of the 60 points sampled (Fig. 6). The highest frequency of seedlings was at one of the mixed species sites (22 of 60 points sampled). Both thinned and mixed sites showed a higher occurrence of seedlings than dense pohutukawa in two out of three sites. Seedling numbers in thinned sites were only slightly lower than in mixed sites.

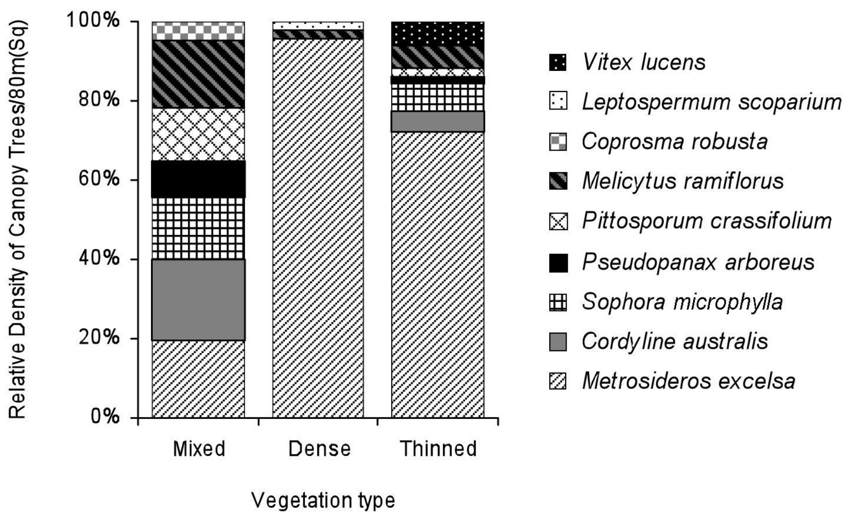

Figure 2. Relative density (No. of individuals of each species/total number of species) of canopy trees in each of the three vegetation types (where "mixed" is mixed planted vegetation, "dense" is densely planted pohutukawa, and "thinned" is thinned pohutukawa) on Tiritiri Matangi Island, determined using the point-centered-quarter method.

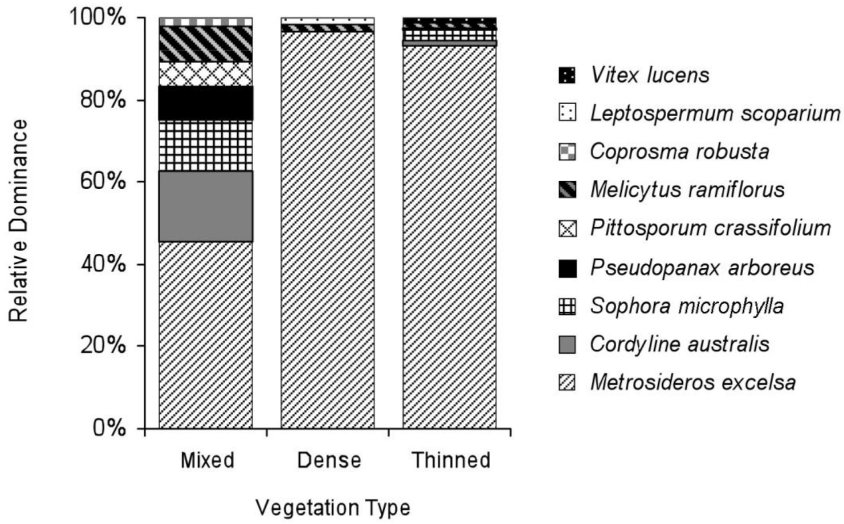

Figure 3. Relative dominance (mean basal area x density of tree species) of each canopy tree species in the three vegetation types (as in Fig. 2).

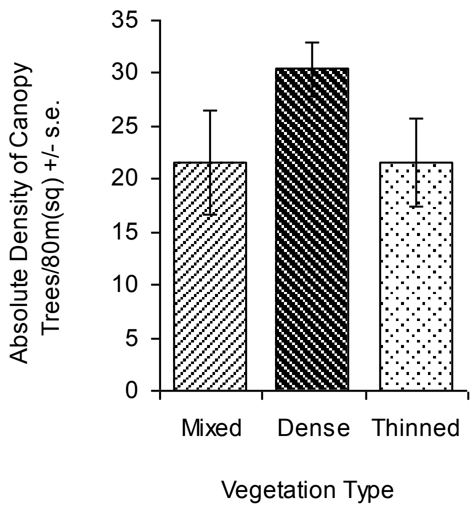

Figure 4. Absolute density of canopy trees in the three vegetation types (as in Fig. 2).

