Vehicle damage to vegetation of the Rangipo Desert, Tongariro National Park, New Zealand

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Abstract

Rangipo Desert, Tongariro National Park, Central North Island, New Zealand, contains one of New Zealand's unique habitats due to the desert-like environment containing cushions, low lying species, and native grasses which create a diverse mosaic of plant species and colour. This area is under anthropogenic threat from drivers operating vehicles over the vegetation. My aim was is investigate the damage to vegetation and substrates which have been driven over by vehicles.

Aerial images were used to draw information about the Desert's ecosystem, and driver's manoeuvring preferences which were ground-truthed. A Canonical Correspondence Analysis was used to evaluate the accuracy of categories from the aerials after ground-truthing. A Paired t test was used to show varying vegetation densities against other tested variables. A Chi Square Analysis was used to examine where drivers preferred to drive. The results indicate drivers prefer to drive over bare substrate and sparsely vegetated areas within the desert, avoiding dense vegetation, deeply cut channels and rough, un-driveable terrain.

The direct damage done by vehicles to vegetation and surrounding substrate was tested by running a simulated tyre over the substrate and plants. A plant having had a tyre pushed over it by hand was compared to a plant that had been previously damaged by vehicles, and a control (undamaged) plant. Analysis of Variance was used to test differences in the growth of the plants within each treatment and the change in topography. There is evidence of plant damage; however, different species reacted differently to treatments, depending on which variable was being tested, making it difficult to identify which species are most affected by vehicle damage.

The tyres alter the substrate instantly. Intact and broken substrates were compared by creating wind and rain with a leaf blower and watering can. The change in substrate height was measured and Analysis of Variance was used to test the amount of substrate erosion. Results show broken substrates are eroded at a greater rate than intact substrates, and the erosion rate is increased when the substrate is dry. Wet, sandy substrates in windy conditions and wet, pumice substrates in rain have the lowest amount of substrate movement after damage.

The Rangipo Desert’s dry and open ecosystem and vegetation is vulnerable to damage from vehicles. Vehicles cause plant die-back, increase erosion and have the potential to change the current ecosystem. Preventing vehicles driving into the Desert, and educating members of the public about ecosystem damage are good starting points to manage and preserve this area of Tongariro National Park.

KEYWORDS Arid ecosystems, vehicle damage, erosion, plant changes, micro-topography.

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Dedicated to
My grandson Raymond
May there still be some healthy earth for your Grandchildren!

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Chapter 1

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1.1 General Introduction

Globally, a consequence of human invasion is anthropogenic disturbance resulting in either death of individual organisms or the extinction of species (Gibbs 2006, Alroy 2001, Vitousek *et al*. 1997) affecting ecosystems (Groom *et al.* 2007, Vitousek *et al*. 1997). Anthropogenic activities increase disturbance within ecosystems and can disrupt entire ecological units through vegetation damage, soil instability, stream disturbance and altering animal behaviour which can in turn lead to population declines of both plants and animals. The resulting effects on ecosystems are not only evident at varying ecological scales, but can be immediate or delayed, direct or indirect, or a combination of these.

New Zealand is a country that is greatly affected by human activities, and also contains many unique ecosystems which are highly vulnerable to disturbance. In particular our estuaries are vulnerable to the dumping of rubbish, our rivers are contaminated by industrial pollution, riparian strips which are breeding grounds for native *Galaxias* are used by farmers to graze their cattle, and sand dunes and desert-like ecosystems are repeatedly being driven over. The aim of this study is to look at the effects of vehicles driving over the vegetation and substrates of New Zealand’s Rangipo Desert, Tongariro National Park, Central North Island.

Background

In 700AD before recorded human settlement in New Zealand, much of the fauna was unique to this country (Gibbs 2006) and 100 percent of the flora was native and covered 75 percent of New Zealand; only the sandy coastlines and above tree-line limits of mountainous ranges were un-vegetated (McGlone 1989, Foster 2008). In New Zealand, 85 percent of native seed plants and 41 percent of its ferns are endemic; this endemism in plants is higher than can be found anywhere else in the world (Godley 1976, Glasby 1991), suggesting that New Zealand is unique. Early

Polynesian setters used fires to clear the forested landscape for village settlements (McGlone 1989), to prepare transport routes, and to flush out ground dwelling birds (Foster 2008). These first colonists reduced the extent of native cover on the main islands to 50 percent (McGlone 1989, Mark & McLennan 2005) and caused the extinction of both plant and animal species (Holdaway 1989, Holdaway 1999, Foster 2008). Since European settlement around 1840, native vegetation cover has been reduced even further to 23 percent (Foster 2008) and the number of extinct species of both plants and animals has risen.

The New Zealand landscape is changing; the amount of land covered by indigenous forest is decreasing, while urbanisation and the number of large industrial complexes being built are increasing (McDowall 1984). Forests have made way for urbanisation, and primary industries such as agriculture, horticulture, mining, tourism and ecotourism, while pastoral land use is intensifying (McDowall 1984). Alluvial floodplain forests, fertile wetlands and indigenous grasslands are now largely replaced with agricultural landscapes which are predominantly pastures of introduced grasses and clovers (*Trifolium* spp.) (MacLeod & Moller 2006). Tourism is another increasingly important component of New Zealand's economy (Hall & Kearsley 2001). The number of tourists that come to New Zealand annually is increasing (Lawson *et al* .1998; Cloke & Perkins 2010). New attractions and facilities are being designed and built for the increasing number of tourists (Richie 1998). The increased infra-structural development applies more pressure on the environment (Cohen 1978), which can potentially create enough damage to lessen the value of the areas used for tourism and recreation (Pickering & Hill 2007).

In addition to the damage done to the environment on a large scale, caused by deforestation and infra-structural development, smaller scale damage by humans can be just as devastating ecologically and temporally. Smaller scale effects can include noise pollution, trampling, eutrophication, increased CO_2 emissions, and reproductive disturbance of flora and fauna (Vollmer *et al*. 1976, Chen *et al.* 2007, Swaddle & Page 2007, Winsley 2007, Lengagne 2008, Rusterholz *et al*. 2009).

Humans can also alter ecosystems through eutrophication; nitrogen and phosphorous addition to depleted soils runs the risk of surplus nutrients leaching into our waterways (Winsley 2007). The over-use of these elements is recognised as the major causes of eutrophication (Chamber *et al.* 2006) of streams and rivers worldwide, resulting in consequences for both aquatic communities and ecosystem processes (Gukis *et al.* 2006).

Activities such as camping and barbequing have the potential to change the soil pH, soil organic matter and nutrient composition (Kissling *et al.* 2009). Activities such as hiking, horse trekking, mountain bikes and all-terrain vehicle action increase acoustic disturbances. Noise pollution, for example, in terrestrial and aquatic environments, can reduce opportunities for animals to perceive natural sounds which can reduce fitness (Lengagne 2008), reduce foraging ability in bats (Jones 2008), alter mating behaviours in birds (Swaddle & Page 2007), or interfere with echo transmitting communication signals of dolphins (Lusseau & Higham 2004). Trampling experiments reveal that the extent of damage depends on the frequency of visitors and the kind of recreational activity undertaken (Kissling *et al.* 2009*).*

Off-road impacts

Off-road activities increase trampling of vegetation and vehicles can serve as dispersal vectors for alien plant propagules (Schmidt 1989) and seed (Hodkinson & Thompson 1997). Trampling, horse trekking, and off-road vehicles, both motorised and self-propelled, exert friction on vegetation that can result in mechanical damage to plants by squashing and breaking shoots, reducing seed set and dispersal, dislodging root systems, and disturbing soils. Longer-term, trampling can potentially influence the entire ground vegetation system including leaf litter and soil layer reactions (Rusterholz *et al.* 2009), including either breakage or compaction. Soil compaction through tramping reduces microbial activity; plant-microbe interactions are essential for plant survival and productivity, and plants in turn directly influence the diversity and activity of soil microbial communities (Kissling *et al.* 2009). When trampling activities take place near streams and waterways the trampling effects can increase the sediment load of streams, degrading stream quality and preventing migratory activities of stream inhabitants (Wilkerson & Whitman 2009).

At the community scale, trampling can do damage to vegetation, soils, animals, and can alter community composition (Vollmer *et al*. 1976, Monz 2002, Pickering *et al.*

2010). Trampling decreases the species' diversity of vegetation (Yu *et al.* 2008) as certain vegetation types have different thresholds of vulnerability (Cole 1995a, Yorks *et al.* 1997). For example alpine vegetation could be more resistant than subalpine and low-elevation plant types (Whinam & Chilcott 1999). While graminoids are most resistant, matted and rosette forbs are moderately resistant and least resistant are erect forbs (Cole 1995b). According to Whinam & Chilcott (1999) plant height is also an important morphological feature that influences resistance. Species that are more resistant are more likely to persist after trampling and become more numerous, while less tolerant species are more prone to death or dieback resulting in vegetation diversity decline, altering plant community composition. Alterations in plant communities could possibly increase faunal loss too, especially when the plants and pollinators have a mutualistic relationship and the pollinator relies on the plant for shelter or food (Fortuna & Bascompte 2006). The extent of damage depends on the frequency of visitors and trampling intensity (Sun & Liddle 1993, Cole 1995a, Kissling *et al.* 2009).

Off-road motor vehicles not only adversely affect vegetation (Tonnesen & Ebersole 1997) and soil substrates (Belnap & Gillette 1998), but they also confound ecosystem damage by elevating pollution, through carbon emissions (Chen *et al*. 2007) and leaching of heavy metal concentrations into top-soil on roadsides. Metal concentrations were significantly higher with increased traffic density and increased speed of vehicles (Hjortenkrans *et al*. 2006).

At the plant scale, trampling can cause immediate damage to the roots and shoots of vegetation. Roots can become exposed (Pickering *et al.* 2010), and shoots can become fragmented as they are being driven over (Sun & Liddle 1993). Fragmentation decreases the height of the vegetation, which is followed by a decline in cover leading to the subsequent death of vegetation (Rickard *et al*. 1994). Furthermore this disturbance can decrease genetic diversity of plants by reducing the sexual reproductive potential; damaged flowers may abort seed (Rusterholz *et al.* 2009). Areas of vegetation which become isolated reduce effective population size which can also lead to a decrease in genetic diversity through inbreeding, further increasing the risk of local extinction through accumulation of deleterious alleles (Severns 2003; Groom 1998). The decrease in leaf litter biomass as plant numbers lessen reduces nutrient turnover, altering enzyme activities which could mitigate successful re-establishment and growth of plants (Kissling *et al.* 2009). The reduction of live vegetative material also results in larger areas of bare soil which are prone to alteration without a functional vegetation cover.

While a functional plant cover provides soil stability (Pohl *et al.* 2009), damage to this cover can contribute to soil disturbances consisting of either surface breakage or surface compaction, increasing the likelihood of wind- or water-borne erosion which results in environmental damage by reducing plant development (Ayres 1994), plant vigour and recovery, and increasing plant mortality (Affleck 2005). Soil compaction can change hydrological processes. The porosity of the soil is decreased, resulting in a shortage of oxygen and a changed water regime. Without the porous holes water penetration is prevented, increasing surface run-off, and amplifying water borne erosion (Hegarty & Royal 1978; Brainbridge & Virginia 1990; Kissling *et al*. 2009). Microbes may respond to these environmental stresses by changing their activity, growth or resource allocation (Schimel *et al*. 2007), potentially altering the production of the soil enzymes responsible for catalyzing carbon, nitrogen and phosphorus cycling (Kissling *et al*. 2009), altering both microbe communities, soil nutrients, organic matter quantity and quantity, and pH levels. Substrate damage also widens trails, exposing rocks and plant roots (Pickering *et al*. 2010, Balbulena *et al.* 2002, Kissling *et al.* 2009). Compaction due to human disturbance increases bulk density which can impede seedling emergence and survival, altering vegetation and ecosystem processes.

Humans and their activities are encroaching upon arid environments and altering the natural land cover (Gill 1996). Soils disturbed by surface breakage are more common in arid environments where surface crusts develop (Belnap & Gillette 1997). The breakage of the soil's surface alters the topography, increasing the area exposed to wind and water erosion. A small amount of surface loss can result in the loss of many micro-organisms, reducing site productivity and nutrient availability (Belnap & Gillette 1998). The disturbance regimes and forces of erosion generated increase the likelihood of roots becoming exposed; plants are unable to survive on eroding surfaces owing to desiccation and dislodging of their root systems (Maun 1994). Aeolian dust liberated by erosive episodes is not only harmful to vegetation; it can also be harmful to humans and water bodies (Goudie 1978). Sediments can harm traffic flow, fill in ditches, and decrease agricultural production (Bilbro & Fryrear 1994). Soils can become increasingly susceptible to wind erosion when they have been affected by anthropogenic activities (Breed 1999). The combination of soil breakage, compaction and erosion can lend itself to an unnatural sorting of layered substrates, and wind-blown dust infiltrates into loose, permeable sediment and alters the soil's structural development (Reheis 1999) altering the substrate layering.

Scientific papers agree that the more passes a vehicle makes over vegetation the more significant the damage (Cole 1995a, Monz 2002). While there have been papers that discuss damage done by either motorised vehicles, trampling and horse trekking, there are few papers that compare the impacts to vegetation and soil between various forms of trampling. Pickering *et al.* (2010) compared non-motorised trampling agents (horses, mountain bikes and tramping), and concluded damage done by horses is more severe than hiking. Wilson & Seney (1994) compared soil erosion created by horses, hikers, off-road bicycles, and motorcycles on mountain tracks in Montana and found horses produced significantly larger quantities of sediment. Wilkerson & Whitman (2009), in a comparison test between motorised and non motorised variables, found all-terrain vehicles and ski-mobiles produced greater soil disturbance, erosion and more frequent ruts than mountain bike riding or hiking, suggesting that motorised forms of transport and horses do greater damage to plants and the environment than any other forms of transport.

The full extent of vehicle disturbance may not be evident until long after the original impact (Vollmer *et al.* 1976). Both plant damage and substrate damage continue long after initial impacts. Alpine plants grow in harsh environments, with nutrient-poor soils, in low temperatures, exposed to high winds and radiation levels. Substrate conditions are usually dry and the damage to substrates by vehicles is immediate, vehicles have the potential to both compact and break soil surfaces, as time progresses wind and water-borne erosion wears away at the damaged substrate.

Aims

The aims of this study are to investigate vehicles roaming across an arid ecosystem, by identifying which vehicles are most likely to drive off road, how far they are willing to drive, which substrates they prefer to drive on, and the vegetation densities they prefer to drive through. Differences between vegetation that has been run over by a vehicle previously will be compared to one that has been manipulated by pushing a weighted tyre over it and to an untouched control plant. The immediate change in topography will be measured and compared with changes over time to identify long term effects of vehicle movement on substrates. And finally broken and intact substrates will be compared to indicate differences in speed of erosion between these two substrate conditions.

Study site

Tongariro National Park situated within State Highways 1, 4, 46, 47, 49, in the central North Island (Figure 1.1), became the world's fourth and New Zealand's first National Park in 1894. The process began in 1887 when the Maori chief of Ngati Tuwharetoa tribe, Horonuku Te Heuheu Tukino IV gifted the summits of Mt. Tongariro, Mt. Ngauruhoe and Mt. Ruapehu, an area of 2640 hectares (26.4km^2), to the Crown (Hall & Piggen 2002). The volcanic peaks were set aside to be protected for and enjoyed by all of the people of New Zealand. A deed on behalf of the Ngati Tuwharetoa tribe was drawn up in the Taupo Court on 23 September 1887. However the size of the area gifted was considered too small for the purposes of a National Park, so in the early 1890s the Crown made large-scale purchases of land to increase the gift's area. By the time the Tongariro National Park Act was passed in late 1894, the park area had grown to 25,000 hectares (250km^2) (Hall & Piggin 2002). Today the Park covers 795.89km^2 (79,589 hectares), has three ski fields open to the public, two being commercial concessions and one a small club-operated field, with access via the Rangipo Desert area. Due to Tongariro National Park being given World Heritage status in 1990, any further infrastructural development is now heavily curtailed in the Park (Hall & Piggin 2002).

This volcanic mountainous area consists of Mount Ruapehu (2,797m), New Zealand's largest andesite strato-volcano, which forms the heart of Tongariro

National Park (Lecointre *et al*. 2004). Other volcanoes in the Park are Ngauruhoe (2,280m), Tongariro (1,968m) and the extinct Hauhungatahi (1591m). Ongoing volcanic activity over central New Zealand has resulted in different ejecta being deposited in different areas of the Park resulting in different substrate surfaces being laid down (Horrocks & Ogden 2000). The layering of tephra deposits from volcanic activity throughout the Holocene overlay coarse rhyolitic rock from the earlier Taupo eruptions. Due to the volcanoes, the Park produces extreme climate conditions resulting in different areas receiving different gradients of rain and wind, creating a mosaic landscape.

A **B**

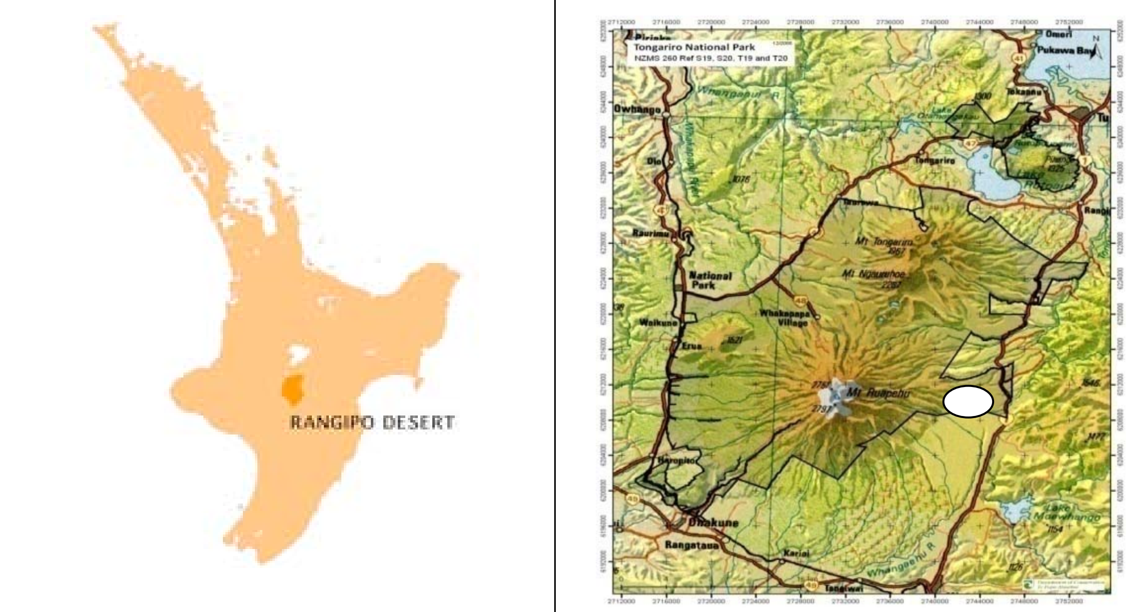

Figure 1.1 Tongariro National Park, North Island, New Zealand, with white dot showing Rangipo Desert, sampling area.
(A= Rangipo Desert, Wikipedia 2013, B= NZMS 260 S19, S20, T19, T20)

The Park consists of many different vegetation types, from terrestrial to wetland, from tall forests, to low stature plants, to wetland rushes and many different substrate types from boulders to loam fields (Atkinson 1985). Montane forest and sub-alpine vegetation can be found on the lower volcanic slopes, while fern land and alpine species can be found above the tree line. Areas of poor draining soils and peat formations are situated on the Mount Hauhungatahi slopes on the western side of the Park (Atkinson 1981). On the eastern side the soils consist of tuff (rock consisting of consolidated volcanic fragments), tephra and scoriaceous lapilli mixed with andesitic diamictons or aeolian sands and rhyolitic tephras deposited from the more northerly Taupo and Okatania volcanic centres (Donoghue *et al.* 1997). Due to the porous nature of the ejecta and windblown tephra-rich sand (Lecointre *et al.* 2004), drier free draining soils and tussock grassland lie on eastern side of the mountain this is known as “The Rangipo Desert”.

The Rangipo Desert, 39^{o}S, 175^{o}E, altitude ~900m is not a desert in the conventional sense as it receives 1100mm average annual rainfall (Ohno *et al.* 2012), a high rainfall on the international scale. General classifications of arid ecosystems suggest that deserts receive less than 60-100mm mean annual precipitation, arid environments receive from 100mm-250mm mean annual precipitation, and semi arid environments receive from 250-500mm of mean annual precipitation (Noy-Meir 1973), which is considerably lower than Rangipo. Rangipo resembles a desert due to its porous, poor quality soils and sparsely placed scrubby vegetation, interspersed with open barren areas of sand, gravel, scoria and pumice substrate, generating a desolate landscape covered by wind-blown, tephra-rich sand dunes (Lecointre *et al.* 2004).

Tyre marks have become a frequent sight off-road and throughout the more arid area of the Park, and there is evidence of vegetation being driven over within the unique arid countryside of the Rangipo Desert, with its barren patches of sparsely placed, low-lying prostrate vegetation.

Outline of Study

Although there is a lot of literature written regarding vehicles driving through arid ecosystems, erosion of soils, and trampling effects of vegetation, there is no literature on vehicle damage within the unique environment of the Rangipo Desert’s sub alpine vegetation.

