Sand dune restoration in New Zealand:

Methods, Motives, and Monitoring

Figure one: Pet cat looking out over restored dunes at Eastbourne. Photo taken by author November 2008.

Samantha Lee Jamieson

A thesis submitted for the partial fulfilment for the degree of

Master of Science in Ecological Restoration

Victoria University of Wellington

School of Biological Sciences

2010

ABSTRACT

Sand dunes are critically endangered ecosystems, supporting a wide variety of specialist native flora and fauna. They have declined significantly in the past century, due to coastal development, exotic invasions, and stabilization using marram grass (*Ammophilia arenaria*). An increasing number of restoration groups have carried out small scale rehabilitations of using native sand binding plants spinifex (*Spinifex sericeus*) and pingao (*Desmoschoenus spiralis*). However like many other restoration ventures, efforts are not formally monitored, despite the potential for conservation of species in decline. This thesis seeks to investigate the social and ecological aspects of sand dune restoration in New Zealand.

Firstly, the status of restoration in New Zealand was examined using web based surveys of dune restoration groups, identifying motivations, methods, and the use of monitoring in the restoration process. Secondly, the ecology of restored and marram dominated sand dunes was assessed. Vegetation surveys were conducted using transects of the width and length of dunes, measuring community composition. Invertebrates were caught using pitfall traps and sweep netting, sorted to order, and spiders, beetles and ants identified down to Recognizable Taxonomic Units (RTUs) or species where possible. Lizards were caught in pitfall traps, and tracking tunnels tracked the presence of small mammals in the dunes. Analysis of each variable involved the comparison of biodiversity data between restored and marram dominated dunes, at six sites across the Wellington region.

The survey of dune restoration practitioners confirmed that restoration was generally based on the motivation of erosion protection and foreshore stabilization, however an increasing number of groups were interested in the conservation of flora. Conservation of fauna was a priority for only one of the respondents. Informal monitoring of restoration attempts was carried out by the majority of groups, but specific biodiversity monitoring or monitoring using systematic scientific methods was carried by only a small proportion of groups. Re-vegetation of dunes commonly used a small suite of native sand binding species mostly pingao and spinifex. Species in decline such as sand tussock (*Austrofestuca littoralis*) and sand daphne (*Pimelia arenaria*) were only planted at a small proportion of sites. Restoration of dune ecosystems has the potential to not only enhance erosion protection and sand stabilization mechanisms, but to benefit native flora and fauna endemic to sand dunes. Identifying biological change and carrying out biodiversity monitoring may be beneficial in maximizing the ecological effectiveness of restoration attempts.

Marram dunes contained higher foliage cover, vegetation height and vegetation species diversity than restored dunes. Abundance and diversity of beetle, spider, and ant families were higher in marram dominated dunes. Estimated population size of common skink (*O. nigraplantare polychroma*) and mouse population density was also higher in marram dunes. These results were positively correlated with the percentage of vegetation foliage cover and vegetation species diversity, suggesting that the habitat conditions created by marram grass were favored by fauna.

These results suggest that for maximum biodiversity gains, future dune restoration attempts should increase vegetation cover, and include a wider range of plant species. Species in decline known to be important for fauna, such as pohuehue (*Muehlenbeckia spp.),* sand pimelia, and sand coprosma (*Coprosma acerosa*) should also be included for reciprocal benefits for conservation of flora and fauna. Marram grass could also be incorporated into restoration, as its mass removal may have considerable consequences for fauna using it as a refuge, and it appears to provide desirable habitat for fauna.

ACKNOWLEDGEMENTS

Thanks and aroha to...

My supervisors, Dr Stephen Hartley for having all the answers, for helping me understand statistics like I never thought I could and for coming in on his holidays to help me finish up; and Dr Murray Williams for inspiring me with his incessant wisdom, and making me keep going, even when I really didn't think I could.

Dr Nicky Nelson and Halema Jamieson for advice on reptile matters, and Sean Crossland and Susie Cooper the skink catching experts. Robyn Smith of Greater Wellington Regional Council and the Trustees of the Dune Restoration Trust especially Dave Bergin, Graeme Lacock, Gregg Jenks, and Natalie the secretary.

Lesley Milicich – SBS technician for helping sort what seemed like a million samples to order.

From Lincoln University, Dr Hannah Buckley for helping organise my trip to Christchurch, and for coordinating my insect identification team: Nathan for the lesson in the art of pinning insects, Mathilde for sorting through the samples and Jagoba the spider expert. Also Dr John Marris – curator of the Lincoln entomology museum for his patience identifying the beetles. Habteab Habtom for helping identify the ants.

Greater Wellington Regional Council, Wellington Botanical Society and the Wellington Branch of the Federation of Graduate Women for their financial support. New Zealand Ecological Society and the Centre for Biodiversity and Restoration Ecology for funding my attendance at the International Ecology Congress in Brisbane 2009 to present my work.

Kevin Reynolds, John Conly, and Warwick Allen for being wonderful field assistants.

My parents Elaine and Paul Jamieson their financial and moral support, and for putting up with my moodiness and making sure I wasn't having a nap went I was meant to be writing.

Shane, for asserting my nerd status, and for his support, interest and love even when I was grumpy and tired.

My brother Matt, Hannah, Danni, Rose, my boss Alison and my wonderful and talented colleagues at Vic for always being supportive and interested in what I was doing.

And finally, thank you to the wonderful individuals who tirelessly work to restore our precious sand dune ecosystems.

TABLE OF CONTENTS

Appendices

LIST OF FIGURES

LIST OF TABLES

Chapter one

The degradation of sand dunes in New Zealand; Ecological Restoration as a panacea

Figure 1.1: lone female spinifex (*Spinifex sericeus*) seed head on beach.

Photograph taken by the author, Paraparaumu beach 2008.

1.1 Research context

This thesis aims to assess the practice of dune restoration in New Zealand and measure biodiversity gains that come with restoration. It will do so by; (i) identifying the motivations behind community groups conducting small scale dune re-plantings, and the support and knowledge required for them to achieve their goals; and (ii) comparing the floral and faunal biodiversity of sand dunes replanted with native sand binding species against dunes dominated by exotic marram grass (*Ammophila arenaria*).

This study arises within a context of ignorance and necessity. Coastal dunes are one of New Zealand's most critically endangered environments. Ignorantly, they are also the most poorly studied. Restoration seeks to fill the void for a necessary resolution to humankind's widespread detriment and modification of these fragile and unique systems. Restoration of dunes is becoming increasingly widespread, and has the potential to conserve that native flora and fauna that are restricted to the dynamic environment that buffers the land from the sea.

1.2 The decline of dunes

Dune areas in New Zealand have undergone a phenomenal decline since the arrival of humans (Hesp 2001). Prior to the 1900's, dunes were burned by the indigenous Māori people to facilitate the growth of bracken fern (*Pteridium esculentum*) for food, and dune forests cleared for timber (Hesp 2001). When European colonists arrived, large areas of dunes were leased from the Māori for stock grazing; rabbits and deer were introduced, and further dune areas were burned. The widespread loss of vegetation cover meant large areas of unstable shifting sand resulted, threatening to engulf farmland and infrastructure (Hilton et al. 2000). Marram grass was introduced to New Zealand after early studies by botanist Leonard Cockayne (1909; 1911) recommended that it be planted to stabilise the shifting sand, and to develop pasture and farmland. Large scale planting began in 1911, and forestry plantations of radiata pine (*Pinus radiata*) followed in many newly stabilised areas (Given 1981; Gadgil 1998; Hilton et al. 2000). Even without the aid of intentional planting, marram has now succeeded in invading the majority of natural dune areas, displacing native sand binding plants (Partridge 1995), and significantly altering natural character (Hilton et al. 2000).

Figure 1.2 Hand planting marram grass on the Aupouri Peninsula in 1973. Image courtesy of Ministry of Culture & Heritage (2005).

Population growth in coastal areas places additional pressure on the already highly modified dune environment. Driving and walking over the dunes cause detriment to the fragile dune plants and potentially increases sand erosion (Given 1981; Milne & Sawyer 2002). Under threat from multiple degrading factors, dunes now occupy less than 30% of their original area, and the remaining areas are highly modified (Hilton et al. 2000). Dunes dominated by native vegetation are rare (Given 1981; Sykes & Wilson 1991), now classified as critically endangered ecosystems (Sawyer 2004; Hilton 2006). Conservation and restoration of these significant areas is vital for the continued existence of the unique plants and animals that inhabit them.

The remaining dunes support a range of rare and specialised flora and fauna, many significant to Māori. Pīngao (golden sand sedge, pikao, *Desmoschoenus spiralis*) and spinifex (silvery sand grass, kowhangatara, *Spinifex sericeus*) are still used extensively for weaving (Bergin & Kimberly 1999) (figure 1.3). To the indigenous Māori people, the pīngao plant is highly sacred, as it prevents the erosion that implicates the survival of the sacred and increasingly rare Toheroa shellfish (*Paphies ventricosa*) (Beentjes et al. 2006) and provides habitat to the katipō spider (translates as 'night stinger') (Patrick 2002). New Zealanders have a particular affinity to the coast; beaches being popular for recreation (figure 1.4) and development and containing historical significance (Miller & Paul

Figure 1.3: Elder teaching student how to weave pingao. Photograph by the author March 2008.

2007). The beach is also a desirable place to live, with a large proportion of New Zealanders living within 10km of the coast (Hesp 2000; Spence et al. 2007). Dunes and beaches are of high importance to many New Zealanders, which makes their conservation even more of a priority.

Figure 1.4. Restored dunes at Mount Maunganui, Bay of Plenty are well fenced to prevent people walking or driving on the fragile plants. Photograph by the author (December 2009)

Not only are they important for cultural and recreational reasons, coastal dunes provide a protective barrier between the land and the sea (Carter 1991; Dahm et al. 2005). There are a range of different types of dunes, dependant on vegetation cover, wind conditions and sand supply. Native fore dune plants, known as sand binders and sand trappers, assist dune stabilisation by either trapping sand in their roots and vegetation, or extending many branching stems or rhizomes across the sand, anchored by long roots (Given 1981). Dunes created by native species such as pīngao and spinifex tend to create lower, gently sloping dunes that are able to accrete sand following an erosion event (Esler 1970), while dunes created by marram grass tend to be taller with a steep fore dune (Hilton et al. 2005) (See figure 1.5) .

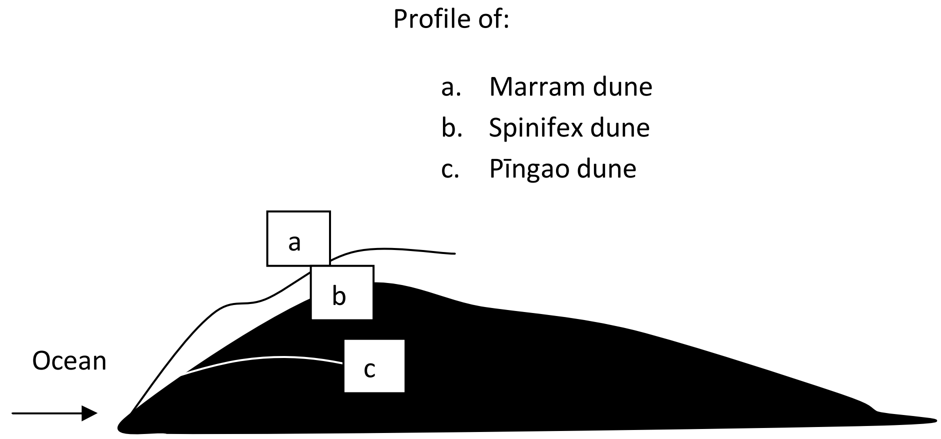

Figure 1.5 Profiles of fore dune formed by marram (a), spinifex (b), and pīngao (c). Adapted from Esler (1970).

With current predictions of sea level rise between 0.18-0.59m by 2090 (Niwa 2008), dunes have an important role to play in protection of our coastal areas (Dahm et al. 2005; Spence et al. 2007). Increased storm events are also forecast; with increased coastal erosion events likely (Niwa 2008). Therefore, the purpose of dune restoration using sand binding plants is often for erosion protection and stabilisation of sand. Vegetation cover on dunes is the most effective way to ensure the land behind is protected from storm surges and wave action, and sand binding vegetation ensures the dune is repaired between storm events (Dahm et al. 2005). Use of rock walls on the coast is an expensive way of protecting property resulting in the loss of natural beach character

(Dahm et al. 2005), and coastal hazard mitigation using vegetation is most desirable in the face of climate change.

1.2.1 Sand dune biodiversity

Compared to many other countries, New Zealand's knowledge of coastal dune ecology and biodiversity is lacking. In a review of the international coastal dune literature, Bonte & Hoffman (2005) observed that the majority of published studies on the effects of management on biodiversity were from Europe, North America and South Africa. Studies in Asia and Australasia were rare, and no studies from New Zealand were mentioned. Studies in the literature on New Zealand sand dunes are limited to vegetation, particularly the role of marram grass, dune geomorphology and a small number of studies on charismatic lizards and invertebrates.

The ecology of native sand dune vegetation has been described by a number of studies. Inventories have mapped the decline of dunes at a national scale (Hilton et al. 2000; Hilton 2006), and identified areas of conservation priority based on native vegetation biodiversity (for example; The Sand dune and Beach Vegetation Inventory of New Zealand: Johnson 1992; Partridge 1992). Extensive surveys have been conducted as part of the Protected Natural Area Program (PNAP), but have only been carried out at a few sites (for example; Ravine 1992). A number of studies have assessed the composition of sand dune vegetation using one particular system as an example; Manawatu, (Esler 1970); Whatipu Beach, Manakau Harbour (Pegman & Rapson 2005); Cole Creek, West Coast South Island (Sykes & Wilson 1991); and Ocean Beach, Hawkes Bay (Walls 1998). At a regional scale, work by the Department of

Conservation (DOC) in Wellington for example (Milne & Sawyer 2002) has surveyed the distribution of five key sand dune plant species, offering recommendations for protection of key sites. Unfortunately, there still remains a lack of a comprehensive monitoring programme for the conservation and protection of native plants in the few dune areas that remain (Lee et al. 2005).

Aside from research into flagship species (e.g. katipō), dune fauna are poorly represented in the published literature. Furthermore, the majority of sand dune research and management documents are based on the assumption that construction of habitat will result in the return of fauna. The conservation status and distributions of many native animal species endemic to dunes is unknown. In what follows, the current knowledge of dune biodiversity is discussed.

1.2.1.1. Sand dune flora

Cockayne (1909; 1911; 1967) described a diverse array of coastal plants when he first began to survey dunes in the late 1800s. Only small pockets of these native systems remain. Native New Zealand plants including pīngao, spinifex, sand tussock (*Austrofestuca littoralis*), shore bind weed (*Calystegia soldonella)*, and sand sedge (*Carex pumila)* (Sykes & Wilson 1991), are specialised for growth in the exposed fore dune. Fore dune plants are well adapted to the dynamic environment, tolerating high temperatures, low moisture conditions, salt spray and burial by sand (Esler 1970). These factors limit growth of most other plants and result in zonation of vegetation from the front to the back of the dune system (Sykes & Wilson 1991).

Shore spurge (*Euphorbia glauca)*, sand daphne (*Pimelia arenaria),* creeping pohuehue *(Muehlenbeckia* axillaris), pohuehue (*Muehlenbeckia complexa*), sand coprosma (*Coprosma acerosa),* and mingimingi *(Coprosma propinqua)* are specialised in the mid dune area (Cockayne 1967; Given 1981). Dune slacks, the troughs between the dune crests, tend to be moist areas and typically containing a range of sedges and rushes such as leafless rush (*Juncus gregiflorus)*, knobby club rush (*Ficinia nodosa)* and spike sedge (*Eleocharis neozelandica).* Rear dune species can include a range of tree and shrub species, such as flax (*Phormium spp.),* broad leaf (*Griselinia littoralis)*, cabbage tree (*Cordyline australis)*, coastal tree daisy (*Olearia solandri)* and thick leaved mahoe (*Melicytus crassifolius).* However, due to coastal development and farming practices extending close to the shore, most dune sequences are now limited to a remnant fore dune, and a number of native plant species mentioned above are now threatened. Shore spurge is classified as in serious decline, while sand pimelia, sand tussock, spike sedge and pīngao are in gradual decline (Hitchmough et al. 2007) (See appendix 3 for detailed description of native plants and status).

Marram grass has been used throughout the world for stabilisation of sand and fore shore protection (Hilton et al. 2005). Originally from Europe, it is now widespread throughout the coasts of Australia (Webb et al. 2000), North America (Russo et al.1998), and South Africa (Avis 1989; Hertling & Lubke, 1999), where it has displaced native species and significantly altered natural character. In New Zealand, marram's higher tolerance to burial and drought make it a superior competitor (Partridge 1995; Gadgil, 2006), allowing it to displace native sand binders such as spinifex and pīngao in certain situations (Hilton et al. 2005). However, it has been shown to coexist with natives in certain conditions (Partridge 1995; pers. observation). Marram has proved highly successful in stabilising large areas of unstable sand, but creates high steep dunes (Esler 1970) that are prone to blow outs and under-cutting by storm surges (Hilton et al. 2005). Other exotic plants in dunes include gorse (*Ulex europeaus),* blackberry (*Rubus fruticosus)*, ice plant (*Carpobrotus spp.),* lupin *(Lupin arboreus* and bone seed *(Chrysanthemoides monilifera)* (pers. obs).

1.2.1.2 Sand dune fauna

Despite their often barren and exposed nature, sand dunes can provide habitat for a wide range of specialised and unique fauna. Our understanding of the ecology of fauna in sand dunes is not as developed as our knowledge of vegetation ecology, but studies are beginning to appear. These investigations are commonly limited to studies into conservation of charismatic species such as the katipō spider (*Latrodectus sp.)* and lizards. Ecological restoration should consider faunal communities as well as the flora (Young 2000; Majer 2009), although our understanding of these communities is currently limited to incorporate their conservation requirements into management efforts. The effect that sand dune restoration has on fauna is largely unknown. Although it is apparent that the plant species in the dunes will influence the faunal community (Patrick 1994; Costall 2006; Lettink et al. 2008), and widely recognised that faunal diversity and abundance will be a function of habitat heterogeneity and diversity (Crisp et al. 1998; Tews et al. 2004).

Invertebrates

‘Without invertebrates, much of the life on earth today would cease to exist.’

(McGuiness 2001; pp8)

Indigenous invertebrates are vulnerable to loss of native vegetation, and predation from introduced pests (Crisp et al. 1998). Invertebrates are essential components of ecosystems, recycling nutrients, and pollinating plants (McGuiness 2001). Aside from some taxonomic studies of flagship species such as the katipō spider or moths, there is little available information on the ecologies and assemblages of invertebrate communities in New Zealand sand dunes (Stephenson 1999; Costall 2006).

Lepidoptera (moths and butterflies) make up one of the largest orders of invertebrates (New 2004). Patrick (1994) found 130 species of moth at Kaitorete spit in Canterbury, including several nationally rare species (Hitchmough et al. 2007). *Ericodesma aerodana, Kupea electilis, Kiwaia jeanae* (Patrick & Dugdale 2000) and a number of *Notoreas* moths (Patrick 1994) are species known to be endemic to sand dunes but are now in decline (Pawson & Emberson 2000; Hitchmough et al. 2007). Patrick (1994) observed that moths associate with particular plant species, including rare species such as native broom (*Carmichealia appressa*), sand daphne, pohuehue and mingimingi. Other endemic invertebrates known to occur in sand dunes include the seashore earwig (*Anisolabis littorea*), and sand scarab beetles (*Pericoptus frontalis*) (Brockie 1957).

Figure 1.6. *Kupea electis* from Birdlings Flat, Canterbury. Photograph from Pawson & Emberson, 2000.

Katipō spider *Latrodectus katipō & L. atritus*

The katipō are a flag ship species, representing the plight of fauna in sand dunes (Patrick 2002). *Latrodectus katipō* (red katipō) and *L. atritus* (black katipō) are endemic widow spiders found only in coastal dunes in New Zealand (Griffiths et al. 2005; Costall 2006). They have undergone a dramatic contraction in geographic range and decline in numbers since European settlement (Hann 1990; Patrick 2002; Costall 2006). Their exact distribution and population sizes are unknown, due to a lack of a consistent monitoring method (Costall 2006) but it has been inferred that both species are now in 'serious decline' by the Department of Conservation classification system (Hitchmough et al. 2007). Katipō were recently found to be present at only 46% of sites at which they had been previously sighted (Patrick 2002; as cited by Lettink & Patrick 2006). Although a recent survey by Costall (2006) using artificial cover objects (ACOs) found katipō to be more abundant than previously thought. This was attributed to the inclusion of the more conspicuous males and juveniles in the sampling and highlights the need for a standard monitoring method to accurately describe their populations. The method tested by Costall could potentially be used for the development of a more accurate sampling method as opposed to previous less reliable search methods.

The invasion of marram grass and loss of native habitat has been implicated in their decline, as has urban development, farming, forestry, and increases in recreational use (Patrick 2002, Costall 2006; Costall & Death 2009). *Steatoda capensis*, or 'false katipō' (Sutton et al. 2006) a spider introduced from South Africa, has been found to be more successful than the katipō at colonising vacant habitat, and may displace katipō (Hann 1990; Patrick 2002), being found in high numbers in known katipō habitat (Costall 2006). It is also likely that house mouse (*Mus musculus*) and other small introduced mammals may be predators of katipō (Miller & Webb 2001).

A recent study along the Manawatu/Wanganui coastline found katipō present in native and exotic plant species (Costall 2006; Costall & Death 2009). An experimental study also by Costall (2006) suggests that katipō tend to avoid marram grass completely when selecting sites for web construction. A large proportion of juvenile katipō (spiderlings) were found in marram where the grass is in low densities, while mature females were more likely to be found in areas with vegetation coverage of between 34-66%, containing native plant species (Costall 2006). Native species such as sand coprosma, spinifex and pīngao were preferentially selected for building webs. Sand daphne and pohuehue also provided desirable habitat. However, the effect of vegetation restoration on the katipō is unknown. For katipō to be rescued from decline, their habitat requirements and monitoring should be incorporated into dune management activities.

Lizards

Studies on lizards have been carried out in sand dunes, particularly in areas of high conservation value such as Kaitorete Spit in Canterbury (Freeman 1994; 1997; Lettink et al. 2008). Lizard species found in dunes vary regionally, but species that have been observed in dunes include common gecko (*Hoplodactylus maculatus)*, common skink (*Oligosoma nigriplantare polychroma)*, spotted skink (*O. lineoocellatum)*, brown skink (*O. zealandicum),* and copper skink (*Cyclodina aenea)* (Milne & Sawyer 2002). Remains of tuatara have also been found in dunes (Walls 1998). Lizards in sand dunes are commonly sampled using pitfall trapping, although new methods using artificial retreats are being developed (Lettink et al. 2008). The response of skinks to dune restoration has rarely been investigated.

Vegetation structure is a key determinant for the size and diversity of lizard populations (Jellinek et al. 2004) but in general, dense vegetation is desirable to hide from predators (Norbury et al. 2009). Lizards are prone to predation by introduced mammals (Wilson et al. 2007), with many native species now restricted to pest free islands (Newman 1994; Montoya & Burns 2007; Lettink et al. 2008). Hedgehogs were found to be significant predators of skinks in tussock grassland in Otago (Spitzen – van der Sluijs et al. 2009), while mice and cats are also known to be major predators (Miller & Webb 2001; Lettink et al. 2008). These introduced mammals may also compete with lizards for food (Norbury et al. 2009). Lizards are generalist foragers, although spiders and flies tend to be the most popular prey items for skinks in the dunes and their diet may also include other invertebrates and fruits (Freeman 1997).

Introduced mammals

Introduced mammals have been implicated in the decline of hundreds of native plants and animals in New Zealand, many of which now only survive on pest free islands and parks (Atkinson 2001). Rabbits (*Oryctolagus cuniculus*) are the most devastating animal pest found in dunes. Due to their burrowing nature, they exacerbate erosion, as well as browsing on the leaves and shoots of native vegetation, and hindering recruitment of new seedlings (Norbury 1996). Mice are common in the dune environment, and prey on invertebrates, lizards, and consume the seeds of a number of native dune grass species, potentially hindering regeneration. Stomach contents analysis has revealed that moth larvae, spiders and beetles are generally the most popular prey items for mice (Miller & Webb 2001; Jones & Toft 2006). Feral cats (*Felis cattus*) and hedgehogs (*Erinaceus europaeus*) have been found to be abundant in sand dunes, also preying on lizards and invertebrates (Lettink et al. 2008). However, control of predators should be planned carefully, as removal of a top predator (e.g. cats) can result in increased predation of native fauna by 'mesopredators' (e.g. mice). Mice population irruptions have been observed following pest control in restoration (Lettink et al. 2008).

Control of these pests is a costly endeavour, and is generally restricted only to dune systems under intense management. For example, Ocean Beach dune system in the Hawkes Bay, and Ocean Beach in Tawharanui Open Sanctuary in the Hauraki Gulf (Wedding 2007), are part of wider areas protected by predator proof fencing. Dune flora and fauna are able to thrive in the absence of all introduced mammals except mice. In most local restorations, pest management on this scale is out of reach due to constraints on funding and resources. Control of rabbits and fencing to exclude stock is of highest priority to dune managers to prevent wasted planting efforts.

1.3. The Science of Ecological Restoration

The practice of ecological restoration has become a panacea for fostering recovery of the ecosystems of the earth damaged by humans (Aronson et al. 2006). Ecological restoration is defined by the Society of Ecological Restoration International as 'the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed' (SER 2004 pp 3). More specifically, 'Restoration returns an ecosystem to its historic trajectory and recovers its former biotic expressions to the extent that contemporary conditions allow,' (Clewall & Aronson 2006 pp 421). However, one's definition of restoration will be based on their own needs, perspectives and expectations (Hackney 2000). Restoration primarily is based on removal of a disturbance (SER 2004), but may also involve reintroducing native plant species (Atkinson 1994), constructing habitat for endangered fauna, controlling exotic pests, or the reinstatement of disturbance regimes. The extent of the restoration will come down to the aspirations and motivations of the stakeholders involved in the project (Clewall & Rieger 1997).

There are a wide variety of reasons that motivate restoration. Idealistic motivations, such as atonement for damage caused to the environment are commonly expressed by small groups tending a site in their local area (Cairns Jr 2000). A strong sense of community empowerment can come from reconnecting with nature through restoration (Leigh 2005). Technocratic restorations conducted by government or large companies are typically large scale projects, often for mitigation of environmental damage caused by developments (Clewall & Aronson 2006). Whatever the motivations for restoration, the social dimension is highly important, and without dedicated volunteers, most restorations would not succeed. However, they require guidance and support from knowledgeable authorities in order to achieve their goals (Clewall & Rieger 1997). Ensuring that the guidance they receive will result in the best ecological outcome for the site is paramount not only to the ecology of the flora and fauna, but the satisfaction of all those involved.

Restoration ecologists argue that for optimal ecological outcomes, restoration needs to be based on science (Clewall & Rieger 1997; Winterhalder et al. 2004; Clewall & Aronson 2006). Restoration ecology is a developing science that is becoming increasingly sophisticated (Clewall & Rieger 1997) attempting to turn what is a technique (restoration) into a science (Halle & Fattorini 2004), based on elements of community ecology, population ecology and other disciplines including soil science, hydrology and geomorphology (Ehrenfield 2000; Davis & Slobodkin 2004; van Andel & Grootjans 2006). As outlined by Palmer et al. (2006); a scientific restoration has:

(a) clear goals,

(b) a design based on knowledge of ecological principles,

(c) quantitative analysis of biodiversity gains, and

(d) adaptive management to allow the application of results to other situations.

Ecological principles underlie many actions undertaken by the restoration group (Winterhalder et al. 2004). However, often principles developed by academics lack practical application, and are hard for practitioners to understand. It is important to ensure that there is a balance between the influence of realistic scientific guiding principles, and the capabilities and motivations of the practitioners. The ultimate challenge for restoration ecologists is to ensure that ecological knowledge can be translated into steps that can be put into practice in the field. Introduced below are three key components of restoration for application in a small scale context: goal setting, consideration of ecological principles, and analysis of biodiversity gains.

1.3.1 Goal setting

Clear goals and objectives should be outlined prior to commencement of restoration activity (Ehrenfield 2000; Atkinson 2001; Hobbs & Harris, 2001; SER 2004), based on combination of scientific, technical, and economic knowledge (Halle & Fattorini; Greenwood & Robinson 2006). Goals will be shaped by the ecosystem characteristics desired by the practitioners, and their motivations for restoration. Restoration groups commonly don't identify goals (Atkinson 1994), and a survey of river restoration managers by Bernhardt et al. (2007) found that measurable objectives were set by less than half of restoration groups. Without clear objectives and targets to begin with, subsequent ecological evaluation using monitoring and adaptive management becomes difficult (Bakker et al. 2000) and restoration becomes a 'hit or miss' operation (Clewall & Aronson 2006: pp 423).

Restoration is often based on the desire to return an ecosystem to a pre-disturbed state (Cairns Jr 2000; Harris et al. 2006). Current climatic conditions, and the extent of humans impact on the planet make the historical conditions that created these systems unlikely to be repeated (Cairns 2003). Furthermore, our lack of understanding of the complexities of ecosystem structure and function somewhat limits our ability to recreate nature. Ecosystems are dynamic, and changing constantly with the forces of nature and humankind, therefore imposing a static perspective on restoration is naive (Hobbs & Norton 1996). Future proofing seeks to ensure the resilience of an ecosystem through preparing for future environmental conditions and anthropogenic influence (Cairns 2003). The changing biophysical conditions that will come with global climate change are now inevitable (Harris et al. 2006), and should be planned for. This may involving letting go of restricting local genotypes to their original area, which potentially restricts their ability to respond to change. Exotic species may have the potential to play important roles in restoration (D'Antonio & Meyerson 2002). The line drawn between native and exotic is becoming debatable, for example marram grass has now been naturalised in New Zealand for over 100 years (Gadgil 2006).

1.3.2 The importance of habitat

In most cases, heterogeneous habitat allows for increased faunal biological diversity (Palmer et al. 1997; Tews et al. 2004), providing protection from predators, shelter from the environment, and habitat for prey (Comor et al. 2008). Furthermore, it is often assumed that native vegetation will harbour more biodiversity than exotic vegetation (Crisp et al. 1998). The recreation of habitat structure with vegetation is commonly perceived to result in the return of animals to the restored environment (Hobbs & Norton 1996; Young 2000). This "Field of Dreams Hypothesis", (Palmer et al. 1997 pp295) however, is a widely untested assumption (Keesing & Wratten 1998; Brady et al. 2002). Barriers to dispersal and lack of a nearby source population will prevent the animals colonising the restored environment (Halle & Fattorini 2004; Brady et al. 2002). Furthermore, restoration is commonly focussed on the vegetation component (Young 2000) with minimal consideration of fauna.

1.3.3 Analysis of biodiversity gains

Biodiversity monitoring can be used to track and assess changes in an ecosystem (Anderson & Majer 2004), to measure progress towards restoration goals (Hobbs & Harris 2001), and to evaluate effectiveness of the current management regime (Atkinson 2001; McGuinness 2001; McCoy & Mushinsky 2002; Milne & Sawyer 2002; Harris & van Digglen 2006; and others). However in practice, restoration actions are often not accompanied by formal biodiversity monitoring (Atkinson 1994; Kremen et al. 1994; Clewall & Rieger 1997; Palmer et al. 2006; Phillips 2005; and others). Often there is no money available for monitoring (Bakker et al. 2000) and time or understanding may be limited (Lee et al. 2005; Miller & Paul 2007). For monitoring to be accessible to community groups, it needs to be user friendly, involving methods that do not require complex statistical analysis or specimen identification. Clear objectives to measure progress against and success criteria for comparison of results also make the process worthwhile.

Fauna have been successfully incorporated into the monitoring of restoration projects in a number of systems (Nicols & Nicols 2003; Ruiz-Jaen & Aide 2005), however monitoring is commonly biased towards plant and soil components of restoration projects (Keesing & Wratten 1998; Longcore 2003) with faunal components commonly overlooked (Halle & Fattorini 2004). The rate at which faunal populations recover following restoration is becoming increasingly studied (Nicols & Nicols, 2003; Watts et al. 2008; Majer 2009). Invertebrates are useful taxa for the monitoring of restoration because of their short generation times, functional diversity and ability to respond rapidly to change (Longcore 2003; Anderson 2004; Andersen & Majer 2004; Comor et al. 2008). Their effectiveness as bio-indicators has been illustrated in a number of systems, particularly that of restored mine sites in Australia (Andersen 1997; Andersen 2004; Andersen & Majer 2004), and occasionally in sand dunes (Webb 2000; Longcore 2003). In the recent literature, studies have used ants (Anderson 2004); beetles (Comor et al. 2008); spiders (Simmonds et al. 1994); or assemblages of orders (Nakamura 2003) as indicators of restoration progress. Both beetles and spiders have been used as indicators in sand dune environments (Webb et al. 2000; Longcore 2003). Analysis of invertebrate communities however, can be time intensive, requiring professional taxonomic knowledge, as well as knowledge of the ecology to draw meaningful conclusions (Majer 2009). Knowledge of invertebrate assemblages and ecology is generally poor in New Zealand (McGuiness 2001) making it difficult to interpret monitoring data. Therefore it is commonly placed in the ‘too hard’ basket by practitioners. Development of a common monitoring methodology and its basic interpretation is required to alleviate this.

1.4 New Zealand's sand dune restoration movement

The implementation of the Resource Management Act (Parliament of New Zealand 1991) advocated for land managers to preserve the 'natural character' of the coast. This saw a shift from planting marram grass, to re-vegetation of sand dunes with a small suite of native sand binding species such as spinifex and pīngao. Degraded fore dunes became popular as candidates for ecological restoration (Miller & Paul 2007), and groups of volunteers began to conduct small scale restorations of their local sand dune. This has evolved into a widespread movement involving at least 80 community groups and many hundreds of volunteers, facilitated by the Dune Restoration Trust of New Zealand and local councils. The Trust is composed of 13 trustees who aim to share information on restoring natural character, form and function of sand dunes, oversee sand dune research, and provide practical guidance (Dunes Restoration Trust of New Zealand 2007). An annual dune restoration conference is held, attracting members of dune groups throughout the country to network and gain skills and ideas for their own projects from field trips, lectures and workshops (Spence et al. 2007).