Table 1. Differences in canopy cover between forest types (where “mixed” is mixed species planted vegetation, “dense” is densely planted pohutukawa, and “thinned” is thinned pohutukawa) as determined by Mann-Whitney *U* non-parametric t-test (two-tailed) ($P < 0.05$). Significant *P*-values denoted with *.

Canopy cover	Mann-Whitney *U* statistic	*P*-value
Dense vs mixed	34.5	*0.033
Thinned vs dense	34.5	*0.032
Thinned vs mixed	71.5	1.0

Table 2. Differences in seedling numbers between forest types (where “mixed” is mixed species planted vegetation, “dense” is densely planted pohutukawa, and “thinned” is thinned pohutukawa) determined by Mann-Whitney *U* non-parametric t-test (two-tailed) ($P < 0.05$). Significant *P*-values denoted with *.

Seedling cover	Mann-Whitney *U* statistic	*P*-value
Dense vs mixed	31	*0.019
Thinned vs dense	37	*0.045
Thinned vs mixed	70.5	0.953

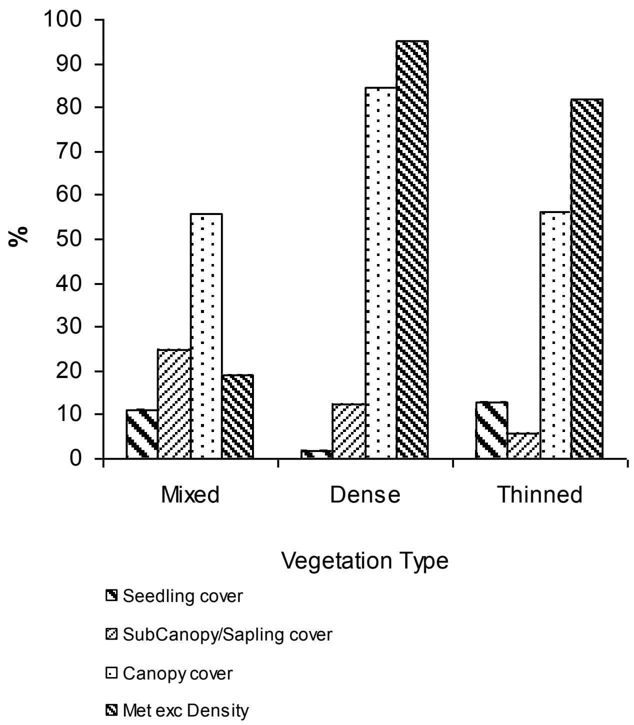

Figure 5. Forest characteristics in the three vegetation types (as in Fig. 1).

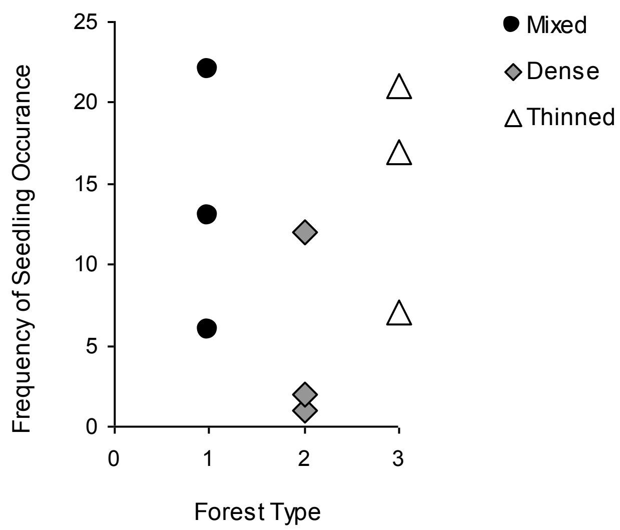

Figure 6. Frequency of seedling occurrence at three sites along a 60-m transect in three vegetation types (where “mixed” is mixed species planted vegetation, “dense” is densely planted pohutukawa, and “thinned” is thinned pohutukawa) on Tiritiri Matangi Island.

Bird conspicuousness and species richness

Relative conspicuousness of indigenous birds differed among the three vegetation types (Fig. 7.) Indigenous birds were less abundant in dense pohutukawa and numbers were significantly lower than in the other two vegetation types. Bird numbers were highest in the mixed plantings. Indigenous bird species richness (McArdle 1987) was significantly lower in dense pohutukawa sites compared with the other two vegetation types. There were no apparent differences in bird species richness between the mixed plantings and thinned pohutukawa sites.