The objectives of this work are to assess which vehicles are most likely to drive off-road, and the vegetation densities and substrates they are most likely to drive on, as well as to observe changes in plant growth caused by being run over, and to identify any modification and erosion responses of the substrate after damage

Literature supports that vehicles, trampling and an increasing number of vehicular passes do more damage to vegetation (Cole 1995a, Monz 2002), and the heavier the trample the greater the damage to vegetation. Hence this study will be testing damage by rolling a sand-filled tyre (a vehicle substitute) over the vegetation. This is the first experiment identified in the literature that compares effects on plants by artificial vehicles with real vehicles and undisturbed controls. Only some of the range of plants found within the Rangipo Desert is used in this study; they are *Raoulia albo-sericea, Rytidosperma setifolia*, *Leucopogon fraseri*, *Gaultheria colensoi*, *Wahlenbergia pygmaea*, *Pimelea prostrata*, *Carmichaelia australis*, and the moss *Andreaea rupestris.*

Figure 1.2 Tyre marks at Rangipo Desert, showing the comparisons between the flatter, unbroken surface crust and the increased surface area of the broken surface crust.

This study will also examine the effects of substrate movement between intact and broken substrates (Figure 1.2). The breakage of soil surface is more noticeable in arid environments that develop surface crusts (Belnap & Gillette 1997). Breakage alters the topography, increasing the area for exposure to wind and water erosion.

Consequently testing to compare erosion differences between intact and damaged substrates is imperative as erosion can potentially have both direct and indirect effects on plant survival.

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Chapter 2

Desert nomads; where do they roam within the Rangipo Desert ecosystem?

2.1 Abstract

Rangipo Desert ecosystem, situated within Tongariro National Park, Central North Island, New Zealand, has sparsely vegetated, low stature vegetation and large areas of bare sandy substrate that are at a high risk of being driven over by all-terrain vehicles, four wheel drives, and trail bikes.

The aim of this chapter is to identify the vehicles that drive off State Highway One, discover which substrate conditions and vegetation densities drivers most commonly drive over, and inspect both the immediate and long term effects of substrate damage after being driven over.

High definition aerial images were used to survey 7.3375km^2 of land within the Rangipo Desert. Vegetation densities, substrate conditions, tyre imprints and road information were extracted from the images and these categories were ground-truthed. Camera equipment and personal observations were used to capture vehicle types that left State Highway One and the Tukino Skifield Road, potentially being able to travel into and over the Desert.

Forty eight percent of observed vehicles were off-road vehicles that left State Highway One. Vehicles ventured over 1 km into the Desert from a constructed road. However there was a negative correlation between the number of tyre marks and distance travelled from a road source. There is evidence that drivers prefer, bare substrate, and low stature vegetation, though not all surfaces record vehicle transits.

Vehicle damage observed in this study is typical of global vehicle activity in arid ecosystems and the mobile substrate makes identification of transit tentative.

KEYWORDS Off road vehicles, All-terrain vehicles, vegetation damage, substrate damage.

2.2 Introduction

Vegetation and soil structures outside the urban environment have not evolved to be driven on (Pickett *et al.* 2001). Use of All-Terrain Vehicles (ATVs) in vulnerable environments may cause vegetation damage and soil erosion that will last for a long time (Tommervik *et al.* 2012), and the growing use of ATVs off-road has, in fact, resulted in considerable damage to environments (Tommervik *et al.* 2012), especially arid, sandy environments (Rickard *et al.*1994, Priskin 2003). When vegetation is directly run over there is an immediate decrease in its height, followed by a further decline in vegetation cover, as the vehicles flatten the plants, breaking off limbs and foliage. This results in less of the plant being able to photosynthesise, increasing the likelihood of dieback, and often leading to the subsequent death of the plants (Rickard *et al.* 1994). As well as the direct effects, such as physical damage, there are indirect effects, such as soil erosion, which increases the rate of vegetation loss (Tonnesen & Ebersole 1997). These can produce serious consequences for the ecosystem as small isolated patches of vegetation have an increased rate of vegetation loss compared to larger patches of vegetation for many reasons. Smaller effective population sizes can lead to an increase in inbreeding, increasing the risk of local extinction through the accumulation of deleterious alleles (Severns 2003). Plants in small patches often fail to be pollinated, as the reward for pollinators is little compared with distance travelled to isolated plants compared to larger patches (Groom 1998). Finally populations which are small in size are highly vulnerable to stochastic events (Lode & Peltier 2005). So vegetation damage can have broader effects than the immediately obvious ones.

Heavily travelled routes can produce significant amounts of air pollution that create gradients of heavy metals in the soil and plants within 20-200m from route corridors (Tombulak & Frissell 2000). The concentrations of Lead (Pb), Zinc (Zn) and Copper (Cu) in soil and plant tissue are increased in areas of higher traffic density and air pollution (Sgardelis *et al.* 1994; Hjortenkrans *et al.* 2006). One consequence is that shoot and root lengths and seed germination rates are lower when there are increases in lead concentrations (Faheed 2005).

Vehicles also compound ecosystem damage by elevating pollution through carbon emissions (Walsh 1990). However, such effects are unlikely to be important in the off-road situation, due to the relatively low rates of incursions, but instead illustrate that we should be mindful of the unseen damage that can result from vehicle pollutants such as fumes and by-product disposal.

Vehicles can also serve as dispersal vectors for alien plant propagules (Schmidt 1989; Hodkinson & Thompson 1997). Soil carried on vehicles can carry viable seed. Because most small seed is of short lived plants, the seed produced from these plants are usually numerous, small, and persistent. Off-road driving ensures rates of seed dispersal several orders of magnitude larger than “conventional” dispersal methods (Hodkinson & Thompson 1997). Seeds, especially of the more adaptive “weedy” type, can germinate in novel habitats having the potential to change the surrounding environment. Vehicles driving throughout the Rangipo Desert could introduce new species to the area, which in time could alter its plant communities.

Vehicles can also damage vegetation and ecosystems through soil compaction (Balbuena *et al.* 2002) and surface breakage (Belnap & Gillette 1997) which can immediately alter the soil micro-topography. A compacted soil can become impermeable to water, and the top soil can crack when it is dry (Hegarty & Royle 1978). Soil compaction impedes seedling emergence (Hegarty & Royle 1976; Brainbridge & Virginia 1990), reducing root growth. Vehicles driving over dry substrates surfaces can break soil crusts (Belnap & Gillette 1997), the hardened top layer that forms over the softer sand beneath, increasing the vulnerability to wind erosion (Belnap & Gillette 1998). Increased wind erosion and environmental damage can in turn decrease plant development, impeding vegetation growth, and decreasing vegetation cover (Ayres 1994). For example, there are trees that have been buried by aeolian sand deposits within the outskirts of the Rangipo Desert (Figure 2.1). Hence, the full extent of vehicle disturbance may not be evident until long after the original impact (Vollmer *et al.* 1976).

There are many different substrates types with the Rangipo Desert area of Tongariro National Park and not all substrate types are affected equally by illegally operated vehicles (Weaver & Dale 1978). It is important therefore to observe which substrate conditions vehicle operators are more likely to drive on, and to obtain information on how attractive these substrates are for vehicles operators.

The aims of this investigation are to use aerial imagery to assess the percentage of the Rangipo Desert that has been driven on and to record the legal roads vehicles leave and the distance vehicles travel over the Desert. I aim to identify plant densities and desert topography that can possibly influence vehicle drivers' choices and the type of vehicles that most frequently offend, by leaving the legal roads, State Highway One and the Tukino Skifield Road, and enter onto the Desert substrates.

Figure 2.1 Trees of *Halocarpus bidwillii* buried by sand deposits within the Tongariro National Park, Rangipo Desert; only the crowns on these ones remain above the sand.

2.3 Methods

2.3.1 Where do vehicles leave roads and how far do they travel?

Since the whole of the Rangipo Desert is too large to survey on foot, the aim is to produce information from aerial images indicating the Desert's topography and substrate conditions, to identify vegetation densities and vehicle movements by tyre indentations. High definition aerial pictures of the Rangipo Desert were taken by New Zealand Aerial Mapping LTD, Hastings, New Zealand, on Wednesday 17 March 2010, and printed at a scale of 1:5000 with super imposed longitude and latitude grid lines (Figure 2.2). These grid lines generated squares; each $1cm^2$ on the image was equal to $2500m^2$ ($0.0025\ km^2$) of land area. A total of 2935 squares of the desert were surveyed using these images, resulting in an area of $7.3375km^2$ surveyed. The areas not surveyed consisted of New Zealand Army land, which lies to the south and east of Tongariro National Park's portion of the Rangipo Desert, areas of dense vegetation at a distance > 50m inland from any bare substrates, and any area further than 7 km along Tukino Skifield road as the vegetation, substrate and topography are notably different after this point, with much of the topography being too steep or undulated for off road vehicles, and not suitable for comparisons with the rest of the area under investigation.

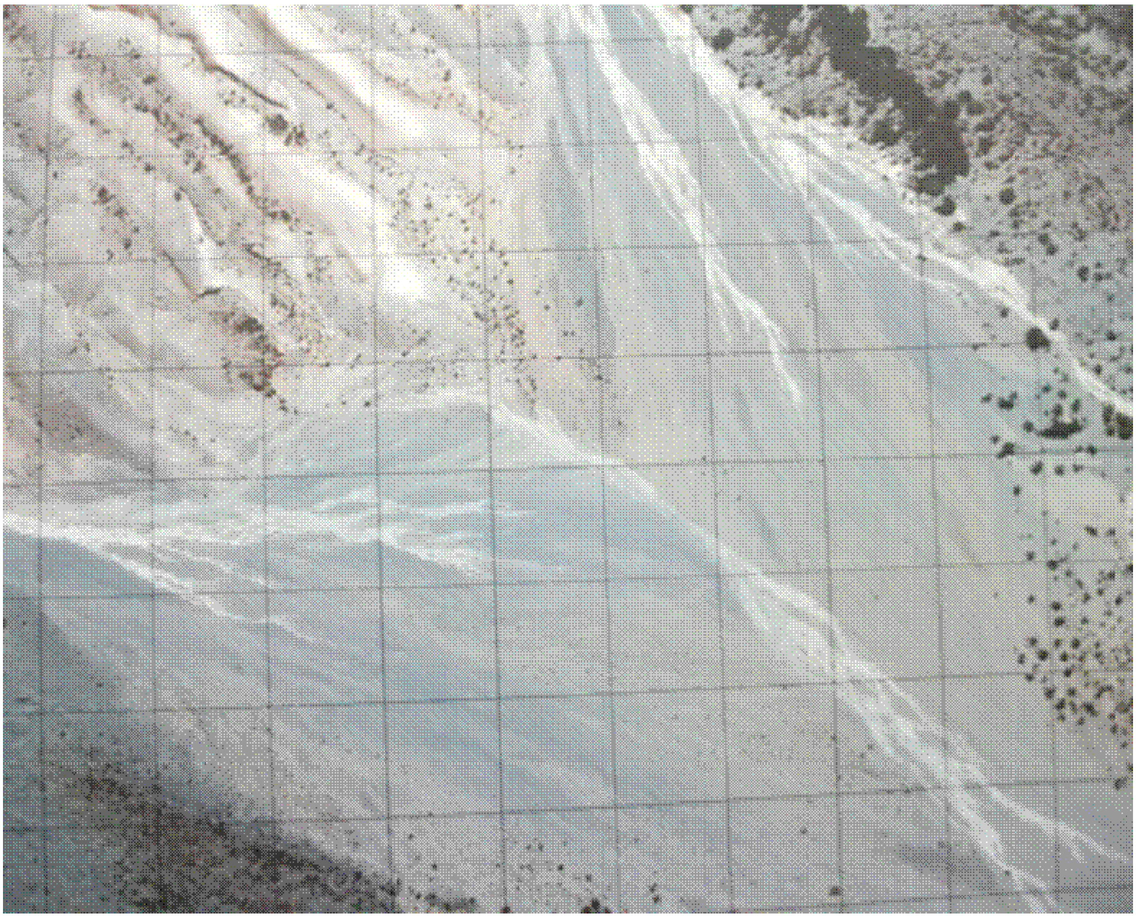

Figure 2.2 A portion of the aerial image of the Rangipo Desert consisting of grid lines (at 50m intervals), vegetation patches and bare land, pumice, and flat and rough surfaces.

The three roads identified on the aerial image were State Highway One, Tukino Skifield Road, both legal roads, and the Pylon track, an access route for power distribution companies to service their pylons, but often used by off-road drivers (Figure 2.3).

Figure 2.3 Three roads identified A: State Highway One, B: State highway One and Tukino Skifield Road intersection C: Tukino Skifield Road D: Tukino Skifeild Road and Pylon track intersections E: Pylon track, legal road for those servicing the pylons only. F: Narrow wet strip of road. G: Fork in Pylon track going to the left, illegal for all drivers. All other visible tracks are off-road vehicle incursions.

Using the computer images at high resolution, tyre marks were identified as long indentations into the substrate, running in parallel lines for vehicles and in continuous single lines for motorbikes. Marks were either exposed in the sand (visible as shadowed lines or compression zones, with a different reflective surface) or were filled with windblown pumice, which is lighter and whiter than the sandy substrate, or were identified by presence of visible tread marks. The percentage of the Desert that had been driven on was estimated from the number of squares (n=169) that contained vehicles marks. The numbers of tyre tracks that left the road was then compared to the length of the road the tyre marks were beside to calculate the percentage of use per road length to assume preference for leaving a particular road.

The distance a vehicle travelled off road into the Desert was measured with a ruler from the centre of any constructed road within a square and along the distance of the tyre marks seen in the aerial imagery; the ruler measurement followed the vector of the tyre marks. This gave an approximation of the minimum distance travelled from the road. Also the road that the vehicle left to enter the Desert was noted. Not all tracks that were off-road could be followed to either an end or a start point. This could be due to the vehicles moving over a hard substrate leaving no tracks, or to sand movement covering the tracks. A best-case assumption was used to connect tracks where they appeared to follow in a line, or if I could not be certain that there were connecting tracks, I took measurements to where the trail stopped. These data were used to calculate how frequently tyre marks could be observed leaving roads, the roads they left from, and the distance travelled into the Desert. Data are presented as a bar graph.

2.3.2 Plant densities, topography, substrate, and driving suitability

Plant densities were sorted into categories of dense, clumped, patchy or sparsely vegetated areas. Each square of the aerial photo was assigned a density. The square was considered bare if there was very little vegetation, i.e., <10% in the entire square. It was patchy when ~10 - <50% percent of the square was filled with scattered plants. It was clumped when ~50 - 80% of the square had scattered clumped vegetation, and was dense when the entire square was filled >80%.

With respect to identifying squares available to drive on, the topography of each square of the aerial image was categorised as flat surface or channelled. A channel was distinguished from flats by the shading and colouring of the image. Channels are made by water flow, and any substrate that looked U-shaped that may or may not currently contain a continuous stream of running water, was considered a channel. The flat category does not necessarily mean the square is without a horizontal gradient; rather the surface was not U-shaped.

Wet areas can present deterrents to off road drivers. Presence or absence of pumice, wet or dry substrates were recorded for each square in the aerial image. Pumice is light and floats, and hence is often found in deposits in dried-out water channels. Much of the wet substrate occurred on poorer draining soils, or areas of snow melt drainage. If the substrate was not currently wet, or did not contain pumice it was noted as dry.

Any substrate was deemed suitable for driving on if it was flat, i.e. without any large obstacles, or deep channelled river systems with steep banks or tight, narrow U-shaped channels. This was regardless of the vegetation density or wetness.

Any combination of the above categories was recorded if they were identified within a square. These categories were firstly collected and tallied within the entire testable area. Counts and percentages were calculated to give an indication of the desert's composition. Then the process was repeated using just the 169 squares containing tyre marks to differentiate between the general desert and the areas driven over. The area of each category containing tyre marks was then divided by the area of total surveyed land of that category to give an idea of the percentage of each influenced by tyres.

2.3.3 Ground-truthing

The above scores for plant categories were tallied and substrate conditions were ground-truthed in the field in December 2012 by randomly choosing and visiting 10 grid reference squares assigned to each of the four plant categories (n=40 randomly chosen plots). A 50 x 50m quadrat was set up as to as closely as possible to each square as delimited in the aerial image using Global Positioning System (GPS) points and landmark features. To determine differences in the different vegetation densities the number of species present, the height of the tallest plant within the plot, vegetation cover percentage, substrate cover percentage, and tyre print cover percentage were measured. These data gave a more comprehensive representation of differences between vegetation density plots.

A Canonical Correspondence Analysis (CCA) was run using CANOCO (ter Braak & Smilauer 2002) to see if the forty squares did sort into the categories I had assigned them to. A square root transformation was used to normalise the squares' cover data which was in percents, and the CCA mapped these in conjunction with vectors describing various environmental parameters of each square (see Figure 2.6 for details). Paired t tests were run to show statistical differences between the average number of species, the maximum height, the percent of vegetation and bare substrate covers and the percent of tyre marks present.

2.3.4 Vehicle types

The types of vehicles that are most likely driven off-road were determined using two approaches. One was an "I spy" 5-Mega Pixel Game and Security Camera (Andytek Enterprises LTD, Cambridge, New Zealand). The "I Spy Cam" was set up at either of two locations, one along the Pylon service road where vehicles tend to slow down for a wet section of substrate, and the other on the Tukino Skifield Road where cars had to slow down for a ford. As well I noted down vehicles personally seen during other field work, sometimes taking discreet pictures of them. Vehicle observations were then collated and separated into eight categories: buses, trucks, campervans, vans, 4 wheel drives, 2 wheel drives, motorbikes and pushbikes. Percentages of vehicles in each category were calculated. The frequency of incursions is expressed as amount of days I have a record of a vehicle either personally or with a Spy Cam, and divided this by the number of cars recorded. This number is biased as I was not on the desert for an entire 24 hour day, and the camera could only be set up at either one of two possible locations, missing collecting data from other areas.

2.3.5 Choice test

A choice test was used to determine from the tyre marks where drivers were choosing to drive within the desert. Of the 169 squares containing tyres marks 9 randomly chosen sets were used, with the restriction that no set could overlap with another. In a set the central square must contain a tyre mark and all 8 surrounding squares were the available choices (Figure 2.4). The centre squares containing the tyre marks were not considered a choice, but used as the spot the drivers made their choice from. The possible squares where the driver could choose to drive and the choices the driver actually made were tested under four categories to endeavour to understand why drivers made their choices. Choices were studied regardless of the actual direction of movement of the vehicle, which could not be determined from the aerial images.

Categories were as above in section 2.3.2; namely plant density, topography, substrate wetness, and drivability. These data were then tested using a chi square test with Systat 8.0 (Systat 1998). The tests were by weighted frequency using both Pearson Chi-square and Likelihood ratio to test the statistics, as the latter handles smaller numbers better than Pearson (Table 2.5).

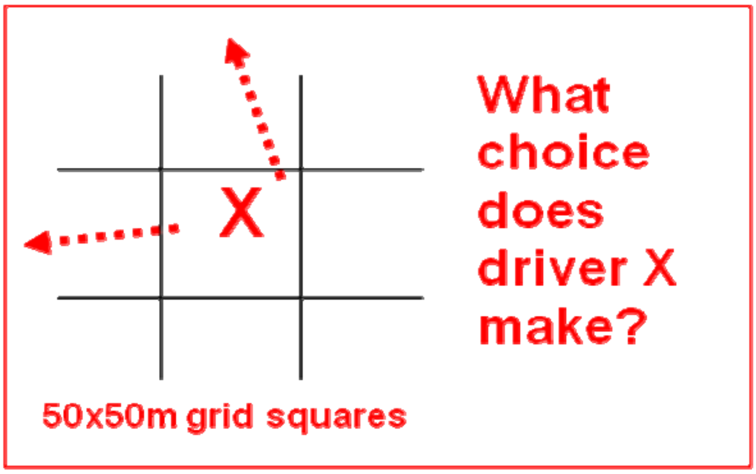

Figure 2.4: Example of the nine squares used for the choice test. The central square (X), was randomly chosen from those available, contained the focal tyre marks and was taken as a starting point for the driver. The remaining 8 squares were the possible squares the driver could choose to drive over. The driver could choose more than one square.

2.4 Results

2.4.1 Where are the roads and how far does a vehicle travel from these roads?

Using the aerial images taken on Wednesday 17 March 2010, a total of 2935 squares were surveyed, i.e. 7.3375 km^2 or just under 1% of the 795.89km^2 area that makes up the Tongariro National Park, ~14% of the Rangipo Desert (Cox 1997). Roads were observed in 256 of the 2935 squares analysed (9%), i.e. State Highway one (n=58), Tukino Skifield Road (n=181) and Pylon track (n=17). Off road tyre marks were found in another 169 squares (5.8%) of the studied area.

Comparing the lengths of surveyed road (Tukino Skifield Road 7000m, State Highway One 2600 m, and the Pylon track 700m), with the number of tyre marks exiting or entering each road gave an indication of the average vehicle points per metre of each road source. I found 2.3 tyre marks per metre on average left the Plyon track (n=16), compared to 1.11 tyre marks per metre leaving the Tukino Skifield road (n=78), and 0.12 tyre marks per metre leaving State Highway One (n=3). Over twice as many tyre marks were seen per metre on the Pylon track, an off road service track, compared to the Tukino Skifield Road. 80.4% of vehicle marks left or entered from the Tukino Skifield Road, compared to 16.5% and 3.1% of the tyre marks leaving or entering the Pylon track and State Highway One respectively.

Of all the tyre marks observed 57% (n=97) were within 0.050km of a road's edge. The greatest distance a tyre mark was tracked was 1.8km from a road, and it connected to State Highway One. The frequency of tyre marks reduced as the distance from the roads increased (Figure 2.5).