The Department of Conservation has been involved in a small number of large scale projects, such as the mass spraying of marram dunes on Stewart Island, and its replacement with pīngao over a large area (Hilton et al. 2005; DOC 2006). After three applications of herbicide, marram has been virtually eradicated from Mason Bay (Hilton et al. 2005). Private enterprises have surrounded dunes with predator proof fencing to allow dune flora and fauna to thrive in a pest free environment (for example Ocean Beach in Hawkes Bay, Tawharanui Open Sanctuary in the Hauraki Gulf). Dune restoration on this scale requires a huge investment in time and resources, and is too expensive and intensive to apply more widely.

Figure 1.7. Ocean Beach dunes are protected by a predator proof enclosure. Photograph by the author, March 2008.

District and regional councils are generally the first point of contact for community dune groups, with most coastal councils having a 'Coast care' coordinator, or person in charge of community restoration groups. A number of websites provide information for local dune groups (Environment Waikato 2007; Environment Bay of Plenty 2009; Northland Regional Council 2009). Many councils have funding available for community restoration groups; for example the Greater Wellington Regional Council offer "Take care" funding offers financial support of between $1000-$5000 per year for 5 years. This money can be used for materials required, signage, pest control and environmental education associated with the project (Greater Wellington Regional Council 2009).

1.4.1 The dune restoration process

Dune restoration typically begins with the control or removal of marram grass by either spraying with herbicide, hand pulling, or digging out with a bulldozer. The dune is often mechanically reshaped with earthmoving equipment to ensure an effective dune profile for foreshore protection. A small suite of native sand binding species are planted, including spinifex, pīngao, and sometimes sand tussock, sand coprosma, flax and sand daphne. Depending on the scale of the project, the project may include pest animal control for rabbits, and occasionally rats and mustelids. Maintenance involves weeding by hand pulling or applying herbicide, and gradually extending the planted area as time and resources allow. Volunteers are the backbone of the dune restoration community, and are heavily involved in all levels of the restoration process.

The basic ecology and practicalities of establishing native sand-binding vegetation for restoration have been studied extensively by Forest Research Rotorua (Bergin & Kimberly 1999). These guidelines for propagation and establishment are now well recognized as best practice throughout the country, and have been translated into a user-friendly bulletin series by the Dune Restoration Trust (Bergin 1999). The series includes detailed botanical information for species such as pīngao (Bergin & Herbert 1998), spinifex (Bergin 1999); as well as descriptions of coastal form and function (Hesp 2000) and guidelines for vegetation monitoring (Miller & Paul 2007).

In many small scale dune restoration projects, biodiversity has not been a key reason for restoration (Hilton et al. 2000). Interest has been in re-vegetating a fore dune for functions such as coastal hazard management (Hilton et al. 2000), aesthetics, or recreation (Bergin & Kimberly 1999; Miller & Paul 2007). Conservation of specialist plants have only recently become a motive for restoration, and native fauna are generally not included in restoration priorities. It is widely assumed that construction of structural habitat will result in the return of fauna, but this 'field of dreams' (Palmer et al. 1997 pp295) theory is largely untested in many ecosystems (Brady et al. 2002).

Restorations are often not accompanied by monitoring, which could be attributed to a lack of guidance and understanding (Lee et al. 2005; Miller & Paul 2007). It is not known what effect the removal of marram and the subsequent planting of native species will have on the faunal communities of sand dunes. Re-vegetation of dunes has the potential to contribute much more in terms of conserving native biodiversity of flora *and* fauna, but requires a firmer ecological foundation in which to conduct restoration activity.

1.5 Research aims

This thesis aims to investigate the social and ecological realms of dune restoration in New Zealand. The main aim is to see whether current practice of dune restoration in New Zealand is; a) applying best practice (as described in 1.3); and b) leading to biodiversity gains (as described in 1.2). The following questions will be answered:

1. What are the motivations, and management practices of existing dune restoration groups in New Zealand?
2. Are dune restorations in New Zealand followed up with monitoring?
3. Are there differences in biodiversity in restored dunes and marram dominated dunes?
4. What are the key monitoring aims for sand dune restoration in New Zealand?

This information will prove invaluable for all authorities involved with coastal dunes in Wellington, including Greater Wellington Regional Council, the Department of Conservation, the Dune Restoration Trust, and of course the restoration groups themselves. This study has fostered a partnership with Lincoln University which will involve more in depth investigations into the ecology of restored dunes throughout the country.

1.6 Thesis structure

This remainder of the thesis is divided into three chapters. Chapter two explores the social dimension of dune restoration in New Zealand, assessing the motivations of practitioners, and investigating the application of science in small scale restoration projects. Chapter three compares the biodiversity of marram and restored dunes, and seeks to find invertebrates that could potentially be used as indicators for monitoring in dune restoration. Chapters two and three have been prepared as manuscripts for journal submission, therefore differ slightly in style and contain some repetition. Chapter four contains a summary of the preceding chapters, and offers recommendations for monitoring programmes and future work.

References

Andersen AN, Sparling GP 1997. Ants as Indicators of Restoration Success: Relationship with Soil Microbial Biomass in the Australian Seasonal Tropics. Restoration Ecology 5(2): 109-114.

Andersen AN, Majer JD 2004. Ants show the way Down Under: invertebrates as bio indicators in land management. Frontiers in Ecology and Environment 2(6): 291-298

Andersen AN, Fisher A, Hoffman BD, Read JL, Richards R 2004. Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. Austral Ecology 29: 87-92.

Aronson J, Clewall AF, Blignaut JN, Milton SJ 2006. Ecological restoration: A new frontier for nature conservation and economics. Journal for Nature Conservation 14: 135-139.

Atkinson IAE 1994. Guidelines to the development and monitoring of ecological restoration programmes. Department of Conservation Technical Series 7. Wellington, Department of Conservation. 36p.

Atkinson IAE 2001. Introduced mammals and models for restoration. Biological Conservation 99: 81-96.

Avis AM 1989. A review of Coastal Dune Stabilization in the Cape Province of South Africa. Landscape and Urban Planning 18: 55-68.

Bakker JP, Grootjans AP, Hermy M, Poschlod P 2000. How to define targets for ecological restoration? Applied Vegetation Science 3: 1-72.

Beentjes MP, Carbines GD, Willsman AP 2006. Effects of beach erosion on abundance and distribution of toheroa (*Paphies ventricosa*) at Bluecliffs Beach, Southland, New Zealand. New Zealand Journal of Marine and Freshwater Research 40: 439-453.

Bergin DO, Herbert JW 1998. Pīngao on coastal and dunes; Guidelines for seed collection, propagation and establishment. CDVN Technical Bulletin New Zealand Forest Research Institute Limited.

Bergin DO 1999. Spinifex on coastal sand dunes; guidelines for seed collection, propagation and establishment. CDVN Technical Bulletin, New Zealand Forest Research Institute Limited.

Bergin DO, Kimberly MO 1999. Rehabilitation of coastal foredunes in New Zealand using indigenous sand-binding species. Science for Conservation 122. Wellington, Department of Conservation. 52p.

Bernhardt ES, Sudduth EB, Palmer MA, Allan JD, Meyer JL, Alexander G, Follastad-Shah J, Hassett B, Jenkinson R, Lave R, Rumps J, Pagano L 2007.

Restoring Rivers One Reach at a Time: Results from a Survey of U.S. River Restoration Practitioners. Restoration Ecology 15(3): 482-493.

Bonte D, Hoffman M 2005. Are coastal dune management actions for biodiversity restoration and conservation underpinned by internationally published scientific research? International Conference on Nature Restoration Practices in European Coastal Habitats Belgium, 2005.

Brady VJ, Cardinale BJ, Gathman JP, Burton TM 2002. Does facilitation of faunal recruitment benefit ecosystem restoration? An experimental study of invertebrate assemblages in wetland mesocosms. Restoration Ecology 10(4): 617-626.

Brockie RE 1957. The Hedgehog population and Invertebrate Fauna of the West Coast Sand Dunes. Proceedings of the New Zealand Ecological Society 5:27

Cairns J Jr 2000. Setting ecological restoration goals for technical feasibility and scientific validity. Ecological Engineering 15: 171-180.

Cairns JJ 2003. Ethical issues in ecological restoration. Ethics in Science and Environmental Politics: 50-61.

Carter RWG 1991. Near-future sea level impacts on coastal dune landscapes. Landscape Ecology 6(1/2): 29-39.

Clewall A, Rieger JP 1997. What Practitioners Need from Restoration Ecologists. Restoration Ecology 5(4): 350-354.

Clewall A, Aronson J 2006. Motivations for the Restoration of Ecosystems. Conservation Biology 20(2): 420-428.

Cockayne L 1909. Report on the sand dunes of New Zealand: the geology and botany, with their economic bearing. Department of Lands.

Cockayne L 1911. Report on the dune areas of New Zealand: their geology, botany, and reclamation. Department of Lands.

Cockayne L 1967. New Zealand Plants and their story. 4th Edition. Edited by Godley, E.J. R.E Owen, Government Printer, Wellington, New Zealand.

Comor V, Orgeas J, Ponel P, Rolando C, Dellettre YR 2008. Impact of anthropogenic disturbances on beetle communities of French Mediterranean coastal dunes. Biodiversity Conservation 17: 1837-1852.

Costall J A 2006. The ecology and conservation of *Latrodectus katipō*, New Zealand's endangered widow spider. Unpublished MSc thesis. Massey University, Palmerston North, New Zealand.

Costall JA, Death RA 2009. Population structure and habitat use by the spider *Latrodectus katipō* along the Manawatu-Wanganui coastline. New Zealand Journal of Zoology 36: 407-415.

Crisp PN, Dickinson KJM, Gibbs GW 1998. Does native invertebrate diversity reflect native plant diversity? A case study from New Zealand and implications for conservation. Biological Conservation 83(2): 209-220.

Dahm J, Jenks G, Bergin D 2005. Community-based Dune Management for the mitigation of Coastal Hazards and Climate Change Effects: A Guide for Local Authorities. http://www.lgnz.co.nz/projects/EnvironmentalSustainability/ClimateChange/CommunityBasedDuneMangementpart1.pdf. Downloaded January 2010.

D'Antonio CD, Meyerson LA 2002. Exotic Plant Species as Problems and Solutions in Ecological Restoration: A synthesis. Restoration Ecology 10(4): 703-713.

Davis MA, Slobodkin LB 2004. The Science and Values of Restoration Ecology. Restoration Ecology 12(1): 1-3.

Department of Conservation 2005. Pikao (or Pīngao) the Golden Sand Sedge. http://www.doc.govt.nz/publications/conservation/native-plants/pikao-or-pingao-the-golden-sand-sedge/. Downloaded on 14th December 2009.

Department of Conservation 2006. Mason Bay Dune Restoration. Christchurch, Department of Conservation, Southland Conservancy.

Dunes Restoration Trust of New Zealand 2007. About Us. www.dunestrust.org.nz Downloaded December 2009.

Ehrenfield JG 2000. Defining the Limits of Restoration: The Need for Realistic Goals. Restoration Ecology 8(1): 2-9.

Esler AE 1970. Manawatu sand dune vegetation. Proceedings of the New Zealand Ecological Society 17: 41-46.

Environment Bay of Plenty 2009. Coast care. www.envbop.govt.nz/sustainable-communities/coast-care.aspx. Downloaded December 2009.

Environment Waikato 2007. Beach care. www.ew.govt.nz/projects/beachcare. Downloaded December 2009.

Freeman AB 1994. An ecological study of the lizard fauna of Kaitorete Spit, Canterbury. Unpublished MSc thesis. Lincoln University, Canterbury.

Freeman AB 1997. Comparative ecology of two *Oligosoma* skinks in Coastal Canterbury: a contrast with Central Otago. New Zealand Journal of Ecology 21(2): 153-160.

Gadgil RL, Ede FJ 1998. Application of Scientific principles to sand dune stabilization in New Zealand: past progress and future needs. Land Degradation and Development 9: 131-142.

Gadgil RL 2006. Marram Grass: Friend or foe. CDVN Technical Bulletin No. 5. New Zealand Forest Research Institute Liimited. 32p.

Given DR 1981. Plants of the Coast. In: Rare and Endangered plants of New Zealand, A.H & A.W Reed Ltd.

Griffiths JW, Paterson AM, Vink CJ 2005. Molecular insights into the biogeography and species status of New Zealand's endemic *Latrodectus* spider species; *L. katipō* and *L. atritus* (Araneae, Theridiidae). The Journal of Arachnology 33: 776-784.

Greater Wellington Regional Council. 2009. Take care. www.gw.govt.nz/takecare/ downloaded December 2009.

Greenwood, JJD, Robinson RA 2006. Principles of Sampling. In: Sutherland WJ (ed), Ecological Census Techniques. Cambridge University Press: 13-85.

Hackney CT 2000. Restoration of Coastal habitats: expectation and reality. Ecological Engineering 15: 165–170.

Halle S, Fattorini M 2004. Advances in Restoration Ecology: Insights from Aquatic and Terrestrial Ecosystems. In: Temperton VM, Hobbs RJ, Nuttle T, Halle S (eds) Assembly rules and restoration ecology: bridging the gap between theory and practice. Island Press, Washington. 439p.

Hann SW 1990. Evidence for the displacement of an endemic New Zealand spider, *Latrodectus katipō* (Powell) by the South African species *Steatoda capensis* (Hann) (Araneae: Theridiiae). New Zealand Journal of Zoology 17: 295-307.

Harris JA, van Digglen R 2006. Ecological restoration as a project for global society. In: van Andel J, Aronson J (eds). Restoration Ecology: The New Frontier, Blackwell Publishing. Pp 3-15.

Harris JA, Hobbs RJ, Higgs E, Aronson J 2006. Ecological Restoration and Global Climate Change. Restoration Ecology 14(2): 170-176.

Hertling UM, Lubke RA 1999. Use of *Ammophila arenaria* for Dune Stabilization in South Africa and its current distribution - perceptions and problems. Environmental Management 24(4): 467-482

Hesp PA 2000. Coastal Sand dunes; form and function. CDVN technical bulletin, Coastal Dune Vegetation Network, New Zealand Forest Research Institute Limited.

Hesp PA 2001. The Manawatu Dunefield: Environmental Change and Human Impacts. New Zealand Geographer 57(2). 33- 39

Hilton MJ, Macauley U, Henderson R 2000. Inventory of New Zealand's active dunelands. Science for Conservation 157. Wellington, Department of Conservation. 34p.

Hilton MJ, Duncan M, Jul A 2005. Processes of *Ammophila arenaria* (Marram Grass) Invasion and Indigenous Species Displacement, Stewart Island, New Zealand. Journal of Coastal Research 21(1): 175-185.

Hilton MJ 2006. The loss of New Zealands' active dunes and the spread of Marram grass. New Zealand Geographer 62: 105–120.

Hitchmough R, Bull L, Cromarty P 2007. New Zealand Threat Classification System lists - 2005. Wellington, Department of Conservation. 194p.

Hobbs RJ, Harris JA 2001. Restoration Ecology: Repairing the Earth's Ecosystems in the New Millennium. Restoration Ecology 9(2): 239-246.

Hobbs RJ, Norton DA 1996. Towards a conceptual framework for restoration ecology. Restoration Ecology 4: 93-110.

Jellinek S, Driscoll DA, Kirkpatrick JB 2004. Environmental and vegetation variables have a greater influence than habitat fragmentation in structuring lizard communities in remnant urban bushland. Austral Ecology 29: 294-304.

Johnson PN 1992. The sand dune and beach vegetation inventory of New Zealand. South Island and Stewart Island, DSIR Land Resources Scientific Report.

Jones C, Toft R 2006. Impacts of mice and hedgehogs on native forest invertebrates: a pilot study. DOC Research and Development Series 245. Wellington, Department of Conservation 245: 32.

Keesing V, Wratten SD 1998. Indigenous invertebrate components in ecological restoration in agricultural landscapes. New Zealand Journal of Ecology 22(1): 99-104.

Kremen C, Merenlender AM, Murphy D 1994. Ecological Monitoring: A Vital Need for Integrated Conservation and Development Programs in the Tropics. Conservation Biology 8(2): 388-397.

Lee W, McGlone M, Wright E 2005. Biodiversity Inventory and Monitoring: A review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. Landcare Research Contract Report: LC0405/122. 218p.

Leigh P 2005. The ecological crisis, the human condition, and community-based restoration as an instrument for its cure. Ethics in Science and Environmental Politics: 3-15.

Lettink M, Patrick BH 2006. Use of artificial cover objects for detecting red katipō, *Latrodectus katipō* Powell (Araneae: Theridiiae). New Zealand Entomologist 29: 99-102.

Lettink M, Cree A, Norbury G, Seddon PJ 2008. Monitoring and restoration options for lizards on Kaitorete Spit, Canterbury. DOC Research and Development Series 301. Wellington, Department of Conservation.

Longcore T 2003. Terrestrial Arthropods as Indicators of Ecological Restoration Success in Coastal Sage Scrub (California, USA). Restoration Ecology 11(4): 397-409.

Majer JD 2009. Animals in the Restoration Process- Progressing the Trends. Restoration Ecology 17(4): 315-319

McCoy ED, Mushinsky HR 2002. Measuring the Success of Wildlife Community Restoration. Ecological Applications 12(6): 1861-1871.

McGuinness CA 2001. The conservation requirements of New Zealand's nationally threatened invertebrates. Threatened Species Occasional Publication 20. Wellington, Department of Conservation.

Miller E, Paul T 2007. Measuring success: guidelines for the management of Sand Dune Revegetation Programmes. CDVN Technical Bulletin, Coastal Dune Vegetation Network, New Zealand Forest Research Institute Limited.

Miller AP, Webb PI 2001. Diet of house mice (*Mus musculus L.)* on coastal sand dunes, Otago, New Zealand. New Zealand Journal of Zoology 28: 49-55.

Milne R, Sawyer J 2002. Coastal fore dune vegetation in the Wellington Conservancy: Current status and future management. Wellington, Department of Conservation. 82p.

Ministry for Culture and Heritage 2005. Dunelands. http://www.teara.govt.nz/en/dune-lands Downloaded on 14th November 2009.

Montoya I, Burns KC 2007. Community-wide character displacement in New Zealand skinks. Journal of Biogeography 34: 2139-2147.

Nakamura A, Proctor H, Catterall CP 2003. Using soil and litter arthropods to assess the state of rainforest restoration. Ecological Management & Restoration 4 Supplement: S20- S28.

New TR 2004. Moths (Insecta: Lepidoptera) and conservation: background and perspective. Journal of Insect Conservation 8: 79-94.

Newman DG 1994. Effects of a mouse, *Mus musculus*, eradication programme and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregors skink, *Cyclodina macgregori*. New Zealand Journal of Zoology 21: 443-456.

Nicols OG, Nicols FM 2003. Long-Term Trends in Faunal Recolonization After Bauxite Mining in the Jarrah Forest of Southwestern Australia. Restoration Ecology 11(3): 261-272.

NIWA 2008. Climate change projections for New Zealand. NIWA National Climate Centre www.niwa.co.nz Downloaded November 2009.

Norbury D 1996. The effect of rabbits on conservation values. Science for Conservation 34. Wellington, Department of Conservation.

Northland Regional Council 2009. Coast care. www.nrc.govt.nz/Environment/coast/take-action/coastcare. Downloaded December 2009.

Palmer MA, Ambrose RF, Poff NL 1997. Ecological Theory and Community Restoration Ecology. Restoration Ecology 5(4): 291-300.

Palmer MA, Falk MA, Zedler JB 2006. Ecological Theory and Restoration Ecology. In: Falk DA (ed) Foundations of Restoration Ecology. Washington, Island Press: 1-10.

Parliament of New Zealand 1991. Resource Management Act 1991. Public Act No 69. New Zealand.

Partridge TR 1992. The sand dune and beach inventory of New Zealand. North Island. DSIR Land Resources Scientific Report Number 15. DSIR Land Resources, Christchurch. 253p.

Partridge TR 1995. Interaction between Pīngao and Marram on Sand Dunes - completion of permanent plot studies. Science for Conservation 3. Wellington Department of Conservation.

Patrick B 1994. Lepidoptera of Kaitorete Spit, Canterbury. New Zealand Entomologist 17: 52-63.

Patrick B 2002. Conservation status of the New Zealand red Katipō spider (*Latrodectus katipō).* Science for Conservation 194. Wellington, Department of Conservation.

Patrick BH, Dugdale JS 2000. Conservation status of New Zealand Lepidoptera Science for Conservation 136. Wellington, Department of Conservation. 32p.

Pawson SM, Emberson RM 2000. The conservation status of invertebrates in Canterbury. Conservation Advisory Science Notes 320. Department of Conservation. Wellington. 50p

Pegman AP, Rapson GL 2005. Plant succession and dune dynamics on actively prograding dunes, Whatipu beach, northern New Zealand. New Zealand Journal of Botany 43: 223-244.

Phillips C 2005. Erosion and Sediment Control Using New Zealand Native Plants - What do we know? Proceedings of Erosion Control Seminar, Protecting the environment as an asset. NZ Institute of Highway Technology, 11-13 September, 2005 Palmerston North.

Ravine DA 1992. Foxton Ecological District: Survey Report for the Protected Natural Areas Programme. Wanganui, Department of Conservation. 264 p.

Ruiz-Jaen MC, Aide TM 2005. Restoration Success: How is it being measured? Restoration Ecology 13(3): 569-577.

Russo M, Pickart A, Morse L, Young R 1998. Element Stewardship Abstract for *Ammophila arenaria*. The Nature Conservancy, Virginia. ?

Sawyer JD 2004. Plant Conservation Strategy: Wellington Conservancy 2004-2010. Wellington, Department of Conservation.

Simmonds SJ, Majer JD, Nicols OG 1994. A Comparative Study of Spider (Araneae) Communities of Rehabilitated Bauxite Mines and Surrounding Forest in the Southwest of Australia. Restoration Ecology 2(4): 247-260.

Society for Ecological Restoration International Science & Policy Working Group 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International. http://www.ser.org/content/ecological_restoration_primer.asp Downloaded February 2009.

Spence HR, Bergin DO, Dean MJ 2007. Ten Years of Research and Implementation: Dune Restoration Trust of New Zealand. International Conference on the Management and Restoration of Coastal Dunes. 3-5th October, 2007. Santander, Spain.

Spitzen-van der Sluijs AM, Spitzen J, Houston D, Stumpel AHP 2009. Skink predation by hedgehogs at Macraes Flat, Otago, New Zealand. New Zealand Journal of Ecology 33(2): 205-207.

Stephenson G 1999. Vehicle impacts on the biota of sandy beaches and coastal dunes: A review from a New Zealand Perspective. Science for Conservation 121. Wellington, Department of Conservation.

Sutton ME, Christensen BR, Hutcheson, JA 2006. Field identification of katipō. DOC Research and Development Series 237. Wellington, Department of Conservation. 8p.

Sykes MT, Wilson JB 1991. Vegetation of a Coastal Sand Dune System in Southern New Zealand. Journal of Vegetation Science 2(4): 531-538.

Tews J, Bros U, Grimm V, Tielborger K, Wichmann MC, Schwager M, Jeltsch F 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography 31: 79-92.

Towns DR, Elliot GP 1996. Effects of habitat structure on distribution and abundance of lizards at Pukerua Bay, Wellington, New Zealand. New Zealand Journal of Ecology 20(2): 191-206.

van Andel J, Grootjans AbP 2006. Concepts in Restoration Ecology. In: van Andel J, Aronson J (eds). Restoration Ecology. Blackwell Publishing UK.

Walls G 1998. Simply sand? Ocean Beach Dunes, Hawkes Bay. Conservation Advisory Science Notes 21.3. Wellington, Department of Conservation.

Watts CH, Clarkson BR, Didham RK 2008. Rapid beetle community convergence following experimental habitat restoration in a mined peat bog. Biological Conservation 141: 568-579.

Webb CE, Oliver I, Pik A 2000. Does Coastal Foredune Stabilization with *Ammophila arenaria* Restore Plant and Arthropod Communities in Southeastern Australia? Restoration Ecology 8(3): 283-288.

Wedding CJ 2007. Aspects of the Impacts of Mouse (*Mus musculus*) Control on Skinks in Auckland, New Zealand. Unpublished MSc thesis, Massey University, Auckland.

Wilson DJ, Mulvey RL, Clark RD 2007. Sampling skinks and geckos in artificial cover objects in a dry mixed grassland-shrubland with mammalian predator control. New Zealand Journal of Ecology 31(2): 169-185.

Winterhalder K, Clewall AF, Aronson J 2004. Values and Science in Ecological Restoration - A Response to Davis and Slobodkin. Restoration Ecology 12(1): 4-7.

Young TP 2000. Restoration ecology and conservation biology. Biological Conservation 92: 73-83.

Chapter two

The methods and motivations behind dune restoration in New Zealand

Figure 2.1: Signage at Piha Beach dune restoration. Photograph taken by the author at Piha Beach, 2009.

Abstract

A survey of restoration practitioners aimed to identify motivations and evaluate the use of principles recommended by restoration ecologists. This survey showed that practices advocated by restoration ecologists as important to restoration are not being incorporated in New Zealand sand dune restoration projects. Restoration is based on best practice methods developed by the Dune Restoration Trust (DRT) for the stabilisation of sand and erosion protection; planting spinifex (*Spinifex sericeus*) and pīngao (*Desmoschoenus spiralis*). However, these projects have significant potential to contribute to the conservation of rare and endemic dune flora and fauna by including these species in dune management. Furthermore, the importance of monitoring is not widely recognised. Groups identified constraints of funding, time and knowledge as preventing monitoring from being carried out. Specific biodiversity monitoring was carried out by a small proportion of groups. Restoration groups identified a number of important resources they require more of in the future, which presents the perfect opportunity to make conservation and the incorporation of restoration science a priority in dune restoration.

Introduction

Restoration ecology has evolved greatly as a science over the past few decades (Young 2000; Harris & van Digglen 2006; Hobbs 2007). As restoration practice becomes increasingly sophisticated, restoration ecologists argue that the success of restoration activities will depend on the application of increasingly complex scientific and ecological principles (for example: Hobbs & Harris 2001; Clewall & Aronson 2006; Miller & Hobbs 2007; and others) while practitioners are often quite happy with their ‘hit and miss’ or ‘trial and error’ approach. Numerous papers have been published demanding the inclusion of planning, success criteria, future proofing, monitoring and conceptual frameworks but restoration actions often go ahead with very limited scientific knowledge (Hobbs & Norton 1996; Hackney 2000; Lake 2001). Although many papers argue to form a linkage between theory and practice, few studies have questioned practitioners. In the words of Hobbs (2006 pp ix) ‘theory has to make sense in practice’. Does this theory actually make sense in practice?

Motivations for restoration and restoration planning

Restoration is based on the desire to return a system to a former biotic or functional state. The process of restoration planning will largely be shaped by the specific motivations of the practitioners and stakeholders involved in the project, not necessarily the views of science. Measuring progress in restoration in a systematic way is vital to ensure the success of a project. In a survey of US river restoration practitioners, Bernhardt et al. (2007) found that measurable objectives had been set by less than half of projects. However most of these groups viewed their restoration as a success. The definition of success will depend on the goals the groups have set for their site, which has the potential to make a reliable measure of outcomes difficult to gather and compare.

Not only does restoration benefit the environment, it promotes conservation ethics, a connection with the land, and develops ones sense of place within nature (Leigh 2005). Through restoration, humans become reconnected with nature (Allison 2007; Leigh 2005) from which we have become so separate. Getting people involved in the planning process is critical for the success of the restoration (Atkinson 2001). The inclusion of conservation in the restoration process is becoming increasingly important, as the biota of the worlds ecosystems continue to decline. While restoration seeks to rehabilitate vegetation assemblages (Young 2000), conservation science also has a key role to play, to enhance the biodiversity and ecological success of a project.

Biodiversity Monitoring

Monitoring is a way of recording change in biotic and abiotic parameters at the restoration site, to measure progress and success of the current method (Lee et al. 2005). An effective monitoring program needs to use a range of ecological indicators that represent varying components of the system, and that can be measured relatively easily (Harris & van Digglen 2006). However, restoration is commonly based on botanical components of an ecosystem (Atkinson 1994; Young 2000), involving the rehabilitation of a suite of species known to previously inhabit the area. Animals are generally left to fend for themselves (Majer 2009), and expected to return once the habitat has been reconstructed. There are different ways of carrying out formal monitoring as outlined by Lee et al. (2005):

Inventory monitoring: documentation of current population at certain point in time

Status and trend monitoring: regular re-measurements of a population

Surveillance monitoring: surveillance of a threat or problem in an ecosystem eg- a pest plant

Management monitoring: may be pre- or post intervention. Assessment monitoring is a form of baseline inventory carried out prior to management action, and can be compared with outcome monitoring post intervention.

Research monitoring: monitoring undertaken in long term ecological research projects, which may be used to answer ecological questions about the system.

Although restoration action may be informally evaluated without scientific input, if these results are not documented, there is no potential for future projects to benefit (Michener 1997). Small community groups conducting restoration tend to be limited by time, knowledge and resources, therefore are restricted in their ability to monitor a number of attributes (Lee et al. 2005; Ruiz-Jaen & Aide 2005). In the majority of restorations, volunteers are the key players, and volunteers may lack formal scientific training, learning by the slow process of trial and error (Hackney 2000). Therefore the quality of the advice and resources they received to guide their restoration practice is paramount to the ecological success of their project.

Restoration of sand dunes

Coastal sand dunes are unique and dynamic ecosystems that have undergone significant decline throughout the world. In New Zealand, early efforts to make sand dunes productive involved the planting of exotic Marram grass (*Ammophila arenaria)* to stabilise dunes for forestry and pasture (Gadgil & Ede 1998; Hilton et al. 2000; Hilton 2006). The unique and specialised biota that dominated these dune systems were significantly reduced, many species now under threat of extinction due to habitat loss, fragmentation, and predation by introduced mammals. Growing interest in the field of ecological restoration and raised environmental awareness has seen the development of new and existing beach care groups throughout New Zealand (Miller & Paul 2007). Despite this increase, there has been little scientific evaluation of ecological outcomes.

Restoration of dunes is mainly focussed on re-vegetation using native plant species for the purpose of stabilising sand as opposed to biological conservation (Hilton et al. 2000; Miller & Paul 2007). These activities are generally initiated by volunteers or local stakeholders (Young 2000), and are carried out with a small scale, site specific approach (Gadgil & Ede 1995). The approach generally involves the removal of marram grass and planting of native sand binding species such as spinifex and pīngao. There is a wide range of support and resources available from local councils, the Dune Restoration Trust, and the Department of Conservation. Despite excellent knowledge of best practice methods for establishment of native sand binders, pīngao, spinifex and sand tussock; knowledge of the effects of restoration on flora and fauna in sand dunes is lacking. Improvement is needed to ensure more effective management and optimal ecological outcomes (Hilton et al. 2000).

As in many other systems, sand dune restoration techniques have progressed on a site specific, largely ad-hoc basis (Hobbs & Norton 1996). Dune managers often wonder if their efforts are making a difference ecologically (Robyn Smith, pers. comm. 2008), and the effect of restoration on faunal communities has not yet been investigated and documented. There is a wealth of information available to dune restoration groups on how to initiate the restoration process and establish the main plant species but much less available for following up restoration actions through monitoring and maintenance. The main monitoring resource available to dune restoration groups is for vegetation monitoring only (Measuring Success - Miller & Paul 2007). Furthermore, many restorations rest on the assumption that the planting of native sand binders will result in the return of a fully functioning ecosystem. The use of goal-setting and monitoring has not yet been quantified in New Zealand coastal dune restoration projects. Restoration of dune ecosystems should not be limited to a ‘plant native sand-binding species and see what happens’ approach, it needs to incorporate knowledge of restoration ecology including restoration planning and monitoring to ensure ecological success.

This chapter seeks to investigate the methods and motivations behind New Zealand coastal dune restorations. Specific questions were:

1. What are the motivations, structure, and management practices of existing dune restoration groups in New Zealand?
2. Are dune restorations in New Zealand followed up with monitoring?

Methods

The dune restoration community was surveyed using a web based questionnaire. This approach was chosen as mail-out surveys have been found to have a slower response (Wheaton et al. 2006). To our knowledge, no one has attempted to conduct a web based survey on the dune restoration community in New Zealand.

Study subjects

The dune restoration community consists of approximately 80 groups throughout the country, restoring a sand dune in their local area. The groups are made up of local stakeholders who are generally supported by a representative of their nearby regional or city council.

Data collection

The email addresses of dune restoration practitioners throughout New Zealand were sourced with help from the Dune Restoration Trust of New Zealand. A live questionnaire form was developed using Google documents, and the link emailed to a representative of each restoration programme. A second survey was developed following the completion of the first survey and sent to the respondents, to further investigate monitoring practice, as some questions required clarification.

Survey structure

Initially, the survey established whether the participant was a volunteer or paid worker, as responses from each were likely to vary. The survey began with broad questions to establish the involvement of volunteers, and levels of support from outside organisations, and the extent of restoration and pest control. It then went on to probe motivations for carrying out the restoration, and what monitoring was involved in the restoration. The second survey asked specific questions on the use of biodiversity monitoring. Questions were structured to allow selection from a list of options, as well as the option of adding additional answers as free text.

Copies of the questionnaires are found in Appendix 1.

Data analysis

Data was collated into a spreadsheet and the categorical data analysed using descriptive statistics.

Results

Introductory statistics

Overall, responses from 28 restoration groups were received for the survey. 68% of respondents were volunteers, 21% were paid to assist with restoration, and the remainder (11%) were both volunteers and paid assistants (e.g. a council worker who also conducted restoration in their own time). The age of restoration sites varied widely, approximately one-third (36%) of groups being active at the site for more than six years. Groups active for 1-2 years, 3-4 years and 5-6 years accounted for 18%, 28% and 18% respectively (Figure. 2.2). Working bees were mostly held only 1-3 times per year (57%). The remainder of groups held working bees weekly or fortnightly (14%), monthly (14%), or as required (14%) (Figure 2.3).