Discussion

The structure, diversity and species occupation of revegetated habitats can be influenced by the composition and density of initial plantings. In this study, we found that tree species

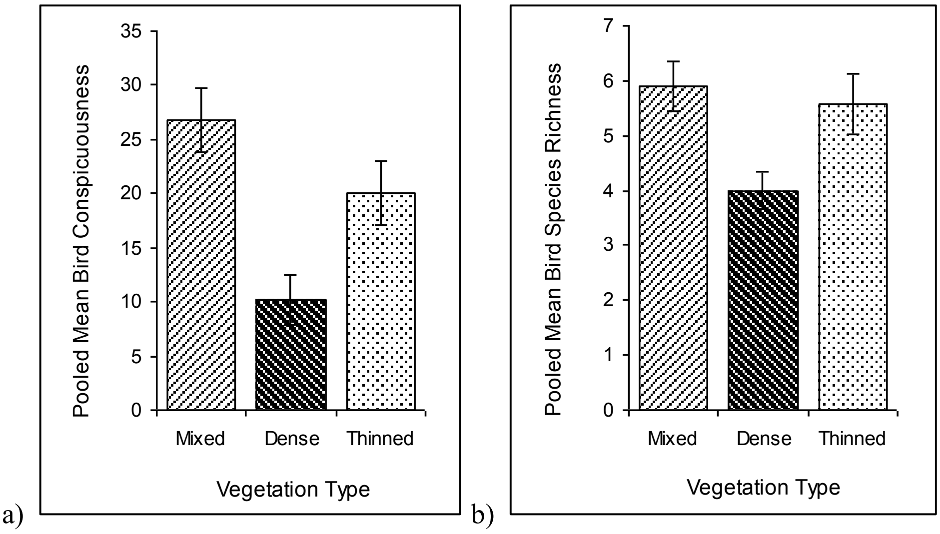

Figure 7. a) Pooled mean indigenous bird conspicuousness, and b) Pooled mean indigenous bird species richness in three forest types (Dense = Dense pohutukawa plantings, Thinned = Thinned pohutukawa plantings, Mixed = Mixed species plantings) on Tiritiri Matangi Island.

richness and the amount of regeneration were greater in both thinned and mixed sites than in dense pohutukawa sites. Moreover, dense pohutukawa appeared to suppress the establishment of other plant species and presumably failed to attract a wide range of bird species. Two attributes, low species diversity and poor regeneration in densely planted pohutukawa stands are most likely to be the result of a combination of factors including tree density, low light levels, and leaf litter density (Atkinson 2004). In addition, in the case of Tiritiri Matangi, these attributes have resulted from large areas of single species plantings (Clout & Craig 1998). Our results are in accordance with other studies that show that highest seedling survival occurs under widely-spaced trees and in light gaps, and declines with closer spacings and low light intensities (Brokaw & Busing 2000; Mason et al. 2004).

There was lower bird conspicuousness and fewer species in the dense pohutukawa stands compared with thinned or mixed sites. This finding supports several previous studies of bird numbers in regenerating forest areas (Parker et al. 1994; Robertson & Hackwell 1995) which found that birds preferred habitats with higher plant diversity and lower stem density. Other similar studies have found that bird visitation rates are higher on forest edges and in gaps compared with the forest interior (Montgomery et al. 2003; Burgess et al. 2005). This may be because flowers are more visible and accessible for nectivorous species. For similar reasons, Vitz and Rodewald (2006) concluded that regenerating clear cuts provided important benefits for frugivorous birds. Thinning the pohutukawa monocultures did appear to increase diversity. This reflects similar studies on regeneration in monoculture forests at different light intensities; research by Ogden et al. (1997) and Brockerhoff et al. (2003) indicated that an increase in light and tree spacing led to a more diverse understorey. Other research on thinned plantations found that thinning facilitated diversity, regeneration and succession (Mason et al. 2004; Cummings et al. 2007). Cummings et al. (2007) found that thinning could initiate succession. Factors known to positively influence plant species abundance and diversity include light-creating disturbances such as tree mortality, and edge creation (Hardy 2002).