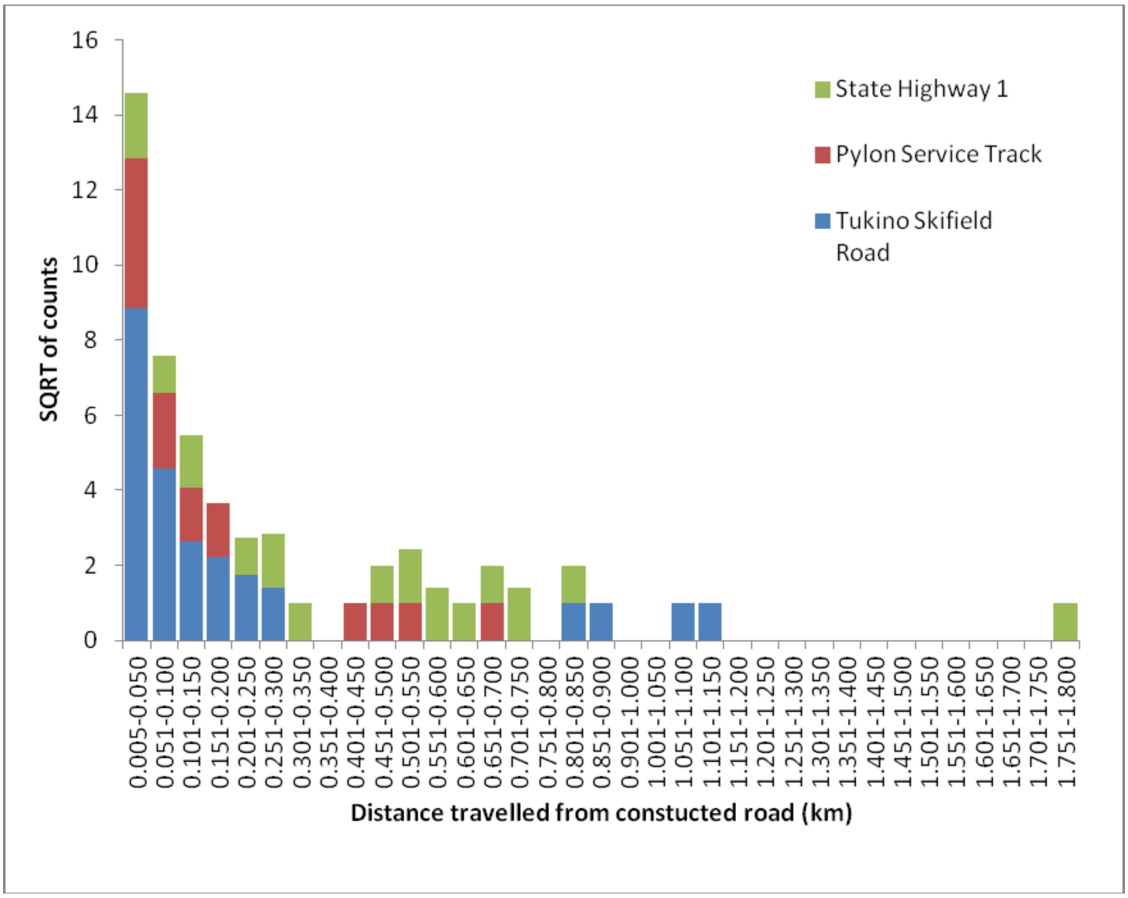

Figure 2.5 The counts (square root transformed) measuring the distance that vehicle marks travelled into the Desert from one of three focal constructed roads observed from aerial imagery.

2.4.2 Substrate and plant density studies: desert composition

The sparsely vegetated areas made up almost 59.2% of the measured desert ecosystem. Patchy (22.0%) and clumped (10.3%) areas appeared scattered throughout the desert, while one densely vegetated area called “Student Island” was within the desert and the remainder of the densely vegetated areas were on the perimeter of the desert system, totalling 8.5% of dense bush in the surveyed area.

The majority of the Desert’s topography type was sand (95.4%); channels made up only 2.2%, the remaining 2.4% of the desert was covered with vegetation too dense to identify the underlying topography from the aerial images.

The substrates were mainly made up of dry sand areas 93.7%, wet substrate made up 4.7% of the substrate, and pumice made up 1.6% of the land surface area. Area considered flat and suitable for driving made up 43.7% of the desert; this substrate consisted of flat substrates of sand or seasonally dry river systems, or areas that otherwise appeared suitable to drive on. Alternatively 56.3% was deemed “rough” or unsuitable to drive on; this substrate was densely vegetated or had deeply channelled systems or areas that I knew from personal observation that cars could not possibly drive over (Table 2.1).

Table 2.1 Summary of variables observed, giving an overview of the surveyed area of Rangipo Desert. N=2935 squares

Impact types	**Number of squares categories observed in**	**Surveyed area (%)**
Roads	256	9.0
Tyre marks	169	5.8
Untyred desert	2507	85.2
TOTAL	**2935**	**100**
Plant densities		
Sparse	1739	59.2
Patchy	645	22.0
Clumped	302	10.3
Dense	249	8.5
TOTAL	**2935**	**100**
Topography types		
Sand	2801.6	95.4
Channel	64.4	2.2
Too dense for data collection	69.0	2.4
TOTAL	**2935**	**100**
Substrate condition		
Pumice	47	1.6
Wet	139	4.7
Dry	2680	91.3
Too dense for data collection	69.0	2.4
TOTAL	**2935**	**100**
Drivability		
Unsuitable (rough)	1652	56.3
Suitable (flat)	1283	43.7
TOTAL	**2935**	**100**

Concentrating on only the 5.8% of surveyed squares (equating to ~ 0.5km^2 of the surveyed Desert area) that contained tyre imprints (Table 2.2), I calculated the percentage of tyre marks found within a particular variable category within the surveyed Desert area, by dividing the number of squares each variable was observed in from Table 2.2 by the number of squares each variable was observed in from Table 2.1. I found that of all the sparsely vegetated area only 7% of the area contained tyre marks. While this was the highest percentage it was only a little higher than clumped areas 6.9% of which contained tyre marks. The patchy surveyed area contained 3% of tyre marks, and the densely vegetated survey area contained 1.6% of tyre marks. Of the sand area surveyed 5.5% contained tyre marks and 20% were found on channelled areas. 57% of the pumiced area surveyed contained tyre marks, which was more than the dry sand where 4.5% contained tyre marks and 14% of surveyed wet sand contained tyre marks. 2% of the land deemed unsuitable for passage contained tyre marks compared to the 10% of land thought drivable. This suggests that vehicle operators prefer to drive on substrates that are dry, flat, and sandy with sparsely placed vegetation (Table 2.2).

Table 2.2 Summary of variables found in the 169 squares containing tyre marks indicating where tyre marks are most likely to be found.

Site of tyre mark Impacts (169 squares)	Number of squares observed	Tyre marks (% of observed squares)
Plant densities		
Sparse	123	72.8
Patch	21	12.4
Clumped	21	12.4
Dense	4	2.4
TOTAL	**169**	**100**
Topography types		
Sand	155.55	92.0
Channel	13.45	8.0
TOTAL	**169**	**100**
Substrate conditions		
Pumice	27	15.9
Wet	20	11.8
Dry	122	72.3
TOTAL	**169**	**100**
Drivability		
Unsuitable (Rough)	37	21.9
Suitable (flat)	132	78.1
TOTAL	**169**	**100**

2.4.3 Ground-truthing

Ground-truthing validated the vegetation category assignments. Bare plots had fewer species, short vegetation height, barer substrate and vegetation cover which was sparse (Figure 2.6, Table 2.3). This was unlike the dense plots that had a greater number of species, taller vegetation, less bare substrate and a higher percentage of vegetation cover. There was a gradient of plant density covers between the four categories, with the patchy and clumped patches being intermediate between sparse and dense vegetation squares. A Canonical Correspondence Analysis explained 62% of the ground-truthed data on the first two axes and grouped most of the 10 replicated plots for each density type, except for one plot of the clumped category, while the patchy category was rather dispersed, with differential responses to cushion and fungi covers. Dense plots were predictably associated with high moss, fern, herb and shrub covers. These results suggest that the categories recorded from the aerial images were appropriate given the general difficulty of interpretation from aerials (Figure 2.6).

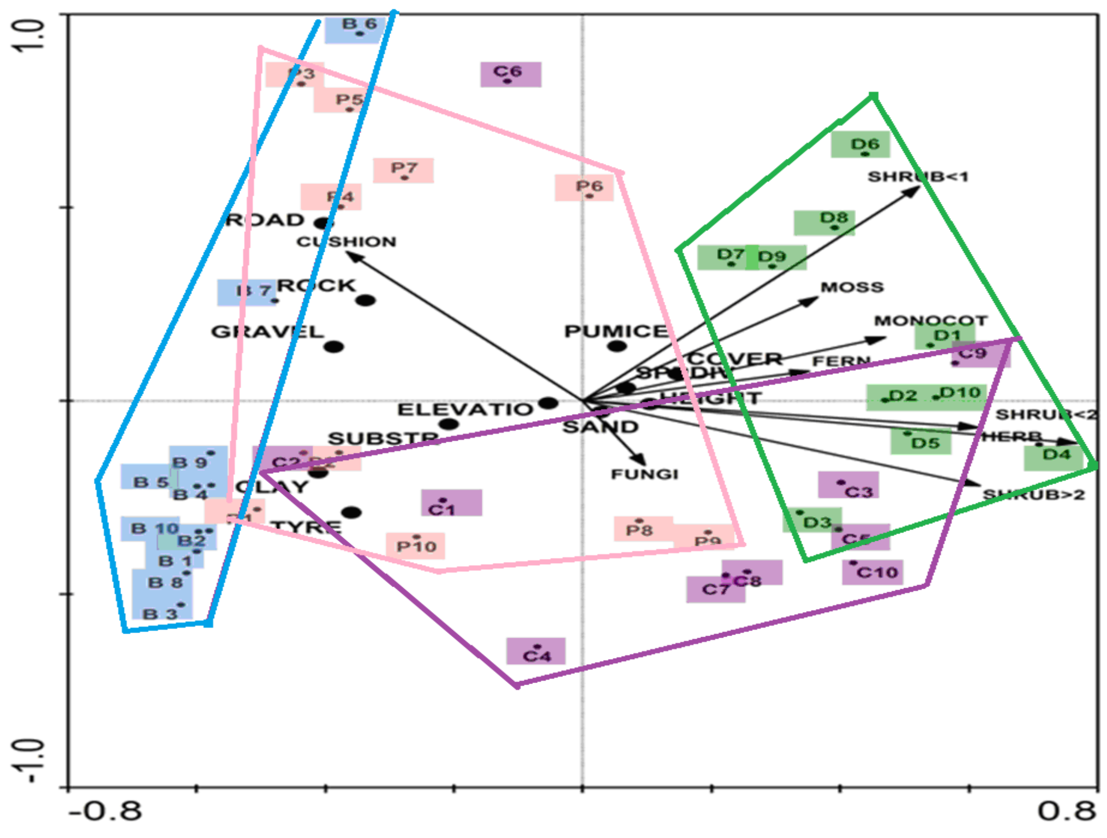

Figure 2.6 (CCA) Canonical Correspondence Analysis (after square root transformation of covers) showing the Desert's vegetation density and substrate composition. D=dense vegetation cover, C=clumped vegetation cover, P=patchy vegetation cover and B=sparse vegetative cover. The arrows are the variables associated with the underlying categories. Best fit polygons are included for all except Plot C6.

The Canonical Correspondence Analysis identified that sparse patches were associated with tyres marks and roads, higher covers of gravel, rock, and cushion plants and higher altitude. Patchy areas were strongly associated with roads, clay soils and altitude. Densely vegetated areas had much less gravel and stone, more shrubs, herbs, and monocot species, higher species' diversity and taller vegetation heights. Best fit polygons illustrate that sparsely vegetated areas are most unlike densely vegetated areas, but show an overlap between all vegetation densities.

Paired t tests (Table 2.3) showed significant differences between the average number of species found in the dense and sparse squares (P<0.001), and between the dense and patchy squares (P=0.003). No significant difference was found between the dense and clumped squares. The maximum height, and average number of species differed significantly for all caterories except the clumped/dense paired comparision. There were significant differences for bare substrates and vegetation cover among all categories. There was a significant difference in the number of tyre marks between dense/sparse vegetation densities in the paired comparision to a 8% level (Table 2.3).

There were significant differences between the densely vegetated areas and the sparsely vegetated areas for most categories with a 5% probability, and tyre marks at a <10% probability. There was very little significant difference between the clumped vegetation and the densely vegetated squares for the number of species and vegetation height and the number of tyre marks present, but significant difference in vegetation cover and bare substrate.

Table 2.3: Paired t tests showing statistical results of varying vegetation categorgies and other measured variables with their degrees of freedom (D.F), t test and P values. The relation of these categories to presence of tyres is also listed. P values significant at 5% or less are in bold, those to 10% in italics.

Paired t test	**D.F**	**Average number of species**		**Maximum vege height**		**Vegetation cover**		**Bare substrate cover**		**Tyre marks present**	
		t	**P**	**t**	**P**	**t**	**P**	**t**	**P**	**t**	**P**
Dense/Patchy	**9**	3.989	**0.003**	-3.277	**0.010**	-8.100	**0.000**	7.665	**0.000**	1.267	0.237
Dense/Clumped	**9**	0.590	0.570	0.632	0.543	-3.879	**0.004**	3.879	**0.004**	0.500	0.168
Dense/Sparse	**9**	-8.075	**0.000**	-8.045	**0.000**	-26.51	**0.000**	26.515	**0.000**	1.973	*0.080*
Clumped/Patchy	**9**	5.634	**0.000**	-3.160	**0.012**	-4.358	**0.002**	3.992	**0.003**	0.918	0.383
Clumped/Sparse	**9**	6.059	**0.000**	-6.621	**0.000**	-6.221	**0.000**	6.221	**0.000**	1.181	0.102
Patchy/Sparse	**9**	-3.375	**0.008**	-4.077	**0.003**	-5.336	**0.000**	5.314	**0.000**	1.515	0.164

2.4.4 Vehicle types

A total of 50 vehicles were recorded (see Appendix A for details) over a period of 16 days, when I was sampling close enough to roads to make records, through 4 months between April 2010 and March 2012. An average of 50/16 = 3.125 vehicles was noted daily. 48% of vehicles observed were off-road models with the capacity to drive off-road and illegally enter the Desert, consisting of four wheel drives and motorbikes. Push bikes made up 10%, while buses and campervans and large trucks made up 20% and 22% 2WD cars and vans (Table 2.4).

Table 2.4. Number and percent of vehicles recorded at the Rangipo Desert between April 2010 and March 2012 (values in parentheses show respective number of each sub category).

Category	Number	Percent
4WD	20	40
Pushbikes	5	10
Motorbikes	4	8
Buses (large & metro)	4 (1 & 3)	8
Campervans	3	6
Vans	4	8
Trucks large (tandem axle and A train)	3 (2 &1)	6
2 WD cars	7	14
TOTAL	**50**	**100**

All three trucks were service trucks, two with a Hiab (a truck mounted hoist), and one was a Department of Conservation flat deck, presumably accessing the Skifield. Throughout the 24 month period I observed only 3 fresh sets of vehicle marks (since the aerials were taken) situated at distances between 0.3 m and 0.25 km from the Pylon track and Tukino Skifield roads. Additionally four trail bikes were visually noted travelling through the Desert off-road together.

2.4.5 Choice test

Off-road drivers make constant choices about the conditions they are willing or able to drive over. Of the 72 squares that could have been driven over in the 9 random sets examined, 24 of the surrounding squares contained tyre marks while 48 of the surrounding squares did not. Vehicles are more frequently driven over sparsely vegetated areas of the desert; no choice was made to drive on the densely populated vegetated areas (Figure 2.7).

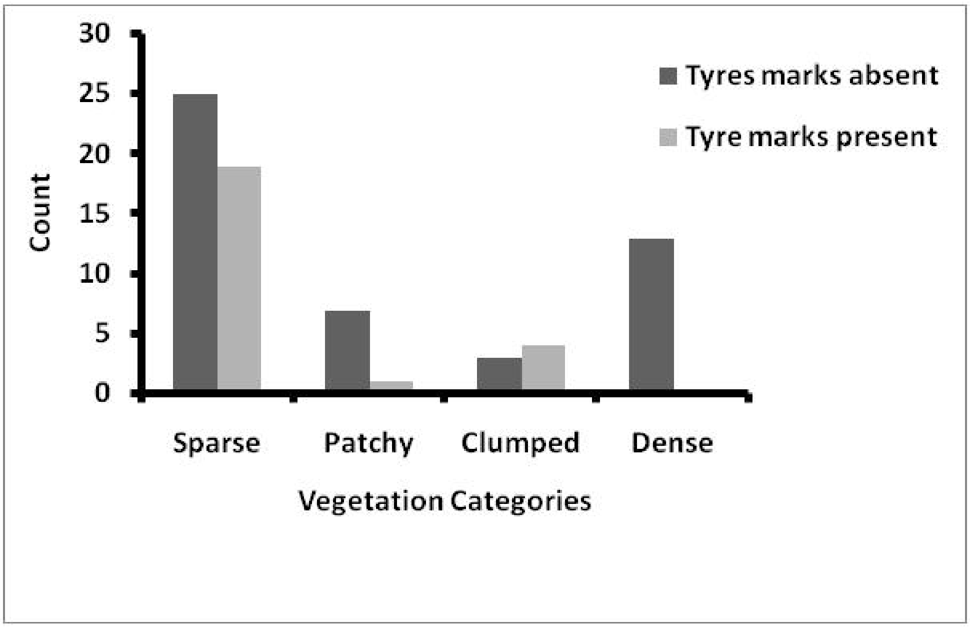

Figure 2.7 Drivers' choice for driving or avoiding (tyre marks absent) vegetation density categories.

Chi square tests for the drivers' choice experiment showed a significance difference in drivers' preferences for areas they preferred to drive over (Table 2.5). Drivers prefer to drive on sparsely vegetated, flatter areas, with little consideration for substrate or topography variances. Both Peasons Chi-square and Likelihood ratio Chi-square were used for the analysis, as both are suitable for tables larger than 2x2, however, due to the small numbers in the tables I thought likelihood ratio chi-square would be more suitable, both are represented for comparison.

Table 2.5 Chi square results for drivers' choice experiment. Squares which were too densely vegetated to be assigned to some categories were omitted from the analysis. Tyre marks P=present, A=absent. D.f = degrees of freedom. P values significant at 5% are in bold, those to 10% in Italics.

		Vegetation Density								Topography				Substrate						Driver Suitability			
Variables		Sparse		Patchy		Clumped		Dense		Sand		Channel		Dry		Pumice		Wet		Flat		Rough	
Tyre marks		A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
		25	19	7	1	3	4	13	0	43	21	5	3	45	20	0	2	3	2	15	22	3 3	2
Pearsons Chi-square	Value	11.769								2.653				4.292						23.379			
	D. f	3.000								1.000				2.000						1.000			
	Prob.	**0.008**								0.103				0.117						**0.000**			
Likelihood ratio Chi Square	Value	15.893								2.566				4.686						26.365			
	D. f	3.000								1.000				2.000						1.000			
	Prob.	**0.001**								0.109				*0.096*						**0.000**			

2.5. Discussion

The aims of this chapter were to assess which vehicles were most likely to leave legal roads and travel over the Desert, and to assess which substrates and plant densities they prefer to drive over and how far they are likely to travel through the Desert. We found drivers prefer to drive over sparsely vegetated, dry, flat areas of desert and 48% of vehicles entering into the surveyed area were off-road vehicles.

Tyre imprints are a good indication of where vehicles are moving in the softer portions of the Desert but can be more difficult to access on the harder substrates, and areas where sand is very mobile as these can obscure tyre marks. The use of high definition images to detect vehicles and damage on vegetation is not new. Tommervik *et al.* (2012) published a paper suggesting that using high resolution optical satellite imagery is well suited to detect tracks caused by medium and light all terrain vehicles. Using aerial imagery to collect these data encapsulates a snap-shot in time, as vehicle movements may vary weekly, seasonally or over holiday periods, and it is not clear how long tracks will even persist in this desert environment. Using high definition aerial images for this study, roads were identified, and evidence of vehicles leaving these roads, through tyre marks, could be followed into the Desert. Different substrate surfaces and plant densities could be identified, as well as areas that drivers prefer to drive over.

State Highway One is the only highway running past the Rangipo Desert. All vehicles heading into the desert need to enter from this road either directly into the Desert or from a secondary road such as the Tukino Skifield Road which intersects State Highway One. The Pylon track is an off-road track servicing the power transmission grid, the entrance situated ~ 600m along the Tukino Skifield Road from the State Highway One - Tukino Skifield Road intersection. These three roads showed differences in the percentage of tracks per metre of road, the frequency that tyre marks left the roads and distance vehicles travelled from roads.

Slightly more than half of the tyre marks were found within 50m from the roads' edges suggesting that although cars often pull off these roads, less than half of the drivers drive into the Desert ecosystem. There were few tyre impressions within 50m of State Highway One, compared to the higher numbers beside the Tukino Skifield Road and the Pylon track. This could suggest paucity of areas to safely pull off the

State Highway unless using lay-bys or side roads such as the Tukino Skifield Road. There was evidence of one set of marks travelling a distance of 1.8km into the Desert directly from State Highway One, where the vehicles could travel directly off this road and into the Desert via a seasonally dry river system. However this access route was altered during road works along the Desert Road in November 2010; artificial barrier mounds of clean fill debris was placed along the road side preventing vehicle access from this point, and continuing to inhibit access until March 2013, when one incursion across the eroding barrier was noted (*Pers obs.).*

The length of the Tukino Skifield Road had the greatest occurrence of tyre marks connected to it and is most likely to be due to the easy access from State Highway One and ease of contact onto the Desert, as there are very few areas along this road with either artificial or natural barriers preventing drivers leaving the road. By contrast the Pylon track, (c.f. the Tukino Skifield Road), which is an off-road, non-legal route, for all vehicles other than the Pylon service vehicles utilising it, appears to have a low occurrence of vehicle marks leaving it.