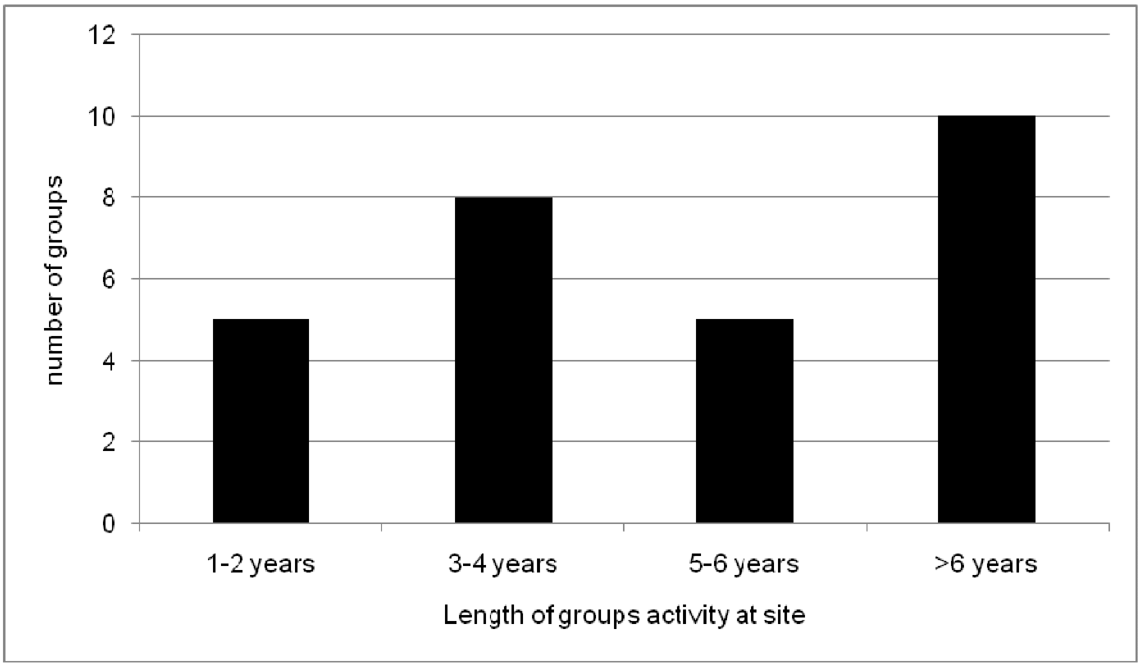

Figure 2.2 (above): Length of groups activity at their dune restoration site.

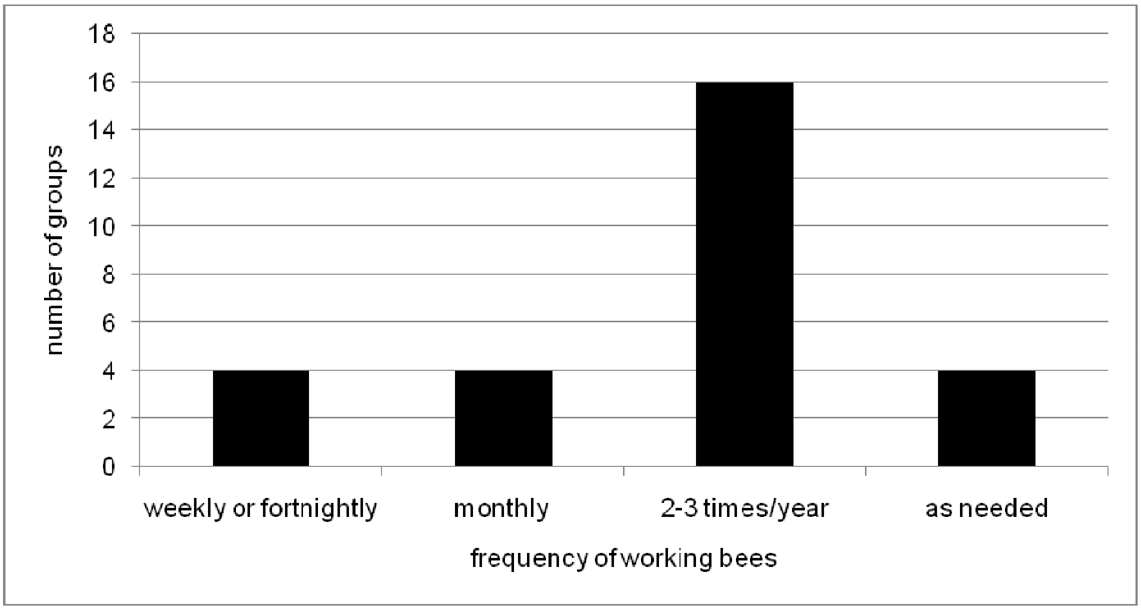

Figure 2.3: Frequency of working bees/maintenance days held by the restoration group.

Ecology of the site

All groups had planted spinifex, aside from one group in Otago (below the southern limit of spinifex). 86% of groups planted pīngao. In comparison, less common plant species such as sand daphne (*Pimelia arenaria),* shore spurge (*Euphorbia glauca)*, pohuehue (*Muehlenbeckia complexa*), sand tussock (*Austrofestuca littoralis*), and sand coprosma (*Coprosma acerosa*) were only planted in a small minority of dunes (each species around 15%) (figure 2.4).

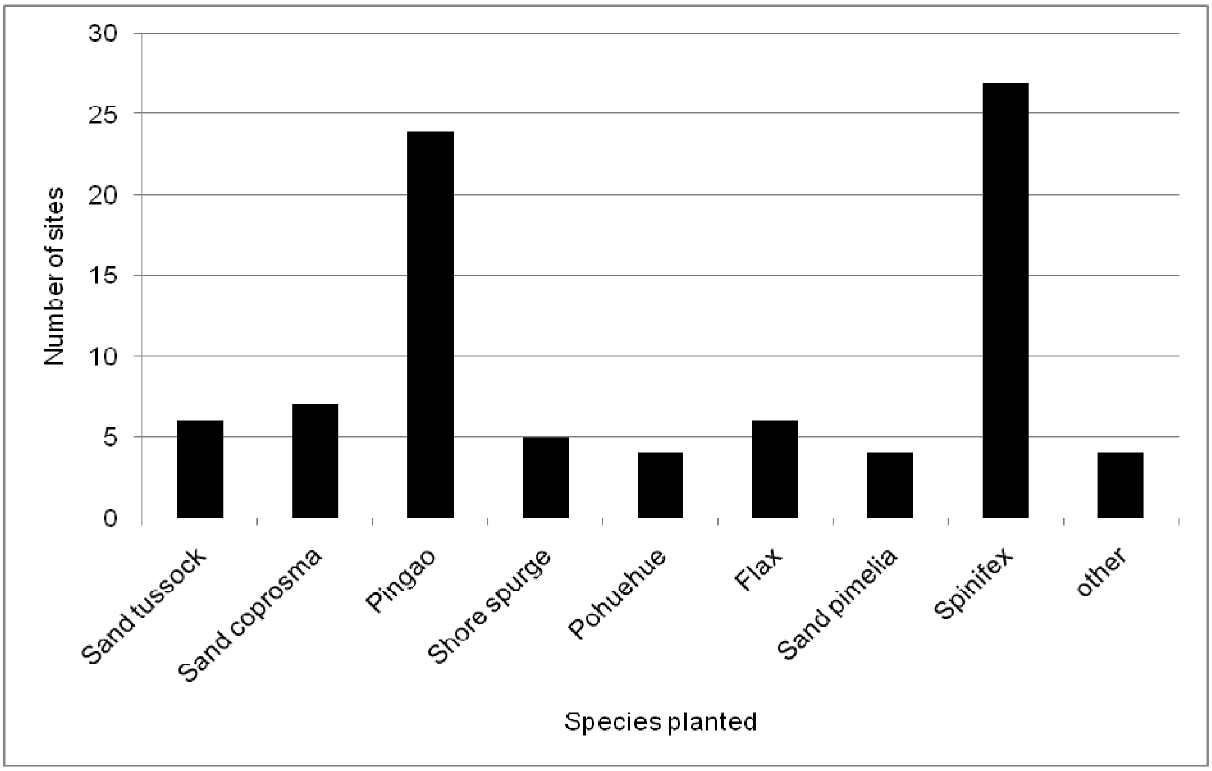

Figure 2.4: Native species planted by restoration groups

Marram grass was a problem in 75% of dunes, but was actively controlled in 39% of those dunes where it was a problem. Other exotic plants that were a problem were lupin (present in 46% of dunes), ice plant (50%), boneseed (29%), garden weeds (46%), and pasture grasses (39%). Exotic plant pests were controlled by hand pulling (18%), herbicide spray such as gallant (haloxyfop 6%

solution) or Round up (Glyphosphate 1% solution) (14%); a combination of both methods (54%); or not controlled at all (7%).

Rabbits were identified as the most troublesome animal pest (present in 79% of dunes), but only 18% of those groups who identified rabbits as a problem carried out rabbit control. Cats were present in 32% of dunes, and controlled at 75% of those sites. Mustelids (stoats weasels and ferrets) (18%) and rats (11%) were also identified as present. 21% of groups were unsure what animal pests were present in their dune (figure 2.5).

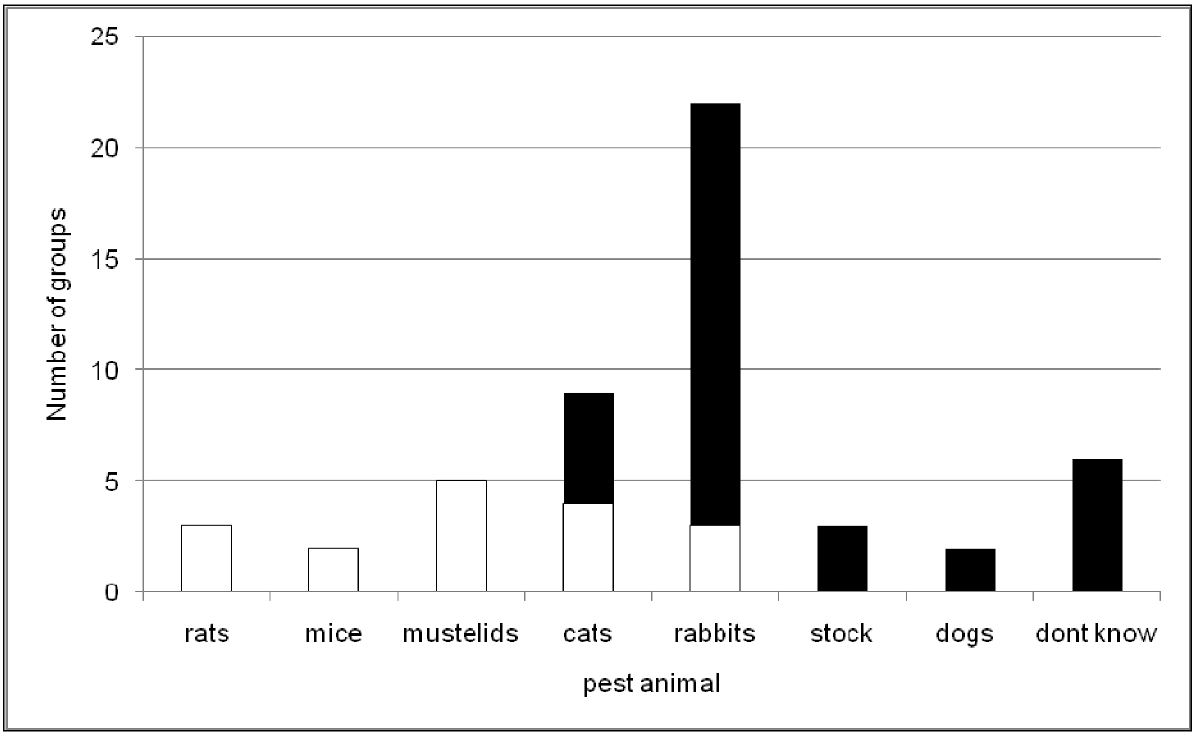

Figure 2.5: Presence of pest animals (black bars) with the proportion of sites in which they are controlled (white bars)

Motivations for restoration

Survey participants identified foreshore stabilisation and erosion control as the most important motivation behind their restoration efforts (68%). Plant conservation and animal conservation were less frequently identified as motivating factors, with (28%) and (4%) respectively (figure 2.6).

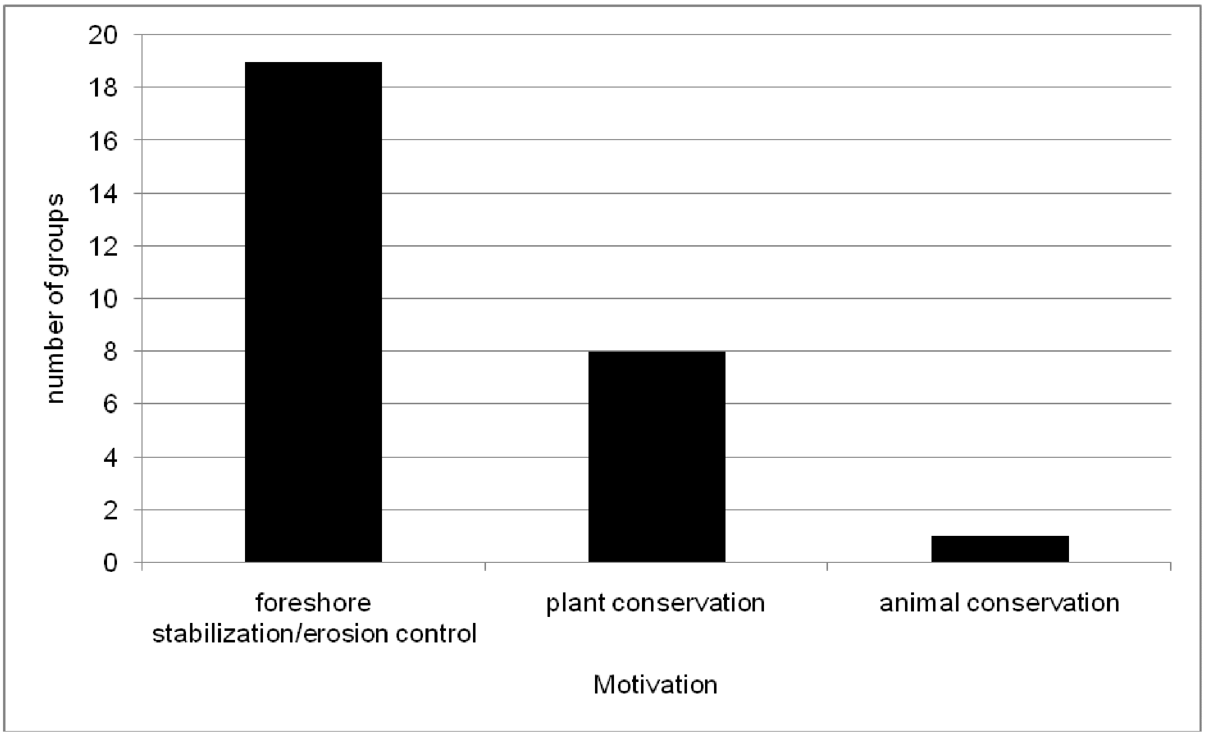

Figure 2.6: The most important motivation behind small scale dune restoration attempts as identified by survey participants.

Monitoring

Monitoring was said to be carried out by 93% of groups. Groups generally only monitored one factor of the dune restoration. Dune profile was the most common component that was monitored (42% of groups); native vegetation monitoring was also carried out by a number of groups (38%). Plant pests were monitored by two groups; endangered plants were monitored by only one group.

Birds were monitored by (11%) of groups, and one group had their lizard populations surveyed by an independent contractor. Only one group monitored animal pest numbers, and one group monitored invertebrates.

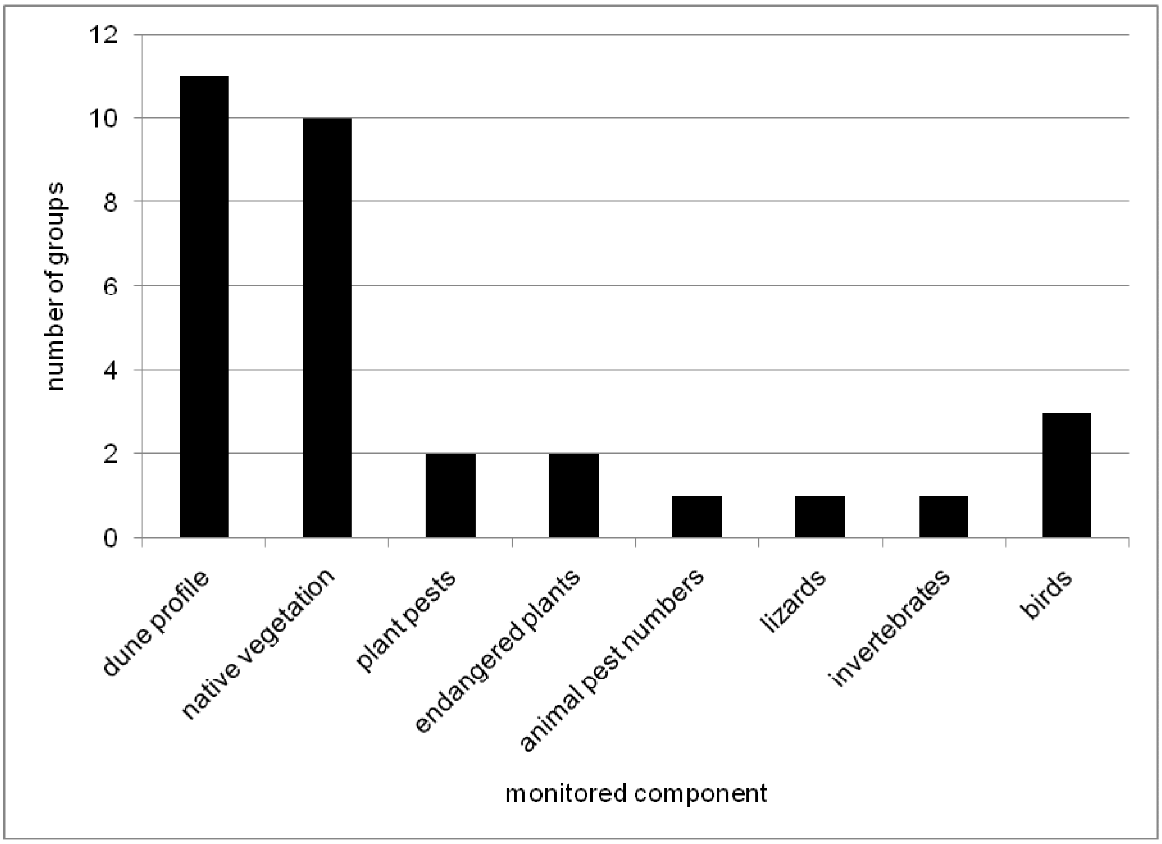

Figure 2.7: Components of restoration that were monitored by restoration groups.

Groups that carried out monitoring found it useful for observing positive (77%) and negative (42%) outcomes; helping develop more effective techniques (50%); and helping with funding applications (38%). Monitoring was also useful for recruiting volunteers (19%) (see figure 2.8). When asked if any significant results were found, no reports of biodiversity increases or sound scientific answers were given.

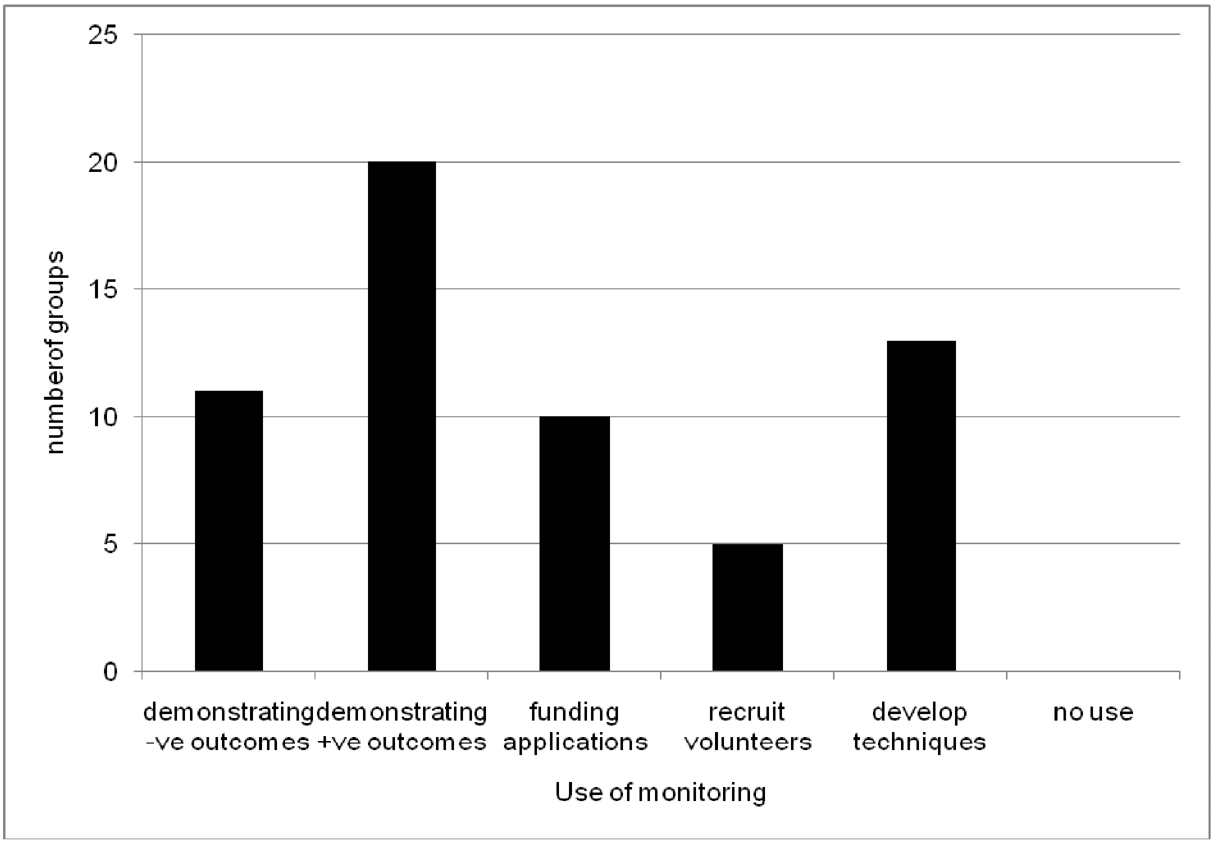

Figure 2.8: Use of monitoring results in dune restoration programmes

Groups that hadn't carried out monitoring, or hadn't done as much as they'd like to, identified lack of time (86%); knowledge (14%); and funding (57%) as limiting factors.

In the secondary monitoring survey, 10 responses were received. Of those respondents, 40% carried out specific biodiversity monitoring in their restoration project. Vegetation components monitored were pest plants (30%), native plants (30%) and threatened plants (20%). Faunal aspects monitored were counts of pest animals (20%), birds (20%), lizards (10%) and invertebrates (10%). Groups who didn't carry out monitoring either didn't know how (20%), didn't think it was necessary (20%), had a lack of time (20%), money (10%), support (10%) or thought it was too hard (10%). Consulting ecologists were the most helpful resource (20%), but also helpful was advice from the Dune

Restoration Trust (10%), or the local council (10%). No groups mentioned 'Measuring Success' (Miller & Paul 2007) as an important resource, despite being designed for the purpose as a monitoring resource.

Funding and Support

Many groups were supported with funding from the local council (57%).Some groups were funded by a Department of Conservation grant (14%). Other groups (14%) carried out fundraising on their own, and some groups were funded by a variety of sources (14%).

Ninety three percent of groups had access to a council worker or coast-care coordinator, mostly utilised for advice (71% of groups); help with funding (71%), and accessing information (68%). They also helped coordinate regular meetings (21% of groups).

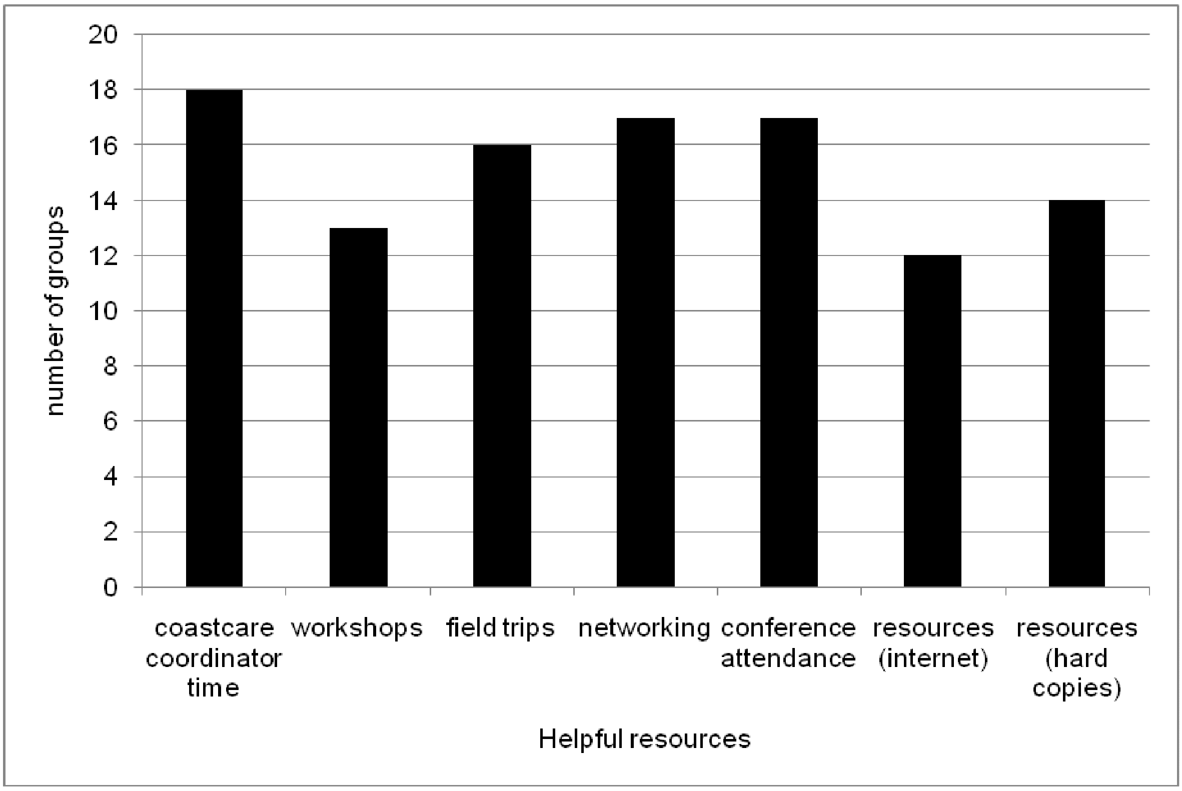

Figure 2.9: Resources that groups identified that would be helpful in the future.

Nonetheless, 64% of groups said they would benefit from increased time with a coast-care coordinator; increased networking with other groups in the area (61%); and more workshops or lectures from experts (46%). Attendance at the Dunes Trust conference was also considered valuable (61%), as was increased supply of resources and information through the internet (43%) or as hard copies (50%) (Figure 2.9).

The bulletin series and support provided by the Dune Restoration Trust were identified as the most useful resources (61%). Local councils (26%) and the Department of Conservation (13%) were also stated as important sources of information.

The majority of groups were members of the Dune Restoration Trust (71%). (7%) of groups had not heard of the trust, and (7%) of groups said they had enough knowledge to do the job. Fifteen percent of groups said they were unable to afford to be members of the trust. The individuals who completed the survey were clearly passionate about what they do.

Discussion

Although this survey reached only a small portion of dune groups around the country, it gives a clear picture of the overriding motivations for restoring a local fore dune system. These findings give evidence for claims made by restoration ecologists Hobbs & Norton (1996) that restoration is not accompanied by systematic monitoring or based on sound science. It also identifies the main goal for many dune restorations is to prevent erosion and stabilise the foreshore, with conservation of plants and animals being secondary motivations. In what follows the importance of considering all ecosystem components is discussed, whilst taking into account the social limitations which may be constraining the use of an efficient monitoring method.

The main motivation for restoration of the dune was erosion protection and stabilisation, as suggested by Hilton et al*.* (2000), and Miller & Paul (2007). Monitoring of dune profiles or vegetation growth was generally carried out by groups who identified this as a priority. Plant conservation was an important motivation for a number of groups, which is also illustrated by the inclusion of threatened species such as shore spurge and sand daphne in some restoration plantings. Though for most groups, the planting of threatened plant species was not followed up with monitoring. From the survey, it appears that plant species other than spinifex and pīngao are only occasionally being included in planting regimes. A number of New Zealand dune species are now threatened or in decline, many now appearing in our threatened species classification lists (Hitchmough et al. 2007). There is potential for these species to be included in restoration, which will not only benefit the plants, but will also provide potential habitat for endemic sand dune fauna. This will also fulfil the main aim of restoring the dune for erosion protection and foreshore stabilisation, as a number of native species have specialist sand trapping properties. For example, threatened species such as sand tussock, pohuehue and sand coprosma assist in the accumulation of sand (Esler 1970; Milne & Sawyer 2002).

Conservation of native animals was the main motivation for only one group, who actively controlled introduced predators – cats, and mustelids. However, no monitoring of the effect of restoration on animal populations was carried out, despite the dune being a key habitat for an endangered bird species, the banded dotterel (*Charidrius bicinctus*). Control of introduced predators should include whole predator guilds. For example, removal of only the top predator (e.g. cats) may result in hyper predation of native fauna by predators lower down the food chain (e.g. mice) (Norbury 2001; Lettink et al. 2008). This results when mice populations increase rapidly following the removal of cats, and subsequently cause increased predation on native fauna. Pest control needs to be accompanied with monitoring to ensure the effectiveness of the current method, and to assess any indirect effects of the control regime.

The results show that although great things are being done by the restoration groups, such as planting endangered species, and controlling pests to protect native fauna, these actions are not being coupled with a formal monitoring regime to document their level of success or as a basis for making changes to their approach if required. Furthermore, for restoration to reach its full potential for conservation of dwindling populations of endemic sand dune flora and fauna, it needs to incorporate these species into restoration. The Dune Restoration Trust have stated they would support projects investigating the incorporation of fauna into restoration (Spence et al. 2007), although it is not currently on their list of research priorities.

Nearly all groups stated that they carried out monitoring, but generally only one component was monitored, for example dune profile or vegetation. When questioned further on monitoring, only four out of the ten respondents stated they carried out specific biodiversity monitoring – mostly of vegetation presence and abundance. Invertebrates and lizards were only monitored at one site, and this was done by a consultant. Birds and pest animals were more commonly monitored but this was still by a small minority of groups. These results support the notion that restoration is primarily botanical, and fauna are often left to their own devices (Young 2000; Majer 2009). The consideration of fauna in the restoration process is beneficial, as animals have key roles to play in ecosystem functioning (Young 2000; Majer 2009). Majer (2009) implies that practitioners are beginning to monitor a wider range of parameters in the restoration process. The results of this study seem to suggest that dune restoration practitioners in New Zealand may still be limited in their ability to do so due to a lack of knowledge, time and resources for the purpose.

Groups found that the monitoring they carried out helped demonstrate positive (and negative) outcomes, and helped demonstrate more effective techniques. Some groups also mentioned that it helped with funding applications and the recruitment of volunteers. Lack of time and funding were identified as limiting factors, but interestingly, only one group admitted they lacked the knowledge to carry out monitoring. It is suspected that this question may have been misinterpreted based on varying definitions of monitoring. For example, visual inspection is one form of casual monitoring, recording species occurrence in randomly placed quadrats or traps is a more time-consuming method, but more effective for assessing ecological outcomes.

A similar web based questionnaire was used in a large international survey of the river restoration community by Bernhardt et al. (2007) who observed that measurable objectives were set by less than half of groups. Without explicit goals and objectives in the restoration, there is nothing to test the monitoring results against. The lack of planning and monitoring could be attributed to a combination of a lack of knowledge, time and funding. This is familiar with most restoration projects (Lee et al. 2005); however dune restoration in New Zealand has a strong foundation to build additional knowledge onto to ensure increased ecological effectiveness.

The majority of groups had access to a local council worker, who was utilised mostly for advice, but also for funding applications and access to information. Almost every group said their group would benefit from additional support from a coast care coordinator, workshops or lectures from experts, and increased networking between groups. The Dune Restoration Trust is clearly a highly respected authority, and will continue to be the main source of information and scientific guidance for groups. The trust has the power to significantly influence restoration projects if a change in practice is recommended. Groups thought they would benefit from increased assistance from a coast care coordinator. The information produced by the Trust such as the Bulletins were clearly very useful for the groups. However, it is likely these resources are under utilised possibly due to their inaccessibility – groups are required to purchase the bulletins. There is potential for information to be more easily accessed through the internet, and many groups identified increased access to resources would be beneficial to their project.

Now is the perfect opportunity for best practice methods to be assessed. The inclusion of threatened plant species and consideration of fauna will increase the ecological success of dune restoration. With additional scientific knowledge, funding and resources, these restorations could contribute much more in terms of improving native flora and fauna that are now so highly restricted. Chapter three investigates the faunal assemblages of restored and exotic sand dune systems to identify areas that could possibly be improved. One possible solution to the monitoring problem is to have a few sites intensively monitored by scientists and to extrapolate the results of these findings more widely. In addition, low cost, rule-of-thumb monitoring techniques can be implemented more extensively to assess the wider picture and to help draw attention to anomalies worthy of further research. Chapter four discusses the possibilities of varied monitoring approaches.