Results of this study support previous findings that revegetation using a diverse range of species is more likely to result in a more diverse ecosystem. In contrast, monoculture plantings, particularly when planted densely, may have the opposite effect. However, using diversity as a measure of successful revegetation may not fit with all project goals or may exclude other important but simpler ecosystems types. Bergin and Hosking (2006) suggest that pohutukawa-dominated habitats are sufficiently distinct to be considered a specific habitat type, and therefore may contribute positively to the overall biodiversity of a given area. For instance, nectivorous birds feed seasonally on pohutukawa nectar, and insects can be abundant on the bark, rotten wood and foliage, attracting a range of indigenous insectivorous birds. However, observations by the Island's DOC staff and volunteers suggest that the planted pohutukawa surveyed in this study are still yet to flower, > 20 years after planting. This may be causing a gap in food availability for some fauna (Craig et al. 1981; Stewart & Craig 1985; Abbott 1998; Wotherspoon 1993). Bellbird (*Anthornis melanura*), tui (*Prosthemadera novaeseelandiae*) and kereru (*Hemiphaga novaeseelandiae*) are all key species in forest regeneration due to their roles as pollinators and seed dispersers (Castro & Robertson 1997; Anderson 2003; Atkinson 2004). These birds also move seed into plantings, enhancing the overall restoration process (Reay & Norton 1999; Jansen 2005). The dense stands of non-flowering pohutukawa on Tiritiri Matangi probably have limited value for nectivorous or frugivorous birds, or pollinating invertebrates. The absence of these species from dense pohutukawa forest on Tiritiri may mean regeneration processes within these planted areas is slowed.

Weed suppression is commonly a goal of revegetation (Stanley 2009) and in such circumstances establishing canopy cover is a priority. Pohutukawa on Tiritiri Matangi was planted as it could withstand harsh coastal conditions, shade out dense grass areas, and provide canopy cover for regeneration; the first two of which were successfully achieved. Manuka and kanuka-dominated revegetation projects are commonly used for the same reason and in mainland situations they often mimic natural successional processes. There, diversity may be the long-term goal but allowing natural sucession to take place is the priority. That may mean lower diversity initially; however, there are threatened species that rely on these scrub habitats, (so they should not be regarded as low value habitats). Threatened species found in scrub include the Auckland green gecko (*Naultinus elegans*) and green mistletoe (*Ileostylus micranthus*). Similarly, dense pohutukawa plantings on Tiritiri

Matangi are of low diversity but high habitat value; they provide habitat for the little spotted kiwi, and these places offer easy viewing by visiting public because of the lack of understorey.

Manipulating pohutukawa plantings would help to raise landscape heterogeneity, which generally leads to a high species diversity (Ogden et al. 1997; Verberk et al. 2006) as different habitats provide for specialist species. However, while thinning of pohutukawa throughout the island would increase vegetation diversity, it might also result in negative effects on other values. Regardless of future pohutukawa management choices, the experimental approaches to revegetation on Tiritiri Matangi have, and will continue to, provide important opportunities for monitoring and research.

Conclusions

The revegetation of Tiritiri was carried out in the absence of a successful template and much of the planting was experimental. Ecosystems are dynamic and complex, with multiple components interacting through a variety of processes (Hobbs 1998). This makes ecological restoration exceptionally complicated because of the need to rebuild lost, possibly complex processes and trophic interactions (Manning et al. 2006). The restoration of Tiritiri has been very successful in its goal of providing habitat for threatened species and the island has become an international icon for ecological restoration. However, the results of this study suggest that the island's ability to return to a more diverse and functioning ecosystem may be inhibited by large areas of densely-planted pohutukawa. Our study indicates that thinning of pohutukawa has been beneficial, resulting in the development of a more abundant and species-rich flora and fauna. However the requirements of some fauna, such as little spotted kiwi, are also as important (but these were not addressed in our study).

Our results support predictions that dense pohutukawa plantings on Tiritiri Matangi would inhibit forest regeneration and the restoration of plant species diversity and habitat for indigenous birds. The limited number of thinned sites, their ad-hoc placement, and the minimal time between treatment and data collection placed some limitations on this study. Further studies with longer timeframes post-treatment and/or a larger data set would clearly be useful to monitor ongoing trends in regeneration on the island. Studies are also needed on how various fauna species use different vegetation types. It also needs to be recognized that Tiritiri Matangi is a community-based restoration project. The aspirations and values of stakeholders have been important in this restoration project and have influenced the ecological outcomes of the island. Given this, data were collected on Tiritiri Matangi stakeholder values as part of this study; those findings are reported separately (Forbes 2007).

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