Two possible reasons for this is that where the track splits in two ~ 300m north from its junction with the Tukino Skifield Road (Figure 2.3; G) the track to the west is flat, with a sparse low lying vegetation on a mosaic of hard substrate and gravel, none of which exhibit tyre marks. This area is illegal for all vehicle passage, stated by signs from the Department Of Conservation asking drivers to keep off the Desert. The track to the east is densely vegetated on both sides, possibly acting as a natural barrier or deterrent to drivers wanting to leave the track. However it is feasible to believe that there are fewer vehicles that do actually enter the Desert via this track, compared to the Tukino skifield road, because, over the 16 days that the vehicles were counted, only one car was seen heading north on the Pylon track, and only one set of fresh prints (not included in the cars spotted) has been seen, over the 23 month period working on the Rangipo Desert, suggesting this track now gets used infrequently.

A possible reason for the limited usage could be the very wet, narrow segment, through a wet area. This area has quite possibly become increasingly wet due to drivers use in the past compacting the narrow area of passage way, situated before the fork in the track that would be impassable for some vehicles (Figure 2.3 F).

Therefore the greater percent of tyre marks per lineal metre of road was seen on a small stretch of Pylon track just off the Tukino Skifield Road – Pylon track intersection, where there is a dry and flat area of land with low lying, sparsely vegetated flora, and is most likely to be the result of cars that choose to turn around here. The combined roads showed a negative correlation between the number of vehicles and the distance travelled, 57.4% of tyre marks were found within 50m from a legal road, 15.4% travelled up to 100m, and 6% up to 150m. The remaining 21.2% of vehicles are the few that travel greater distances into the Desert. Although there were numerous published works shown when I searched with the key words "correlation between the number of off road vehicles and distance travelled" I could not find any publications that matched what I had observed; the negative correlation between vehicle numbers and the distances vehicles travel over the Desert.

Different substrate conditions were clearly defined within the aerial images, and were supported with ground-truthing. Bare substrate was correlated with presence of tyre marks. According to my results 95.4% percent of the surveyed Desert is composed of sand which was dry when my images were taken. 1.6% of the desert contains pumice. There are areas of the Desert that are wet with rain flow or snow melt but these are further up Mount Ruapehu, to the west of the studied area. The dry areas of the Desert are all volatile substrate types that are prone to substrate movement via wind or rain. Not all substrate types are affected equally when driven on (Weaver & Dale 1978). Atkinson (1981) describes two substrate types within the Tongariro National Park, sandfields and gravelfields. While the sand fields are prone to movement tyre depth is not as great in a stony gravelfield soil (applying Weaver & Dale 1978). The harder volcanic substrates are less likely to show tyre prints. Hence the number of tyre marks reported in this study can be considered conservative as the Desert topography constantly changes due to naturally drifting sand, and other desert substrates are too firm to leave imprints of tyre tracks. Further, tyre marks recorded in an image one year are sometimes not there the next visit (*Pers. obs*.). Nevertheless for this study we used what we saw in the one snap shot of time. Vehicle marks within the Desert environment also were mainly observed on open, flattish land compared to the more undulating channels; these results are comparable with Priskin (2003) who found low elevation dunes provided easier four wheel drive access than higher ridges in a coastal environment. Both environments are harsh, arid and sandy.

Desert environments have sparse plant cover due to climatic conditions (Wilshire 1983). While over half of the Rangipo Desert study area was made up of sparsely vegetated areas, different vegetation densities were observed in the aerial images and these were ground-truthed. The Canonical Correspondence Analysis shows differences in vegetation densities and a plant density gradient with sparsely vegetated environments being most similar to patchy environments and clump environments to dense environments. Sparsely vegetated areas were associated with road, tyre marks, gravel and rock; patchy vegetated areas were related to roads, tyre marks and sand; clumped vegetation was coupled with sand and cover and dense vegetation was linked with vegetation heights and covers.

From our aerial imagery 72.8% of tyre marks were found on sparsely vegetated, low stature vegetation. But this reflects choice, not availability of substrate as only 59.2% of the Desert is covered in such areas. The choice tests confirmed that drivers prefer to operate vehicles over low stature, sparsely populated areas of vegetation. According to Brooks and Lair (2005) more accessible bare patches of land are most likely to be driven on in desert regions and drivers utilise sparse vegetation as a suitable, easy access route for their vehicles.

Using paired t tests I found significant differences between the plant density categories, in the amount of substrate and, of course, the vegetation cover. There were no significant differences in the maximum height between the dense and clumped categories suggesting that there was not much difference between the heights or diversity in these two categories.

Where I have not identified any vehicle passage through larger vegetation I can be fairly certain that vehicles have not regularly passed, as even one pass of a vehicle through dense vegetation shows visual signs of passage by either broken limbs, or tyre marks (Rickard *et al.* 1994). If vehicles are deterred by dense vegetation I would expect to see fewer vehicle marks in these plots. There was no significance difference between vegetation density variables or tyre marks except for differences significant at the10% level between dense and bare plots, suggesting that there are more vehicle marks in sparsely vegetated areas compared to vegetation that is dense and clumped. But I suggest that vegetation density is the largest deterrent to drivers, as when the percent of clumped vegetation that contained tyre marks were calculated, a larger area of clumped vegetation had tyre marks compared to densely vegetated areas, while there was no significant different in height for these two categories. The reduced number of vehicle marks over patchy, clumped and densely vegetated plots suggests an aversion for taking a vehicle through vegetation as it becomes denser. This is supported by Wilshire (1983), who suggests that although small shrubs are not generally large enough to deter direct vehicle impacts, larger trees and shrubs tend to “discourage” drivers from driving through them. However as height and density of vegetation are closely linked it is difficult to assess which is the largest deterrent for the driver.

These aerial images only gave us a snap shot in time, the time the photographs were taken, but the images did not indicate what type of vehicles have driven in the Desert and the times they frequented the Desert. However a spy camera and a hand camera were better at capturing this information. Unfortunately the camera could only be set up covertly on either the Tukino Skifield Road or the Pylon service tracks, only a tiny fraction of the spots possible for vehicles to drive onto the Desert.

State Highway One and the Tukino Skifield Road are legally allowed to be driven on; the issue is when vehicles are driven illegally off-road. Of all the vehicles observed within the 16 day survey period, I saw no evidence of the bicycles venturing off-road and to the Desert, if they did, the damage created would be less compared with motorized vehicles (Wilson & Seney 1994). The buses, campervans and large trucks would also mostly be vehicles that adhered to the constructed roads. The 2WD drive vehicles could potentially go off road, as reported by Lonsdale & Lane (1994); however, off-road vehicles are four times as likely to be driven off-road than two-wheel drive vehicles.

The real issue is that, of the eight vehicular categories, four-wheel drives made up the highest percent (40%) of vehicles seen along the Tukino Skifield Road. Four-wheel drives have different tyre impressions (Figure 2.8) than standard two-wheel drive car tyres, and have the potential to make the marks that have been observed off road. Off-road vehicles can compact soil, remove vegetation cover, and increase soil erosion (Li *et al*. 2007). With the addition of the off-road trail bikes seen driving in a group, over the Desert, a total of 48% of vehicles observed during the 16 day observation period were off-road vehicles.

Off-road vehicles driving into the Desert, alter the substrate, increase erosion and damage the vegetation, potentially changing an ecosystem and resulting in considerable damage to the environment (Tommervik *et al.* 2012). The four trail bikes seen riding over the Desert, over an open, sandy, sparsely vegetated area, are just as much a concern as the off-road vehicles, as motorbikes, can do just as much damage to plants and soils as a result of limb breakage, dislodged root systems and through soil compaction (Kutiel *et al.* 2000; Weaver & Dale 1978). Motorbikes, like automobiles, decrease the height of vegetation and the total amount of ground cover; they also reduce species' richness and diversity (Kutiel *et al.* 2000) by removing vegetation (Weaver & Dale 1978). Similarly motorcycles also compact soil and increase the percentage of bare ground (Weaver & Dale 1978, Ayres 1994).

Undamaged bare ground in arid and semi arid environments eventually produces a solid crust which reduces wind erosion of soil surfaces. These crusts are highly susceptible to disturbance (Belnap & Gillette 1997). Vehicle traffic over these surfaces break them and reduce soil surface resistance to wind and water erosion (Belnap & Gillette 1998). Hence vegetation can still be destroyed by erosion and aeolian sediment caused by vehicular denudation of adjacent land (Wilshire 1983).

One pass of a vehicle through vegetation is all that is required to break limbs from plants damaging vegetation, and the more passes over vegetation the more significant the damage (Monz 2002, Cole 1995). Further increases in the number of passes reduce plant height and overall plant cover (Rickard *et al.* 1994). Similar to off-road vehicles there is a delay between the initial passage of the motorcycle and signs of statistically significant damage (Kutiel *et al.* 2000) to plant height, plant cover, species diversity and soil substrates. In the Rangipo Desert study area, the more heavly used areas such as the Tukino Skifield Road and Plyon service track intersection are mostly barren now. Their intersection, especially just into the Pylon track, has the highest number of tyre marks within 50m from the road. The substrate here is quite barren. As vehicles move across the substrate it becomes compacted altering the soil pores (Hegarty & Royle 1978), changing hydrology systems (Affleck 2005) and preventing seedling emergence (Maun & Lepierre 1986), further reducing the likelihood of plant recovery, and preventing vegetation re-growth in these barren areas.

As well as vehicles damaging vegetation, compacting soil and promoting barren landscapes, their routes are also primary pathways for plant invasion into arid and semi arid ecosystems (Amor & Stevens 1976). Increased visitor numbers have been positively correlated to increased weeds (Priskin 2003). A range of exotic weeds occur within the Rangipo desert: *Pinus contorta* (McQueen 1993), *Hypochaeris radicata, Pilosella officinarum, Holcus lanatus, Dactylis glomeratus, Linum catharticum* and *Calluna vulgaris* (Chapman & Bannister 1990), are all noxious exotic species that have been observed in the Rangipo Desert. The weeds made up 0.05% of all the "other species" I found beneath my focal plants in Chapter three. *C. vulgaris* is considered a particularly undesirable exotic weed capable of invading and radically altering native plant communities (Bagnall 1982); the decline in red tussock at Tongariro National Park between 1960 and 1984 is primary due to the increase in *C. vulgaris* (Chapman & Bannister 1990). This has implications for the environment as sandy soils, commonly found at Rangipo, are the most sensitive to recreation-induced disturbance as they react rapidly (Priskin 2003). It is now generally accepted that tourism is potentially harmful to the environment, and tourism is on the increase in New Zealand (Becken & Simmons 2002).

The findings of this study verify vehicle incursions throughout the Rangipo Desert, and that drivers prefer low stature, sparsely populated vegetation. Published articles confirm that off-road vehicles damage vegetation, compact substrate surfaces, and alter environments. The damage done to vegetation, soil compaction, and the increase in erosion resulting from vehicle transit through the Rangipo Desert needs to be addressed and tested. The use of aerial images to identify vehicular transit was satisfactory, but did not give an indication of vehicle types, which can be distinguished by tyre impressions.

Figure 2.8 Above: pair of Off road tyre imprints which have distinctively different tyre pattern than a two wheel drive vehicle, driving off-road, over bare, sandy substrate between clumped patches of *R. setifolia.* Below: 2WD tyre marks on the road, 4WD tyre marks off-road to the right hand side of the picture.

2.6 Conclusion

From the aerial images it appears drivers prefer to drive on bare or sparsely vegetated, and easily accessible substrates, throughout the Desert ecosystem. Forty eight percent of the vehicles observed on the Tukino Skifield road were off road vehicles.

Taller vegetation is generally avoided by vehicles and appears seldom driven over, as sign of damage to a well developed area of flora is quite noticeable. When a new route is punched through vegetation such as the “Kaimanawa walkway” (opposite Tukino Skifield Road), branch breakage is a conspicuous feature.

This type of damage probably did occur also when the Pylon track was first put in (though legally), and subsequent branches off the Pylon track (illegally) are obviously newly created, allowing access into the Desert, over short stature vegetation, which includes not only alpine herbs, but also seedlings. Any shrubland driven through has probably been removed due to the time lapse since the Pylon route was first opened.

Vehicles that access the Rangipo Desert vary in the distances travelled from a constructed road, and the aerials show at least some vehicles go a long way, disrupting vegetation and substrates. Any of these off-road vehicles can decrease vegetation height, remove vegetation cover, decrease diversity, and increase soil compaction and erosion (Weaver & Dale 1978, Kutiel *et al.* 2000, Li *et al*. 2007). These vehicles are also a vector for weed imports (Priskin 2003) and a source of pollutants for plants (Tombulak & Frissell 2000), and there is a high likelihood that the damage is long term and not seen until well after the offenders have left the area.

Given the sensitivity of desert habitats to disturbance and the slow nature of recovery, the best management option is to limit the extent and intensity of impacts as much as possible (Lovich & Brainbridge 1999). Blocking off access routes, where feasible, is a reasonable management option, which worked well as an off-road deterrent when the State Highway One changes were made.

While it might prove impossible to completely prevent traffic moving through vulnerable vegetation and environments, it is possible to minimise damage by setting out isolated (e.g. fenced or with bunds or other barriers) routes to prevent users from going off-road. Alternately the existing roads could be planted on either side of the road with tall, more densely populated plants, which are more likely to deter drivers driving off road (Wilshire 1983).

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2.8 Appendices

2.8.1 Appendix A. Vehicles sighted between April 2010 and March 2012.

Date	Description of vehicle	Category placed in
9.4.2010	Van	Van
9.4.2010	Van	Van
9.4.2010	Car	2WD
9.4.2010	Car	2WD
9.4.2010	Shuttle sized bus	Bus
9.4.2010	Push bike	Pushbike
9.4.2010	Push bike	Pushbike
15.4.2010	Utility van	4 WD
15.12.2010	Trail bike	Motorbike
15.12.2010	Trail bike	Motorbike
15.12.2010	Trail bike	Motorbike
15.12.2010	Trail bike	Motorbike
12.3.2011	Daihatsu Terios	4WD
12.3.2011	Mini bus	Bus
12.3.2011	Toyota Surf	4WD
9.4.2011	Apollo Campervan	Campervans
9.4.2011	Volvo SUV	4WD
9.4.2011	Hiab truck and trailer unit	Truck
23.12.2011	SUV towing caravan	4WD
23.12.2011	Nissan Sedan	2WD
26.12.2011	Holden wagon	4WD
26.12.2011	Isuzu Mu	4WD
27.12.2011	Coach sized bus	Bus
27.12.2011	Nissan Safari	4WD
27.12.2011	Land–drover (early model)	4WD
27.12.2011	Rav 4	4WD
2.1.2012	Shuttle sized bus	Bus
2.1.2012	Mazda BT 50	4WD
2.1.2012	2 door hatchback	2 WD
16.1.2012	Apollo campervan	Campervans
16.1.2012	Ford Explorer	4WD
9.3.2012	Toyota Hilux	4 WD
9.3.2012	Rental “Juicy” Van	Van
16.3.2012	Toyota Hilux	4 WD
16.3.2012	Mitsubishi Triton	4 WD
17.3.2012	Subaru Legacy	4WD
17.3.2012	Mazda Bongo campervan	Campervan
17.3.2012	Subaru Sedan	2WD
17.3.2012	Subaru Forester AWD	4WD
17.3.2012	Subaru (unsure of make)	2WD
18.3.2012	Push bike	Pushbike
18.3.2012	Push bike	Pushbike
18.3.2012	Flat deck truck (4x2) possibly DOC owned	Truck
29.3.2012	Mitsubishi Triton	4 WD
29.3.2012	Hire pool flat deck truck (4x2)	Truck
30.3.2012	Daihatsu 4WD	4WD
30.3.2012	Kia Sorento	2WD
31.3.2012	Ford Transit Van	Van
31.3.2012	Push bike	Pushbike
31.3.2012	Nissan Maxima	2WD

2.8.2 Appendix B. Count of squares tyre marks and roads were observed in and distances travelled.

Distance Travelled (km)	Tukino Skifield Road	Pylon Track	State Highway 1	Total count
0.005-0.050	78	16	3	97
0.051-0.100	21	4	1	26
0.101-0.150	7	2	2	11
0.151-0.200	5	2	0	7
0.201-0.250	3	0	1	4
0.251-0.300	2	0	2	4
0.301-0.350	0	0	1	1
0.351-0.400	0	0	0	0
0.401-0.450	0	1	0	1
0.451-0.500	0	1	1	2
0.501-0.550	0	1	2	3
0.551-0.600	0	0	2	2
0.601-0.650	0	0	1	1
0.651-0.700	0	1	1	2
0.701-0.750	0		2	2
0.751-0.800	0		0	0
0.801-0.850	1		1	2
0.851-0.900	1		0	1
0.901-1.000	0		0	0
1.001-1.050	0		0	0
1.051-1.100	1		0	1
1.101-1.150	1		0	1
1.151-1.200			0	0
1.201-1.250			0	0
1.251-1.300			0	0
1.301-1.350			0	0
1.351-1.400			0	0
1.401-1.450			0	0
1.451-1.500			0	0
1.501-1.550			0	0
1.551-1.600			0	0
1.601-1.650			0	0
1.651-1.700			0	0
1.701-1.750			0	0
1.751-1.800			1	1
Total count	120	28	21	169

Chapter 3

Vehicles: do they make an impression on vegetation and substrates?

3.1 Abstract

Tongariro National Park's Rangipo Desert is a sparsely vegetated landscape that is visited by vehicles that leave constructed roads and drive over the surrounding land areas and low stature vegetation. In this study I measured the amount of damage done by vehicles to the vegetation and their substrates at three different sites within this semi-desert landscape.

I set up 36 sets of trios of plants. A trio of a plant species consisted of three treatments: a control, a plant that had already been run over by a vehicle, and a plant that was to be manipulated by running a hand-pushed tyre over the substrate and the plant to simulate a vehicle tyre's passage. Various measurements were taken from the plants at time 1, the beginning of the experiment and again at time 2, 15-23 months later. The substrate damage was measured using micro-topography and testing the changes in the substrate before and after a hand-pushed tyre ran over the substrate and plant at time 1 simulating a vehicle. I also counted the number of species found under each of the plants to identify seedling diversity differences between treatments. The changes in the micro-topography, plant damage and differences in seedling diversity were tested using Analysis of Variance.

There were significant differences in the micro-topography between the immediate impact zone of the tyre and the non-impact areas after the substrate was run over. The substrate was compacted beneath the area of impact and was pushed up on either side of the tyre tracks breaking the surface crust. Running over plants appears to increase species' diversity under some species, especially *Andreaea rupestris* and *Carmichaelia australis* that were run over. Results also showed a difference in tolerance levels between species; the live cover increased over time for *Leucopogon fraseri, Raoulia albo-sericea,* and *Wahlenbergia pygmaea* but decreased for *Rytidosperma setifolia.* The shoot density of *Gaultheria colensoi* and *Leucopogon fraseri* increased over time while that of all other species tested decreased. The only significant change in radius was a decrease for *Rytidosperma setifolia.*

KEYWORDS vehicle damage, desert, barren landscapes, vegetation, soil compaction, vegetation.

3.2 Introduction

Humans and their activities are encroaching upon arid environments and altering the natural land cover (Gill 1996) affecting both plants and soils. Soils are being compacted and broken by tyre pressure from vehicles driving over the Desert. Consequently soils become increasingly susceptible to wind erosion (Breed 1999). Aeolian dust can also be harmful to humans, vegetation, and water bodies (Goudie 1978), and sediments can harm traffic flow, and fill in ditches (Bilbro & Fryrear 1994) altering an environment.

Vehicles also cause immediate damage to the roots and shoots of vegetation. Roots can become exposed (Pickering *et al.* 2010), and shoots damaged as they are being driven over (Sun & Liddle 1993). Fragmentation of plants and stems decreases the height of vegetation which is followed by a decline in cover potentially leading to the death of vegetation (Rickard *et al*. 1994). As the vegetation becomes isolated the effective population size is reduced, decreasing pollination visitation, which can also lead to a decrease in genetic diversity through inbreeding, further increasing the risk of local extinction through accumulation of deleterious alleles (Groom 1998, Severns 2003). The reduction of live vegetative material also results in larger areas of bare soil which are prone to modification without the protection of vegetation cover (Figure 3.1). Hence damage to the plant and the environment can continue long after the vehicle has left the area.

Vehicular impacts when driving over plants and bare substrates include soil disturbance which can cause environmental damage by decreasing plant development (Ayres 1994), plant vigor, and plant recovery (Affleck 2005). Soil compaction increases bulk density which can impede seedling emergence and survival (Hegarty & Royal 1978). Through compaction the porosity of the soil is decreased, resulting in a shortage of oxygen and changing water regimes increasing water runoff and soil erosion (Kozlowski 1999). Microbes may respond to these environmental stresses by changing their activity, growth or resource allocation

(Schimel *et al.* 2007), potentially altering the production of the soil enzymes responsible for catalyzing carbon, nitrogen and phosphorus cycling (Kissling *et al.* 2009).

Figure 3.1 Fragmentation in plant cover and areas of bare soil in Rangipo Desert. Tyre marks are visible on the far left, within red circle.

Vehicle disturbance can also result in soil surface breakage; this is more noticeable in arid environments that develop surface crusts (Belnap & Gillette 1997). The breakage of the soil surface alters the topography, increasing the area for exposure to wind and water erosion. A small amount of surface loss can result in a significant loss of many organisms, reducing site productivity, and nutrients (Belnap & Gillette 1998). The disturbance regimes and forces of erosion increase the likelihood of roots becoming exposed; plants are unable to survive on eroding surfaces owing to desiccation of their root systems (Maun 1994).