Limitations of the survey

There are some limitations with a web based survey. It is possible that some groups may not have had internet access, therefore reducing their ability to participate in the survey. In addition, only one representative from each group completed the survey, therefore their responses may have differed from the rest of the group. The survey was not compulsory, and there was no incentive, therefore less participation was to be expected.

There was room for misinterpretation of some questions, especially in regard to the use of monitoring. Monitoring can mean a range of things to different people, and may not necessarily be the scientific kind as identified above. For example, some groups may class visual assessment of vegetation as monitoring, while another may use a more quantitative method. More rigorous questioning of a larger proportion of groups will be required to fully quantify the practices of sand dune restoration. Further research is needed to maximise the ecological effectiveness of dune restoration in New Zealand.

Conclusion

Small scale restoration of sand dunes was carried out mainly for the purposes of erosion protection and foreshore stabilisation. In comparison, plant and animal conservation were the main motivations for only a small minority of groups. Groups are becoming generally more aware of conservation issues, but may be limited by knowledge, time and resources to include conservation of flora and fauna in their restoration priorities. Consideration of motivations is vital to ensure that goals and objectives are shaped accordingly. To ensure biodiversity values and conservation of native biota is included within restoration priorities, a shift in thinking is required. Little is known of the ecology of our dune systems, and restoration provides opportunities to learn more about the ecosystem to better inform its management. Incorporation of a user friendly monitoring method may help alleviate this. Monitoring was carried out by most groups, but may not have involved quantitative analysis to assess biodiversity gains or quantify the effect of restoration on the ecosystem functioning. Monitoring was commonly based on vegetation, and would benefit from including fauna in the future.

Restoration methods commonly used in the restoration community should be evaluated to determine their ecological effectiveness (Hobbs 2005; as cited by Bernhardt et al. 2005). Chapter three seeks to investigate the biodiversity of restored dunes, to establish an understanding of the floral and faunal communities of restored and marram grass dominated dunes.

References

Allen EB 2003. New Directions and Growth of Restoration Ecology. Restoration Ecology 11(1): 1-2.

Atkinson IAE 1994. Guidelines to the development and monitoring of ecological restoration programmes. Department of Conservation Technical Series 7. pp

Atkinson IAE 2001. Introduced mammals and models for restoration. Biological Conservation 99. Pp.

Bernhardt ES, Sudduth EB, Palmer MA, Allan JD, Meyer JL, Alexander G, Follastad-Shah J, Hassett B, Jenkinson R, Lave R, Rumps J, Pagano L 2007. Restoring Rivers One Reach at a Time: Results from a Survey of U.S. River Restoration Practitioners. Restoration Ecology 15(3): 482-493.

Byrd J 2008. Kiwis Counting Kiwis: Biodiversity Monitoring on Private Land in New Zealand. Victoria University of Wellington. Unpublished MSc thesis. 175p.

Clewall A, Aronson J 2006. Motivations for the Restoration of Ecosystems. Conservation Biology 20(2): 420-428.

Davis MA, Slobodkin LB 2004. The Science and Values of Restoration Ecology. Restoration Ecology 12(1): 1-3

Ehrenfield JG 2000. Defining the Limits of Restoration: The Need for Realistic Goals. Restoration Ecology 8(1): 2-9.

Gadgil RL, Ede FJ 1998. Application of scientific principles to sand dune stabilization in New Zealand: past progress and future needs. Land Degradation and Development 9: 131-142.

Greenwood JJD, Robinson RA 2006. Principles of Sampling. In: Ecological Census Techniques. Sutherland WJ (ed). Cambridge University Press: 13-85.

Hackney CT 2000. Restoration of Coastal habitats: expectation and reality. Ecological Engineering 15: 165–170.

Harris JA, van Digglen R 2006. Ecological restoration as a project for global society. In: van Andel J, Aronson J (eds). Restoration Ecology: The New Frontier. Blackwell Publishing.

Herrick JE, Schuman GE, Rango A 2006. Monitoring ecological processes for restoration projects. Journal for Nature Conservation 14: 161-171.

Higgs ES 1997. What is Good Ecological Restoration? Conservation Biology 11(2): 338-348.

Hilton MJ, Macauley U, Henderson R 2000. Inventory of New Zealand's active dunelands. Science for Conservation 157. Department of Conservation, Wellington, New Zealand.

Hobbs RJ, Harris JA 2001. Restoration Ecology: Repairing the Earth's Ecosystems in the New Millennium. Restoration Ecology 9(2): 239-246.

Hobbs RJ, Norton DA 1996. Towards a Conceptual Framework for Restoration Ecology. Restoration Ecology 4: 93-110.

Hobbs RJ 2006. Foreword. In : Falk DA, Palmer MA, Zedler JB. Foundations of Restoration Ecology. Washington D.C. Island Press. Pp

Hobbs RJ 2007. Setting Effective and Realistic Restoration Goals: Key Directions for Research. Restoration Ecology 15(2): 354-357.

Kentula ME 2000. Perspectives on setting success criteria for wetland restoration. Ecological Engineering 15: 199-209.

Lake PS 2001. On the maturing of restoration: Linking ecological research and restoration. Ecological Management & Restoration 2(2): 110-115.

Lee W, McGlone M, Wright E 2005. Biodiversity Inventory and Monitoring: A review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. Landcare Research Contract Report: LC0405/122. 218p

Leigh P 2005. The ecological crisis, the human condition, and community-based restoration as an instrument for its cure. Ethics in Science and Environmental Politics: 3-15.

Lettink M, Cree A, Norbury G, Seddon PJ 2008. Monitoring and restoration options for lizards on Kaitorete Spit, Canterbury. DOC Research and Development Series 301. Wellington, Department of Conservation.

McCoy ED, Mushinsky HR 2002. Measuring the Success of Wildlife Community Restoration. Ecological Applications 12(6): 1861-1871.

Miller JR, Hobbs RJ 2007. Habitat Restoration- Do We Know What We're Doing? Restoration Ecology 15(3): 382-390.

Palmer MA, Falk MA, Zedler JB 2006. Ecological Theory and Restoration Ecology. In: Falk DA (ed) Foundations of Restoration Ecology. Washington, Island Press: 1-10.

Ruiz-Jaen MC, Aide TM 2005. Restoration Success: How is it being measured? Restoration Ecology 13(3): 569-577.

Smith, R. 2008. Personal communication with Robyn Smith: Community Environmental Projects team leader, Greater Wellington Regional Council, September 2008.

Society for Ecological Restoration International Science & Policy Working Group 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International. http://www.ser.org/content/ecological_restoration_primer.asp Downloaded February 2009.

Thom RM 2000. Adaptive management of coastal restoration projects. Ecological Engineering 15: 365-372.

Wheaton JM, Darby SE, Sear DA, Milne JA 2006. Does scientific conjecture accurately describe restoration practice? Insight from an international river restoration survey. Area 38(2): 128-142.

Young TP 2000. Restoration ecology and conservation biology. Biological Conservation 92: 73-83.

Chapter three

The inclusion of native fauna in New Zealand's dune restoration movement

Figure 3.1: Marram dominated fore dune at Petone Beach, Wellington. Photograph taken by author November 2008.

Abstract

Coastal sand dunes in New Zealand are critically endangered ecosystems, supporting a wide variety of specialist native flora and fauna. Dunes have declined significantly in area over the past century, due to coastal development and stabilization using marram grass (*Ammophilia arenaria*). Interest in the restoration of dune ecosystems is becoming increasingly widespread throughout the country. Many groups have carried out small scale rehabilitations, aiming to restore natural character and ensure erosion protection. Efforts are generally not monitored, and often rest on the assumption that replacement of exotic vegetation with native sand binders will result in the restoration of a fully functioning ecosystem. This chapter investigates whether restored dunes have higher biodiversity values, based on their invertebrate, reptile and mammalian fauna.

Plant and animal biodiversity was sampled at fore dunes under restoration with native sand-binding species, paired with nearby fore dunes dominated by marram grass. Marram dunes contained higher vegetation, with greater projected foliage cover than restored dunes. Mouse population density was higher in marram dunes, as was population size of common skink (*Oligosoma nigraplantare polychroma*). Marram dunes contained higher abundance and diversity of invertebrates, especially spiders and beetles. Beetle species richness was significantly higher in marram dunes. The orders Amphipoda (hoppers), Coleoptera (beetles), and Mantodea (Preying mantids) were identified as potential indicator orders, occurring significantly more often in Marram dunes. Marram grass appears to provide desirable habitat for a diverse and abundant range of fauna due to its greater foliage cover and height. Steps

can be taken to ensure that dune restoration projects are designed to benefit fauna. User friendly monitoring of animal assemblages can be carried out using the indicator species identified by this study.

Introduction

The introduction of marram grass (*Ammophila arenaria*) into New Zealand's unique coastal dune environment has resulted in a serious decline of the unique and specialised flora described by early botanists (Cockayne 1909; 1911; 1967). Marram grass was initially introduced and planted *en masse* to stabilise large active dunes in order to protect farmland and to establish plantation forestry a short distance inland. This Northern hemisphere grass species has since become naturalised and succeeded in invading most dunes throughout the country (Hilton et al. 2000; Dixon et al. 2004). Grazing, urban and pastoral development and the introduction of exotic herbivores have also contributed to the significant loss of habitat for the unique and specialised native fauna. Many dune plants are now in decline (see appendix three), and the state of dune faunal assemblages is unknown, aside from charismatic species such as the katipō spider (*Lactrodectus sp.*). The katipō is probably the animal that people most commonly associate with New Zealand sand dunes, although it is now in serious decline (Hitchmough et al. 2007) largely due to habitat loss (Patrick 2002; Costall 2006; Costall & Death 2009). Numerous endemic moth species have been found in sand dunes, but there have only been limited investigations at certain sites (for example: Patrick 1994). Skinks have been studied in unmodified sand dune environments using pitfall trapping (Freeman 1997; Lettink & Cree 2006; Wedding 2007) and artificial retreats (Lettink & Cree

2007; Lettink et al. 2008) and many species are now in decline (Hitchmough et al. 2007).

Rehabilitation of these fragile ecosystems has become increasingly common, becoming a feature of many city and regional council coastal management programmes. A feature of these programmes is to restore the 'natural character' of dunes for erosion control, removing marram grass and planting native sand binding species such as pingaō (*Desmoschoenus spiralis*) and spinifex (*Spinifex sericeus*) (Spence et al. 2007). These efforts are generally successful in achieving their goals of preventing erosion, but there is great potential for small scale restoration to incorporate conservation of threatened flora and fauna.

Use of restoration as a tool to facilitate habitat recovery and conserve biodiversity requires an ecological community based approach, incorporating management of floral and faunal assemblages (Keesing & Wratten 1998; Watts & Gibbs 2002). However, restoration ecology is typically a botanically based discipline (Young 2000), often focussing on re-establishing the vegetation structure of historic communities with little explicit consideration for the animal assemblages that may have been associated with them (Keesing & Wratten 1998). Furthermore, the practitioner often believes that rehabilitation of the structural vegetative components of a habitat will automatically result in the return of the appropriate fauna (Clewall & Rieger 1997; Palmer et al. 1997; Longcore 2003). The return of fauna is seldom monitored (Clewall & Rieger 1997), but a number of studies have demonstrated that restoration of vegetation does not result in the restoration of fauna, particularly invertebrates (Keesing & Wratten 1998; Webb et al. 2000; Longcore 2003). Invertebrates provide important ecosystem functions including decomposition and pollination (McGuiness 2001) Studies show that invertebrates tend to be slower at colonising restored habitats than their vertebrate counterparts, and that animals such as reptiles have quite specific habitat requirements that need to be catered for in the restoration process (Nicols & Grant 2007; Lettink et al. 2008). Majer (2009) suggests that fauna are becoming increasingly represented in the restoration literature, but it is clear that the science of restoring habitats for faunal biodiversity is still at an early stage (Miller & Hobbs 2007).

The fauna of New Zealand are highly vulnerable to predation by introduced mammals, habitat loss, and habitat fragmentation (Crisp et al. 1998; McGuiness 2001). However, little is known about the relationships between vegetation and animal abundance and diversity in restored sand dunes. Plant communities generally influence the physical structure of a habitat, and therefore influence the distribution of fauna (Tews et al. 2004). Habitat requirements differ between species, but a general rule in ecology is that the more complex a habitat, the more species it will contain (Palmer et al. 1997; Tews et al. 2004). In New Zealand sand dunes, native plant species such as pohuehue, sand coprosma and sand daphne provide habitat and a food source and habitat for lizards, moths and other invertebrates (Patrick 1994; Lettink et al. 2008; and others). Katipō are known to prefer native vegetation, particularly spinifex, sand coprosma, and pingaō (Costall 2006), while other invertebrates and skinks require adequate vegetation cover (Norbury et al. 2009). Due to widespread loss of native habitat, many species may now use exotic vegetation as refuges (Crisp et al. 1998; McGuiness 2001; Costall 2006); therefore the mass removal of marram grass for restoration is likely to have negative implications for native fauna. The inclusion of rare sand dune plants will have reciprocal benefits for flora *and* fauna. To conserve the remaining biodiversity of sand dune ecosystems, it is important that the effect of restoration on these communities is investigated.

The main objective of this study therefore was to investigate the faunal assemblages of fore dune sites undergoing restoration with native sand-binding plants, to compare with their marram grass dominated counterparts in the Wellington region. Two specific hypotheses were:

(1) That marram dunes contain higher vegetation and greater projected foliage cover than restored dunes;

(2) That restored dunes have higher biodiversity values, as indicated by sampling of invertebrates (beetle, ant, spider), lizards and mice

From this investigation, I aimed to provide recommendations for the incorporation of faunal conservation and monitoring into sand dune re-vegetation projects.

Methods

Site selection

Six study sites containing examples of both marram dominated dunes and 'restored' dunes were selected along the western coastline of the greater Wellington Region. Sites were considered restored if they had been intentionally replanted within the last 5-6 years with native sand binding plants such as spinifex (*Spinifex sericeus*) and pīngao (*Desmoschoenus spiralis*). Restored sites were only selected if they had an adjacent marram-dominated dune. Marram dunes were densely vegetated with marram grass (*Ammophila arenaria*), and other exotic species such as iceplant (*Carpobrotus spp.*), brown top (*Agrostis capillaris*), ripgut brome (*Bromus diandrus*), and hares tail (*Lagarus ovata*). Table 3.1 contains GPS coordinates for each site, Figure 3.1 shows their location around Wellington and see appendix five for detailed site characteristics and aerial photos.

Table 3.1. Locations of six sampling sites with New Zealand Map Grid coordinates (NZ1949 geodatum).

Site	Abbr.	Marram	Restored
Lyall Bay	Lyal	S41 19.864 E174 47.547	S41 19.686 E174 48.02
Eastbourne	Eas	S41 17.436 E174 53.654	S41 17.652 E174 53.599
Petone 1	Pet1	S41 13.609 E174 52.235	S41 13.668 E174 52.460
Petone 2	Pet2	S41 14.010 E174 53.498	S41 13.951 E174 53.393
Paraparaumu	Para	S40 52.617 E175 00.110	S40 52.604 E174 59.640
Otaki	Otak	S40 43.879 E175 07.172	S40 43.854 E175 07.271

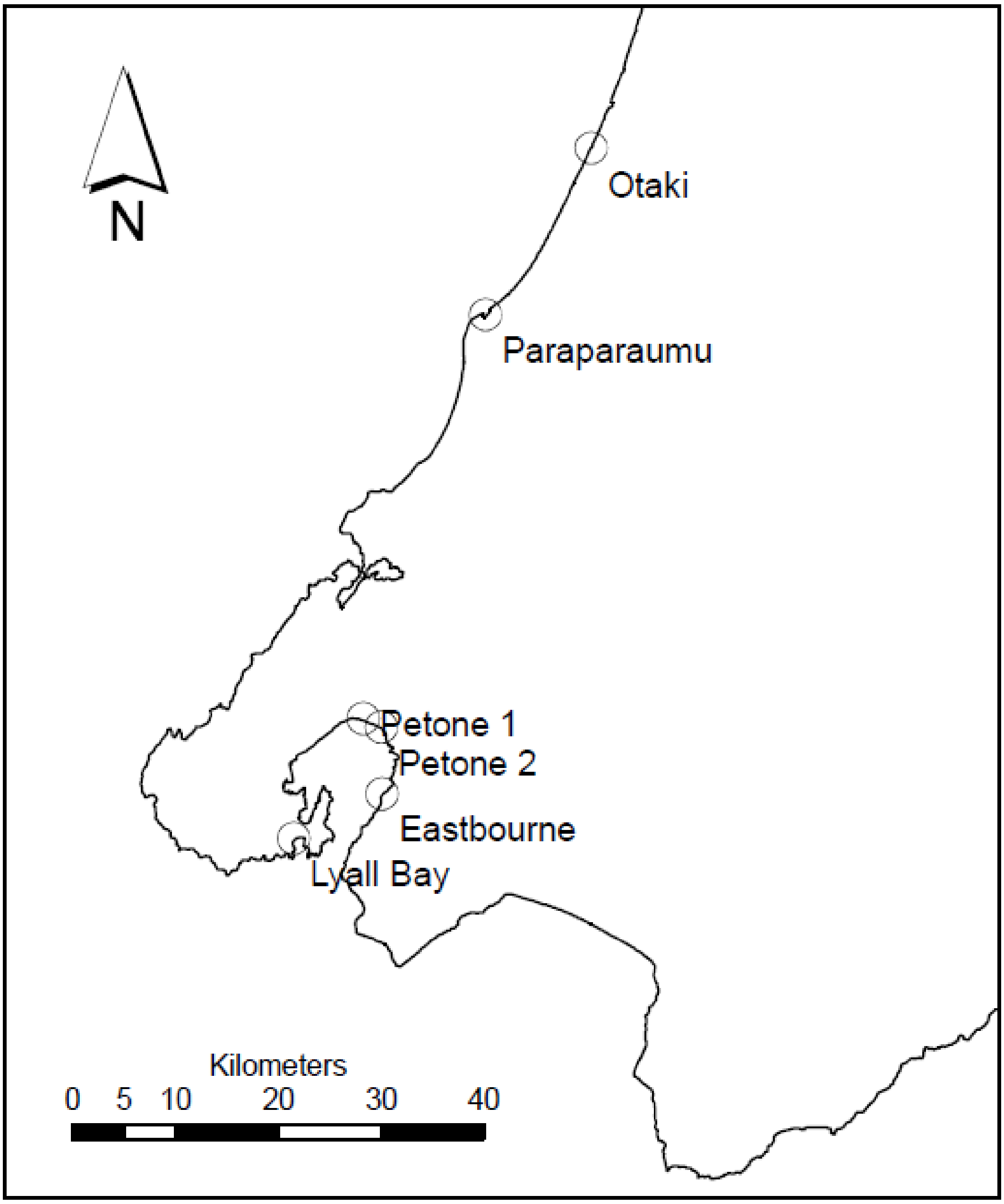

Figure 3.2: Outline of lower North Island of New Zealand, featuring the six sample sites.

Experimental design and layout

The sampling method included an array of pitfall traps, quadrats and tracking tunnels as portrayed in figure 3.3. The design was replicated once within each marram and restored pair. Vegetation was assessed in November, 2008; invertebrates were sampled in December 2008 and February 2009; and lizards and mammals were sampled in February 2009.

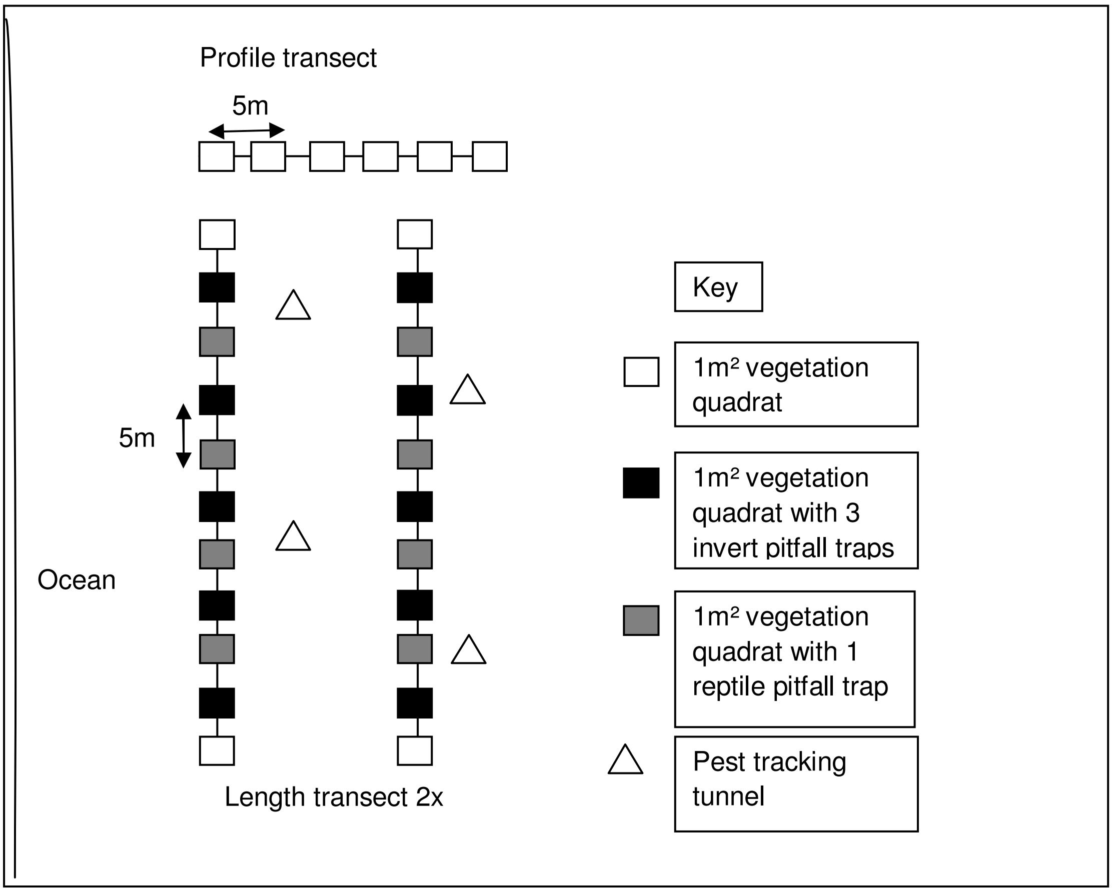

Figure 3.3: experimental design showing vegetation transects and quadrat layout, position of invertebrate and skink pitfall traps, and position of pest tracking tunnels.

Vegetation

Vegetation was assessed using measures of density, percentage cover, and height. Sessile plants are easier to assess than mobile fauna, although throughout the seasons they may undergo phenological changes (Bullock 2006). All vegetation was assessed in the month of November, giving only a snapshot of plant structure for spring.

Three randomly placed transects ran perpendicular to the ocean the width of the dune. 1m² quadrats placed at each five metre mark beginning at zero. The purpose of these transects was to describe the physical profile and botanical zonation of the sand dune across the dominant environmental gradient. Information from the profile transect was used to help locate the position of the length-ways transects. The two 50m transects running parallel to the ocean were used to obtain a more complete survey of biodiversity within the typical "fore-dune" zone. The beginning of each transect was established randomly, and marked with a GPS waypoint (within 5m accuracy) and marker tape, to ensure the same area was sampled on each visit.

Especially in a sand dune environment, it can be difficult to distinguish between individual plants, due to underground rhizomes (Bullock 2006), and can be time expensive counting individual plants within a quadrat. Therefore, in addition to counting numbers of individuals, a cover based measurement was developed, as recommended by Miller & Paul (2007). Overall percentage cover for each quadrat was estimated (see table 3.2), plus the percentage cover of dominant species, and percentage cover of the vegetation biomass at three height classes (0-50cm; 51-100cm; >101cm).

Table 3.2: categories of percentage cover (adapted from Miller & Paul (2007)).

Category	Percentage cover
0	0%
1	1-20%
2	21-40%
3	41-60%
4	61-80%
5	81-100%

Invertebrates

Monitoring insect assemblages is known to be challenging due to seasonal fluctuation, responses to weather, and levels of activity (Jones & Toft 2004). Sampling of invertebrate indicator groups is a more common and less intensive approach to sampling an entire assemblage of invertebrates for biodiversity monitoring purposes (Anderson et al. 2004). Pitfall trapping used in conjunction with sweep netting is an effective method of sampling both epigeic and vegetation dwelling invertebrates (Galle 1991), and provides an effective measure of relative abundance (Ausden & Drake, 2006). In the present study, invertebrates were sampled using pitfall traps and sweep netting, and identified with varying degrees of taxonomic resolution.

Pitfall trapping

Three pitfall traps (200ml plastic cups; 8cm diameter) were buried to the rim with sand within every second longitudinal vegetation quadrat in the

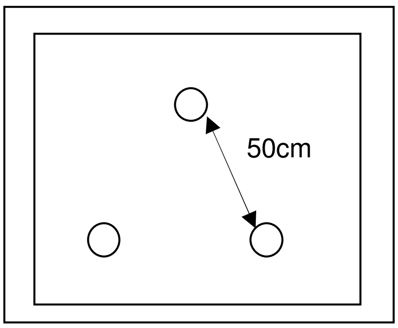

Figure 3.4: layout of invertebrate pitfall traps

shape of an equilateral triangle (see figure 3.4; layout as shown in figure 3.3). A second cup was placed inside each for ease of sample removal, flush with the sand surface. Each trap was quarter filled with a salt water solution (NaCl, 100g/L) and 2-3ml of detergent to break the surface tension of the water. Using a more toxic solution such as Gaults solution (Crisp et al. 1996), or Ethylene glycol (Ausden & Drake 2006, Norbury et al. 2009), was unnecessary, due to the short term nature of the sampling, and undesirable due to the proximity of the sites to public recreation areas. Traps were left for two nights, and the samples were collected after 44-48 hours. Each sample was drained and refilled with alcohol (ethanol 70%) to preserve the specimens. Sampling was carried out in December, and repeated in February (see Appendix five for exact dates at each site).

Sweep netting

A sweep netting method was employed to ensure arboreal and flying insects were included in the study. Prior to laying out the pitfall traps in the morning (between 1000 – 1200hrs), a large sweep net (30cm diameter) was systematically swept through the vegetation two metres to each side of each transect, while walking its length. Caught individuals were sucked up with an aspirator and placed in a specimen jar, and preserved with ethanol (70%). This was repeated twice per transect: once prior to setting pitfall traps, and once prior to bringing them in 2 days later.

Identification of invertebrates

Individuals were identified using a dissection microscope. Body length of each invertebrate was measured for calculation of biomass in each habitat. Each sample was identified down to order, and then a few groups – Coleoptera, Formicidae, and Araneae (beetles, ants and spiders) were further investigated. Recognisable Taxonomic Units (RTUs) were developed in conjunction with the Entomology group at Lincoln University, and were identified to family, genus or species were possible with assistance from a specialist (John Marris for Coleoptera, Habteab Habtom for ants and Jagoba Malumbres-Olarte for the spiders). Detailed lists of these RTUs are in appendix two.

Katipō

Searches for *L. katipō* were carried out along each longitudinal vegetation transect. The searcher spent exactly five minutes searching through possible habitat within five metres either side of the transect. Individuals found were noted, and surrounding habitat assessed. This method was adapted from a nationwide katipō survey carried out by Patrick (2002). The difficulty of locating katipō in amateur habitat searches is acknowledged (Costall 2006).

Lizards

Non-lethal pitfall trapping has been used to monitor lizards in sand dunes (Lettink et al, 2008) and was decided to be the most appropriate method for this study. Pitfall traps (4 litre plastic buckets) were buried to the rim in sand and placed within every other quadrat along each transect (layout as shown in figure 3.2). Small holes were drilled in the bottom for drainage. Each bucket contained a piece of pear as bait, and a wet sponge for moisture. Pear was found to be an effective bait by Whitaker (1967), and meat based baits may have attracted predators. Driftwood, vegetation or dry seaweed was placed over the top of the each trap to prevent predation and sun exposure. This method was adapted from Newman (1994) who used rocks to cover the traps. Traps were left over night for a period of three nights, and checked after 24 hours. Captured individuals were identified to species. Adults were sexed; males by averting the hemipenes, and individuals without hemipenes were assumed to be female or juvenile depending on their size. Snout vent length (SVL) and tail to vent length measurements (TVL) were taken using a millimetre ruler. Presence or absence of tail and tail regeneration was noted.

Each individual was then marked on the ventral surface with a unique number with non toxic silver pen and released back into the environment immediately (VUW AEC permit 2008R11, DOC research permit WE/338/RES). The trap was then reset with pear and wet sponge.

Mice

To observe presence of mice, tracking tunnels were placed in the sand dunes for the duration of the lizard trapping (three nights). Tracking rates may reflect either levels of activity or population density (Brown et al. 1996) and for the purpose of this study, tunnels tracked was used as a measure of density. Tracking tunnels consisted of a long metal base with an ink pad in the middle and slots for blotting paper on each end (see figure 3.5 below). A 60cm long metal tunnel fitted over the base. The ink pad was charged with black stamp ink, and peanut butter was placed in the middle as bait as recommended by Lettink et al. (2008).

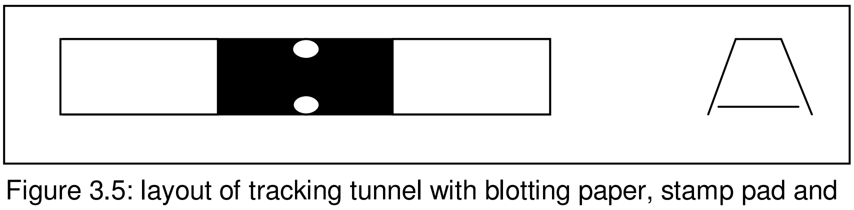

Figure 3.5: layout of tracking tunnel with blotting paper, stamp pad and peanut butter bait (left) and side on view of tunnel with base (right)

Statistical analysis

The R computer package (2.8.1) (R Core Development Team 2009) was used to conduct statistical analysis of the biodiversity data. For the majority of tests, data were summarized at the level of the transect, and the main interest was in comparing between the two types of dune (habitat = restored vs marram). Thus 'habitat' was the fixed factor, and the transect pair nested within site were random factors, as determined by the spatial structure of the sampling.

Vegetation

Percentage cover of vegetation biomass was quantified by chi square, to assess difference in vegetation cover between habitats. The relative height distribution of biomass present was compared by graphing the medians and the inter-quartile range of the vegetation height data. Species abundances were plotted on abundance/occupancy matrices, separately for marram and restored sites, and dominant species identified. Simpson's diversity index was calculated for each transect (eqn 3.1), and this was compared using a Linear Mixed effects model in R and graphing Simpson index of the average of each pair of transects (with range expressed as error bars).

$$D \equiv \frac{\sum n(n-1)}{N(N-1)}$$ eqn (3.1)

Where, *n* is the total number of organisms of a particular species, and N is the total number of organisms of all species. A measure of community dissimilarity of the vegetation data between transects was calculated using the Bray/Curtis distance, which was used as input for a principle coordinates analysis of community structure using the 'pco' function in the 'labdsv' package in R

(Roberts 2008). This was repeated omitting the 3 main sand binding species (spinifex, marram and pīngao) as they would be expected to be major determinants of community composition. An 'ord' test was conducted to test whether habitat was influential in determining the plant community.

Lizard population estimates

The Peterson estimate (Begon, 1979) was used to provide an estimate of population size at each site in the two habitats, modified due to the small sample sizes (eqn 3.2). Standard error was calculated for each site and habitat (eqn 3.3).

$$\hat{N} \equiv \frac{r(n+1)}{(m+1)} \qquad \text{(eqn 3.2)}$$

$$SE_{\hat{N}} \equiv \sqrt{\frac{r^2(n+1)(n-m)}{(m+1)^2(m+2)}} \qquad \text{(eqn 3.3)}$$

Where, *r* is the total number of individuals captured (marked and unmarked), *n* is the total number of marked individuals, *m* is the number of recaptures. This method assumes that each individual has an equal chance of being caught and that being caught and handled does not influence the capture rate (Begon, 1979). Estimated population size for each site was square-root transformed to normalize a Poisson distribution, and a paired Student's *t*-test run to test for a difference in means between habitats.

Invertebrates

Biomass of invertebrates at each site was determined by pooling the body length measurements from pitfall and sweep net samples of each individual by treatment and sample round. A linear mixed effects model was conducted using the ‘lm’ function on the square rooted data to test for a difference of means between habitats.

RTU richness of the different habitats was compared at the transect level using linear mixed effects models (lme). Abundance/occupancy graphs were plotted for order diversity, beetle RTUs and spider families, separately for each habitat. Further linear mixed effects models were conducted on individual RTUs and families to determine differences in abundances of each RTU/family between habitats. A community dissimilarity matrix was produced for each data set (all orders, beetles and spiders). Simpson’s diversity index was calculated for each beetle RTU and spider family, and a linear mixed effects model conducted on this data to detect difference in diversity and richness in each habitat.

A principle coordinates analysis of the dissimilarity matrix of the invertebrate order data was conducted using the ‘pco’ function of the ‘labdsv’ R package (Roberts 2008). Abundance/occupancy plots were generated to compare dominant orders in marram and restored dunes. Linear mixed effects models were conducted on the order abundance data at the transect level to identify any significant differences between the order abundances between habitats. The Dufrene-Legendre indicator species analysis (‘labdsv’ function ‘duleg’) was used to calculate the indicator value of each order (Dufrene & Legendre 1997). Indicator species were selected by their high ‘DuLeg’ value or statistical significance, and then plotted using scatter plots to identify their abundances at transect level within the two habitat types. Regression lines were fitted and correlation coefficients calculated using the linear model ‘lm’ function.

Mice

The proportion of tunnels tracked in each habitat was used as a measure of density, and a linear mixed effects model run on the square root and arc-sine of the proportion data.

Community data

Abundances of fauna were plotted against measures of vegetation cover in scatter plots and correlation coefficients calculated using the 'stats' package and the 'lm' function to test for a difference.