On the sparsely vegetated Rangipo Desert, situated on an actively volcanic site, Tongariro National Park, North Island, New Zealand, there is a unique flora and fauna making up the ecosystem. The flora has ecological significance and plays many roles in establishing the ecosystem. Flora can stabilise soil (Norris 2005, Pohl *et al.* 2009), and prevent soil erosion (Gyssels & Poesen 2003). Plant roots and associated hyphae can be seen to enmesh soil particles, and help aggregate soils into clumps. In the absence of plants the stability of larger aggregates is lost (Oades 1993). The binding of the soil particles and root systems create pores in the soil which aid water penetration, reducing the amount of erosive overland flow (Gyssels & Poesen 2003), and there is a positive correlation between aggregation and organic matter content of the soil (Oades 1993).

The flora plays an important part in supplying organic matter to the soil improving soil properties such as accumulation of nutrients (Singh & Gupta 1977; Holmgren *et al.* 1997; Callaway & Walker 1997; Flores & Enqrique 2003). Legumes may further improve soil nutrient composition due to nitrogen fixation (Gomez-Aparicio *et al.* 2004).

Flora also provides food for fauna (Rathcke & Jules 1993) both above and below the substrate surface. Fruit and flowers feed macro-fauna. Tongariro National Park is home for many species of fauna within this environment which rely on plants for food. Native bees have been observed using flora for food (Godley 1979). Other published articles report birds and insects in the area (King & Moody 1982, Beauchamp 2009).

The flora is supported by a range of substrates that consist of bare or sparsely vegetated scoria and lapilli, bare soil and stony debris on surfaces covered by old tephra, bare areas of fine alluvial scoria or coarser volcanic debris, and sometimes crevices in solid volcanic rock (Burrows 2008).

Cushion plants such as *Raoulia* (Cockayne 1912), *Carmichaelia* (Cockayne 1912), a legume (Jarvis *et al.* 1977), and *Pimelea* (Burrows 2008) trap windblown seeds. The abundant moisture contained within the cushions due to their peat-content, creates habitats suitable for seeds to germinate and young seedlings to thrive (Cockayne 1912). The flora also plays a part in facilitating seedlings of other species by retaining moisture, shade and mulch, lowering temperatures, and providing greater sand stability creating micro-habitats for seed germination to aid germination of plants of later seres (Flores & Jurado 2003). These nurse-protégé interactions are common across diverse environments, but are most frequently reported in arid and semi-arid ecosystems where soil may dry too quickly for seeds to germinate (Flores & Jurado 2003).

Evidence is growing that spatial proximity among plants is beneficial rather than detrimental in environments such as Mediterranean-type ecosystems (Gomez-

Aparicio *et al.* 2004). Under extreme arid conditions the shade provided by nurse plants significantly increases seedling survival because of improved plant water relations preventing the seedling roots from being uprooted by frost heave and exposed to desiccation during the dry spring days. Because of these micro-climatic changes, transpiration demands are lower in the shade, and evaporation from the superficial soil layer is lower (Holmgren *et al.* 1997) increasing the young plants' water intake requirements. Although not a true Mediterranean environment, Rangipo Desert may experience similar effects.

However there is visual evidence that vehicles drive over the Rangipo Desert, altering substrates and crushing low stature vegetation, causing plant die-back and increasing the likelihood of loss of biodiversity resulting from habitat fragmentation (*sensu* Rathcke & Jules 1993). This chapter investigates the direct and indirect impacts to plants and substrate when run over by vehicular traffic within the Rangipo Desert.

There are long and short term aims for this chapter. The short term aim is to test the immediate effects of vehicle impact on topography, by measuring the changes in the topography after a vehicle has driven over the substrate and the plant. The long term aim is to monitor changes in plant growth over time against three treatments. The hypothesis is that we should see plant growth in the control and plant die-back in the manipulated and vehicle damage treatments at the conclusion of the experiment.

3.3 Methods

Eight plant species from eight different families were used from Rangipo Desert to measure alterations in micro-topography and plant changes over time. The plants used and their families are *Raoulia albo-sericea* (Asteraceae); *Rytidosperma setifolia* (Poaceae); *Leucopogon fraseri* (Epacridaceae); *Gaultheria colensoi* (Ericaceae); *Wahlenbergia pygmaea* (Campanulaceae); *Pimelea prostrata* (Thymelaeaceae); *Carmichaelia australis* (Fabaceae); *Andreaea rupestris* (Andreaceae).

The long term aim was to monitor changes in the growth of (n=108) plants, from eight species, over a period between 15 months at the Shooting Box and Army Corner sites and 23 months at the Pylon site (Table 3.1), to compare the growth between three treatments. The treatments were a control, a vehicle treatment which had previously been run over by a vehicle and a manipulated treatment which consisted of a tyre weighing ~ 30 kg being pushed over a previously undamaged plant. Additionally I wanted to investigate both immediate changes in micro-topography when driven over and follow these changes over time.

Table 3.1 The number of plant species used and the sites these were measured from. Number of Trios is given in brackets.

Plant species	All plant species used and sites they are from.			Total number of plants
	Pylon	Shooting Box	Army corner	
Raoulia albo-sericea	**12 (4)**	**6 (2)**	**9(3)**	**27 (9)**
Rytidosperma setifolia	**9 (3)**	**6 (2)**	**9(3)**	**24 (8)**
Leucopogon fraseri	**9 (3)**	**9 (3)**	**9(3)**	**27(9)**
Pimelea prostrata	9 (3)	0	0	9 (3)
Wahlenbergia pygmaea	0	3(1)	0	3(1)
Gautheria colensoi	0	0	3(1)	3 (1)
Carmichaelia australis	0	0	9(3)	9 (3)
Andreaea rupestris	0	0	6(2)	6 (2)
Total	**39 (13)**	**24 (8)**	**45 (15)**	**108 (36)**

3.3.1 Sites

Three sites were used (Figure 3.2); the Pylon site, situated closest to State Highway One ~ 0.9km away was set up in April 2010. The Shooting Box ~2.0 km from State Highway One and the Army Corner site ~ 2.5 km from State Highway One were set up in December 2010 (time 1). These were re-measured in March 2012 (time 2). All sites were at approximately the same altitude of ~ 669m above sea level within the Rangipo Desert. To test for site similarities for experimental and extrapolation purposes I used the three species that were found at all three sites, *R. albo-sericea, R. setifolia, L. fraseri*.

Figure 3.2 The three study sites A: the pylon site, B: the Shooting Box site, C: the Army Corner site.

3.3.2 Species measurements and treatments

On locating a plant that had been run over, I looked in the immediate vicinity to find two other plants of the same species, of about the same size that had no sign of vehicle damage. The plant that had been driven over became the "vehicle" treatment. A toss of a fair coin decided which of the other two plants would become the "control" and "manipulated" treatments. Eight variables were taken from each plant and used to measure change in the vegetation over time. Measurements were always taken from the vehicle treatment first, followed by the control and finally the manipulated treatment. This order was important as the tyre treatment already had a tyre direction from a passing vehicle. By taking measurements from the tyre treatment first, the hand tyre could be pushed over the manipulated treatment in the same direction. The manipulated treatment was set up last as more work was involved in this treatment as two lots of micro-topography data were taken, both before and after the tyre was pushed over the treatment area. The tyre weighing approximately 30kg was pushed over the plant in the same direction as the tyre marks ran through the vehicle treatment. The tyre was pushed over the plant a total of 6 times and the pushing of the tyre was always in the same direction. The tyre was pushed over the plant then pushed around the plant and back over the plant again; this was repeated six times, in the hopes that a 6 repetitions of a 30kg tyre will equate approximately to the weight of quarter of a 720kg vehicle. This was done to create damage equivalent to a 720kg vehicle (180 kg per tyre).

Collection of variables: live, dead, litter, sand, and number of other species

For all plant species with the exception of *L. fraseri*, *G. colensoi*, and *A. rupestris*, 8 compass points were used to place eight bamboo skewers into the ground around the outer margins of the shoots of each plant, and string was wound around the eight sticks to form a convex polygon (Figure 3.3) which completely enclosed all the shoots of the plant. This was done to give a fixed area against which the cover variables could be estimated. The entire plant being within the string, a ninth stick was them placed into the centre of the plant. The percentage cover of dead and live plant, litter, sand, and any other plant species from within the stringed perimeter were recorded, using the concept of the size of the shadow of that variable at solar zenith, even though there was little overlap between layers.

The number of other species growing under each treatment was noted and identified. The plant density was then calculated by dividing the number of plants by their total cover within the polygon. This was to compare the species' abundance between the plants that had been run over and those that had not been. This was tested using SYSTAT 8.0 Analysis of Variance.

Collection of variable Radius

The string was removed and the eight outer sticks were moved towards the plant until they touched the outmost live structure of the focal plant, keeping in line with the eight compass points. A measurement of the radius was taken from the centre stick to the stick marking the plant's edge for all eight radii. These were used to give a measure of the size of the plant. The measurements of the radii between time one and time two was then divided by the number of months the experiment had been set up for (15 months for Shooting Box and Army Corner and 23 months for the

Pylon site) to give a uniform monthly calculation of cushion reaction to make comparisons across the sites, and treatments, assuming for now that all seasons are equal.

Collection of variables, shoot tiller density and shoot tiller length

Shoot tiller density and shoot tiller length were measured by placing a 50x50cm grid over the plant as a reference to take coordinates from using a random number generator. Shoot or tiller density was measured by placing a circle with a circumference of 91.23 mm over the shoots or tillers at the random point and counting. This process was repeated until we had 10 data points. The entire process was used again to record shoot or tiller height. However if there was no shoot or tiller present, another two random numbers were gained until we had 10 data points (zero was not a permitted number when recording the height of missing shoots or tillers).

Collection of variables for *L. fraseri, G. colensoi*, & *A. rupestris*.

Due to *L. fraseri*, and *G. colensoi*'s spreading growth habit, a 50X50cm quadrat was placed over the area that had been run over and the quadrat was used as the outside parameter for measurements. The percentage covers of live, dead, litter, sand and other species were recorded from within the quadrat. A peg was placed into the centre of the quadrat and measurements were taken from it to the furthest part of the plant situated along each compass axis to give an indication of the plant size for both these plants, using the quadrat for the outside perimenter instead of string as above. Shoot length and density were recorded as above.

Covers of live, dead, sand, litter and other species for *A. rupestris* were recorded as for *L. fraseri* and *G. colensoi* above, but instead of the shoots, the number of *Andreaea* balls, (normally a rock species which forms balls in the Desert up to the size of a golf ball), in each quadrat was recorded and so was local shoot frequency (the numbers of squares the balls were present in of the 25 squares on the quadrat). The diameters of all the balls were recorded by measuring across the balls at right angles. Due to the growth habit of *A. rupestris* I could not measure shoot tiller density or length or radii using the same methods as I measured the other plant species. When testing for the variables of radius, shoot tiller density and length, I didn't include *A. rupestris.*

Figure 3.3 Set-up of the polygon and the eight compass points & centre stick on a *C. australis* before being rolled over at the Army Corner site for the manipulated treatment. This method was used to measure the percentage of live and dead material, sand, litter, and other plant species growing within the polygon. The reference peg, (within the red circle), has been placed into the ground under the topography pegs, and marked with a black line to show the topography peg direction. The topography pegs have been put into place at 45^{o} angles to the tyre direction for that particular trio on either side of the quadrat and topography is measured between the topography pegs (see Figure 3.3). The 50x50cm grid has been placed over the plant; this is used to measure *L. fraseri* and *G. colensoi* and as a reference for shoot or tiller density and height on all species.

3.3.3 Micro-topography

The vehicle treatment was measured first, noting the orientation of the tyre marks. After all the eight plant measurements were taken from the vehicle treatment the micro-topography was then measured. This was repeated for the control, and the manipulated treatment. After the topography of the manipulated treatment was measured a weighted tyre was rolled over the plant six times before re-measuring the micro-topography.

A permanent reference peg was placed into the ground until it was flush with the surface in line with micro-topography transect. The micro-topography equipment was set up directly above the reference peg by placing two pegs into the ground outside either side of the quadrat covering the plant and at right angles to the tyre marks, and then placing a ruler across the top of the two pegs. A lower hanging ruler was used to ensure the measuring ruler is truly vertical. A compass bearing was taken so the ruler could be set up in the same direction for the control and manipulated treatments (Figure 3.4) as explained above. A height measurement was taken from the reference peg to the ruler to calibrate between different measurement periods. Measurements were taken off the height from the top of the ruler to the substrate, using a second ruler, at 10mm intervals across the quadrat. The measurement difference between the reference peg and top ruler were recreated to set up the equipment at the end of the experiment time for ease of comparisons to measure change over time.

Figure 3.4 Measuring topography over a *P. prostrata* plant. The upper ruler is the ruler for recording distance along the topography transect. The lower hanging ruler is to ensure the measuring ruler is truly vertical. The measuring ruler is held and moved along the top ruler in 10 mm increments.

This process was repeated for both other treatments, with the addition that after the micro-topography of the manipulated treatment had been completed the top ruler and the quadrat were removed and a sand filled tyre was rolled over the plant 6 times to represent a car. The measuring equipment was put back into place, the top ruler was re-located against the reference peg and the topography re-measured. The immediate change in topography from the manipulated treatments and the difference in the micro-topography over time and between all treatments were analysed using SYSTAT 8.0 Analysis of Variance. The design was 3 sites x 3 species x 2 times (before and after manipulation, called time 1 and time 2) x 2 micro-locations as described in 3.3.4 Statistical analysis

3.3.4 Statistical analysis

Since the same suite of species could not be located at every site, I tested for site similarities using the three species that were found at all three sites: *R. albo-sericea, R. setifolia* and *L. fraseri*. The test was done with SYSTAT 8.0 Analysis of Variance, using the model of 3 species x 3 sites x 3 treatments x 2 times X 2-4 replicates, as a fully balanced design, looking at each of the 8 variates measured.

Subsequently I looked at the differences between all the species regardless of their site. This test was done using SYSTAT 8.0 Analysis of Variance using a model of 7-8 species x 3 treatments x 2 times x 1-12 replicates, pooling the different sites as replicates. *A. rupestris* could not be measured for some variables, and so was excluded from some analyses.

Then to confirm differences among species over time I analysed all the species at each site independently. The model was 4-6 species x 3 treatments x 2 times (of differing lengths, 15-23 months) x 1-4 replicates, and was repeated for each of the Pylon, Shooting Box and Army Corner sites. Next I compared the resident species' diversity within the host species by pooling all the data from control and un-manipulated measurements with those from driven-on and manipulated measurements, using a model of 7 species x 2 levels of manipulation x 8 replicates.

My final analysis was for microtopography, looking at 3 sites x 3 species x 2 times (before and after manipulation,) x 2 micro-locations (directly underneath the tyre and the areas on either side). These repeated analyses of the same data matrix do incur Type 1 errors, but because the test number was low, no adjustment has been made for the acceptable P level.

3.4 Results

3.4.1 Sites

The initial intention was that the sites simply be replicates. However only three species, *R. albo-sericea, R. setifolia* and *L. fraseri*, were shared between all three sites, and thus could be used when testing for site differences. Although I am only interested in both site and species by site interactions in this test, the full ANOVA table is presented for completeness. There were significant differences between sites for more than half of the response variables analysed (Table 3.2).

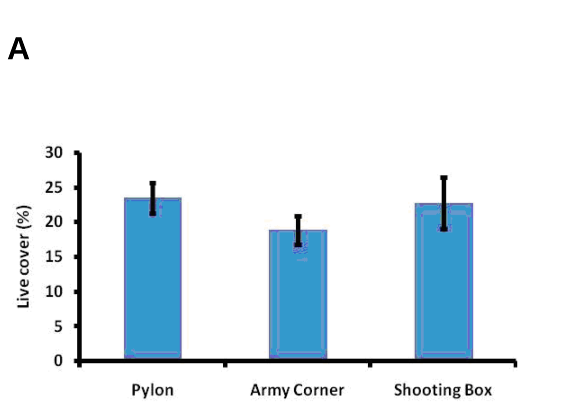
Table 3.2 P values and dependent variables of the three species; *R. albo-sericea, R. setifolia, L. fraseri* at each of the three sites; Shooting Box, Army Corner and Pylon, using the three treatments; Control, Manipulated and Vehicle between time 1 and 2. S/TD = Shoot or tiller density, S/TL = Shoot or tiller length, OSPP = Other species within the host plant sampling area. Statistically significant P≤0.05 bold, P≤0.10 italics.

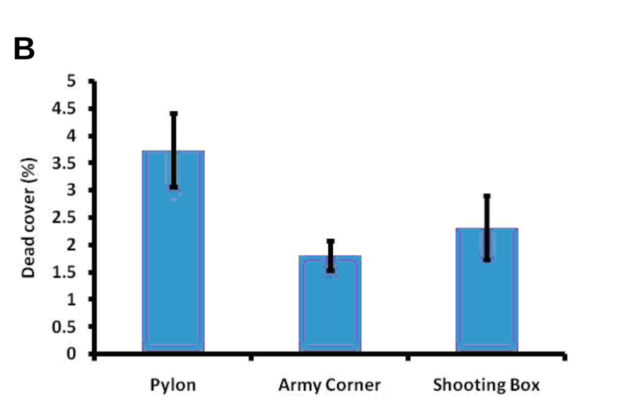
	Dependent variable							
	LIVE	DEAD	SAND	LITTER	OSPP	RADIUS	S/TD	S/TL
Site	**0.032**	**0.002**	**0.030**	**0.000**	0.122	0.324	0.326	**0.001**
Species	**0.000**	**0.000**	**0.000**	*0.081*	**0.018**	**0.000**	**0.000**	**0.000**
Treatment	**0.005**	0.139	*0.065*	0.579	0.456	0.933	0.256	**0.004**
Time	0.285	**0.002**	*0.097*	**0.007**	*0.097*	0.973	0.904	0.467
Site x Species	**0.007**	0.120	**0.010**	**0.003**	**0.031**	**0.000**	**0.000**	**0.001**
Site x Treatment	0.139	0.104	0.911	0.973	**0.020**	0.862	0.873	**0.020**
Site x Time	*0.089*	**0.002**	0.155	0.108	0.385	0.435	0.640	*0.070*
Species x Treatment	0.508	0.426	0.212	0.588	0.280	0.837	0.812	**0.018**
Species x Time	**0.004**	0.100	*0.078*	*0.068*	0.184	0.673	0.648	0.676
Treatment x Time	0.914	0.318	0.847	0.163	0.861	0.961	0.596	0.666
Site x Species x Treatment	0.112	**0.022**	0.104	0.360	**0.026**	0.999	0.890	**0.011**
Site x Species x Time	**0.042**	**0.046**	0.101	0.455	0.312	0.373	0.930	0.398
Site x Treatment x Time	0.665	0.282	0.830	0.855	0.861	0.983	0.992	0.965
Species x Treatment x Time	0.620	0.681	0.959	0.254	0.993	0.996	0.987	0.918
Site x Species x Treatment x Time	0.638	*0.052*	0.967	*0.095*	0.892	0.997	0.998	0.988
Degrees Of Freedom	101	101	101	101	101	101	101	94
Error Mean Square	144.3	8.765	222.6	7.767	57.47	4141.87	19.00	184.76

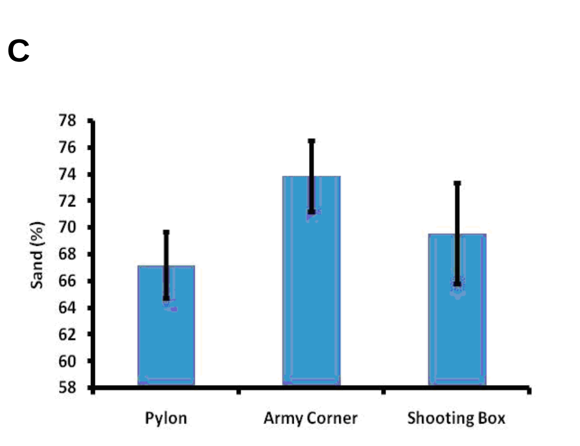
Table 3.3 Mean of site differences and standard deviations for dependent variables of the three species, *R. albo-sericea, R. setifolia, L. fraseri* at each of the three sites; Shooting Box, Army Corner and Pylon, S/TD = Shoot or tiller density, S/TL = Shoot or tiller length, OSPP = Other species within the host plant sampling area.

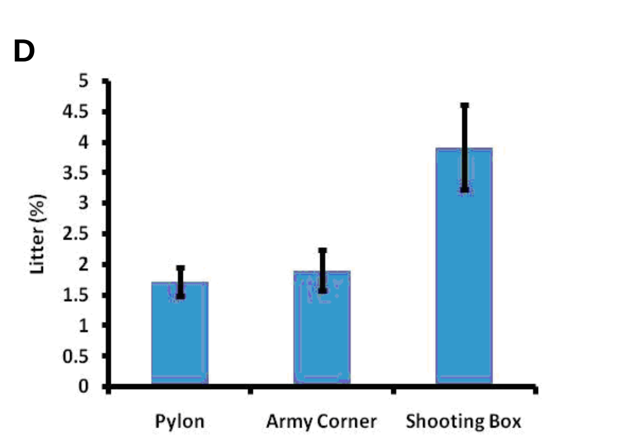
		Live cover (%)	Dead cover (%)	Sand (%)	Litter (%)	OSSP (%)	Radius (mm)	S/TD	S/TL (mm)
Pylon	Mean	23.4	3.7	67.2	1.7	3.8	149.5	3.08	41.0
	S.D	16.8	5.1	18.8	1.8	8.6	66.2	3.05	36.4
Army Corner	Mean	18.8	1.8	73.8	1.9	3.6	136.7	4.24	43.2
	S.D	15.1	2.0	19.7	2.4	10.2	37.7	4.17	40.9
Shooting Box	Mean	22.7	2.3	69.6	3.9	1.3	155.6	3.03	30.3
	S.D	24.2	3.7	24.4	4.5	2.8	81.9	2.98	28.7

The variables reacted differently between sites. There was 5% less live vegetation cover in the Army Corner site when compared with the Pylon site and the Shooting Box site ($P<0.001$; Figure 3.5A). There was 1.9% less dead cover at the Army Corner site and 1.4% less dead cover at the Shooting Box site when comparing it to the dead cover at the Pylon site ($P<0.001$; Figure 3.5B). There is approximately a 6% increase in the percent of sand cover at the Army Corner compared to the Pylon, but no significant difference in sand cover between the Army Corner and the Shooting Box ($P<0.001$; Figure 3.5C). There was approximately 2% more litter at the Shooting Box site than either of the other two sites ($P<0.001$; Figure 3.5D), and the shoot tiller length was 10–13mm shorter that the Pylon site and the Army Corner site, respectively ($P<0.001$; Figure 3.5E).









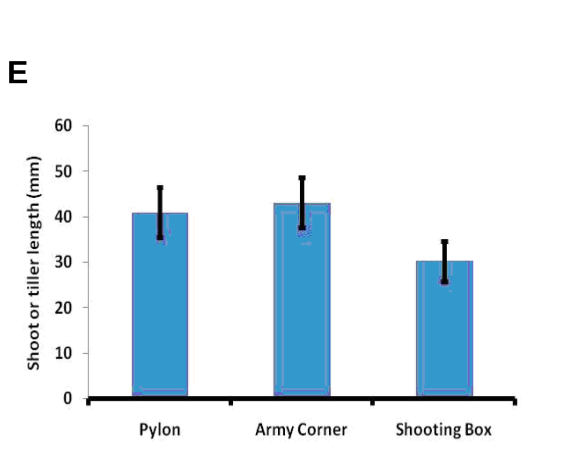


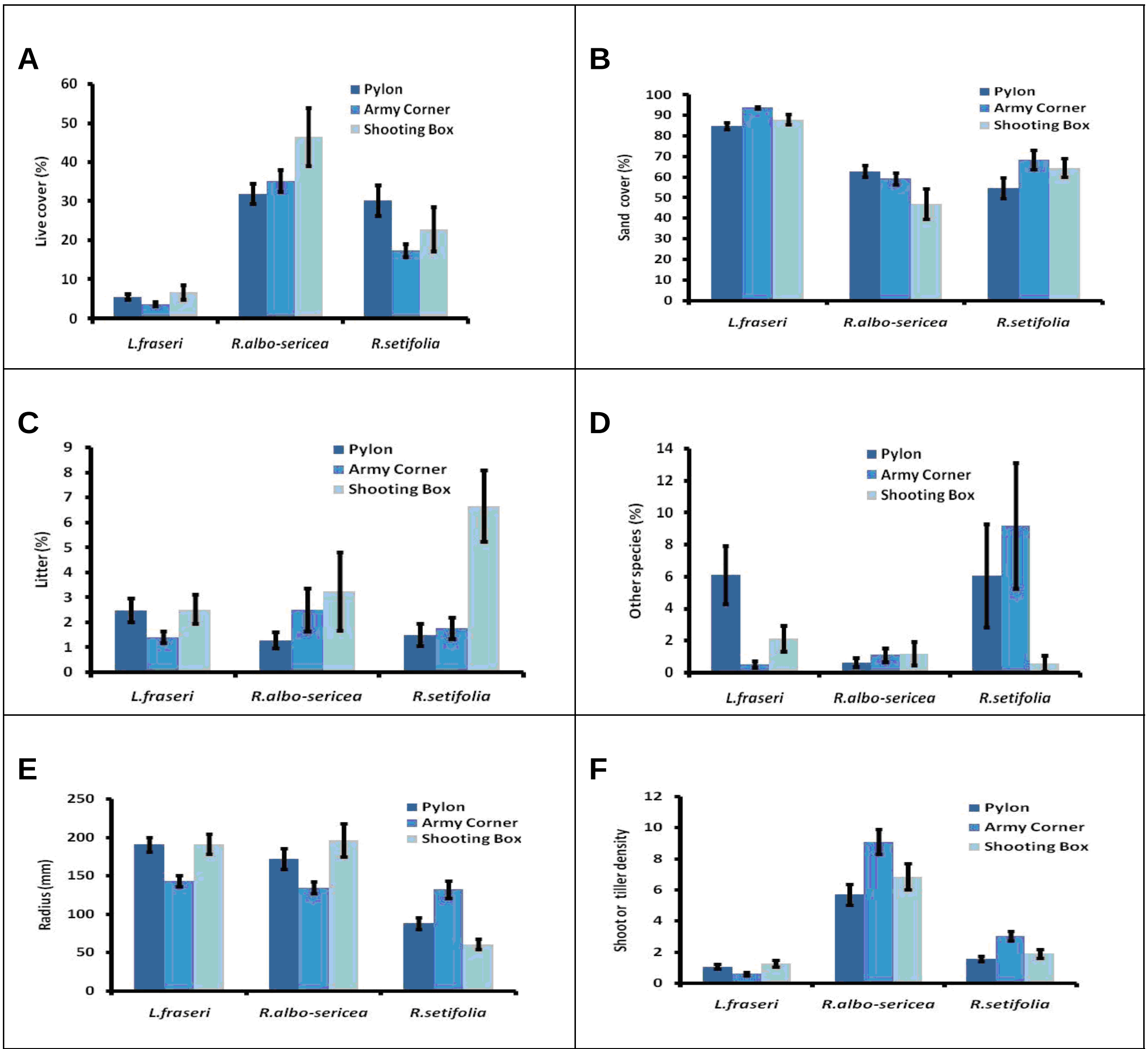
Figure 3.5 Comparisons showing the differences in site reactions represented by five of the variables tested, using three plants *R. albo-sericea, R. setifolia, L. fraseri* at each of the three sites, Shooting Box, Army Corner and Pylon sites.
A: Percent of live vegetation cover. **B**: Percent of dead cover **C**: Percent of sand cover **D**: Percent of litter. **E:** Shoot or tiller length.
Bar ± Standard deviation

Table 3.4 Mean values and standard deviations between species *R. albo-sericea, R. setifolia, L. fraseri* at each of the three sites; Shooting Box, Army Corner and Pylon sites using means and standard deviations of the 8 variables used.

	Live cover of vege (%)	Dead cover of vege (%)	Sand cover (%)	Litter (%)	OSSP (%)	Radius (mm)	S/TD	S/TL (mm)
Pylon *L. fraseri*	5.6 ± 3.3 ±	0.9 ± 1.0	84.84 ± 7.5	2.4 ± 2.0	6.0 ± 7.7	190.9 ± 32.6	1.0 ± 0.6	20.9 ± 3.3
Pylon *R.albo-sericea*	32.0 ± 12.7	3.26 ± 4.3	62.8±13.4	1.2 ± 1.5	0.6 ± 1.3	172.3 ± 66.9	5.7 ± 3.2	9.0 ± 3.2
Pylon *R. setifolia*	30.2 ± 16.4	7.3 ± 6.7	54.7 ± 20.5	1.5 ± 1.8	6.0 ± 13.3	88.0 ± 31.7	1.5 ± 0.7	81.5 ± 23.2
Shooting Box *L. fraseri*	6.7 ± 8.2	0.5 ± 0.5	88.0 ± 11.2	2.5 ± 2.4	2.1 ± 3.4	191.6 ± 56.5	1.2 ± 0.9	20.8 ± 5.9
Shooting Box *R. albo-sericea*	46.5 ± 25.7	2.06 ± 2.8	46.9 ± 25.1	3.25 ± 5.4	1.18 ± 2.5	196.5 ± 75.8	6.85 ± 28.7	7.52 ± 3.06
Shooting Box *R. setifolia*	22.9 ± 19.7	5.25 ± 2.82	64.5 ± 16.1	6.66 ± 4.94	0.54 ± 1.72	60.66 ± 23.5	1.89 ± 0.95	67.35 ± 28.2
Army Corner *L fraseri*	3.75 ± 1.98	0.52 ± 0.48	93.79 ± 2.57	1.42 ± 0.96	0.50 ± 0.76	143.08 ± 31.29	0.58 ± 0.44	26.32 ± 7.55
Army Corner *R. albo-sericea*	35.2 ± 11.7	1.8 ± 1.6	59.2 ± 11.94	2.5 ± 3.6	1.1 ± 1.8	134.79 ± 32.4	9.1 ± 3.43	7.28 ± 3.2
Army Corner *R. setifolia*	17.4 ± 6.9	3.09 ± 2.4	68.5 ± 19.7	1.77 ± 1.8	9.19 ± 16.6	132.3 ± 48.4	3.02 ± 1.25	96.0 ± 23.4

There were also significant differences for at least one of each of the first order interactions involving sites. The percentage of live vegetation cover of *L. fraseri* at ~3% less at the Army Corner, compared with the Shooting Box site. *R*. *setifolia* has 11% less live vegetation cover at the Army Corner, compared with the Pylon site, and *R. albo-sericea* has about 10% more live vegetation at the Shooting Box site compared to the Army Corner (P=0.007; Figure 3.6A). The sand cover is 25% higher for *L. fraseri* at all three sites compared to *R*. *setifolia* and *R. albo-sericea. R. albo-sericea* has about 10% less sand at the Shooting Box site compared to the other two sites within the plant zone (P=0.010; Figure 3.6B). Litter ranges between 1 and 3% for all species at all sites with the exception of up to a 4% increase in change over time in litter with *R*. *setifolia* at the Shooting Box site (P=0.003; Figure 3.6C). Considerably fewer other species appear to be growing under and around *R. albo-sericea* at all sites and *L. fraseri* at the Army corner and Shooting Box sites and R. setifolia at the Shooting Box site. There is a 4% increase in species' abundance in the Pylon site for *R*. *setifolia and L. fraseri* and a 7% increase for *R*. *setifolia* at the Army Corner site (P=0.031; Figure 3.6D). The species radii are significantly different at each site. The radius of *L. fraseri* is about 45mm less at the Army Corner site, than the radii at the other two sites. *R. albo-sericea* shows the same trend. However the difference in radii is 40-60mm between that of the Pylon site and Shooting Box respectively (P<0.001; Figure 3.6E). The shoot tiller density is of *L. fraseri* and *R*. *setifolia* is half the size of *R. albo-sericea.* The shoot tiller density at the Army Corner is between 1-3% taller than the other two sites for *R*. *setifolia and R. albo-sericea* respectively and lower by 0.5% for *L. fraseri* (P<0.001; Figure 3.6F). Shoot or tiller length of *R*. *setifolia* was about 55 mm taller than the length of *L. fraseri and R. albo-sericea* (P=0.001; Figure 3.6G).

The finding that the three sites differed suggests that one cannot extrapolate these results over the entire desert as the plants of different areas react differently to the environment and experimental conditions. Hence the subsequent analyses exclude the effects of site.



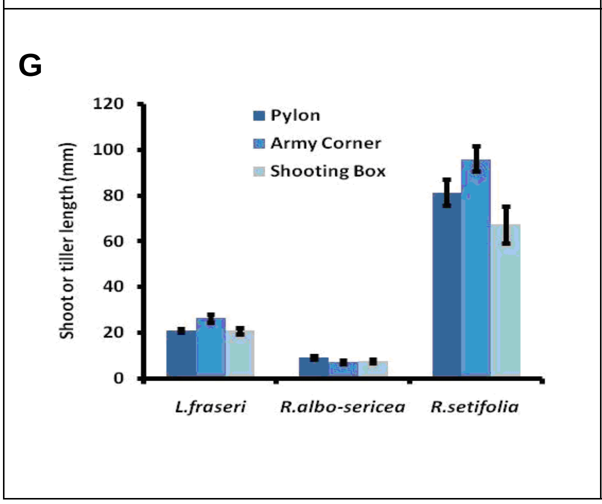


Figure 3.6 Site and species interactions between three species *R. albo-sericea, R. setifolia, L. fraseri* present at each of the three sites, Shooting Box, Army Corner and Pylon sites. **A**: Percent of live vegetation cover. **B**: Percent of sand cover **C**: Percent of litter **D**: Percent of other species **E**: Radius **F**: Shoot or tiller density **G**: Shoot or tiller length. Bar ± Standard deviation

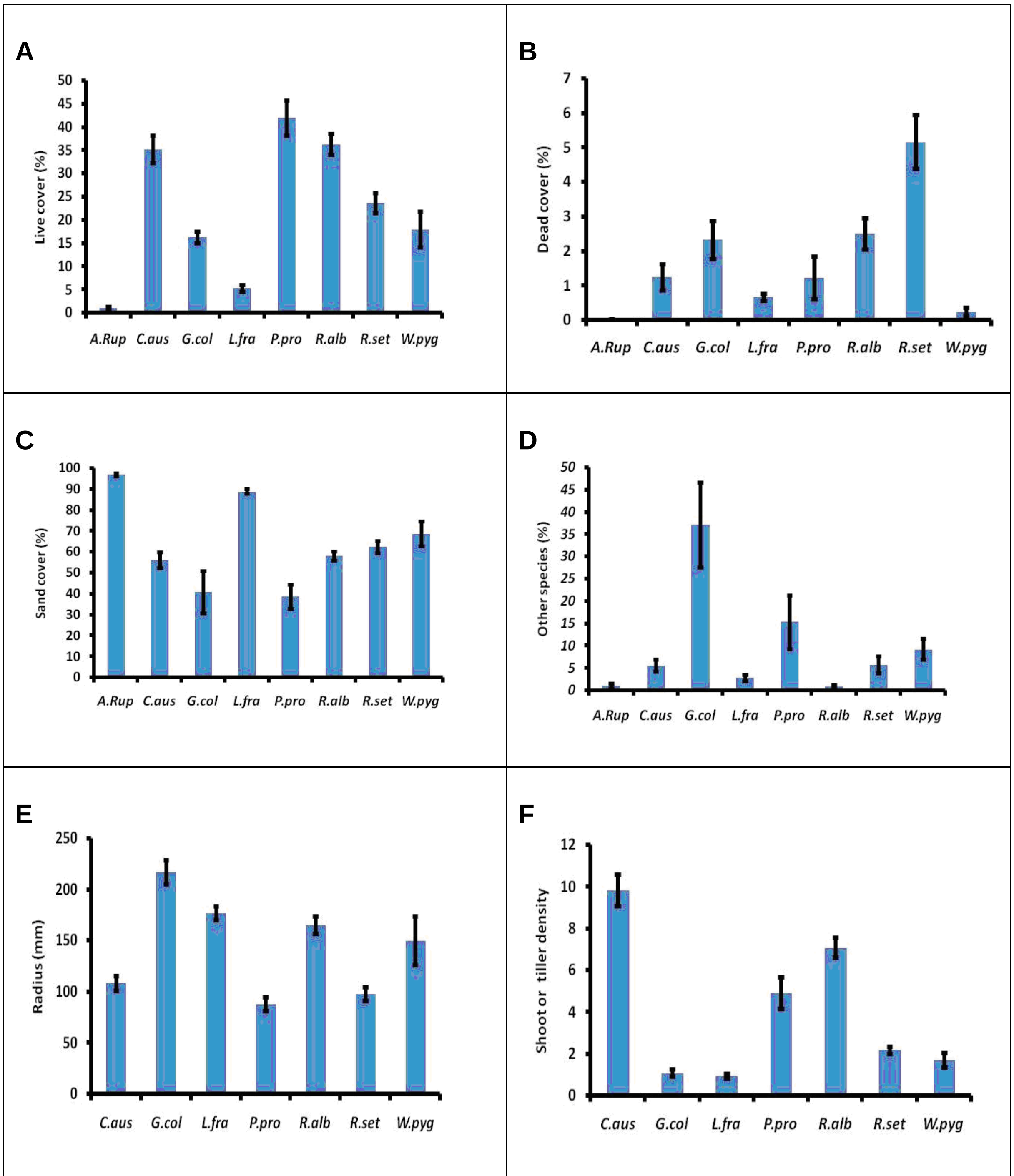
3.4.2 Species

The results also showed that species were different from one another (Table 3.3), and this is most likely due to different growth habits. Although this information could be considered trivial in the scope of this experiment, it could be of interest to botanists and is added also for completion.

Table 3.5 P values of dependent variables of the 8 species taken over the 1-3 sites at which the species occurred, using the three treatments Control, Manipulated and Vehicle between time 1 and 2. S/TD= shoot tiller density, STL= Shoot tiller length, OSPP= other species. *A. rupestris* was not included in the statistical analyses for the three variables marked with * as no data could be taken. Statistically significant P≤0.05 bold, P≤0.10 italics

	Dependent variable							
	LIVE	DEAD	SAND	LITTER	OSPP	RADIUS*	S/TD*	S/TL*
Species	**0.000**	**0.000**	**0.000**	0.314	**0.000**	**0.000**	**0.000**	**0.000**
Treatment	0.260	0.988	0.191	0.620	*0.082*	0.729	**0.041**	0.350
Time	0.559	0.547	0.471	0.881	0.551	0.280	**0.011**	0.651
Species x Treatment	0.982	0.847	*0.052*	0.997	**0.001**	0.551	0.154	0.795
Species x Time	0.485	0.210	0.838	0.115	0.898	0.632	**0.038**	0.886
Treatment x Time	0.857	0.961	0.578	0.131	0.899	0.858	0.845	0.664
Species x Treatment x Time	0.977	0.990	0.993	0.834	0.997	0.986	0.952	0.999
Degrees Of Freedom	166	166	166	166	166	159	159	148
Error Mean Square	181.4	10.83	272.06	8.990	114.64	2748.73	0.95	226.64

For example *A. rupestris* has a less than 5% live vegetation cover and over 95% sand cover, while most other species had a higher percentage of live cover than sand cover (P<0.001; Figure 3.7A) and (P<0.001; Figure 3.7C) respectively. *R. setifolia* had up to twice as much percentage of dead cover than the other species (P<0.001; Figure 3.7B). What was of interest was that *G. colensoi* had more species around and among it than any other species, followed by *P. prostrata.* (P<0.001, Figure 3.7D). There was variation in the radii, and shoot or tiller density between all species (P<0.001, Figure 3.7E and P<0.001, Figure 3.6F respectively). The shoot or tiller length of *R. setifolia* is up to 50mm longer than other species (P<0.001, Figure 3.7G). These findings may also suggest that results from one species cannot be extrapolated to other species, as the species are different.



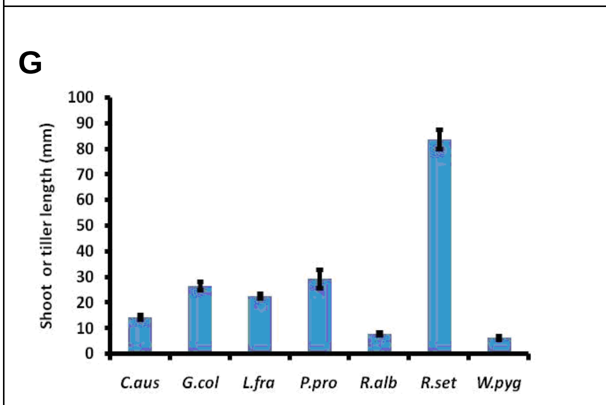


Figure 3.7 Species show significant differences to the tested variables using 7-8 plant species at all three sites. **A**: Percent of live vegetation cover. **B**: Percent of dead cover. **C**: percent of sand cover. **D**: Other species growing in the focal plants' vicinitiy. **E**: Radius. **F**: shoot tiller density. **G**: Shoot tiller length. Bar ± Standard deviation

3.4.3 Treatments

There were some significant differences between the treatments. The manipulated treatment showed immediate sign of damage to the plant as the tyre was pushed over it. Limbs were broken and roots were exposed on some species, (*Pers. obs.).* The shoot or tiller density in the vechile treatment was 1.5 counts on average less than the control (P=0.041, Figure 3.8A). The vehicle treatment's value for the variable "Other Species" was less than the control by 0.5% (P=0.082, Figure 3.8B). The percentage of cover of live vegetation (P=0.005, Figure 3.8C, Table 3.2) was lower under the vehicle treatment, was higher for the control and intermediate for the manipulated treatment. The sand variable increased with the vehicle treatment and was intermediate for the manipulated treatment (P=0.065, Figure 3.8D Table 3.2).