Results

Vegetation

Species composition

Abundance/occupancy plots identified obvious differences in the vegetation species composition of marram (see figure 3.6) and restored dunes (see figure 3.7. In marram dunes, marram grass was the dominant species, occurring in lower numbers, but in the majority of quadrats. Ripgut brome occurred in large numbers but was present in less quadrats. In the restored dunes, spinifex and pīngao occurred in the majority of quadrats.

Using the dominant species data, the mean percent cover of each dominant species per quadrat was calculated. In marram sites, marram grass occupied on average 51% of each quadrats area. Exotic iceplant (*Carpobrotus spp.*) and knobby club rush (*Ficinia nodosa*) were the next most dominant species, occupying 3% and 2% respectively. Other common species with a mean coverage of 1% of quadrats included hare stail, ripgut brome, and brown top. In restored dunes, spinifex was the most dominant species, on average occupying 40% of each quadrats area. Pīngao was the next most dominant species with 21%, followed by introduced species such as marram grass, bone seed and sweet alyssum with 5% and 1% respectively.

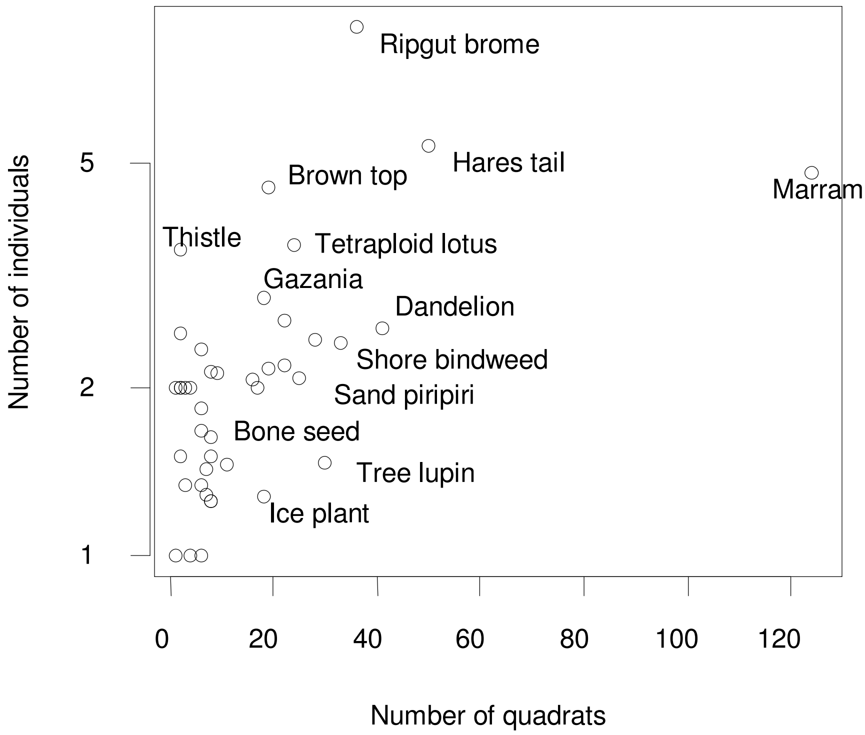

Figure 3.6 (above): Abundance/occupancy plot of plant species in marram dunes, with common species identified.

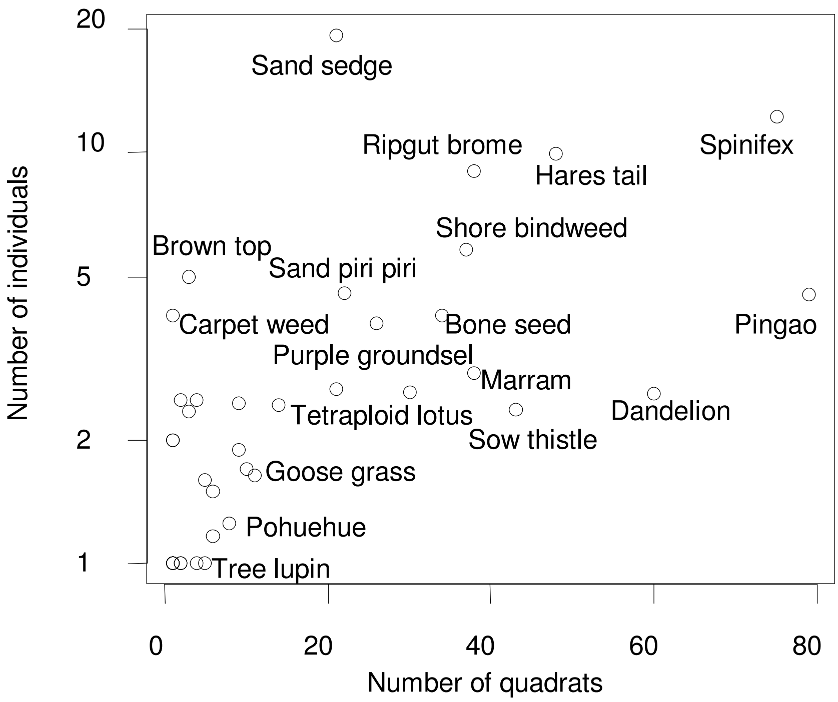

Figure 3.7: Abundance/occupancy plot of plant species in restored dunes, with the most common species identified

Marram dunes tended to have a higher diversity of species at four out of six sites (see figure 3.8, dramatically so at the two sites on the Kapiti coast: Otaki and Paraparaumu. A linear mixed effects model of the Simpson's diversity index data for vegetation showed that the vegetation diversity was higher in marram dunes (t=-1.26 df=5 p=0.2626). Species richness was higher in marram dunes, but this result was not significant (t=-0.99 df=5 p=0.3655).

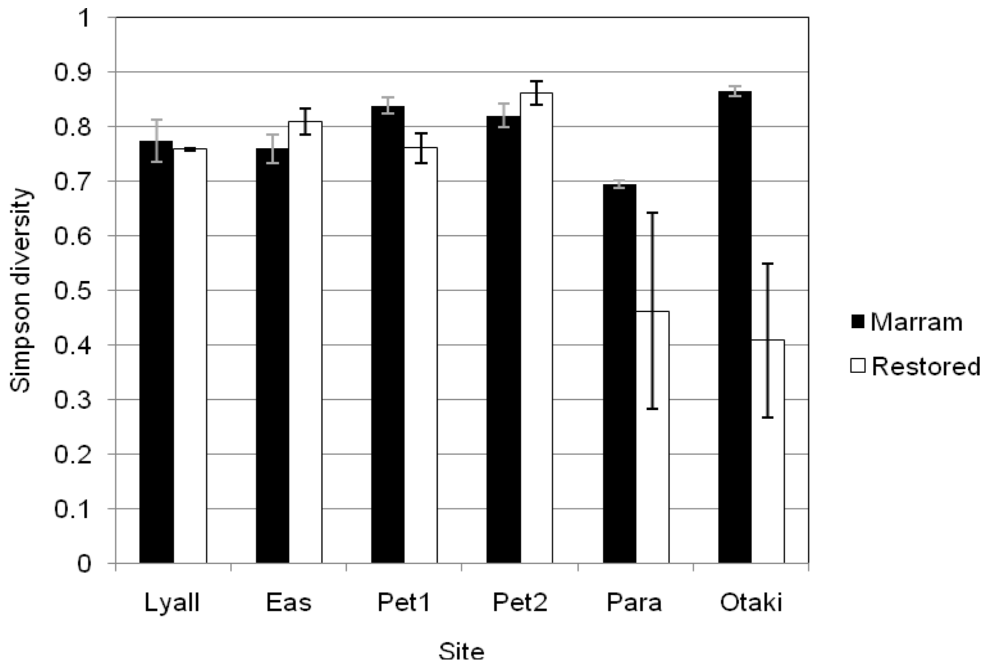

Figure 3.8: Simpson's diversity index of vegetation species in marram (black bars) and restored dunes (white bars). Data is averaged across the two transects, therefore error bars represent maximum and minimum values.

Vegetation structure

Overall percentage vegetation cover was significantly higher in marram dunes, as portrayed by figure 3.9. The majority of marram transects had percentage cover of 80% or more, while restored dunes tended to have a quadrat percentage cover of around 40-80%.

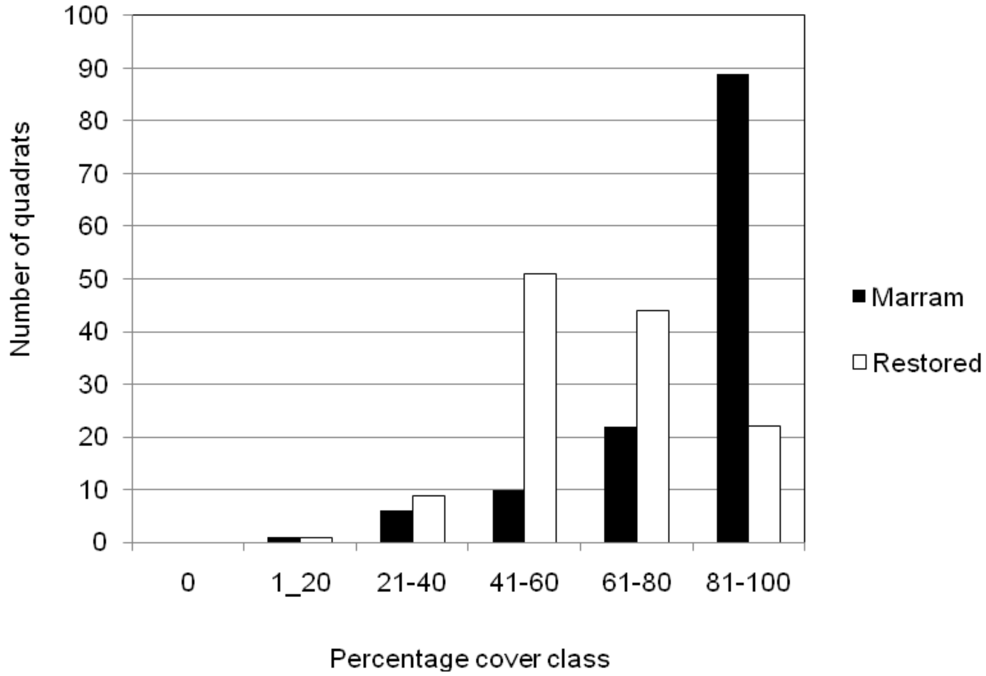

Figure 3.9 Percentage cover class of quadrats in marram (black bars) and restored (white bars) dunes.

Marram dunes tended to have higher vegetation, with quadrats frequently possessing vegetation cover of greater than 1 metre high (figure 3.9). Restored dunes tended to contain vegetation mostly within the 0-50cm height class, occasionally (less than 25% of quadrats) the vegetation in restored dunes exceeding 1 metre high (figure 3.10). A chi squared test confirmed that there is a significant difference between classes of vegetation biomass distribution in marram and restored dunes (χ^2=72.34, df= 2, $p<0.05$).

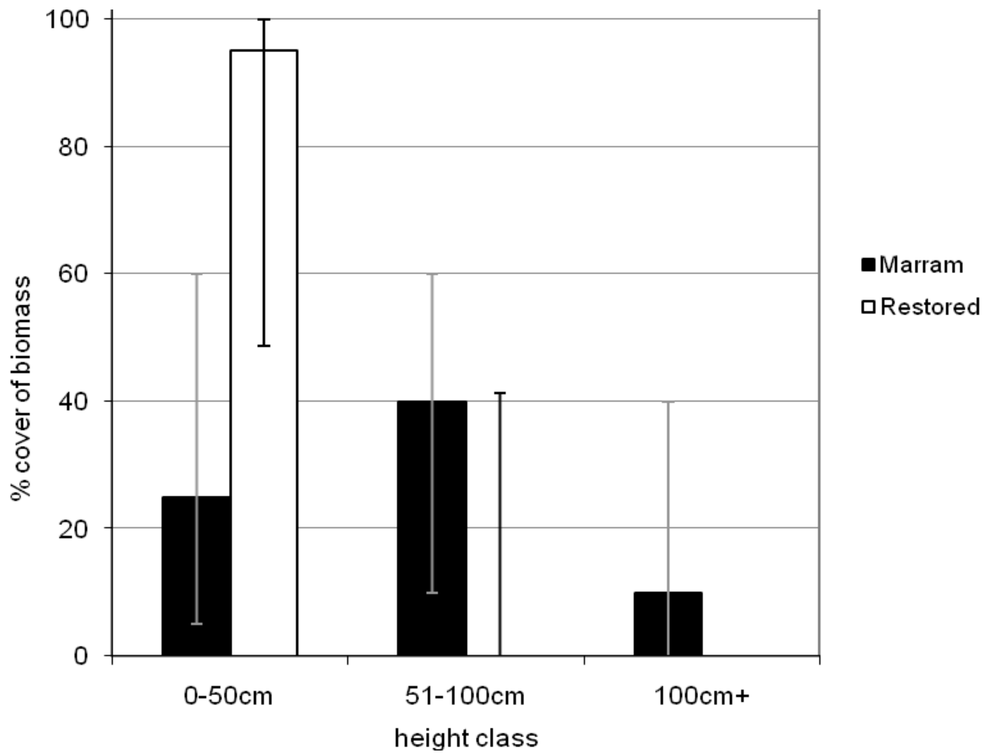

Figure 3.10: Median percentage cover of vegetation in three separate height classes, restored versus marram dunes. Error bars represent upper and lower quartiles. No bar means over half the quadrats contained no vegetation of the corresponding height.

The initial 'principle coordinates analysis' of all plant species showed two obvious clusters of data points, one containing marram transects, the other containing only restored transects (see figure 3.11). This shows that there is a clear difference in the two communities. A permutation 'ord' test of whether habitat was influential in determining the community was statistically significant ($p = 0.0001$).

When the three main sand binding species were removed, the vegetation associated with marram and restored sites showed no strong relationships (figure 3.12). Transects tended to cluster together within sites, suggesting that restored and marram sites in the same vicinity possessed similar vegetation communities. It is clear that the abundances of the dominant sand binding species: marram, pīngao and spinifex play a large role in structuring vegetation communities.

A table of more detailed vegetation results can be found in appendix seven.

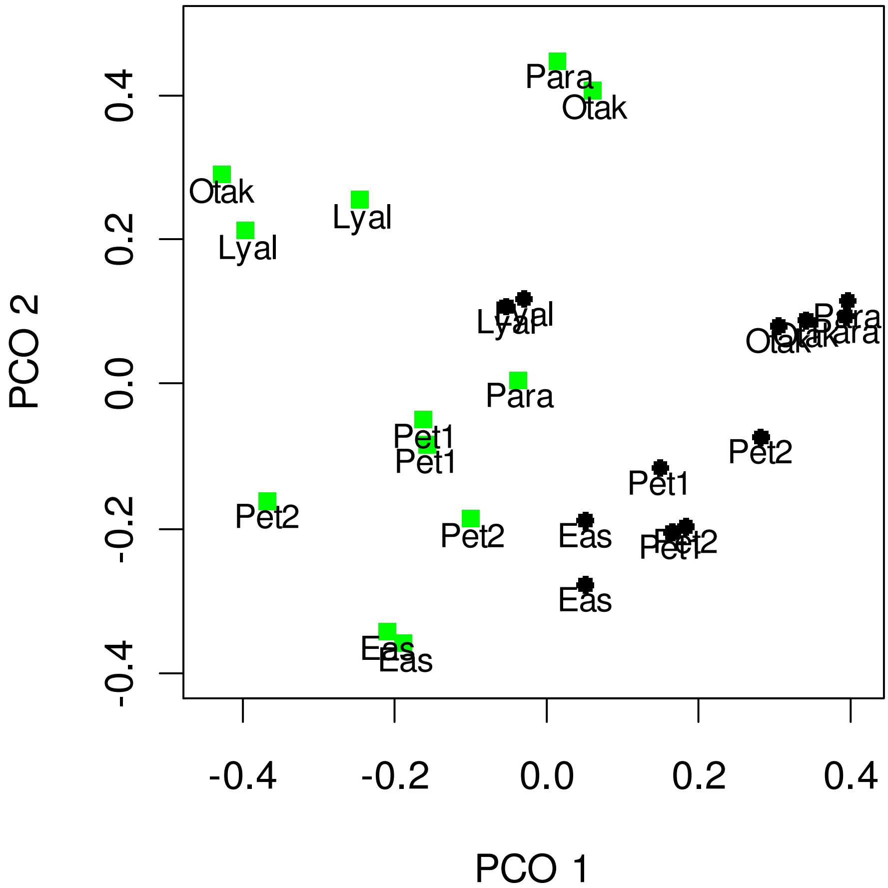

Figure 3.11: Principle Coordinates Analysis showing dissimilarity matrix of vegetation data. Black circles (●) represent marram sites, and the grey squares (■) represent restored sites.. Each point represents one transect. Eigenvalue weights of the first two axes account for 47% of the total variation.

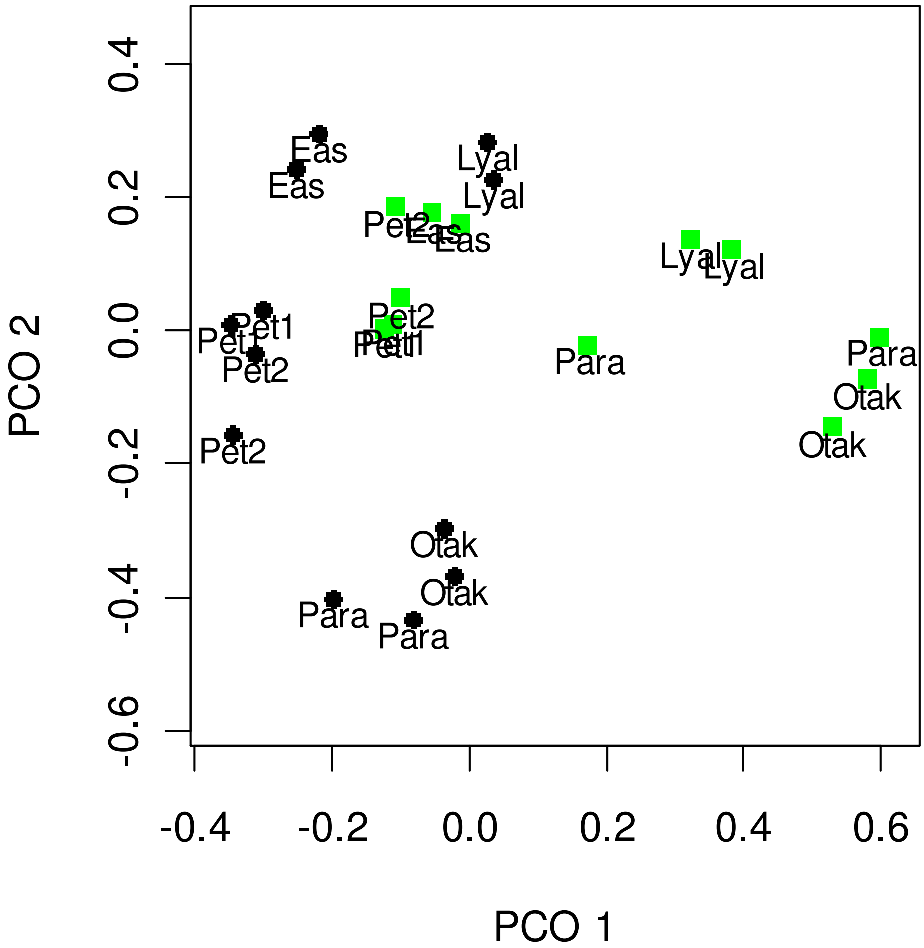

Figure 3.12 Principle coordinates analysis with three major sand binding species removed (Pīngao, marram and spinifex). Black circles (●) represent marram sites, and the grey squares (■) represent restored sites. Each point represents one transect. Eigenvalue weights of the first two axes account for 47% of the total variation.

Lizards

In total, eighty five individual common skink (*Oligosoma nigraplantare polychroma*) were captured in the six sites across the Wellington region. No other lizard species were observed. Of those eighty five, 80% were captured in marram dunes, and 20% in restored dunes.

The Peterson estimate was used to estimate the population size for each site and treatment (see figure 3.13). In four out of the six sites the estimated population size of common skink was larger in marram dominated dunes than in recently restored dunes, particularly at Petone 1 and Eastbourne. A linear mixed effects model of the square root transformed Peterson estimate for each site was statistically significant at the 5% level ($t=-3.05$, $df = 5$, $P=0.0284$) suggesting that overall, marram dunes contain a higher abundance of common skink.

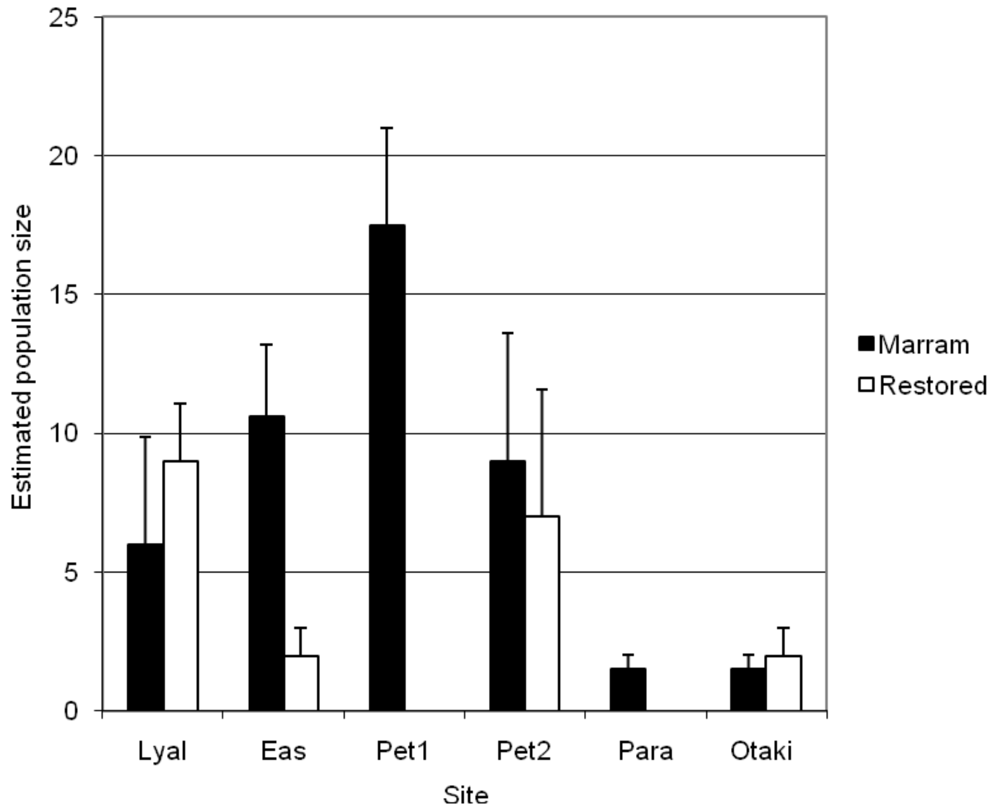

Figure 3.13: Estimated population size using the Peterson estimate of *O.n. polychroma* in marram (black bars) and restored (white bars) dunes. Error bars represent standard error.

Invertebrates

A total of 22 invertebrate orders were represented across all sites. The abundance/occupancy graphs (figure 3.14 and 3.15) show the dominant species in each habitat. In both habitats the most common and abundant species are Collembola and Diptera, and Coleoptera, Hemiptera and Araneae were present in nearly all samples, but with lower abundance.

A linear mixed effects model of Simpson's diversity index of invertebrate order data showed that marram dunes had significantly higher order-level diversity (t= -3.01 df=5 p=0.0297). Order richness was higher in marram dunes, but this result was not significant (t=-1.03 df=5 p=0.3497).

Three orders were shown to have significant higher abundances in marram habitats than their restored counterparts. Amphipods, commonly known as sand hoppers, presented a highly significant result, with higher abundances in marram habitat (t= -5.7 df= 5, p=0.002). Abundances of Hemiptera (t= -0.99 df=5 p=0.03), and Araneae (t= -1.43 df=5 p=0.02) were significantly higher in marram dunes. The majority of t values were negative, implying that the abundances of each invertebrate orders tended to be higher in marram dunes. Some orders, for example, Isopoda, Opilones, and Collembola had higher abundances in restored dunes, however these results were not significant. No clear pattern was observed in the 'principle coordinates analysis' of invertebrate order data, highlighting the importance of investigating certain indicator orders at a finer taxonomic resolution.

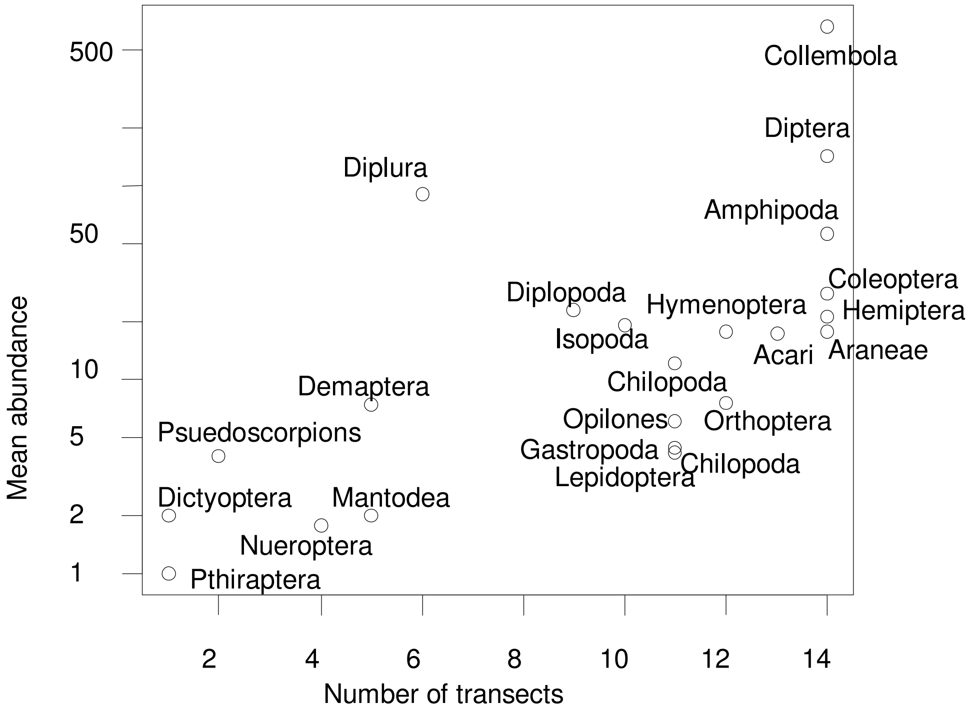

Figure 3.14. Abundance/occupancy plot for marram dunes order presence data.

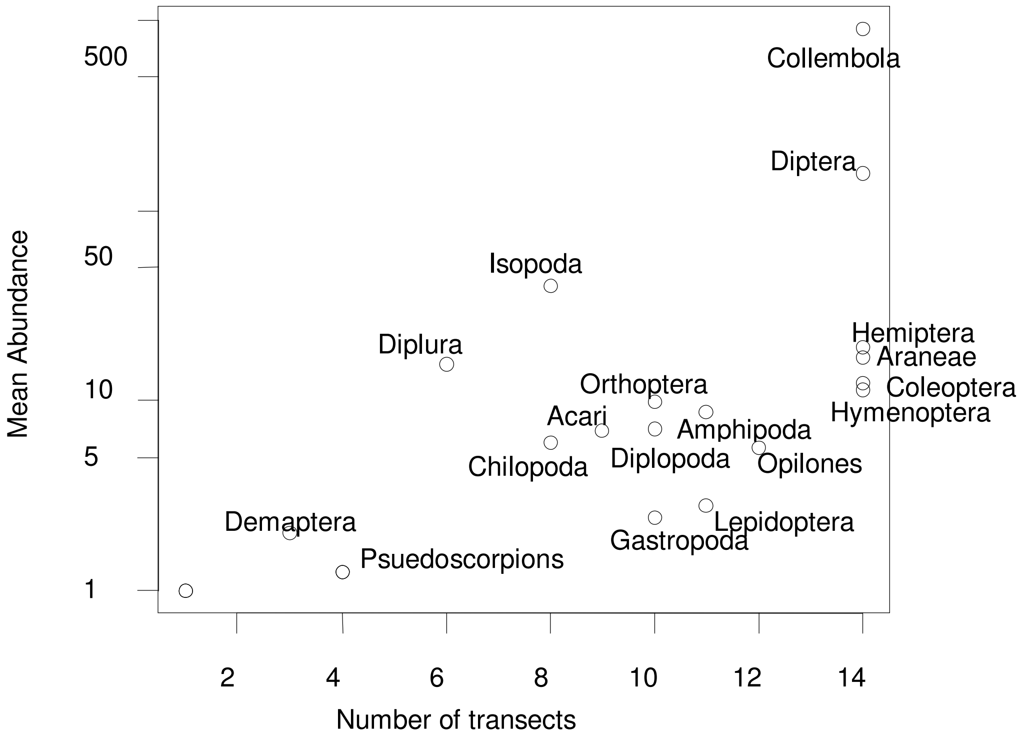

Figure 3.15: Abundance/occupancy plot for restored dunes order presence data.

The Dufrene-Legendre indicator species analysis (Duleg) identified five taxa worthy to be considered for indicator status due to their high statistical significance (Mantodea and Amphipoda) and high duleg value (Coleoptera, Acari, and Araenae). Square rooted Aranaeae and Coleoptera abundances were closely correlated (R^2=0.6012 $F_{1,22}$=35.67 p=5.2x10^{-6}2) as shown in figure 3.16. Both orders were especially abundant at Otaki.

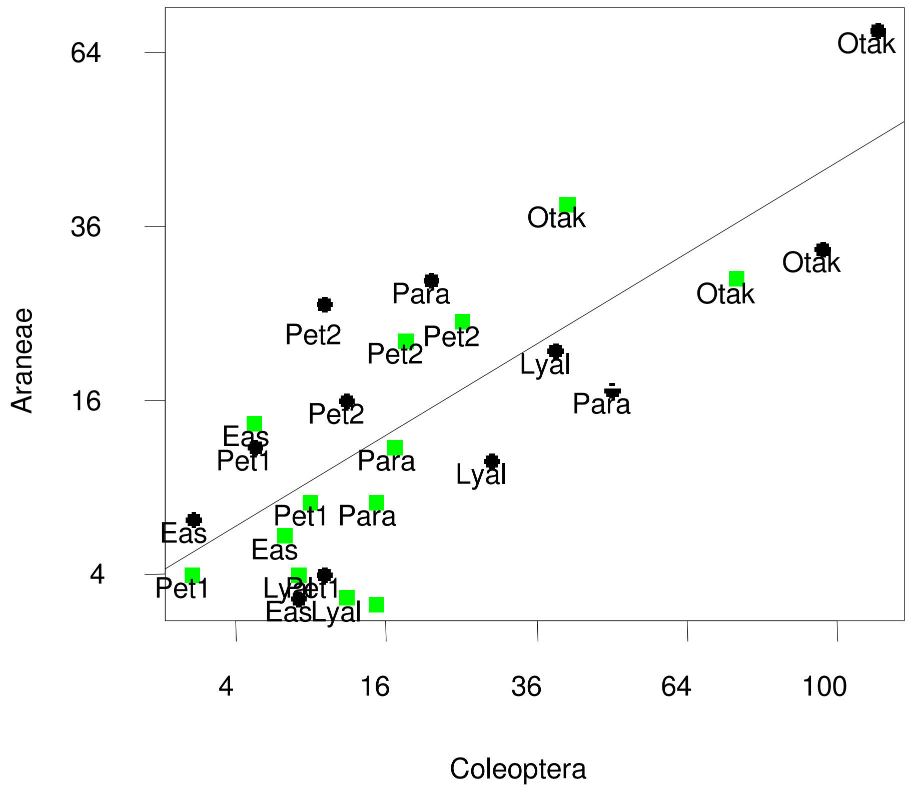

Figure 3.16: Coleopteran abundance plotted against Araneae abundance. Black circles (●) represent marram sites, and the grey squares (■) represent restored sites. Axes have been square-root transformed, but labelled with original values

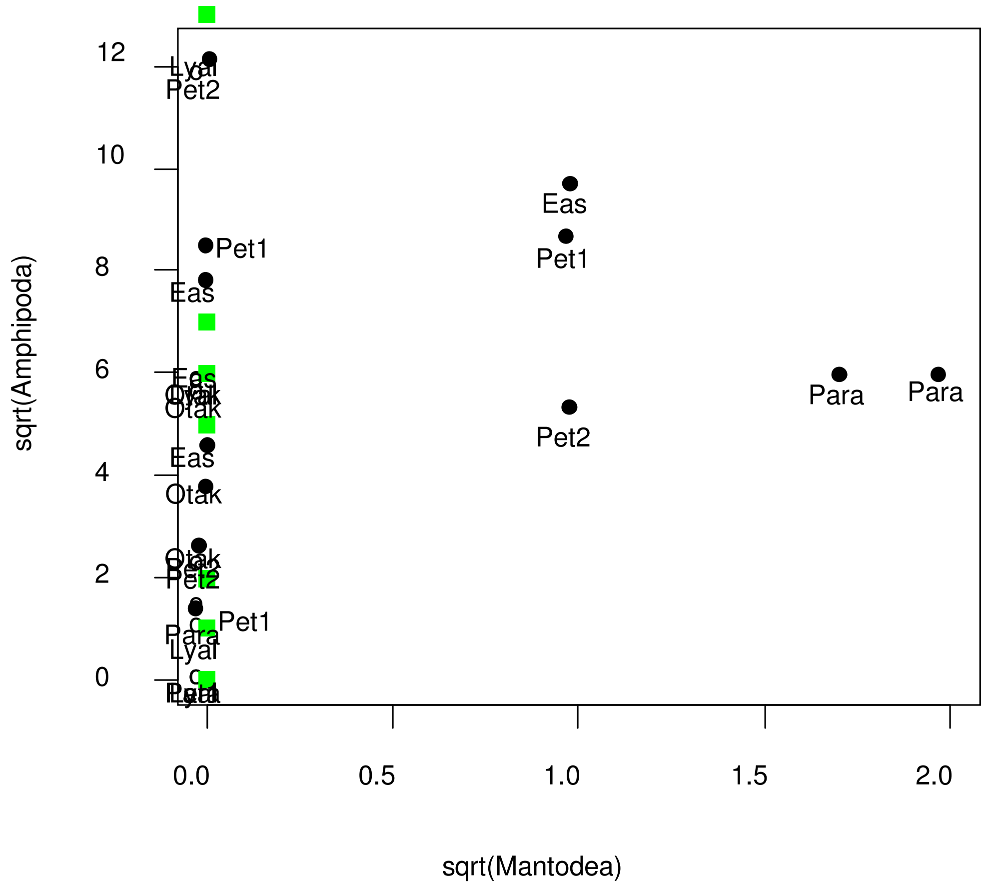

Figure 3.17: Scatterplot of Amphipoda abundance plotted against Mantodea abundance. Black circles (●) represent marram sites, and the grey squares (■) represent restored sites.