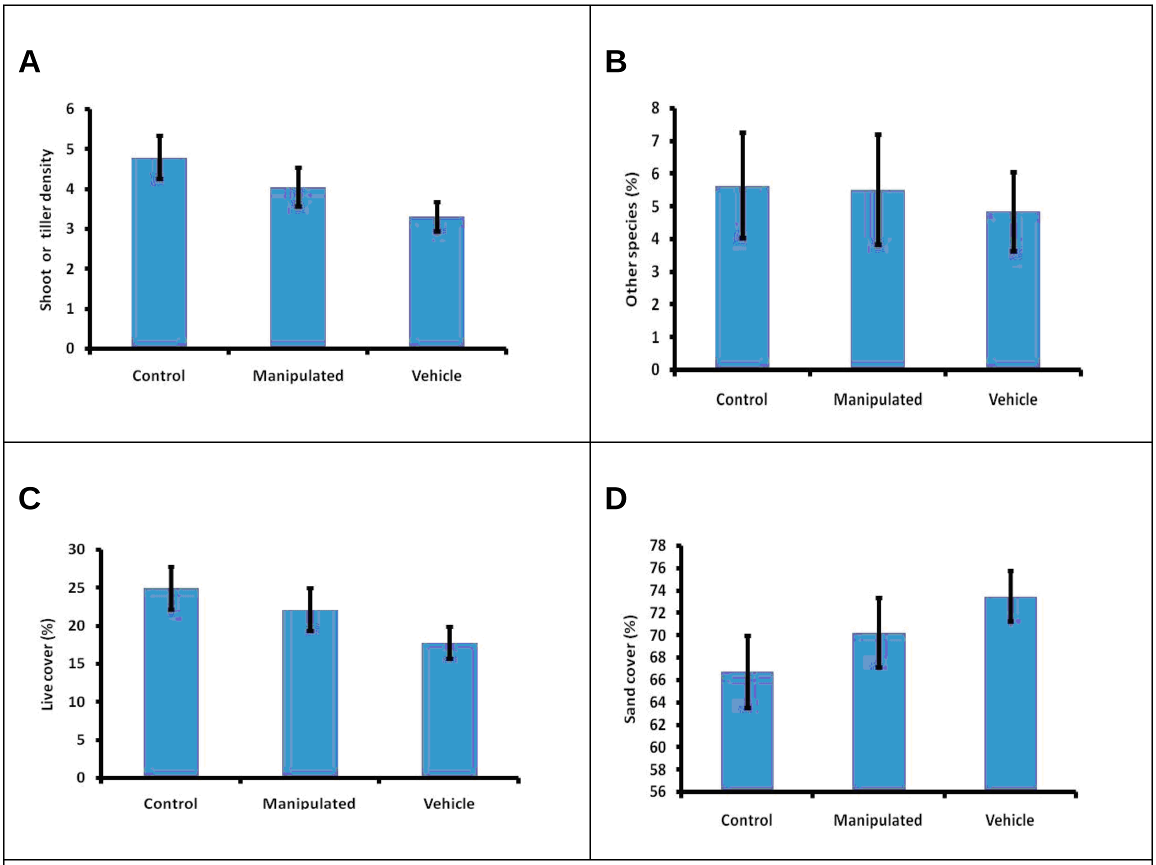
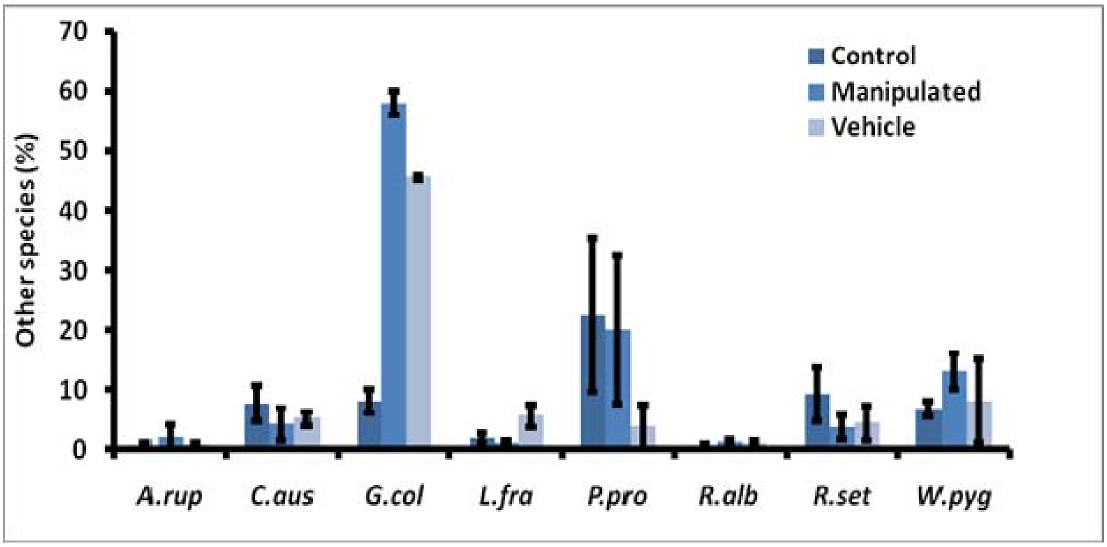


Figure 3.8 Comparing treatments, **A** & **B** (from Table 3.5). **A:** Shoot tiller density for all eight species. **B**: The percentages of the "other species" variable for all eight species, **C** & **D** (from Table 3.2). **C:** The percentage of live vegetation cover using the 3 focal species. **D:** The percentage of sand cover using the 3 focal species. Bar ± Standard deviation

3.4.3.1 Species' interactions with treatments

Species also reacted differently to the treatments (Table 3.3). The tested variable "Other Species" showed for many of the species there was no significant difference between the three treatments. However *G. colensoi*, showed an increase of species' abundance of about 50% under the manipulated treatment when compared to the control. This percentage had dropped 15% for the vehicle treatment which was still significantly different to the control. The vehicle treatment of *L. fraseri* had 5% more species compared to the control. Similarly *W. pygmaea* also showed a significant difference in the manipulated treatment of a 5% increase compared to the control (P=0.001; Figure 3.9 A). Species also differed in their reaction to the variable sand. The percentage of sand remained stable for all three treatments of *A. rupestris*, decreases about 40% over the manipulated and vehicle treatments for *G. colensoi*, and increased for *R. setifolia* and *P. prostrata* by 10% and 20% respectively (P=0.052; Figure 3.9B). These differences futher illustrate the different reactions of the diffent species to the experiment.

A



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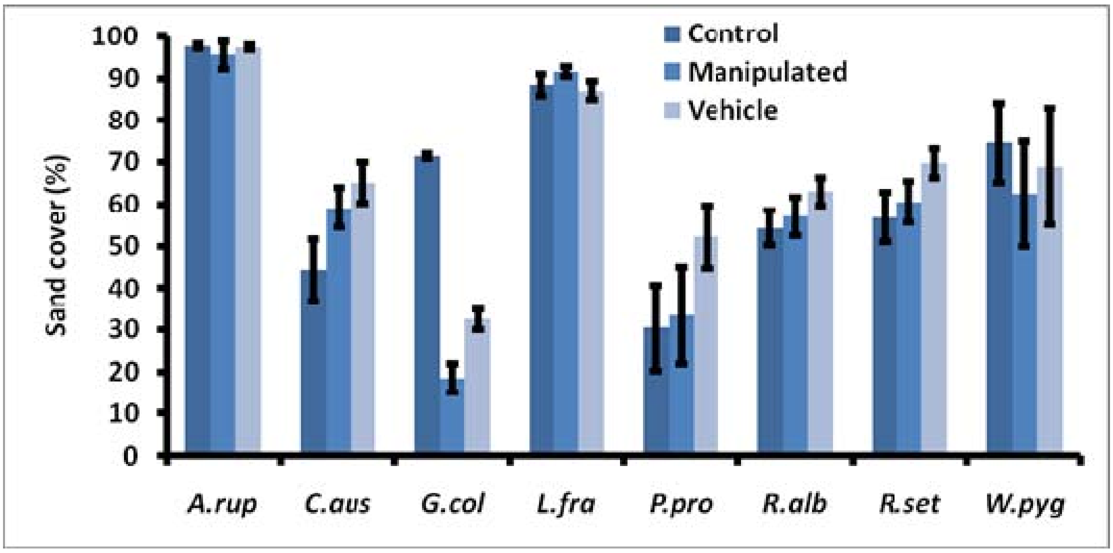


Figure 3.9 **A**: Comparing the differences in reactions of all species between treatments at all sites using the variable "other species". **B**: Comparing the differences in reactions of all species between treatments at all sites using the variable "percentage of sand." Bar ± Standard deviation

3.4.4 Time

There were also some significant differences between species when comparing variable changes between time 1 and time 2. The overall shoot or tiller density was decreased by an average of five counts over time (P=0.011; Figure 3.10).

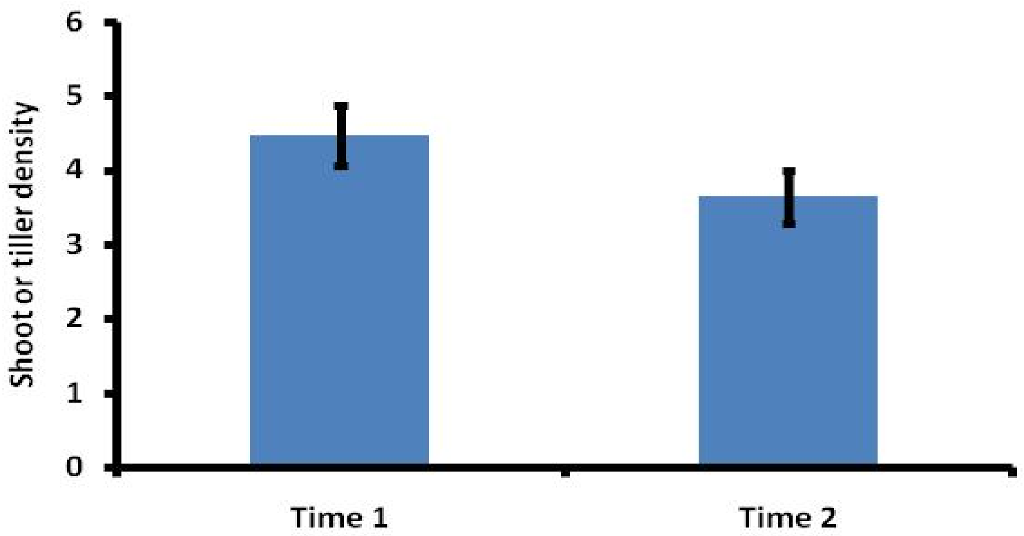


Figure 3.10 Differences in shoot or tiller density over time, taken from all 7 species measured for this variable over all three sites. Bar ± Standard deviation

There were also significant differences between species and time interactions for some variables. The shoot or tiller density had decreased by between 1 and 3 counts on average at time 2 (P=0.038; Figure 3.11), especially for *Carmichaelia australis* and *Pimelea prostrata*.

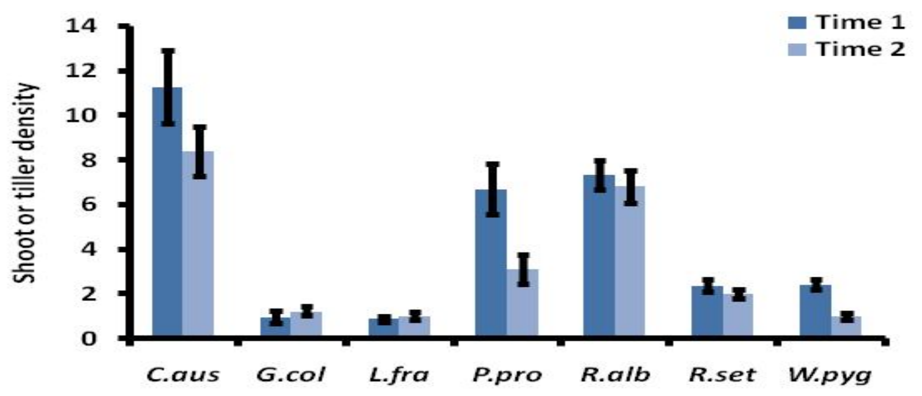


Figure 3.11 Difference in species' interaction over time using shoot and tiller density showing change between time 1 and 2. Bar ± Standard deviation

However, there were other significant results in the Site table (Table 3.2). The dead cover reduced over time by 1.5% (P=0.002; Figure 3.12), while the percent of litter increased over time by 1% (P=0.007; Figure 3.12).

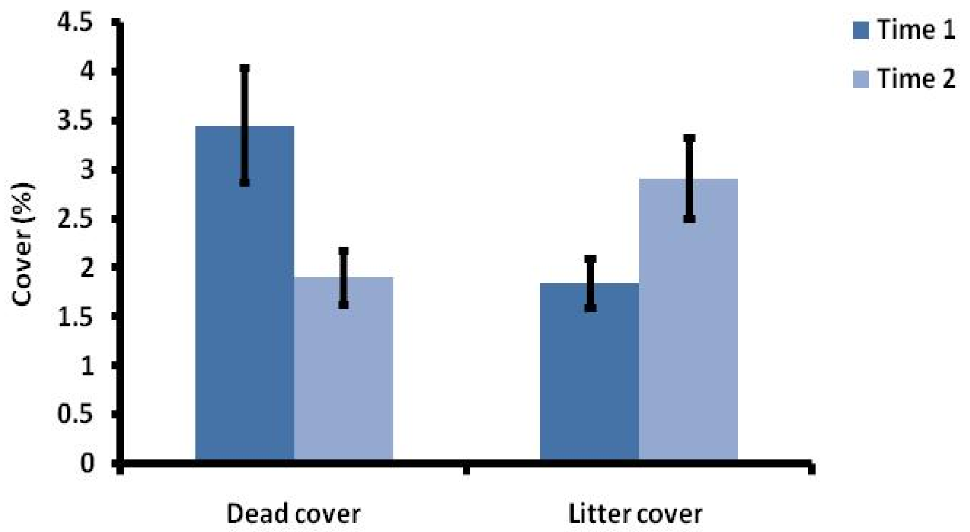


Figure 3.12 Differences between times from table 3.2. The variables percentage of dead cover and percentage of litter cover are used. Bar + Standard deviation

3.4.4.1 Time length of experimental process

The running time of the experiment may have had an impact on the results. There are far more significant results for the Pylon site which ran for 23 months compared to the Shooting Box site and the Army Corner site, that were set up for 15 months (Table 3.6, 3.7 and 3.8). Although the experiment ran for different lengths of time between the sites the lengths of their growing seasons were similar. However it still appears that the longer the experimental time the more significant the results, suggesting that the non-growing season may be important in responding to vehicle damage.

There were more significant values overall for the Pylon site (Table 3.6); this is observed most clearly when comparing the variables “Dead” and “Sand” between all three sites. Although there are significant values at the Army Corner and Shooting Box sites, there were no significant values for differences in treatment, or change over time (Table 3.7 and Table 3.8)

However at the Pylon site where the experiment ran for a longer time period, there were significant results for both how the treatments reacted over time for the Dead variable (P=0.035; Table 3.6) and the interaction betweeen species and treatments over this period (P=0.039; Table 3.6). There were non-significant results for differences in treatments and the interaction between species & treatment & time for the Shooting Box and Army Corner sites which had a lesser experimental time period.

Table 3.6 P values and categorical values of all four plant species, *R. albo-sericea*, *R. setifolia, L. fraseri, P. prostrata*, tested within the Pylon site. S/TD = Shoot or tiller density, S/TL = Shoot or tiller length, OSPP = Other species within the host plant P≤5% bold, P≤10% italics.

	Dependant variable							
SITE: **Pylon Site**	LIVE	DEAD	SAND	LITTER	OSPP	RADIUS	S/TD	S/TL
Species	**0.000**	**0.000**	**0.000**	0.184	**0.029**	**0.001**	*0.078*	**0.000**
Treatment	0.113	*0.077*	0.228	0.950	0.957	0.870	0.240	**0.038**
Time	0.327	**0.000**	0.484	0.990	0.347	0.702	0.795	0.571
Species x Treatment	0.960	**0.001**	0.513	0.885	0.248	0.947	0.982	0.153
Species x Time	0.798	**0.000**	0.992	**0.024**	0.550	0.565	0.490	0.275
Treatment x Time	0.749	**0.035**	0.982	0.177	0.846	0.928	0.907	0.542
Specie x Treat x Time	0.653	**0.039**	0.957	0.832	0.940	0.998	0.982	0.989
Degrees of Freedom	52	52	52	52	52	52	52	45
Error Mean Square	191.74	9.787	354.21	5.395	231.4	5099.5	33.98	169.3

Table 3.7 P values and categorical values of four plants are *R. albo-sericea*, *R. setifolia*, *L. fraseri*, *W. pygmaea* tested within the Shooting Box site. S/TD = Shoot or tiller density, S/TL = Shoot or tiller length, OSPP = Other species within the host plant P≤5% bold, P≤10% italic

	Dependant variable							
SITE: **Shooting Box Site**	LIVE	DEAD	SAND	LITTER	OSPP	RADIUS	STD	STL
Species	**0.000**	**0.002**	**0.000**	**0.040**	0.418	**0.000**	**0.000**	**0.000**
Treatment	0.110	0.237	0.268	0.921	0.375	0.850	0.107	**0.000**
Time	0.237	0.260	0.142	*0.052*	0.982	0.506	0.069	*0.089*
Species x Treatment	0.275	0.303	0.343	0.513	0.641	0.974	**0.046**	**0.000**
Species x Time	**0.044**	0.658	**0.042**	0.329	0.790	0.933	0.354	0.447
Treatment x Time	0.661	0.558	0.573	0.660	0.612	0.916	0.678	0.411
Species x Treat x Time	0.795	0.131	0.929	0.242	0.979	0.985	0.671	0.413
Degrees of Freedom	24	24	24	24	24	24	24	24
Error Mean Square	6885.7	245.3	6805.9	423.5	244.9	113665.3.5	59.6	1813.0

Table 3.8 P values and categorical values of five plants are *R. albo-sericea*, *R. setifolia*, *L. fraseri*, *G. colensoi, C. australis* tested within the Army Corner site. S/TD = Shoot or tiller density, S/TL = Shoot or tiller length, OSPP = Other species within the host plant P≤5% Bold, P≤10% italics

	Dependant variable							
SITE: **Army Corner Site**	LIVE	DEAD	SAND	LITTER	OSPP	RADIUS	STD	STL
Species	**0.000**	**0.000**	**0.000**	0.321	**0.000**	**0.000**	**0.000**	**0.000**
Treatment	0.318	0.582	0.203	0.507	*0.095*	0.837	0.297	0.893
Time	0.380	0.190	0.123	0.396	0.312	0.438	0.318	0.238
Species x Treatment	**0.021**	0.207	**0.000**	0.764	**0.000**	*0.083*	0.120	0.986
Species x Time	0.152	0.198	0.545	0.859	0.864	**0.020**	0.177	0.682
Treatment x Time	0.488	0.797	0.963	0.270	0.739	0.857	0.557	0.787
Species x Treatment x Time	0.979	0.838	1.000	0.523	0.997	0.949	0.989	1.000
Degrees Of Freedom	49	49	49	49	49	49	49	49
Error Mean Square	70.944	2.753	169.67	5.134	72.95	1148.38	5.221	190.61

There are a greater number of significant responses over time at the Pylon site with regards to time, than the Shooting Box and the Army Corner sites. This may reflect the time of the experimental set up.

Pylon differences in time

At the Pylon site there was 3% less dead vegetation cover at time 2, although the change over-time appeared stable, it is significantly significant (P<0.001; Figure 3.13)

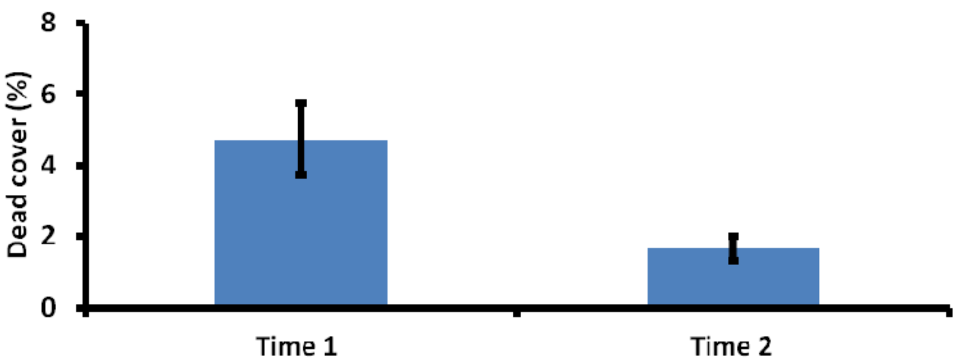


Figure 3.13 Comparing the percentage of dead cover between time 1 and time 2 at the Pylon site. Bar ± Standard deviation

Pylon species and time interaction

The dead cover reduced significantly for *L. fraseri* and *R. setifolia*. However there was no significant difference in the amount of dead material for *P. prostrata* (P<0.001; Figure 3.14A). The Litter had decreased over time by 1% for *L. fraseri* and 2% for *P. prostrata* but increased by 1% and 1.5% for *R. setifolia* and *R. albo-sericea* respectively (P<0.001; Figure 3.14B).

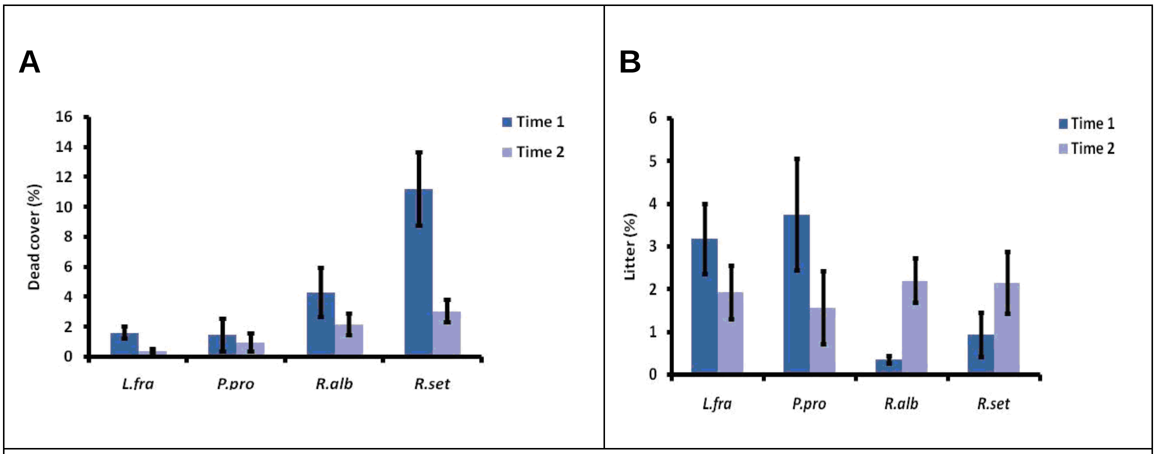


Figure 3.14 At the Pylon site. **A** Comparing the percentage of dead cover between species and time at the Pylon site. **B** Comparing the percentage of litter between species and time. Bar ⊥ Standard deviation

Pylon treatment, time interaction

The dead cover reduced significantly with the manipulated treatment by about 5% and the vehicle treatment by 3%. The reduction in cover was not significant in the control treatment (P=0.035; Figure 3.15).