The scatterplot of Amphipoda and Mantodea abundance showed no linear relationship (figure 3.17), but it clearly shows that amphipods and mantids are more abundant in marram dunes. Mantids were not observed in restored dunes. Preying mantids found in marram dunes were exotic (*Miomastis caffra*). The scatter plot of Acari and Amphipoda showed a clear definition between marram and restored sites, with marram sites clearly showing higher abundances of both orders (see figure 3.18).

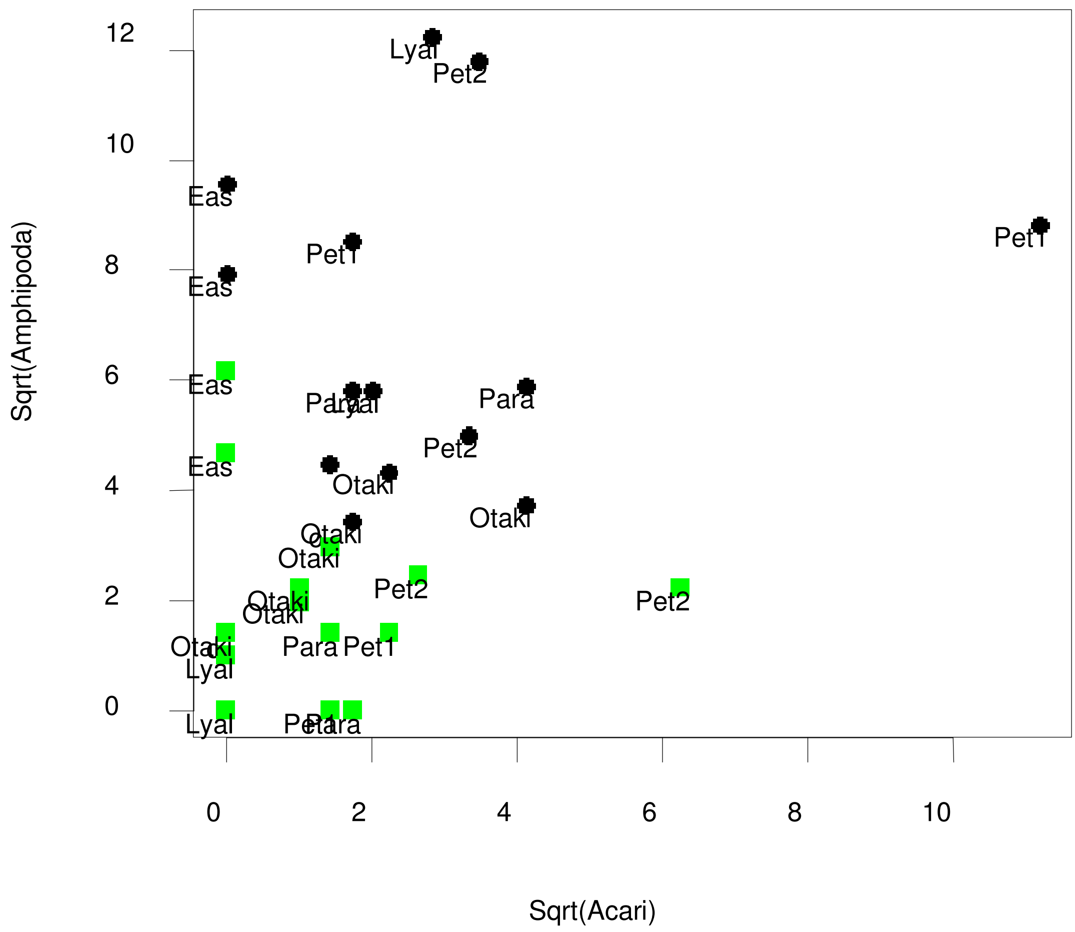

Figure 3.18: Scatterplot of Acari and Amphipoda abundances (squarerooted). Black circles (●) represent marram sites, and the grey squares (■) represent restored sites.

Biomass

A linear mixed effects model of the squarerooted biomass data comparing biomass (pooling body length of each specimen) of marram and restored dunes showed that marram dunes have higher biomass of invertebrates (t =-2.11 df=5 p=0.0885). Although this is not statistically significant.This is demonstrated on figure 3.19 below.

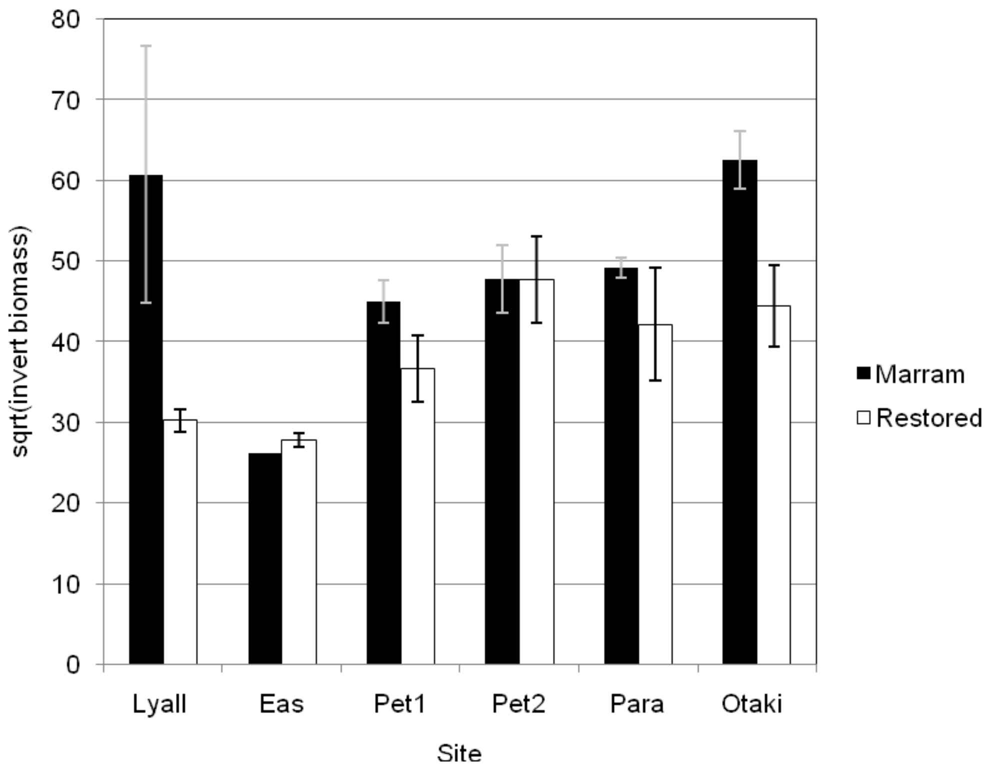

Figure 3.19: Biomass of invertebrates (squarerooted) in the two habitats at each site. Averages were taken across transect one and two therefore error bars represent maximum and minimum value.

Beetle abundance and diversity

A total of 626 individual beetle specimens were collected, 234 (37%) from restored and 392 (63%) from marram dunes, representing 17 families and 37 RTUs. The linear mixed effects model of beetle RTU richness showed that marram dunes had significantly higher RTU richness than restored dunes (t=-

1.03, df = 5, p=0.035). The Simpson's diversity index of beetle RTU diversity data was also significantly different between habitats (t=-3.01 df=5 p=0.029).

The native weevil *Cecyropa spp.* (Curculioniadae) was the most abundant beetle, whose abundance was higher in marram dunes, although a mixed effects model of the transformed abundance data at the transect level did not show a significant result (t= -0.6, df = 5 p=0.57). It was present at all locations. Abundances of the remaining beetle RTUs did not show any significant differences between habitats, although the majority of t values were negative, implying that abundances were higher in marram dunes. The principle coordinates analysis of beetles RTUs (figure 3.20) showed unclear clusters of restored sites (left) and marram sites (right) suggesting communities were not significantly different.

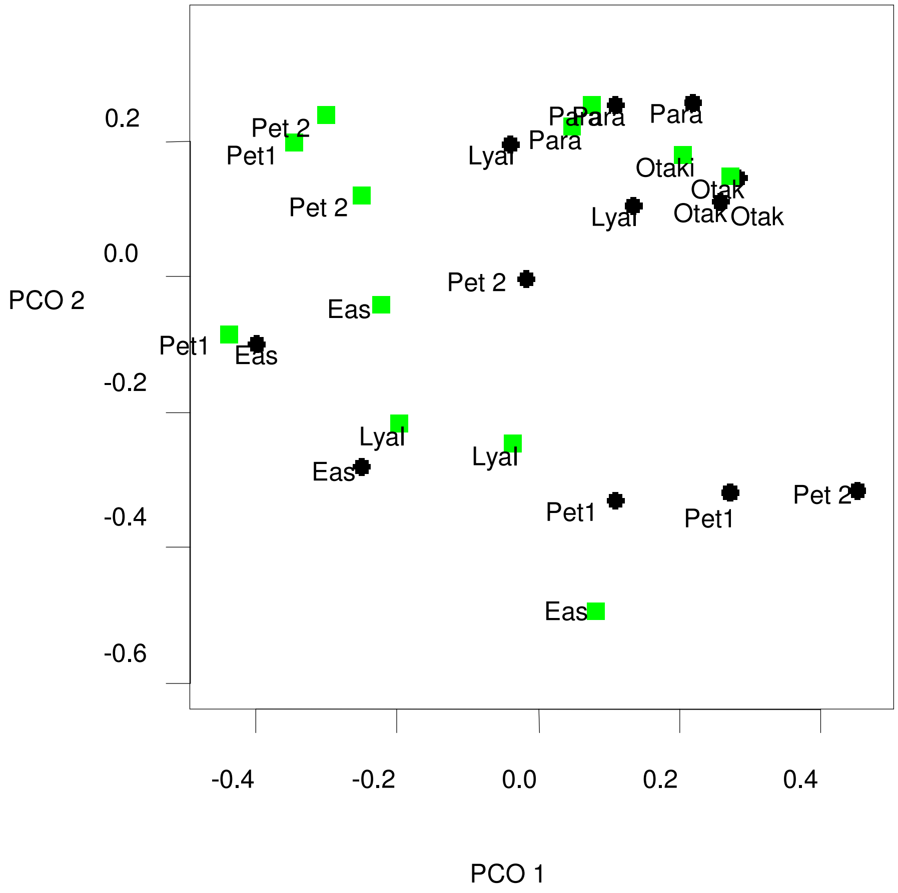

Figure 3.20. PCO of beetle communities (RTU) per transect . Black circles (●) represent marram sites, and the grey squares (■) represent restored sites. Eigenvalue weights of the first two axes account for 39% of the total variation.

Spider abundance and diversity

A total of 420 spider specimens were collected, 247 (59%) from marram dunes and 173 (41%) from restored dunes, representing 8 families and 30 RTUs. Some RTUs could not be identified as specimens were juveniles. Therefore spiders were grouped into families for analysis.

Spider family richness was higher (but not statistically significant) in marram dunes ($t=-2.13$ $df=5$ $p=0.0856$). The linear mixed effects model showed also that spider family diversity using the Simpson's index was higher in marram dunes, but this was not significant ($t=-1.009$ $df=5$ $P=0.3591$). The abundance/occupancy plots show that Lycosidae, Thomsidae and Linyphiidae families were generally the most abundant families in restored and marram dunes (see figure 3.20 & 3.21). The linear mixed effects model of square-root transformed spider data showed that Theriidae and Salticidae had higher abundances in restored dunes with positive t values but the remainder of the families had negative t values, implying that they were more common in marram dunes. The Oxyopidae family had significantly higher abundance in marram dunes ($t=-2.62$ $df=5$ $p=0.0469$).

The principle coordinates analysis (figure 3.22) showed that there were no striking differences between the spider communities of marram and restored dunes. Assemblages at each site (especially Petone 2, Eastbourne, and Otaki) tended to cluster together suggesting marram and restored dunes at each site had similar communities, but there were differences between sites.

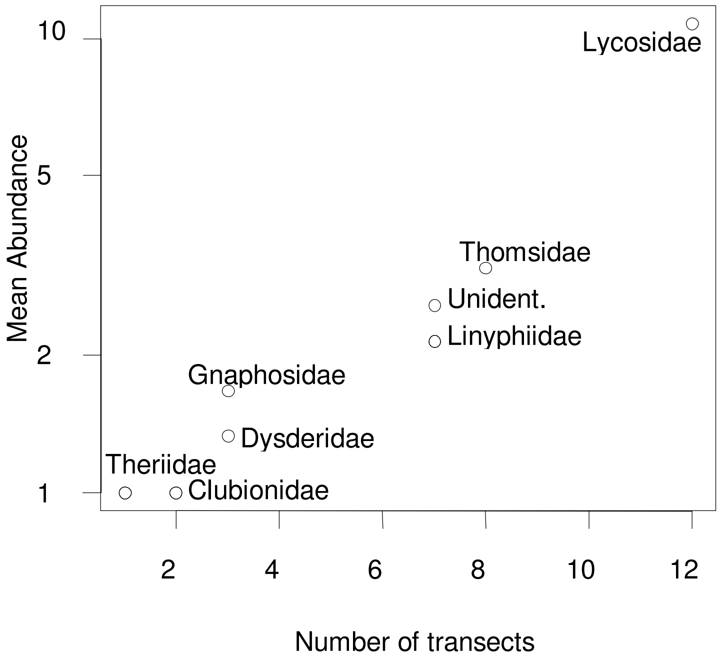

Figure 3.21 (above): abundance/occupancy plot of spider families in marram dunes.

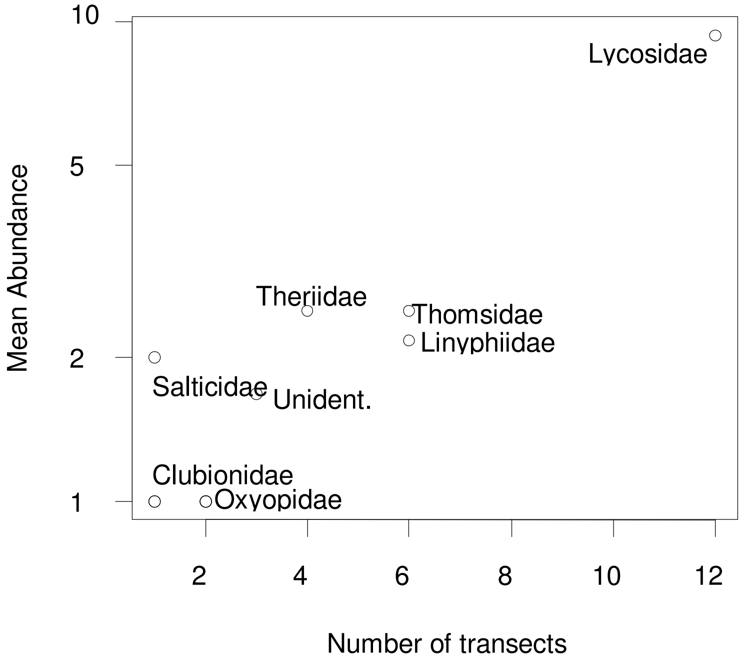

Figure 3.22 abundance/occupancy plot of spider families in restored dunes.

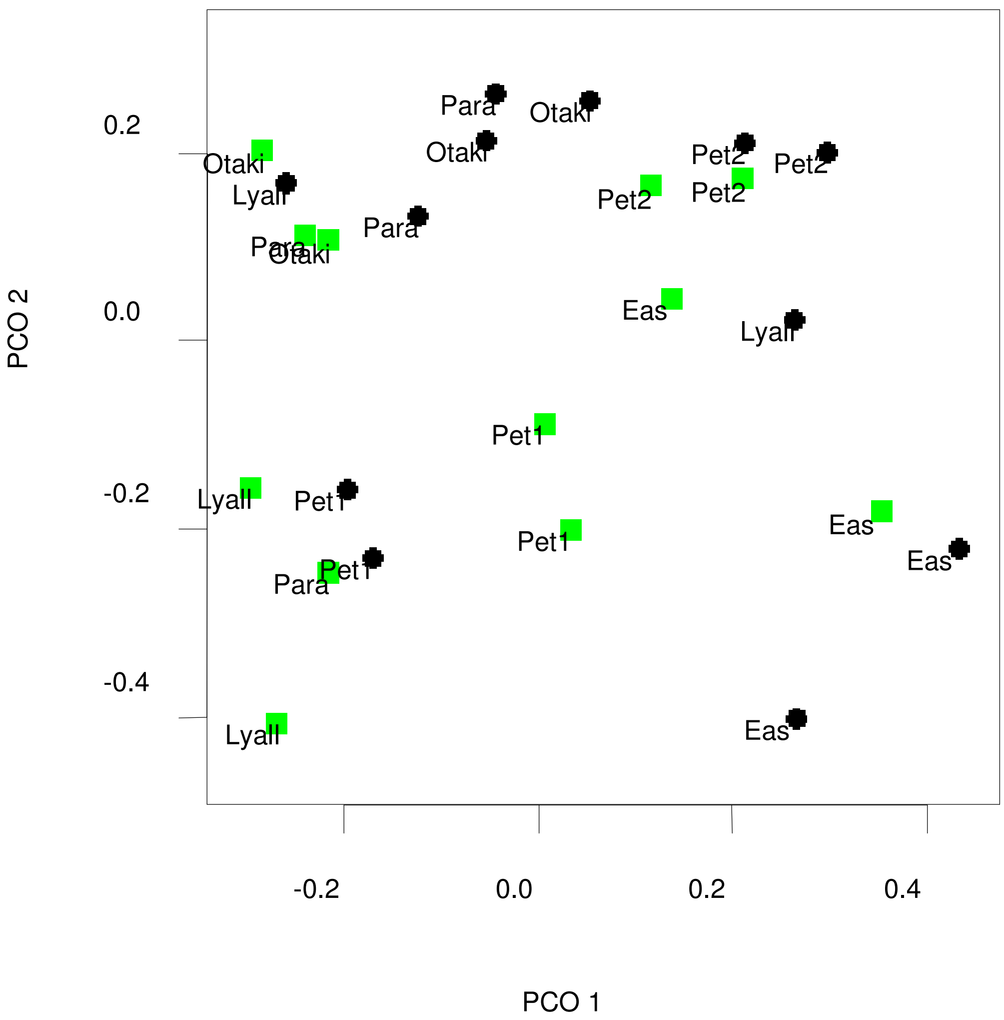

Figure 3.21. Principle coordinates analysis of spider family transect data. Black circles (●) represent marram sites, and the grey squares (■) represent restored sites. Eigenvalue weights of the first two axes account for 52% of the total variation.

Katipō

No *L. katipō* were found at any site during the five minute habitat searches nor in the pitfall traps or sweep net samples.

Ants

Pennant ant *Tetramorium grassii* (introduced from South Africa) was found only in marram dunes (t= -2.2, df= 5, p=0.07). *Tetramorium grassii* is known from sand dunes north of Auckland, but it has not been previously recorded (from any habitat) from the lower North Island of New Zealand (Don & Harris, 2009). The endemic southern ant *Monomorium antarcticum* was found more often in restored dunes although this result was not statistically significant (t= 0.881, df=5, p=0.41). The endemic species, tiny brown ant *Monomorium antipodum* and *Pachycondyla castanea,* and the introduced crypt ant *Hyponera eduardi* were also found, but were in very low numbers commonly in marram dunes. Species richness was higher in marram dunes but this result was not significant (t=-1.745 df=5 p=0.14).

Snails (Gastropoda)

A sizable population of 18 individuals of the introduced glass snail, *Oxychilus spp,* was found in marram dunes at the Petone 1 site.

Earwigs (Dermaptera)

A sizeable population of the endemic coastal earwig *Anisolabis littorea* (figure 3.23), was found only at the Lyall Bay site in marram and restored dunes (23 individuals trapped). The introduced European earwig *Forficula auricularia* was also found in low numbers at Lyall Bay and Paraparaumu marram sites.

Figure. 3.22. Seashore earwig *Anisolabis littoralis.* Photograph: http://soilbugs.massey.ac.nz/insecta.php

Mammalian pests

Tracking tunnels identified a high density of mice in many areas (figure 3.23). Marram dominated sites contained a significantly higher density of mice (figure 3.24). A mixed effects model of mouse abundance size using proportion of tunnels tracked (sqrt and arc sin of data) showed a significant difference between restored and marram sites ($t=-5.5$, $df=5$ $p=0.00264$). Tracking tunnels did not identify the presence of any other mammalian pests although the presence of rabbits was noted from their droppings at all sites, and cats were seen at Eastbourne and Paraparaumu sites.

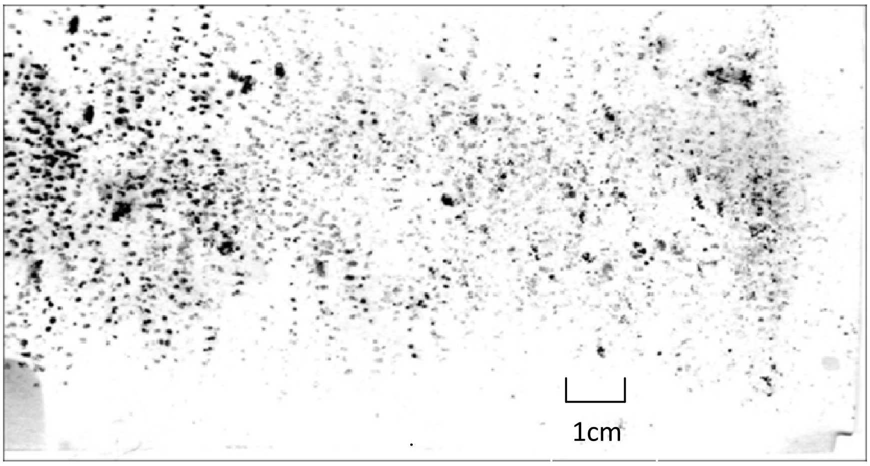

Figure 3.25: example of mouse tracks from tracking tunnel.

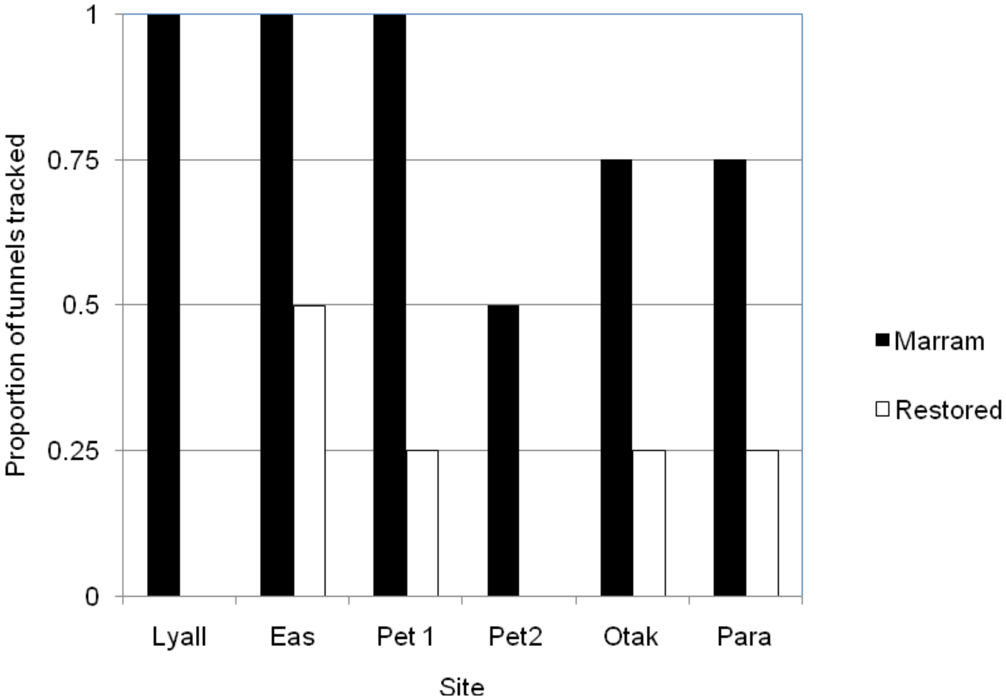

Figure 3.26: proportion of tracking tunnels tracked by mice at each site within marram (black bars) and restored (white bars) dunes.

Effect of vegetation cover

Correlations between vegetation cover (%) and abundance of invertebrates were mostly positive. There was a significant positive correlation between % cover of vegetation and abundance of Amphipoda (r=0.418 $F_{1,22}$= 21.56 p= <0.001) and Acari (r=0.36 $F_{1,22}$= 4.42 p= 0.04668) (figure 3.27), and non-significant positive correlations between beetles, spiders (figure 3.27), Collembola, Isopoda, and Orthoptera (table 3.3). There were weak positive correlations between Simpson diversity of spiders, beetles and all orders and vegetation cover (Figure 3.28). There were positive correlations between percentage cover of vegetation and estimated population size of skinks (r=0.562 $F_{1,10}$ = 4.296 p= 0.065) (figure 3.30) and mice (r=0.53 $F_{1,10}$= 4.877 p= 0.05) (figure 3.29). Diversity of beetle RTUs and skink abundance had a significant positive correlation (r=0.0357 $F_{1,10}$=5.687 p=0.03). Graphs showed a clear differentiation between marram and restored sites – typically because marram sites contained higher vegetation cover, hence influencing the greater abundance and diversity of fauna.

Effect of vegetation diversity

Vegetation diversity did not have a significant effect on any of the faunal assemblages, aside from a non significant positive relationship with skink abundance (r=0.3028 $F_{1,10}$=0.391 p=0.153) and beetle RTU diversity (r=0.346 $F_{1,10}$=2.682 p= 0.758).

Table 3.3 Table of correlation coefficients (r) between sand dune flora and fauna abundance and diversity.

	Vegetation cover (%)	Vegetation diversity	Mice	Skinks
Mice	r=0.53 p= 0.05*	r=0.298 p= 0.3701	-	-
Skinks	r=0.562 p= 0.065	r=0.3028 p= 0.1530	r=0.39 p= 0.25	-
Invert biomass	r=0.1184 p= 0.09	r=0.019 p= 0.51	r=0.07737 p= 0.3813	r=0.01728 p= 0.6838
Invertebrate abundance	r=0.027 p= 0.6034	r=0.0008 p= 0.9	r=0.01835 p= 0.6746	r=0.1432 p= 0.4205
Vegetation diversity	r=0.359 p= 0.129	-	-	-
Order diversity	r=-0.190 p= 0.15	r=-0.08 p= 0.758	r=0.05 p= 0.4268	r=0.0357 p= 0.8494
Beetle RTU diversity	r=0.04 p= 0.884	r=0.346 p= 0.758	r=-0.142 p= 0.4492	r=0.0535 p= 0.03*
Spider family diversity	r=0.317 p= 0.2241	r=0.189 p= 0.7497	r=-0.13 p= 0.7101	r=0.8766 p= 0.5665
Acari	r=0.36 p= 0.046*	r=0.26 p= 0.17		
Amphipoda	r=0.418 p= <0.001**	r=0.25 p= 0.155		
Araneae	r=-0.12 p= 0.489	r=-0.237 p= 0.93		
Coleoptera	r=0.259 p= 0.5	r=-0.007 p= 0.411		
Collembola	r=0.019 p= 0.583	r=-0.06 p= 0.81		
Isopoda	r=0.04 p= 0.613	r=0.17 p= 0.472		
Orthoptera	r=-0.088 p= 0.928	r=0.112 p= 0.3558		

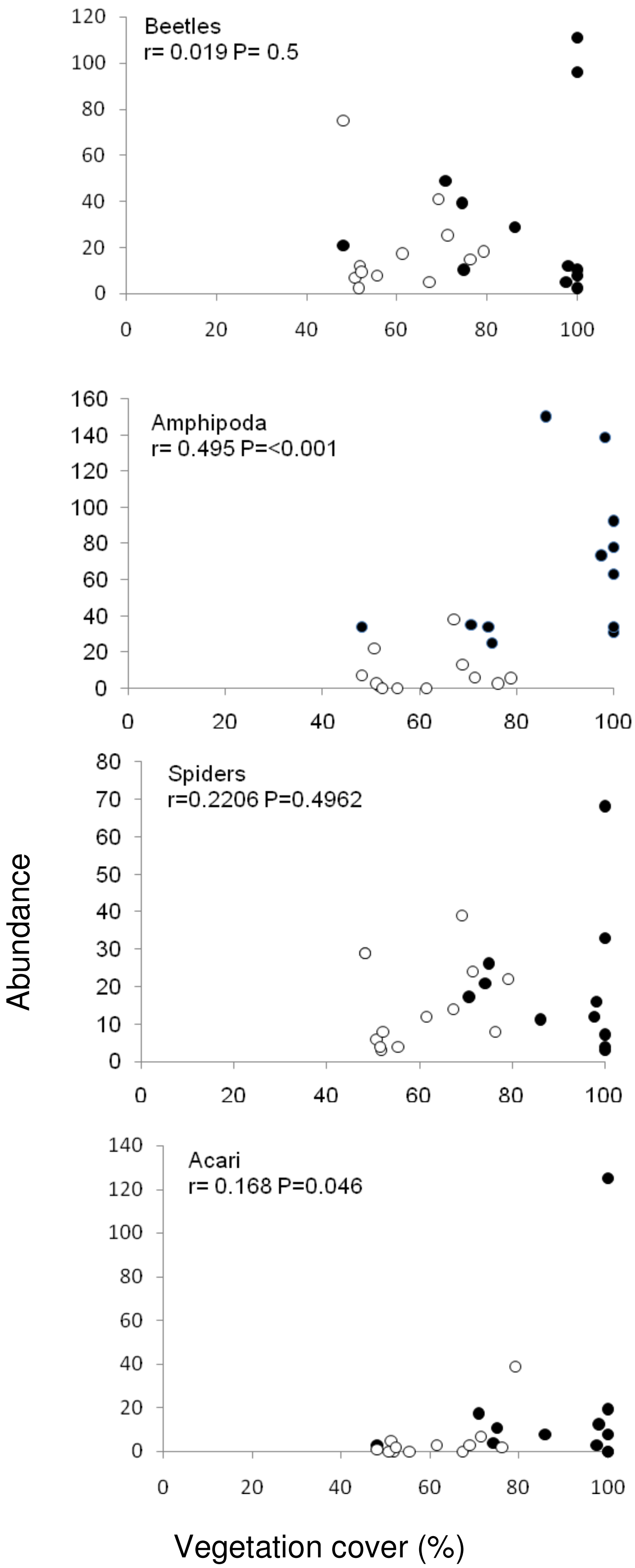

Figure 3.27: Vegetation cover (%) and number of invertebrates caught in pitfall traps in each transect. Black dots represent marram sites (●), white dots represent restored sites (○). r= correlation coefficient.

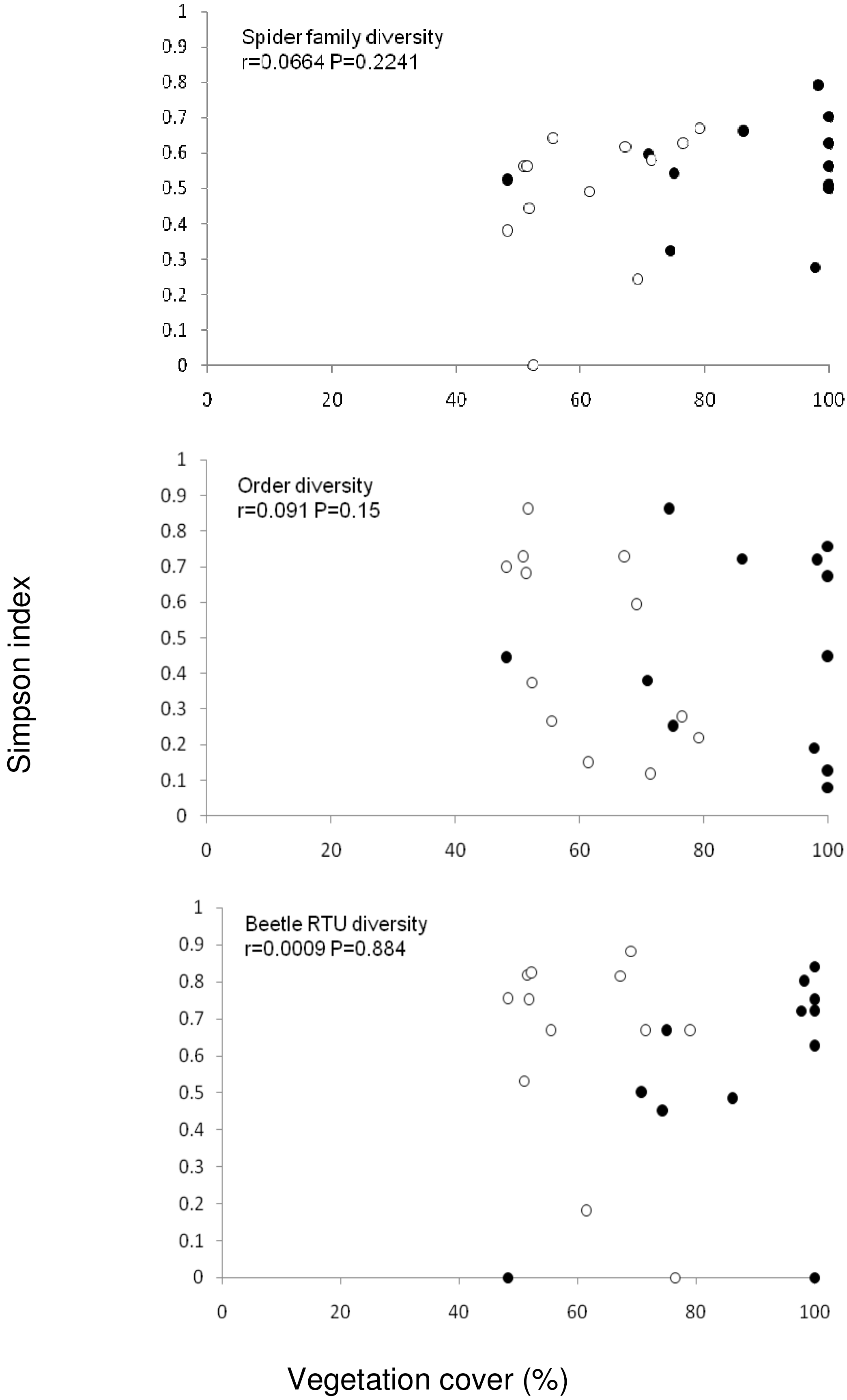

Figure 3.28: Vegetation cover and diversity of beetle RTUs, spider families, and all invertebrate orders. Black circles represent marram sites (●), white circles represent restored sites (○).

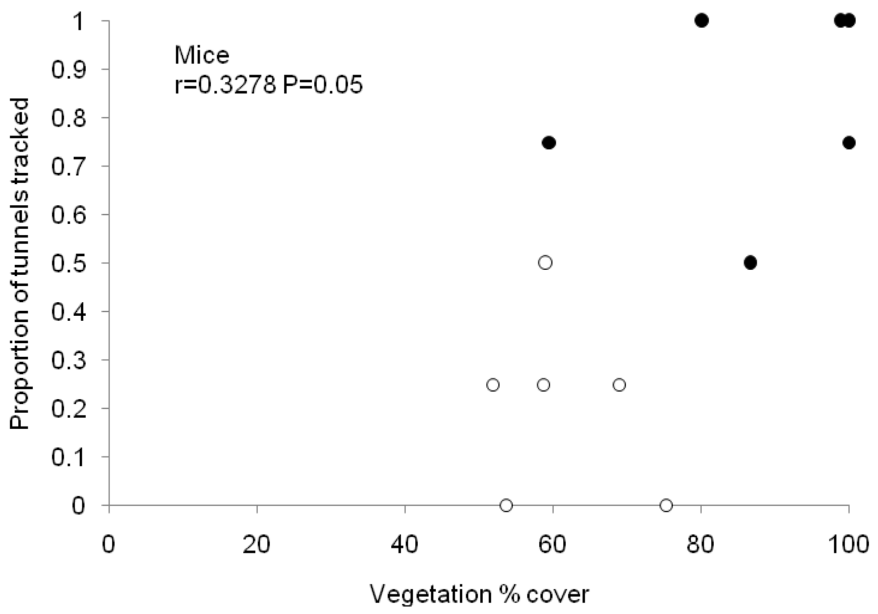

Figure 3.29: proportion of tunnels tracked by mice in marram (●) and restored (○) dunes in relation to cover of vegetation. r= correlation coefficient

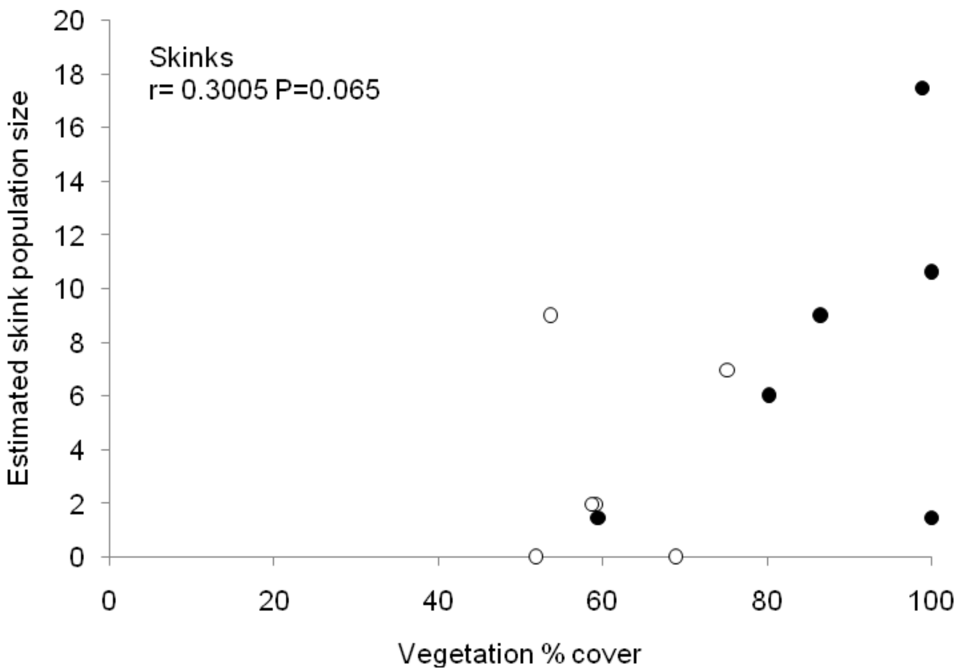

Figure 3.30: Estimated population size of skinks in comparison to % vegetation cover in marram (●) and restored dunes (○). r= correlation coefficient.

Discussion

The main objective of this study was to investigate the floral and faunal assemblages of fore dune sites undergoing restoration with native sand-binding plants, to compare with their marram grass dominated counterparts in the Wellington region. Two specific hypotheses were tested:

1. That marram dunes contain higher vegetation and greater projected foliage cover than restored dunes;
2. That restored dunes have higher biodiversity values, as indicated by sampling of invertebrates (beetle, ant, spider), lizards and mice

Vegetation communities

Dunes dominated with marram grass had significantly higher percentage cover, taller, more heterogeneous vegetation, and a greater diversity and richness of plant species (both native and exotic). Restored dunes however, had lower percentage cover with a lower vegetation height and lower diversity of plant species. Native sand binding plants spinifex and pīngao were the dominant species, which typically possess lower foliage height and less projected foliage cover than that of marram grass. These results confirm that marram and restored dunes differ significantly in the structure and composition of their vegetation communities. The vegetation species compositions of each habitat were significantly different, but when the three sand binding species (marram, pīngao and spinifex) were removed from the analysis, the communities were quite similar. Therefore the three sand binding species were significant in shaping the vegetation communities, and without them, the abundance and diversity of the remaining species were similar.

There were a number of differences between sites, which can be explained by differing management practices. For example, the lower diversity in the restored system at Otaki can be explained by the presence of a restoration group who meet fortnightly to weed the dune. In comparison with the Eastbourne restored site, where a number of weed species were present in large abundances, for example ripgut brome, harestail and sweet briar. However marram sites overall still contained higher diversity of plant species than restored dunes.

Faunal communities

This data rejects the hypothesis that restored dunes contain higher biodiversity values. Marram dunes supported significantly higher abundances of lizards, mice, invertebrate biomass, beetles, preying mantids, and amphipods. The linear mixed effects model of the Simpsons index of invertebrate order diversity showed that diversity of orders was significantly higher in marram dunes. Beetles and spiders have been used in other studies as indicators of restoration progress in coastal areas (Webb et al. 2000; Longcore 2003), therefore their communities were further investigated. Marram dunes contained higher beetle RTU richness and diversity, and the most abundant beetle, the native weevil *Cecyropa* spp. was more abundant in marram dunes. Richness and diversity of spider families were higher in marram sites, and the majority of spider families had higher abundances in marram dunes, especially that of the Oxyopidae (Lynx spiders). Theriidae (comb footed spiders) and Salticidae (jumping spiders) were mostly only present in restored dunes. Springtails (Collembola) and flies (Diptera) had similar abundances in marram and restored dunes, and they are both known to be important detrivores.

Identification of most invertebrate specimens did not allow for differentiation between native and exotic, although a few observations could be made. Marram dunes appeared to contain a number of exotic invertebrates that were not observed in restored dunes. For example, European earwig *Forficula auricularia,* glass snail *Oxychilus spp,* and ant *Tetramorium grassii.* Exotic preying mantids were also found only in marram dunes. The glass snail is potentially a predator of native snails (Mahlfeld, 2000). The presence of exotic invertebrates potentially could be due to the marram grass providing exotic habitat. However, marram dunes also contained high diversity and abundance of native species in addition to exotic species.

No native tiger beetles (*Cicindela spp.)* were found, despite being characteristic of sand dunes in northern New Zealand (Habtom & Hartley, unpub. Data). The native sand scarab beetle, *Pericoptus frontalis* was also not found. The native seashore earwig, *Anisolabis littorea* was described by Hudson (1973) to have a 'very wide coastal distribution'; this statement may no longer apply, as it was found at one site, in marram dunes only. Katipō spider was not found in either marram or restored dunes in the study, which is not surprising as katipō can be difficult to find using search methods (Costall 2006), and their presence in these areas has not previously been described in detail. Further investigation into their ecology in areas where they are known to occur will be required to quantify the effect of restoration on katipō populations.

Comparison of lizard abundances between marram and restored sites using the Petersen estimate showed that common skink population size was significantly higher in marram dunes. The higher population of skinks in marram dunes was positively correlated with percentage vegetation cover, indicating that skinks may prefer marram grass with its higher vegetation cover. The results of this study confirm that skinks prefer habitat with denser vegetation, as vegetation cover was positively correlated with skink abundance. This has been observed in other New Zealand dunes and grass lands (Newman 1994; Norbury et al. 2009). Lizards have been found to prefer utilize plants such as pohuehue and sand coprosma (Lettink et al. 2008), therefore for optimal lizard habitat, these species could be included in restoration plantings. It is likely that lizards better utilise the more stabilised areas of a natural dune, where there is more cover and variety of habitat and species. The marram dune provides good cover and habitat structure, therefore is desirable habitat for lizards.

Marram dunes supported a higher density of mice than restored dunes. Disturbed habitats tend to support high mouse densities (King et al. 1996; as cited by Miller & Webb 2001). Mice feed on invertebrates therefore the high abundance of invertebrates and skinks and the higher foliage cover of marram dunes provides a food source and habitat to support a larger mouse population.

Effect of vegetation on faunal communities

It appears that vegetation cover was the main determinant of faunal diversity and abundance. Abundance of skinks, mice, amphipods and Acari had significantly positive relationships with percentage vegetation cover. Weak positive relationships were observed with other invertebrate taxa, particularly spiders and beetles, but these relationships were not statistically significant, possibly due to their lower abundances. Vegetation cover has been found to influence communities of invertebrates (White 1991; Norbury et al. 2009), and lizards (Jellinek et al. 2004; Norbury et al. 2009) in other dry land ecosystems. The results of this study suggest that vegetation cover needs to be at least 50% to support a variety and abundance of lizards and invertebrates. Vegetation species diversity did not appear to influence the faunal community, aside from weak positive relationships with skink abundance and beetle diversity. Positive relationships have been found between habitat heterogeneity and animal abundance in studies all over the world, particularly in systems modified by humans (Tews et al. 2004). Many sand dune animals for which we have some understanding (such as lizards, leaf litter invertebrates, and katipō spider) prefer heterogeneous environments with adequate moisture and cover. Beetles tend to prefer densely vegetated areas as opposed to bare sand (Comor et al. 2008) and Crisp et al. (1998) found the most beetle species in forest and pastoral areas with the highest plant species richness (both native and exotic). From this, it can be inferred that dune fauna prefer areas with higher percentage cover of vegetation, and that areas with higher diversity of vegetation may also be preferable. Therefore, the conditions created by marram grass (eg high percentage cover, high diversity of vegetation) allow for the higher diversity of and abundance of fauna. It seems that the dunes restored using pīngao and spinifex do not presently provide sufficient habitat to support a wide diversity and abundance of fauna.

An additional factor to take into consideration is the ability of fauna to recolonise the restored environment. This ‘field of dreams’ hypothesis is commonly assumed in restoration, practitioners often expect fauna to return when habitat is reconstructed. Although this cab be used as an explanation in other systems, it is unlikely in this case, as the marram dunes sampled were generally around 100m from restored dunes and there were limited barriers to dispersal, unless the animal was flightless and had a limited home range. Studies in Australia of re-colonization of restored mine sites show that ants and Collembola increase in abundance as the diversity of vegetation and age of the site increases (Andersen & Majer 2004). Long term studies of return of fauna to bauxite mines in South Australia suggest that colonization time depended on the animal group, some taking longer than others (Nicols & Nicols 2003). Therefore it could be expected that over time the faunal abundance and diversity of the restored sites will begin to resemble the assemblages of marram dunes, provided that adequate habitat has been provided.

Limitations

To understand the faunal assemblages and vegetation characteristics of natural reference systems, it would have been beneficial to include them in the sampling as a control. However, there are limited unmodified dunes along the Wellington coastline. The nearest potential reference sites could include Waiterere Beach and Himatangi beach, further up the west coast. A national survey including sampling of natural sites using the same methods described above is currently underway to follow on from this investigation.

Catches of invertebrates in pitfall traps depend on abundance and activity of the organisms (Jones & Toft 2004; Norbury et al. 2009). Therefore it is with caution that conclusions are drawn from the invertebrate data. However, invertebrate assemblages were sampled twice, in December and February, in clear conditions with minimal wind or precipitation. It has been confirmed that pitfall trapping of lizards is an unbiased method for comparing lizard abundances between areas of differing vegetation cover (Schlesinger 2007; as cited by Norbury et al. 2009). Alternative methods could include the use of artificial retreats (Lettink et al. 2008). As the lizard pitfall trapping was only carried out for three days at each site, it may not be a true indication of population abundance. However, the Lincoln-Peterson method was found to be effective at estimating population size over just three days with Tuatara (*Sphenodon sp.)* populations (Moore et al. in press).

Conclusion

Restoration of dunes in New Zealand is generally focussed on restoring the native plant community or stabilising sand for erosion protection. These restoration projects have the potential to contribute much more in terms of improving biodiversity; however faunal communities and subsequent monitoring are often overlooked. This study aimed to compare differences in faunal communities of restored and marram dunes in the Wellington region.

Marram dunes support a higher diversity and abundance of fauna. Populations of common skink, house mouse, and invertebrates such as amphipods and beetles had significantly higher abundance in marram dunes than restored dunes sampled. This could be attributed to the higher structural complexity, diversity, and vegetation cover of marram dunes providing more desirable habitat.

Invertebrates carry out important functions in sand dune ecosystems. Monitoring fauna during the restoration process may be beneficial in identifying the optimal process for ensuring the ecological success of a restoration. Indicator orders such as Amphipoda, Coleoptera and Araneae may be used relatively easily by practitioners to measure the restoration progress of their dune. The applications of this will be discussed further in chapter four.

From a native biodiversity perspective, it is desirable for the sand dune ecosystem to contain healthy populations of native fauna. These findings show that the current assemblages of vegetation in restored dunes (typically pīngao, spinifex and a range of introduced weed species), are less desirable for fauna than the adjacent dunes dominated by marram grass. Although we know that lizards, katipō, and some moths prefer native species such as sand coprosma, sand daphne, and pohuehue, and these species should be incorporated into restoration plantings. Vegetation cover appears to be a significant determinant of faunal diversity, and therefore increasing the foliage cover in restoration plantings is also recommended. Chapter four discusses recommendations for current practice in further detail.

To conclude, marram grass communities appear to harbour the highest abundances of a wider range of sand dune fauna, apparently due to its greater structural complexity and greater foliage cover. Care should be taken when carrying out mass removal of marram grass in favour of a natural character of vegetation, and a faunal biodiversity survey should be carried out prior to removal. Restoration using native species should take into account the habitat requirements of fauna.

References

Andersen AN, Fisher A, Hoffman BD, Read JL, Richards R 2004. Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. Austral Ecology 29: 87-92.

Andersen AN, Majer JD 2004. Ants show the way Down Under: invertebrates as bioindicators in land management. Frontiers in Ecology and Environment 2(6): 291-298.

Ausden M, Drake M 2006. Invertebrates. In: Sutherland WJ ed. Ecological Census Techniques. Cambridge University Press. Pp. 214-249.

Begon M 1979. Investigating Animal Abundance: capture - recapture for biologists. Edward Arnold (Publishers) Limited. 97p.

Blomberg S, Shine R 2006. Reptiles. In: Sutherland, WJ ed. Ecological Census Techniques. Cambridge University Press. Pp. 297-307.

Brown KP, Moller H, Innes J, Alterio N 1996. Calibration of tunnel tracking rates to estimate relative abundance of ship rats (*Rattus rattus*) and mice (*Mus musculus*) in a New Zealand Forest. New Zealand Journal of Ecology 20(2): 271-275

Bullock JM 2006. Plants. In: Sutherland, WJ ed. Ecological Census Techniques. Cambridge University Press**.** Pp. 186-212.

Clewall A, Rieger JP 1997. What Practitioners Need from Restoration Ecologists. Restoration Ecology 5(4): 350-354.

Cockayne L 1909. Report on the sand dunes of New Zealand: the geology and botany, with their economic bearing. Department of Lands, Wellington, New Zealand.

Cockayne L 1911. Report on the dune areas of New Zealand: their geology, botany, and reclamation. Department of Lands, Wellington, New Zealand

Cockayne L 1967. New Zealand Plants and their story. 4th edition. Edited by Godley EJ, Owen RE. Government Printer, Wellington, New Zealand.

Crisp PN, Dickinson KJM, Gibbs GW 1998. Does native invertebrate diversity reflect native plant diversity? A case study from New Zealand and implications for conservation. Biological Conservation 83(2): 209-220.

Costall J A 2006. The ecology and conservation of *Latrodectus katipō*, New Zealand's endangered widow spider. Unpublished MSc thesis. Massey University, Palmerston North, New Zealand.

Costall JA, Death RA 2009. Population structure and habitat use by the spider *Latrodectus katipō* along the Manawatu-Wanganui coastline. New Zealand Journal of Zoology 36: 407-415.

Dawson J, Lucas R 1996. New Zealand coast and mountain plants. Victoria University Press. 176p.

Dixon P, Hilton M, Bannister P 2004. *Desmoschoenus spiralis* displacement by *Ammophila arenaria*: the role of drought. New Zealand Journal of Ecology 28(2): 207- 214.

Don W, Harris R 2009. *Tetramorium grassii* Emery. http://www.landcareresearch.co.nz/research/biocons/invertebrates/ants/infosheets/tetgra_info.asp. Downloaded 11 November 2009.

Dufrene M, Legendre P 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67(3): 345-366.

Freeman AB 1997. Comparative ecology of two Oligosoma skinks in Coastal Canterbury: a contrast with Central Otago. New Zealand Journal of Ecology 21(2): 153-160.

Galle L 1991. Structure and Succession of Ant Assemblages in a North European Sand Dune Area. Holarctic Ecology 14(1):31-37

Greenwood JJD, Robinson RA 2006. Principles of Sampling. In: Sutherland WJ ed. Ecological Census Techniques. Cambridge University Press. Pp. 13-85.

Griffiths JW, Paterson AM, Vink CJ 2005. Molecular insights into the biogeography and species status of New Zealand's endemic *Latrodectus spider* species; *L. katipō* and *L. atritus* (Araneae, Theridiidae). The Journal of Arachnology 33: 776-784.

Habtom H, Hartley S (unpub. data). Invertebrate survey of Piha and Baylys Beach 2009. Victoria University of Wellington.

Hilton MJ, Macauley U, Henderson R 2000. Inventory of New Zealand's active dunelands. Science for Conservation 157. Wellington, New Zealand, Department of Conservation.

Hilton MJ, Duncan M, Jul A 2005. Processes of *Ammophila arenaria* (Marram Grass) Invasion and Indigenous Species Displacement, Stewart Island, New Zealand. Journal of Coastal Research 21(1): 175-185.

Hitchmough RA, Bull L, Cromarty P (comps) 2007. New Zealand Threat Classification System lists 2005. Wellington, Department of Conservation.194p.

Hudson L 1973. A systematic revision of the New Zealand Dermaptera. Journal of the Royal Society of New Zealand 3: 219-254.

Jones C, Toft R 2006 . Impacts of mice and hedgehogs on native forest invertebrates: a pilot study. DOC Research and Development Series 245. Wellington, Department of Conservation. 32p.

Keesing V, Wratten SD 1998. Indigenous invertebrate components in ecological restoration in agricultural landscapes. New Zealand Journal of Ecology 22(1): 99-104.

Krebs C 2006. Mammals. In: Sutherland WJ ed. Ecological Census Techniques. Cambridge University Press. P 351-369.

Massey University. 2009. Guide to New Zealand soil invertebrates. http://soilbugs.massey.ac.nz/insecta.php. Downloaded December 2009.

Lettlink M, Patrick BH 2006. Use of artificial cover objects for detecting red katipō, *Latrodectus katipō* Powell (Araneae: Theridiiae). New Zealand Entomologist 29: 99-102.

Lettink M, Cree A 2006. Predation, by feral house mouse (*Mus musculus*), of McCann's skinks (*Oligosoma maccannii*) constrained in pitfall traps. Herpetofauna 36: 61-62.

Lettink M, Cree A 2007. Relative use of three types of artificial retreats by terrestrial lizards in grazed coastal shrubland, New Zealand. Applied Herpetology 4: 227-243.

Lettlink M, Cree A, Norbury G, Seddon PJ 2008. Monitoring and restoration options for lizards on Kaitorete Spit, Canterbury. DOC Research and Development Series 301. Wellington, Department of Conservation. 44p

Lindsay EA, French K 2006. The impact of the weed *Chrysanthemoides monilifera ssp rotundata* on coastal leaf litter Invertebrates. Biological Invasions 8(2): 177-192.

Longcore T 2003. Terrestrial Arthropods as Indicators of Ecological Restoration Success in Coastal Sage Scrub (California, USA). Restoration Ecology 11(4): 397-409.

Mahlfeld K 2000. Impact of introduced gastropods on molluscan communities, northern North Island. Conservation Advisory Science Notes 277. Wellington, Department of Conservation. 18p.

Majer JD 2009. Animals in the Restoration Process- Progressing the Trends. Restoration Ecology 17(4): 315-319.

McCutcheon ER 1976. Distribution of the Katipō Spiders (Araneae: Theridiiae) of New Zealand. The New Zealand Entomologist 6(2): 204.

McGuinness, CA 2001. The conservation requirements of New Zealand's nationally threatened invertebrates. Department of Conservation Threatened Species Occasional Publication 20. Wellington, Department of Conservation. 44p.

Miller AP, Webb PI 2001. Diet of house mice (*Mus musculus L.*) on coastal sand dunes, Otago, New Zealand. New Zealand Journal of Zoology 28: 49-55

Miller E, Paul T 2007. Measuring success: guidelines for the management of Sand Dune Revegetation Programmes. CDVN Technical Bulletin. Coastal Dune Vegetation Network, New Zealand Forest Research Institute Limited. P

Miller JR, Hobbs RJ 2007. Habitat Restoration- Do We Know What We're Doing? Restoration Ecology 15(3): 382-390.

Moore J, Grant T, Brown D, Keall SN, Nelson NJ 2009. Mark-recapture Accurately Estimates Census for a Burrowing Reptile (Tuatara). The Journal of Wildlife Management. In press.

Moore P, Davis A 2004. Marram grass *Ammophila arenaria* removal and dune restoration to enhance nesting habitat of Chatham Island Oystercatcher *Haemotopus chatamensis*, Chatham Islands, New Zealand. Conservation Evidence 1:8-9.

Newman DG 1994. Effects of a mouse, *Mus musculus*, eradication programme and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregors skink, *Cyclodina macgregori*. New Zealand Journal of Zoology 21: 443-456

Nicols OG, Grant CD 2007. Vertebrate Fauna Recolonization of Restored Bauxite Mines - Key Findings from Almost 30 Years of Monitoring and Research. Restoration Ecology 15(4): S116-S126.

Norbury G, Heyward R, Parkes J 2009. Skink and invertebrate abundance in relation to vegetation, rabbits and predators in a New Zealand dry land ecosystem. New Zealand Journal of Ecology 33(1): 24-31.

Patrick B 1994. Lepidoptera of Kaitorete Spit, Canterbury. New Zealand Entomologist 17: 52-63.

Palmer MA, Ambrose RF, Poff NL 1997. Ecological Theory and Community Restoration Ecology. Restoration Ecology 5(4): 291-300.

Patrick B 2002. Conservation status of the New Zealand red Katipō spider (*Latrodectus katipō*). Science for Conservation 194. Wellington, Department of Conservation. 33p.

R development core team 2009. The R Project for Statistical Computing. http://www.r-project.org/index.html Downloaded in July 2009

Roberts DW 2008. Package 'labdsv'. Ordination and Multivariate Analysis for Ecology 1.3-1. http://ecology.msu.montana.edu/labdsv/R Downloaded in October 2009

Seastedt TR, Crossley DA Jr 1984. The influence of Arthropods on Ecosystems. Bioscience 34(3): 157-161.

Smith DJ 1971. The habitat and distribution of the Katipō Spider at South Brighton Beach, Christchurch, New Zealand. New Zealand Entomologist 5: 96-100.

Tews J, Brose U, Grimm V, Tielborger K, Wichmann MC, Schwager M, Jeltsch F 2004. Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography 31: 79-92.

Towns DR, Elliot GP 1996. Effects of habitat structure on distribution and abundance of lizards at Pukerua Bay, Wellington, New Zealand. New Zealand Journal of Ecology 20(2): 191-206

Watts CH, Gibbs GW 2002. Revegetation and its Effect on the Ground-Dwelling Beetle Fauna of Matiu Somes Island, New Zealand. Restoration Ecology 10(1): 96-196

Webb CE, Oliver I, Pik A 2000. Does Coastal Foredune Stabilization with *Ammophila arenaria* Restore Plant and Arthropod Communities in Southeastern Australia? Restoration Ecology 8(3): 283-288.

Wedding CJ 2007. Aspects of the Impacts of Mouse (*Mus musculus*) Control on Skinks in Auckland, New Zealand. Unpublished MSc thesis. Auckland, Massey University.

Whitaker AH 1967. Baiting pitfall traps for small lizards. Herpetologica 4: 309-310.

Wilson DJ, Mulvey RL, Clark RD 2007. Sampling skinks and geckos in artificial cover objects in a dry mixed grassland-shrubland with mammalian predator control. New Zealand Journal of Ecology 31(2): 169-185.

Young TP 2000. Restoration ecology and conservation biology. Biological Conservation 92: 73-83.

Zeppelini D, Bellini BC, Creao-Duarte AJ, Hernandez MIM. 2009. Collembola as bioindicators of restoration in mined sand dunes of Northeastern Brazil. Biodiversity Conservation 18: 1161-1170.

Chapter four

Overall conclusions and recommendations

Figure 4.1: Student holding common skink caught during sand dune lizard survey. Photograph taken by author at Ocean Beach, Hawkes Bay 2008.

4.1 Summary of key findings

In what follows, the key findings of the two parts of the thesis are presented. The main aim of this thesis was to investigate the social and ecological realms of dune restoration in New Zealand. The main part of the thesis was divided into two parts, the social side (Chapter two) and the ecological side (chapter three) of dune restoration.

What are the motivations and management practices of existing dune restoration groups in New Zealand?

Following a web based survey of dune groups throughout the country; it became clear that the majority of groups were motivated to re-vegetate the dune for erosion protection and foreshore stabilisation. A small number of groups saw native plant conservation as a key priority, and even fewer groups (only one) saw restoration of fauna as an important priority. The majority of groups consisted of volunteers, supported by a paid council worker for advice and help with funding. Working bees were held 2-3 times per year for most groups. Dune restorations are commonly based on the methods developed by the Dune Restoration Trust for the establishment of sand binding species, spinifex (*Spinifex sericeus*) and pīngao (*Desmoschoenus spiralis*) on the dunes. Only a small proportion of groups included less common plant species in their restoration design. However, as many projects are formed for the purpose of stabilising sand for erosion protection, there is less emphasis on conservation of flora and fauna.

Are dune restorations in New Zealand followed up with monitoring?

Overall, the majority of groups stated that they carried out some form of monitoring. This mostly consisted of dune profile and vegetation growth monitoring and the majority of groups only measured one component. Of the groups interested in conservation of flora and fauna, few carried out formal monitoring of populations. Monitoring of floral biodiversity was the most common form of biodiversity monitoring, and fauna were monitored in a very small proportion of situations. The survey identified that lack of time, funding, and knowledge were limiting factors that commonly prevented monitoring from taking place. Groups identified a number of resources that would be beneficial to them in the future, namely increased assistance from a coast care coordinator, and an increased supply of resources.

Are there differences in biodiversity in restored dunes and marram dominated dunes?

Biodiversity sampling of invertebrate, lizard and vegetation assemblages identified a number of significant differences. See table 4.1 below for key results.

Table 4.1: Key results from biodiversity surveys of marram dominated and restored sand dunes in the Wellington region.

	Marram dominated	Restored
Plant species	Marram grass most common; ice plant, knobby club rush, hares tail, ripgut brome, brown top also common. Higher plant species richness and diversity in marram dunes.	Spinifex, pīngao more common species; marram grass, bone seed, sweet alyssum also common. Lower plant species richness and diversity
Vegetation height	Tall vegetation, most quadrats possessed vegetation cover of greater than one metre high.	Most vegetation less than 50cm high.
Vegetation foliage cover	High percentage cover of 80% of quadrat or more.	Lower percentage cover. Quadrat coverage between 40 and 80%.
Lizards	Common skink only, 80% of captures were in marram dunes. Estimated population size significantly higher in marram dunes.	Common skink only, 20% of all captures. Estimated population size lower in restored dunes
Invertebrate biomass	Invertebrate biomass significantly higher in marram dunes.	Lower invertebrate biomass
Invertebrate orders	Amphipods, spiders and bugs had significantly higher abundances in marram dunes. Order diversity and richness higher in marram dunes. Preying mantids found only in marram dunes.	Higher abundances of Opilones & Collembola in restored dunes. Low order diversity and richness
Coleoptera (beetles)	Marram dunes had significantly higher richness of RTUs than restored dunes. Most abundant species – native weevil – more common in marram dunes. Positive relationship between beetle RTU diversity and skink abundance.	Low RTU richness
Araneae (spiders)	Spider families generally had higher abundances in marram dunes. Family Oxyopidae had significantly higher population size	Low abundance of spiders

	in marram dunes.	
Katipō	No katipō were found	No katipō were found
Formidaceae (Ants)	Non-native Pennant ant (*Tetramorium grassii*) found only in Marram dunes. Higher ant species richness in marram dunes	Endemic southern ant (*Monomorium antarcticum)* found more often in restored dunes. Lower ant species richness and diversity than marram dunes.
Dermaptera (earwigs)	Endemic coastal earwig (*Anisolabis littorea)* found only at Lyall Bay site. European earwig (Forficula auricularia) found only in marram sites.	Endemic coastal earwig (*Anisolabis littorea*) found only at Lyall Bay site.
Gastropods (slugs and snails)	Introduced glass snail (*Oxychilus spp.*) found only in marram dunes.	None found
Mammalian pests	Marram dunes contained a significantly higher density of mice.	Lower mouse population density.
Community analysis	Lizards, mice, amphipods had significantly positive relationships with vegetation cover.	Lizards, mice, amphipods had significantly positive relationships with vegetation cover.

Marram dunes tended to contain higher abundance and diversity of fauna, and this was positively correlated with vegetation cover and diversity.

4.2 Implications of the research

This study has raised a number of issues as outlined in 4.1. In what follows, each issue will be discussed in light of the current findings.

4.2.1 Technocratic motivations for restoration with less emphasis on conservation

This study has confirmed that the majority of dune restoration groups see erosion protection and foreshore stabilisation as their main motivation for restoration. This technocratic rationale is commonly employed by agencies to return an ecosystem's function, with less emphasis on biotic components (Clewall & Aronson 2006). From the biotic perspective, groups are less interested in the conservation of flora, and a surprisingly small proportion of groups consider faunal conservation in their restoration activity. Therefore it is not surprising that their actions and goals are narrowed to planting native sand binding species – spinifex and pīngao for the purpose of coastal hazard management. Conservation is generally a secondary motivation for dune re-vegetation, although an increased number of groups are interested in conservation of native vegetation. Restoration actions are clearly based on the vegetation component, which is a common phenomenon in restoration science (Atkinson 1994). There is potential for restoration to have reciprocal benefits for flora *and* fauna, but a unified approach will be required, incorporating all motivations for restoration (Clewall & Aronson 2006). Animals are significant component of ecosystems, conducting many important functions. Recommendations for their inclusion in the dune restoration process are outlined in 4.2.3.

4.2.2 Lack of planning and monitoring

Increased incorporation of biodiversity and conservation in dune restoration projects will require an increase in systematic monitoring practice. From the survey, it is clear that monitoring is not being carried out as much as is necessary for maximum returns. This may be due to a lack of knowledge, time or resources. Monitoring tended to be based on one component, commonly vegetation or dune profile, and wasn't sufficiently quantitative to inform future restoration efforts. Monitoring of vegetation in sand dune restoration has been outlined by Miller & Paul (2007), although my research suggests this resource is under utilised. To ensure that the plant and animal response to restoration follows the intended trajectory, monitoring of progress is essential (Ruiz-Jaen & Aide 2005; Miller & Paul 2007). Without monitoring, we don't know whether our efforts are making a difference, or whether methods need to be altered to ensure an optimal ecological outcome (Atkinson 1994). A framework that can be easily applied by practitioners to allow a holistic approach to restoration, based on basic restoration ecology principles may be beneficial to ensure the ecological success of a project.

There is a challenge in finding the right balance between the scientific requirements of monitoring, and the guidance requirements and capabilities of those carrying out the monitoring (Lee et al. 2005). If the method is not easy to follow and understand, the monitoring will not get done (Atkinson 1994).

A generic monitoring method should:

- Be generic enough so it can be tailored to the objectives of each project, but detailed enough to provide ample information
- Have clear instructions that are simple and easy to follow
- Be accessible to groups through the internet.

The aim is to develop a generic monitoring method that can be applied to all projects and altered to ensure it is relevant to the group's initial objectives. Miller and Paul (2007) produce a good example of this, but it seems that this resource is not being utilised well by the dune restoration community. A method that is accessible and can be personalised to groups will likely be utilised more efficiently.

Potential monitoring methods

In reality, small scale projects do not have access to large amounts of resources that allow huge undertakings for example protection from predators with a fence, or comprehensive monitoring. Large scale projects give us the opportunity to carry out intensive and advanced (and expensive!) biodiversity monitoring which will allow us to understand the ecologies of sand dune fauna. Knowledge gained from monitoring results can then be applied to smaller scale projects, which carry out simple monitoring and record keeping.

Lizards

Lettink et al (2008) recommend the use of artificial retreats for monitoring lizard populations in sand dunes, as they can be easily checked by community group members. They are low cost, reduce the need to handle or contain the animals, and cause much less habitat disturbance than digging holes for pitfall traps! Artificial retreats can also be used for monitoring of katipō spider (Costall 2006; Lettink & Patrick 2006) which reduces the need for less reliable search methods which damage habitat, and may provoke the animal.

Invertebrates

Using ants as bio indicators has proved achievable by land managers in Australian mine restorations (Anderson & Majer 2004). A simple but effective method involves comparing ant species richness of mine sites undergoing restoration, with reference sites to assess the impact of management decisions. The more complex statistical analysis is carried out by an environmental consultant. The present study has identified potential indicators that could be used for measuring restoration progress, however for this to be implemented in restoration projects, further work is needed on our understanding of sand dune invertebrate ecology. This study identifies a number of orders that could be potentially used for monitoring, however further investigation will be required for them to effectively assess restoration progress.

Goal setting

Goals and objectives are often not outlined prior to the commencement of a restoration project (Atkinson 1994). Although it may seem a trivial task, it sets the scene for the future, and will ensure the effectiveness of the restoration for what can be a labour intensive and costly task (Atkinson 1994). The formulation of goals will rest on the motivations of practitioners. As small scale restorations are commonly restricted by time and money (Lee et al. 2005; Miller & Paul 2007), complex conceptual frameworks are not necessary. Required is a set of steps that can be adapted and applied to suit the nature of the project, that are accessible to all groups through a portal, potentially the DRT or Coast Care website. A number of information sources are currently available to groups, but may be difficult to access. Furthermore, the main motivations for restoration tended to be foreshore stabilisation and erosion protection, and other groups tended to believe they were 'doing the right thing' by replacing marram with native sand binders marram and spinifex. Identification of the main motivations for the project will shape the subsequent goals that are set. Possible reasons for dune re-vegetation may be:

- FUNCTIONAL: ie. Stabilisation of mobile sand; erosion control
- BIOLOGICAL: ie. Returning natural character to the dunes by replacing exotic species with natives

Groups identified that they would benefit from an increased supply of resources in the form of support from a coast care coordinator, and information in the form of hard copies or through the internet. Workshops and conferences were also identified as key sources of information. This is the perfect opportunity to alter the best practice methods to incorporate conservation of rare species. Goals and objectives can be altered to include the conservation of flora and fauna that are becoming increasingly rare in dunes. The goals and objectives set in the planning process allow effective evaluation of restoration outcomes using monitoring.

4.2.3 Marram dunes contain higher biodiversity

The higher levels of faunal diversity in marram dunes can most likely be attributed to the increased structural complexity, foliage cover, and diversity of vegetation. Marram dunes possess vegetation that is taller, denser, and contains a wider diversity of plant species, creating a desirable habitat for animals.

Although sand dune restorations are commonly initiated for the purpose of coastal hazard management (Miller & Paul 2007), they have the potential to contribute much more in terms of conservation of our native flora and fauna. Sand dune restoration is commonly focussed on the restoration of function, as opposed to biological conservation. Sand dunes are critically endangered ecosystems that provide habitat for rare and specialised species. With a little adjustment to restoration practice, there is huge potential to assist with the conservation of these species.

Animals play key roles in ecosystem function, therefore should be considered in restoration practice. Fauna are commonly overlooked, which is a common phenomenon throughout the world, although they are becoming increasingly included in the restoration literature (Majer 2009). It is often assumed to fit the assumptions of the ‘field of dreams hypothesis;’ but this assumption is often left untested. However, this study has identified that even after 5-6 years, restored dunes possess lower diversity and abundance of fauna. With the knowledge we have gained from other studies about habitat requirements for key species, we can included these in our restoration planning.

There are a number of plants that could be incorporated that have been identified as beneficial to fauna. Mingimingi (*Coprosma propinqua*), pohuehue (*Muehlenbeckia spp.*), sand coprosma (*Coprosma acerosa*), and sand daphne (*Pimelia arenaria*) provide habitat and a potential food source for lizards and invertebrates. Sand coprosma and spinifex are especially important for katipō (Costall 2006; Costall & Death 2009). Lizards tend to prefer divaricating shrubs and vines as they provide protection from predators (Lettink et al. 2008). These plants may be propagated relatively easily, but methods for their successful establishment on the dunes are still in early stages. Driftwood is also utilised by fauna with invertebrates utilizing crevices, and lizards preferring the moist environment underneath. Therefore driftwood should not be removed from the dunes, and should be incorporated into the restoration design. Native grasses such as *Poa cita* and *Austrofestuca littoralis* form tussocks that more closely resemble the dense structure of Marram, and these species may be suitable for planting in some areas. Following the provision of habitat for fauna, reintroduction may be required, especially of the species whose populations are limited.

The ideals of restoration involving the removal of exotic species and replacement with natives have been outlined by Bergin & Kimberly (1999) and the Forestry Research bulletins. However, the outcomes of this biodiversity survey suggest that marram provides better habitat for a number of native fauna than recently restored areas. The costs and benefits of using marram grass have been outlined by Gadgil (2006) in the 'Marram: friend or foe' booklet. However the potential for marram to act as habitat for native fauna has not been included in the analysis. The removal of marram grass and its replacement with pīngao and spinifex as a part of the restoration process may be restricting the distributions of invertebrates and lizards. This study illustrated that restoration of native sand binding plants did not necessarily result in the flourishing of the fauna community. Many restorations appeared to contain only spinifex and pīngao and threatened plants sand tussock, sand coprosma, shore splurge and pohuehue are commonly not included. This study has highlighted that marram provides desirable habitat for native faunal assemblages. Costall (2006) observed that around 70% of juvenile katipō were found in marram grass as opposed to native species, suggesting that it may be used as a refuge for recruits. In this study, dunes dominated by marram grass tended to contain the most diverse and abundant assemblages of invertebrates, lizards and introduced mice. Dune restoration typically involves the mass removal of marram, and its replacement with native sand binding species. Increased vegetation cover has been found to positively influence faunal abundance by this study, as well as in other systems (e.g. Norbury 2009). However, the effect of its removal and replacement with natives on fauna has not been quantified.

The naturalisation of marram grass in the sand dune environment makes it costly, and often not feasible to eradicate. Marram leaves behind a legacy, underground rhizomes, which continue to grow even after the above ground vegetation is removed. Reinvasion is highly likely, due to the ability of marram rhizomes to survive in seawater and be washed to new sites in the tide (Hilton et al. 2005).

We may need to proceed to incorporate marram into our restoration ventures, to ensure the resilience of our dune systems to inevitable environmental change. Marram is an effective sand stabiliser, having being introduced to New Zealand

and many other countries for this purpose (Hertling & Lubke 1999; Webb et al. 2000; Gadgil 2002). The projected sea level rise of 0.19-0.56cm within the next 80 years (Niwa 2008) and the suggested increase in storm surges, means increased erosion of our dune systems is likely. Marram is the most effective sand dune stabiliser beyond the fore dune crest (Esler 1970; Gadgil 2002). In some systems, exotic species have been used as functional equivalents, to native species no longer tolerant of current conditions (D'Antonio & Meyerson, 2002; SER 2004). Marram grass appears to provide suitable habitat for fauna, and could be incorporated into restoration projects. Therefore it could remain in these areas to ensure adequate habitat is provided, and protection from erosion in the face of climate change.

Partridge identified situations where marram may coexist with native sand binders (Partridge 1995). Marram coexists naturally with pīngao and spinifex in some situations, especially at Himatangi Beach north of Foxton (See figure 4.2 below). The marram dominates the rear of the fore dune, while pīngao and spinifex thrive in the incipient fore dunes closest to the shore. This natural design could be mimicked in restoration to ensure habitat for fauna is provided, and dunes are sufficiently stabilised.

Figure 4.2: Pīngao (front), spinifex (left rear) and marram (right rear) dunes at Himatangi beach, Foxton. Photograph taken by the author, November 2009.

Conclusion

The passion and dedication of volunteers involved in New Zealand’s dune restoration movement is heartening, restoration has significant potential to contribute to the rare and endemic species found within these endangered ecosystems. Current practice of removing marram grass, replanting with pingao and spinifex, followed by a lack of monitoring may not result in desirable outcomes for much of the flora or fauna. The inclusion of rare plant species such as coprosma, sand daphne, shore spurge, and pohuehue will have reciprocal benefits for the plants and animals that are disappearing from these dynamic ecosystems. In what follows, I make recommendations for current practice and future research.

4.3 Summary of recommendations for current practice

1. Identify main motivations for restoration, and shape goals accordingly with increased emphasis on conservation of flora and fauna
2. Develop a set of steps for setting objectives that can be applicable to all groups and accessed through a website or developed with the help of a council or DOC representative
3. Planting of a wider range of species, including those known to provide habitat for fauna such as pohuehue, sand coprosma, and sand pimelia. This will have reciprocal benefits for the plant and the animal
4. If removal of Marram is desirable, phase the removal over several stages, allowing time for each new section of restored dune to mature and for fauna to redistribute themselves
5. Develop a generic monitoring method that can be personalised to suit the goals of the project

4.4 Suggestions for future research

There is potential for restoration of sand dunes to become an 'acid test' for sand dune ecology. What we learn in large scale restoration projects using scientific methods and monitoring can be applied to smaller scale projects. In table 4.2 I make suggestions for directions of future research to ensure the effective conservation and restoration of our endangered sand dune ecosystems.

Table. 4.2 Suggestions for further research into the conservation of dune systems to follow on from this study; including a description (what) and possible method (how) and examples of studies that have touched on the subject in the past (who).

What	How	Who
Development of generic step by step goal setting process.	Developed using eco restoration knowledge and made accessible to all groups through the web.	Miller and Paul (2007) have introduced some simple steps for dune restoration goal setting, needs development.
Development of generic monitoring method that can be personalised and applied to all projects depending on goals	Developed using current ecological knowledge of dunes and made accessible to all groups through the web.	Miller and Paul (2007) have set the ball rolling, development and testing of a more accessible user friendly method is required.
Biodiversity of restored and marram dunes throughout the country	Using current method as outline in chapter 3, but increasing the number of sites sampled in a wider range of areas	Is currently being carried out by Hannah Buckley and Stephen Hartley with a grant from DoC using the methods of this present study.
Effect of restoration on katipō	Further search for katipō in restored sites	Costall (2006; 2009) assessed natural and marram dominated sites for katipō presence.
Diet of house mice in sand dunes - are they hindering the regeneration of native dune plants?	Stomach contents analysis, enclosure experiments	Has been investigated by Miller & Webb (2001) but further work is needed

Identification of important plant species for fauna, and how to incorporate them into restoration	Biodiversity studies – invert and lizard pitfall trapping in natural/restored sites.	Has been investigated in natural systems; Lizards (Lettink et al. 2008) Invertebrates (Patrick 1994).
Effect of restoration over time: do fauna return on their own	Biodiversity inventories carried out over time to observe changes in communities.	Has been investigated in mine sites in Australia (Nicols & Nicols 2003; Andersen & Majer, 2004)
Propagation and establishment of threatened dune plant species; steps for monitoring and management in the field	Field and nursery trials.	Has been carried out for sand binding species – pīngao, spinifex, and sand tussock by the Dune Restoration Trust
Assemblages of sand dune fauna in natural systems	Biodiversity inventories at natural sites	To follow on from the present study.

References

Andersen AN, Majer JD 2004. Ants show the way Down Under: invertebrates as bioindicators in land management. Frontiers in Ecology and Environment 2(6): 291-298.

Costall J A 2006. The ecology and conservation of *Latrodectus katipō*, New Zealand's endangered widow spider. Unpublished MSc thesis. Massey University, Palmerston North, New Zealand.

Costall JA, Death RA 2009. Population structure and habitat use by the spider *Latrodectus katipō* along the Manawatu-Wanganui coastline. New Zealand Journal of Zoology 36: 407-415.

Esler AE 1970. Manawatu sand dune vegetation. Proceedings of the New Zealand Ecological Society 17: 41-46.

Gadgil RL 2002. Marram grass (*Ammophila arenaria*) and coastal sand stability in New Zealand. New Zealand Journal of Forestry Science 32(2): 165-180.

Gadgil RL 2006. Marram Grass: Friend or foe. CDVN Technical Bulletin No. 5. New Zealand Forest Research Institute Liimited. 32p.

Lee W, McGlone M, Wright E 2005. Biodiversity Inventory and Monitoring: A review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. Landcare Research Contract Report: LC0405/122 218

Lettink M, Cree A, Norbury G, Seddon PJ 2008. Monitoring and restoration options for lizards on Kaitorete Spit, Canterbury. DOC Research and Development Series 301. Wellington, Department of Conservation. 44p

Majer JD 2009. Animals in the Restoration Process- Progressing the Trends. Restoration Ecology 17(4): 315-319

Miller E, Paul T 2007. Measuring success: guidelines for the management of Sand Dune Revegetation Programmes. CDVN Technical Bulletin, Coastal Dune Vegetation Network, New Zealand Forest Research Institute Limited.

Miller AP, Webb PI 2001. Diet of house mice (*Mus musculus L.)* on coastal sand dunes, Otago, New Zealand. New Zealand Journal of Zoology 28: 49-55.

Nicols OG, Nicols FM 2003. Long-Term Trends in Faunal Recolonization After Bauxite Mining in the Jarrah Forest of Southwestern Australia. Restoration Ecology 11(3): 261-272.

Ruiz-Jaen MC, Aide TM 2005. Restoration Success: How is it being measured? Restoration Ecology 13(3): 569-577.

Society for Ecological Restoration International Science & Policy Working Group 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International. http://www.ser.org/content/ecological_restoration_primer.asp Downloaded February 2009.

Appendix one: Survey forms

Sand dune restoration in New Zealand

Hi, Im Sam, a Masters student at Victoria University conducting my thesis on coastal sand dune restoration in New Zealand. As part of this research, I am carrying out a survey of dune restoration groups to review aims, aspects of support and funding and what records they take to assess biological change.

This information will be helpful for improving knowledge in regards to the biodiversity of restored dunes, and identifying areas that need improvement in regards to resources and support. I am hoping to work out what can be done to ensure that dune restoration by community groups is sustainable in the future.

The survey is aimed at one representative from each group - you may be a volunteer or a council employee, it doesn't matter! As long as you think you can speak for the members of your group :)

Please answer the following questions as best you can, it won't take long! Responses to the survey will only be reported in aggregate form (ie 10% of respondants said..) so individual answers will be confidential!
Any questions contact me at jammy.sam@gmail.com or on 027 632 5725.

---

* Required

1. Are you...

- ◘ conducting restoration in your own time (ie as a volunteer)
- ◘ paid to assist with restoration work/coordination (ie a ouncil worker)
- ◘ I am both a volunteer and a paid assistant
- ◘ Other: ☐

2. Name of dune restoration site (optional) ☐

3. In what region is the site? * ☐

4. How long has your group been active at this site?

- ◘ 1-2 years
- ◘ 3-4 years
- ◘ 5-6 years
- ◘ More than 6 years

5. How often do you hold working bees? (ie either at the site or doing nursery work)

- ◘ Weekly or fortnightly
- ◘ Monthly
- ◘ Every few months
- ◘ 2-3 times a year
- ◘ Other:

6. How many volunteers are involved with the project?

- ◘ 1-10
- ◘ 11-20
- ◘ 21-50
- ◘ Other:

7. How many paid staff are involved in the project?

- ◘ none
- ◘ 1
- ◘ 2
- ◘ 3
- ◘ 4 or more

8. What has been planted in your dune? Tick all that apply

- ☐ Pingao
- ☐ Spinifex
- ☐ Flax
- ☐ Sand tussock
- ☐ Sand pimelia
- ☐ Euphorbia glauca
- ☐ Coprosma acerosa
- ☐ M Complexa
- ☐ Other:

9. Are invasive weeds a problem in your dune? What species?

- ☐ Marram grass
- ☐ Lupin
- ☐ Boneseed
- ☐ Pasture grasses
- ☐ Pine trees
- ☐ Ice plant
- ☐ Garden weeds
- ☐ Other:

10. Are any of these being actively controlled? What species?

- ☐ Marram grass
- ☐ Lupin
- ☐ Boneseed
- ☐ Pasture grasses
- ☐ Pine trees
- ☐ Ice plant
- ☐ Garden weeds
- ☐ Other: [ ]

11. How are they controlled?

- ☐ Hand pulling
- ☐ Herbicide spray
- ☐ not controlled
- ☐ Other: [ ]

12. Do you know if animal pests are present in your dune? What species?

- ☐ Rats
- ☐ Mice
- ☐ Stoats/mustelids
- ☐ Cats
- ☐ Rabbits
- ☐ Dont know
- ☐ stock
- ☐ none
- ☐ Other: [ ]

13. Are any of these actively controlled? What species?

- ☐ Rats
- ☐ Mice
- ☐ Stoats/mustelids
- ☐ Cats
- ☐ Dont know
- ☐ Other: [ ]

14. How important is foreshore stabilization/erosion control of your dune?

	1	2	3	4	5	
Very important	☐	☐	☐	☐	☐	Not a priority

15. How important is the conservation of native plant diversity in your dune? On a scale of 1 to 5

	1	2	3	4	5	
Very important	◘	◘	◘	◘	◘	Not a priority

16. How important is the conservation of native animal biodiversity, for example lizards and invertebrates?

	1	2	3	4	5	
Very important	◘	◘	◘	◘	◘	Not a priority

17. How important is the dune re-establishment?

	1	2	3	4	5	
Very important	◘	◘	◘	◘	◘	Not a priority

18. Of the above factors, which is the MOST important? Tick the choice that applies

- ◘ Foreshore stabilization/ erosion control
- ◘ native plant conservation
- ◘ native animal conservation
- ◘ dune re-establishment
- ◘ Other: ____

19. Does your group regularly inspect the site to monitor the restoration process? This may include checking for browsing, assessing plant growth.. etc

- □ Yes
- □ No
- □ Other: ____

20. If yes, what aspects are monitored? Tick those that apply

- ◘ native vegetation
- ◘ plant pests
- ◘ animal pest numbers
- ◘ lizards
- ◘ Invertebrates
- ◘ beach/dune profile
- ◘ endangered plants
- ◘ birds
- ◘ Other: ____

21. If yes, has monitoring been useful for: TIck those that apply

- ☐ demonstrating negative outcomes?
- ☐ helping in funding applications?
- ☐ nothing, it has not taught us anything?
- ☐ helping recruit volunteers?
- ☐ helping develop more effective techniques?
- ☐ demonstrating positive outcomes?
- ☐ Other:

22. If no monitoring has been carried out, is it because of: Tick those that apply

- ☐ Lack of time
- ☐ Lack of funding
- ☐ Dont know how
- ☐ we are aiming to do it in the future
- ☐ don't think its necessary
- ☐ Other:

23. If biodiversity monitoring was carried out, were any interesting results found?

24. Are there any resources that your group has found particularly useful for information on the restoration process? Please specify

25. Is there a paid council worker or local authority available to assist with your project?

- ☐ Yes
- ☐ No

26. If yes, how do they assist?

- ☐ Advice
- ☐ Coordinating regular meetings
- ☐ helping with funding
- ☐ help with acess to information and resources
- ☐ Other: [ ]

27. Would the group benefit from: Tick those that apply

- ☐ coast care coordinator time
- ☐ workshops/lectures from experts
- ☐ field trips to other sites
- ☐ networking between care groups
- ☐ attendance at Dunes Trust conference
- ☐ supply of resources through the internet
- ☐ supply of resources - hard copies

28. How is your project funded?

- ☐ Local council
- ☐ fundraising done by the group
- ☐ DOC grant
- ☐ Private sponsor
- ☐ Other: [ ]

29. Can you estimate how much time goes into looking for funding and preparing funding applications?

- ☐ Hours
- ☐ Days
- ☐ Weeks
- ☐ Months
- ☐ Other: [ ]

30. Is this funding work done by ...

- ☐ Council worker
- ☐ volunteers
- ☐ Other: [ ]

31. Please add any other comments that you think may be helpful!

32. Please leave your email address if you would like to be notified of the results!

Is your group a member of the Dune restoration trust? If not, why not?

- We are members
- Havent heard of them
- Cant afford it
- We already have the knowledge to do the job

Monitoring survey

Hello again, thanks for participating in my survey, here are just a few follow up questions that I realised may not have been very clear the first time around. Your participation is greatly appreciated!!

---

* Required

1. Does your restoration have ... * Tick those that apply

- A clear goal or vision
- detailed objectives for measuring success
- No planning as such
- a restoration plan
- Other:

1. Does your group carry out any biodiversity monitoring? * Tick those that apply

- Yes, we do
- No we do not carry out biodiversity monitoring

Use of biodiversity monitoring

Does your group carry out any of the following biodiversity monitoring techniques for vegetation? Tick those that apply

- ☐ Photo points
- ☐ Percentage cover estimates
- ☐ Measures of vegetation growth
- ☐ Presence/abundance of pest plants
- ☐ Presence/abundance of native plants
- ☐ Presence/abundance of threatened plants
- ☐ Not sure
- ☐ Other
- ☐ None of the above

Does your group carry out any of the following monitoring techniques for animals? Tick all that apply

- ☐ Counts of pest animals
- ☐ Counts of lizards
- ☐ Counts of birds
- ☐ Counts of invertebrates
- ☐ Not sure
- ☐ None of the above
- ☐ Other: ☐

Are the results from your monitoring useful for.. tick all that apply

- ☐ Demonstrating positive outcomes
- ☐ Demonstrating negative outcomes
- ☐ Helping with funding applications
- ☐ Helping to recruit volunteers
- ☐ giving advice to other groups
- ☐ Other: ☐

Is this monitoring carried out by.. Tick those that apply

- ☐ volunteers
- ☐ council staff
- ☐ DOC staff
- ☐ Not sure
- ☐ Other: ☐

If yes, is there a resource you find particularly useful for monitoring? Tick all that apply

- ☐ Measuring success booklet - CDVN
- ☐ Coast care coordinator
- ☐ Advice from Dune restoration trust
- ☐ Advice from consultant or ecologist
- ☐ Other: [ ]

[0]

If no biodiversity monitoring is carried out..

If no biodiversity monitoring is carried out is it because.. Tick all that apply

- ☐ We don't know how
- ☐ Dont think its important
- ☐ Lack of time
- ☐ Lack of funding
- ☐ Lack of support
- ☐ We are still in the early stages of our restoration
- ☐ Too hard
- ☐ We aim to do it in the future
- ☐ Other: [ ]

Appendix two: List of fauna observed

Table 1. Coleoptera observed in dunes in the Wellington region. RTUs were developed in conjunction with the Lincoln University Entomology Museum staff and specimens identified with the help of Dr John Marris. Dune specialists are identified in the far right column.

Family	Genus/sp	RTU	Dune specialist?
Anthicidae	*Sp 2*	25	
Anthicidae	*Lagrioida brouni*	55	Driftwood beetle
Anthicidae	*Anthicus sp.*	207	
Anthribidae	*Euiciodes suturalis*	502	
Archaeocrpticidae	*Archaeocrypticous topali*	514	
Carabidae	*Ctenognathus sp*	27	
Cerambycidae	*Somatidia sp.*	506	
Cerambycidae	*Xylotoles sp*	42	
Cerambycidae	*Sp 1*	503	
Cerambycidae	*Sp 2*	504	
Cerambycidae	*Sp 3*	505	
Cerylonidae	*Hypodacnella rubripes*	509	
Coccinellidae	*Coccinella undecimpunctata*	203	
Coccinellidae	*Sp*	205	
Corylophidae	*Sp 1*	510	
Corylophidae	*Sp 2*	511	
Curculionidae	*Cecyropa spp.*	23	Sand weevil
Curculionidae	*? Cossoninae sp 1*	204	
Curculionidae	*? Cossoninae sp 2*	507	
Curculionidae	*? Cossoniniae sp 3*	508	
Elateridae	*Sp*	32	
Hydrophilidae	*Sp*	512	
Leodidae	*Sp*	26	
Melyridae	*"Dasystes" sp.*	501	
Oedemeridae	*Thelyphasa sp*	103	Driftwood beetle
Phycosecidae	*Phycosecis limbata*	500	Beach scavenger beetle
Scarabaeidae	*Acrossidius tasmaniae*	513	
Scarabaeidae	*Odontria sp 1*	31	
Scarabaeidae	*Odontria sp 2*	516	
Scarabaeidae	*Costelytra sp*	515	
Staphylinidae	*Sp*	67	
Tenebrionidae	*Actizeta albata*	15	
Tenebrionidae	*Chaerodes sp*	201	
Tenebrionidae	*Mimopeus sp*	36	
Zopherideae	*Sp*	9	

Table 2: Spiders captured in pitfall trapping of restored and marram dunes in the Wellington region. Specimens identified with the help of Jagoba Mulumbres-Olarte of Lincoln University. Spiders were grouped into family for analysis.

Family	Genus/species	RTU
Araneidae	*Agriope protensa*	319
Araneidae	*?*	312
Clubionidae	*?*	302
Clubionidae	*?*	310
Dysderidae	*Dysdera crocata*	125
Gnaphosidae	*Anzacia gemmea*	314
Linyphiidae	*Microctenoyx subitaneus*	70
Linyphiidae	*Ostearius melanopygius*	93
Linyphiidae	*Dunedinia denticulata*	63
Lycosidae	*Anteropsis hilaris*	52,12
Lycosidae	*Anteropsis litoralis*	88,13
Lycosidae	*?*	95
Lycosidae	*?*	301
Lycosidae	*?*	305
Oxyopidae	*Oxyopes gracilipes*	91,30
Salticidae	*?*	315
Theridiiae	*Cryptachaea 1*	316
Theridiiae	*Cryptachaea blattea*	318
Theridiiae	*?*	309
Theridiiae	*?*	320
Theridiiae	*?*	43
Thomsidae	*Sidymella angularis*	317
Thomsidae	*?*	300

Table 3: Remaining fauna observed in restored and marram dunes in the Wellington region. Please note this list is not exhaustive, it contains only the names of specimens able to be identified past order level.

Fauna observed	Common name	Native or introduced
Mammals		
Mus musculus	House mouse	I
Oryctolagus cuniculus	Rabbit	I
Felis cattus	Cat	I
Reptiles		
Oligosoma nigriplantare polychroma	Common skink	N
Formicideae (ants)		
Hyponera eduardi	Crypt ant	I
Monomorium antarcticum	Southern ant	N
Monomorium antipodum	Tiny brown ant	N
Pachycondyla castanea	none	N
Tetramorium grassii	Pennant ant	I
Dermaptera (earwigs)		
Anisolabis littorea	Seashore earwig	N
Forficula auricularia	European earwig	I
Gastropoda (snails)		
Oxychilus spp.	Glass snail	I

Appendix three: Native flora of sand dunes

Table 4 Native flora known to sand dunes with conservation status (Hitchmough et al. 2007), and those crossed were observed in the present study. For further information on dune flora see Cockayne (1967), Gadgil (1981).

Scientific name	**Common name**	**Status**	**Observed**
Acaena pallida	Sand piripiri		X
Austrofestuca littoralis	Sand tussock	Gradual decline	
Calystegia soldanella	Shore bindweed		X
Carex pumila	Sand sedge		X
Coprosma repens	Tuapata		X
Desmoschoenus spiralis	Pingao	Gradual decline	X
Disphyma australe	Ice plant		X
Euphorbia glauca	Shore spurge	Serious decline	
Ficinia nodosa	Knobby club rush		X
Libertia peregrinans	NZ iris	Gradual decline	X
Muehlenbeckia axillaris	Creeping pohuehue		X
Myoporum laetum	Ngaio		X
Olearia solandri	Coastal tree daisy		X
Phormium tenax	Flax		X
Pimelia aff. arenaria	Sand daphne	Serious decline	
Poa cita	Silver tussock		X
Spinifex sericeus	Silvery sand grass		X
Tetragonia implexicoma	NZ climbing spinach		X
Tetragonia tetragoniodes	NZ spinach	Sparse	

Appendix four: List of introduced flora

Table 5: List of introduced plants observed in marram and restored dunes in the Wellington region

Scientific name	**Common name**
Agapanthus praecox	African lily
Agrostis capillaries	Brown top
Allium triquetum	Onion weed
Ammophila arenaria	Marram grass
Asparagus scandens	Asparagus fern
Brassica oleracea	Wild mustard
Bromus catharticus	Rescue grass
Bromus diandrus	Ripgut brome
Cakile maritima	Sea rocket
Carpobrotus spp.	Ice plant
Chrystemoides monilifera	Bone seed
Cirsium avense	Californian thistle
Dactylis glomerata	Cocks foot
Ehrhata erecta	Veldt grass
Gazania rigen	Treasure flower
Hypochaeris radicata	Catsear
Lagarus ovata	Hares tail
Lupinus arboreus	Tree lupin
Lobularia maritima	Sweet alyssum
Lolium spp.	Perennial ryegrass
Lotus pendunculatus	Tetraploid lotus
Mollugo verticillata	Carpet weed
Plantago coronopus	Buckhorn plantain
Rosa rubignosa	Sweet briar
Senecio elegan	Purple groundsel
Sonchus oleraceus	Common sour thistle
Stenotaphrum secundatum	Buffalo grass
Taraxacum spp.	Dandilion
Trifolium pratense	Broad red clover
Ulex europeus	Gorse

Appendix five: Site photos and dates of sampling

Lyall Bay

Site description: Popular urban beach with thin strip of dune backing onto busy road. Medium wave action, exposed to Southerly.

Dates visited: Vegetation (12th November 2008) Invertebrates (15,16th December 2008; 4,5th Feb 2009), lizards & mammals (3rd,4th,5th Feb 2009)

Figure 1: Aerial photo of Lyall Bay Marram dune

Figure 2: Aerial photo of Lyall Bay restored dune

Eastbourne

Site description: Beach in residential area, dune stabilised, pebble beach. Community restoration group has planted range of native species, and tend the dune occasionally.

Dates visited: Vegetation (13th November 2008) Invertebrates (9th,10th December 2008; 25th,26th Feb 2009), lizards & mammals (25th,26th,27th Feb 2009)

Figure 3: Aerial photo of Eastbourne marram and restored dune (circled)

Petone 1

Site description: Popular urban beach with thin strip of dune backing onto busy road. Low wave action, exposed to southerly. Community group tends dune monthly

Dates visited: Vegetation (14th November 2008) Invertebrates (16th,17th December 2008; 25th,26th Feb 2009), lizards & mammals (25th,26th,27th Feb 2009)

Figure 4: Aerial photo of Petone 1 Marram and restored dune

Petone 2

Site description: Popular urban beach with thin strip of dune backing onto busy road. Low wave action, exposed to southerly. Community group tends dune monthly

Dates visited: Vegetation (15th November 2008) Invertebrates (9th,10th December 2008; 4th,5th Feb 2009), lizards & mammals (3rd,4th,5th Feb 2009)

Figure 5: Aerial photo of Petone 2 restored and marram dune

Paraparaumu

Site description: Dune backing onto residential area, low wave action.

Dates visited: Vegetation (18th November 2008) Invertebrates (3rd,4th December 2008; 18th,19th Feb 2009), lizards & mammals (18th,19th,20th Feb 2009)

NB. Aerial photo unavailable for this area

Otaki

Site description: Dune backing onto farmland and residential area. Community group tends dune regularly. Medium wave action but dune quite a distance from shore line.

Dates visited: Vegetation (18th November 2008) Invertebrates (3rd,4th December 2008; 18th,19th Feb 2009), lizards & mammals (18th,19th,20th Feb 2009)

NB. Aerial photo unavailable for this area.

Appendix six: Abstract for INTECOL presentation

Monitoring of New Zealands' restored sand dunes: are our native fauna being cared for?

Samantha Jamieson[1], Murray Williams[1], Stephen Hartley[1]

[1] *School of Biological Sciences, Victoria University of Wellington; New Zealand*

Coastal sand dunes are critically endangered ecosystems, supporting a wide variety of specialist native flora and fauna. They have declined significantly in the past century, due to coastal development and stabilization using marram grass (*Ammophilia arenaria*). Interest in the restoration of dune ecosystems is becoming increasingly widespread throughout the country. Many groups have carried out small scale rehabilitations, but efforts are generally not monitored, and methods often fail to draw on the science of dune ecology.

In the present study, plant and animal biodiversity was sampled at sites under restoration with native plants, paired with nearby sites dominated by marram grass. Despite intensive investigation, species such as katipo spider (*Latrodectus katipo*), copper skink (*Oligosoma infropunctatum*), and common gecko (*Hoplodactylus maculatus*), thought to inhabit Wellington dunes, were not observed in either marram or restored dunes. Mouse population density was higher in marram dunes, as was population size of common skink, (*O. nigraplantare polychroma*).Although this can most likely be attributed to vegetation cover, it highlights the need for monitoring.

Restoration of dune ecosystems has the potential to benefit not only native flora, but threatened native fauna as well. Identifying biological change and adaptively managing the restoration process may be beneficial in identifying optimal habitat for fauna, but this approach is unfamiliar to the majority of practitioners. A survey of dune restoration practitioners is being conducted to reveal the reasons behind this, and to identify areas in need of improvement in New Zealand's otherwise healthy dune restoration movement. Analysis of invertebrate communities as a part of this investigation is also underway.