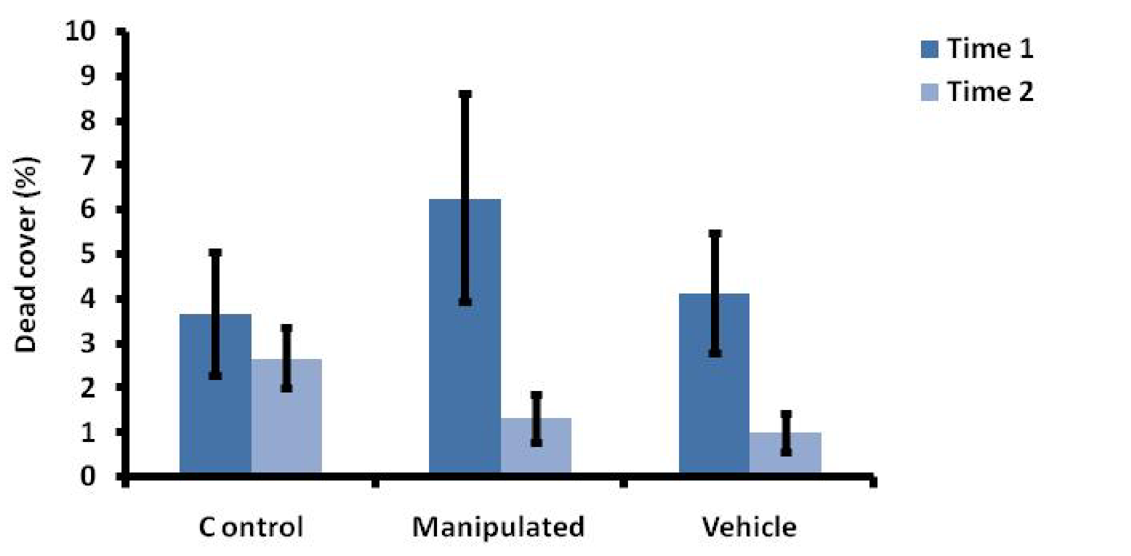


Figure 3.15 At the Pylon site: Comparing the percent of dead cover between treatments over time. Dead cover is the dead material still attached to the vegetation. Bar ± Standard deviation

Shooting Box species by time interaction

The percentage of live cover of all the species, with the exception of *R. setifolia,* increased over time. *R. albo-sericea* had the most substantial increase of 25% (P=0.044; Figure 3.16A). The percentage of sand cover reduced over time for all species with the exception of *R. setifolia*. *R. albo-sericea* had the largest reduction about 25% (P=0.042; Figure 3.16B).

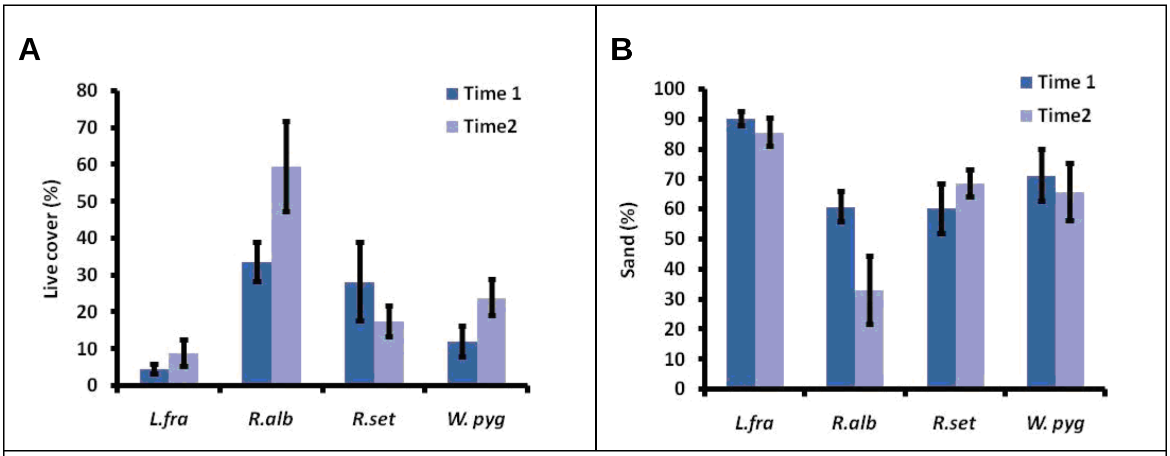


Figure 3.16 At the Shooting Box site **A:** Comparing the species' reaction using the percentage of live vegetation over time **B:** Comparing the species' reaction using the percentage of sand cover over time. Bar ± Standard deviation

Army corner species time interaction

The radius remained relatively unchanged for many of the species over time, but decreased by about 50mm for *R. setifolia* (P= 0.020; Figure 3.17).

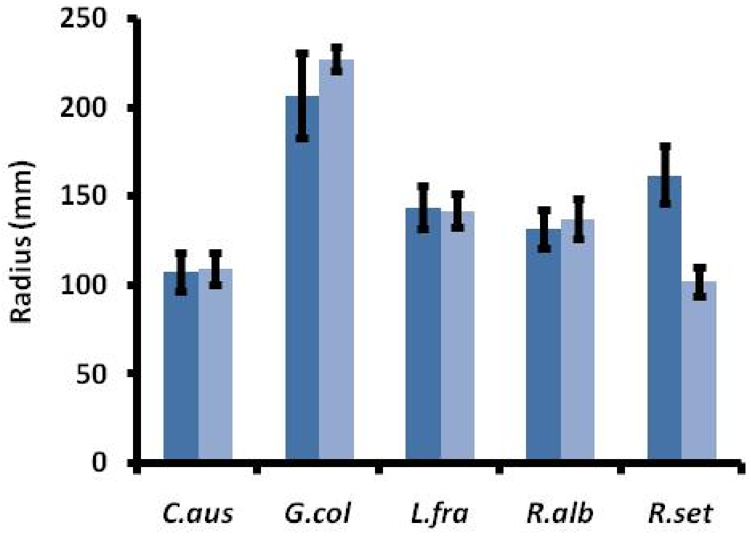


Figure 3.17 At the Army Corner: The change in Radii between species over time. Bar I Standard deviation

3.4.5 Species' abundance under host plants

There were significant differences between the species' abundance under the "host" species tested and how the species' abundance altered when the focal species had been run over by a vehicle (Table 3.9).

Table 3.9 The difference in residence plant abundance under eight species of host plants: *A. rupestris*, *C. australis, G. colensoi, L. fraseri, P. prostrata R. albo-sericea*, *R. setifolia*, *W. pygmaea*, between tyre treatments and control treatments. P≤5% bold, Tyre treatment is the combined results of the vehicle treatments and the control is all the manipulated treatments before they were run over and the control.

	D.F	P value
Species	7	**0.000**
Tyres	1	**0.012**
Species x Tyres	7	**0.015**
Error	92	

There was 0.4% greater species' richness growing under and around plants that have been run over (P= 0.012; Figure 3.18).

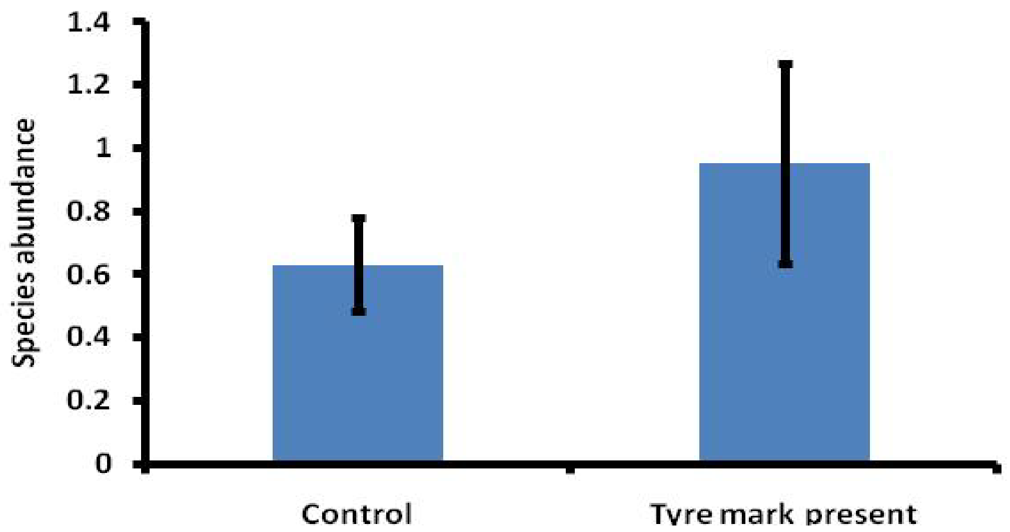


Figure 3.18 The difference in species abundance between control (no tyre marks treatments) and tyred areas. Bar ± Standard deviation species/50cm^2

The host species react differently to being run over in regard to the change in species' abundance. Most of the species had an increase in species' abundance after being run over. *C. australis* had the most significant change; species' abundance increased 5 times under plants that had been run over compared to those that had not been run over. There is also a significant difference in the species' abundance of the species *P. prostrata*, where species' abundance reduced by 50% in the plants that had been run over (P<0.001; Figure 3.19).

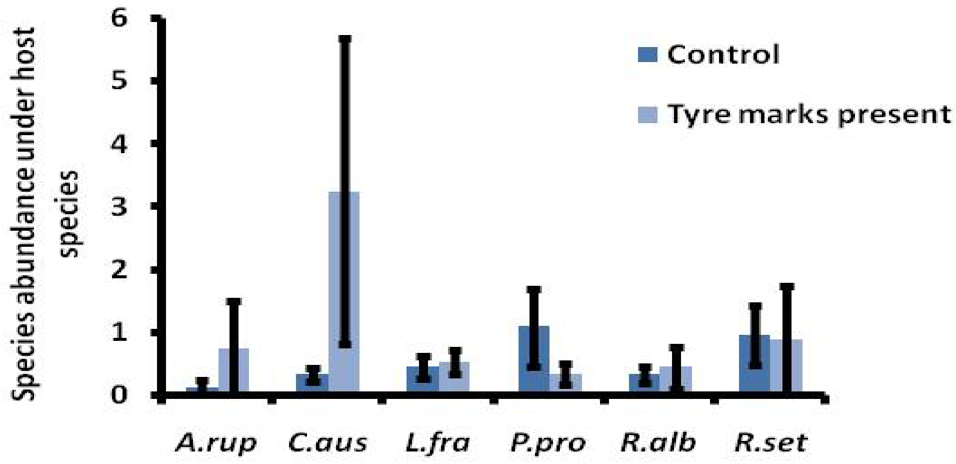


Figure 3.19 The difference of species' diversity under each host species between the control (non tyred) and tyred treatments. Bar ± Standard deviation

3.4.6 Micro-topography

Although I was interested in the tyre by time interaction here, the entire table is presented for completeness. Note that the micro-topography results also show significant differences between sites and species P<0.001 (Table 3.10).

As I had yet to learn that there would be different reactions between sites, I tested this experiment, using the sites as replicates. I found that even with a test for change in micro-topography there are site differences (P<0.001, Table 3.10).

Table 3.10 Differences in Micro-topography, at the three sites, Pylon, Shooting Box, and Army Corner, over two times, before and after being run over, and comparing substrates with and without tyre marks. P≤.0.005 bold.

	D.F	P value
Site	2	**0.000**
Species	2	**0.000**
Time	1	**0.004**
Tyres	1	**0.000**
Site x Species	4	**0.000**
Site x Time	2	0.797
Site x Tyre	2	**0.000**
Species x Time	2	0.926
Species x Tyres	2	**0.000**
Time x Tyre	1	**0.003**
Site x Species x Time	4	0.979
Site x Species xTyre	4	**0.000**
Site x Time x Tyre	2	0.273
Species x Time xTyre	2	0.755
Site x Species x Time xTyre	4	0.944

As I used the sites to test the changes in micro-topography between the three treatments of vehicle (previously ran over), manipulated, (using a weighted tyre to roll over the plant, and the control for comparison. I used the three plants found at all three sites, *Raoulia albo-sericea, Rytidosperma setifolia*, *Leucopogon fraseri*. There were significant differences between species reaction and also significant differences in micro-topography depths between treatments. Although there seems to be ~ 4mm difference in micro-topography between *R. setifolia* and *R. albo-sericea* and only 2mm difference between *R. albo-sericea* and *L. fraseri*, this is statistically significant. The differences could be due to sand catchment and deposition due to the plants' growth habits (Figure 3.20)

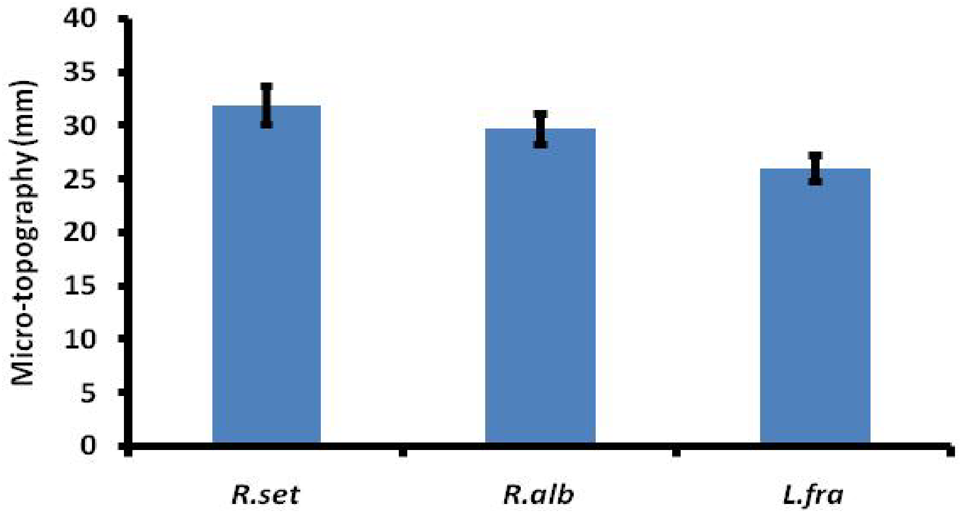


Figure 3.20 The difference in micro-topography when comparing Raoulia albo-sericea, Rytidosperma setifolia, Leucopogon fraseri, using all three sites. Bar ± Standard deviation.

The substrate is compacted around each species after being run over. The substrate around *R. setifolia* compressed ~ 10mm, while the substrate around *R. albo-sericea* was compacted ~14mm, *L. fraseri* was least affected with only ~2mm compaction (Figure 3.21).

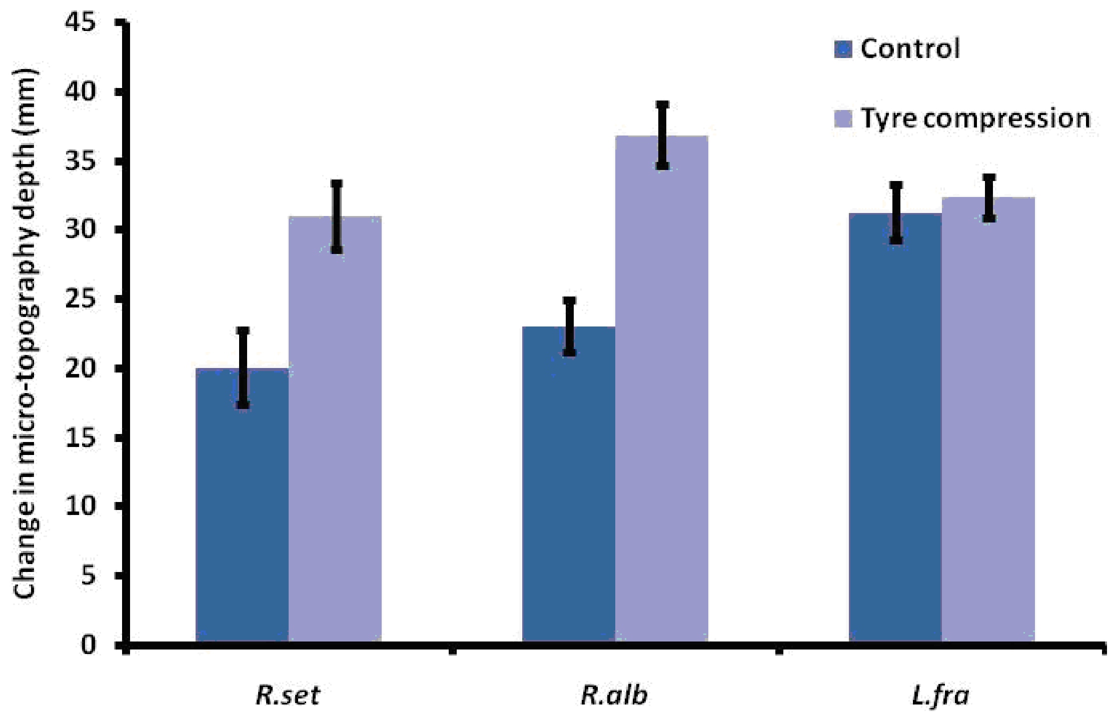


Figure 3.21The difference in the change of micro-topography before and after tyre manipulation comparing the three plants from all sites: *Raoulia albo-sericea, Rytidosperma setifolia*, *Leucopogon fraseri*. Bar ± Standard deviation

The damage done to the substrates' micro-topography when a vehicle drives over it is instant (P= 0.003; Table 3.9). There is ~ 11mm difference between the control and the substrate compressed under the tyres (P=0.003; Figure 3.22). The substrate on either side of the tyre indentation, which has not been run over has had a small increase in substrate height compared to the control.

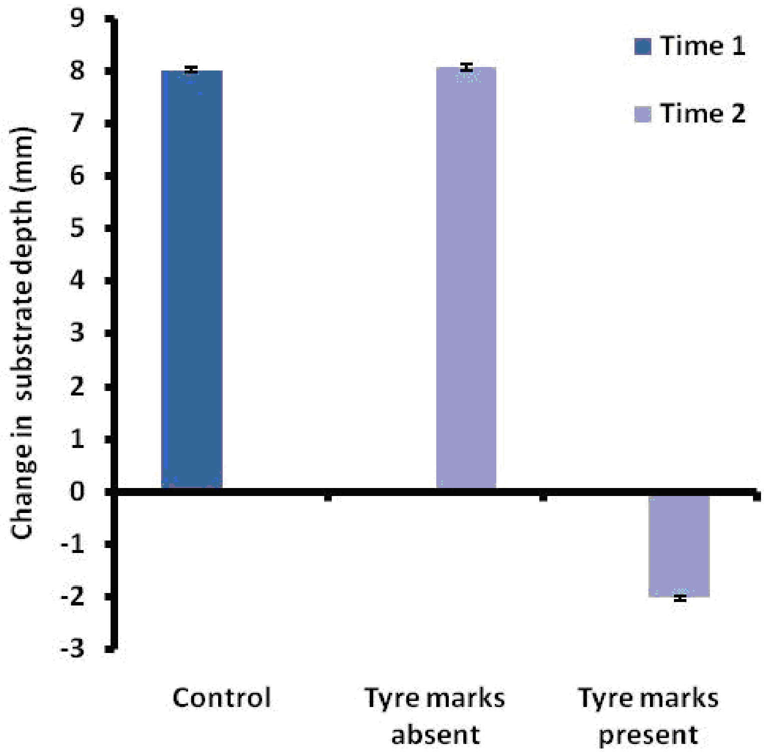
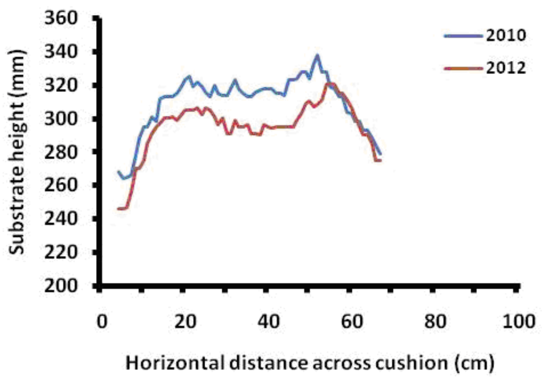


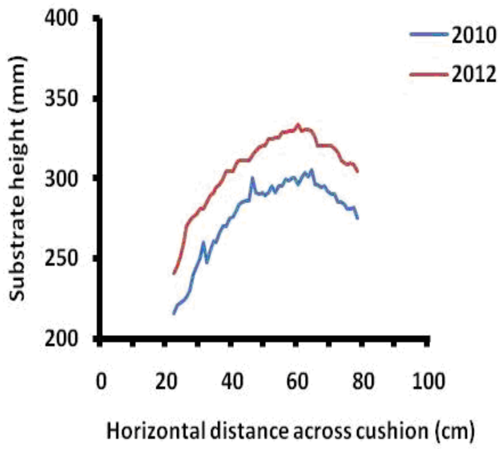
Figure 3.22 The change in micro-topography depth between the control (untouched substrate) at time 1 and substrate at time 2 after the tyre rolled over the substrate (tyre marks present) and the substrate on either side of the tyre marks (tyre marks absent). Bar ± Standard deviation.

Immediate damage occurs once a tyre has passed over the substrate. The substrate is broken and compressed, and over time the area erodes which can continue long after the original damage is done. The difference in treatments is significant (P<0.001; Appendix 3.8.2). The vehicle treatment showed signs of erosion (Figure 3.23A), the control showed signs of deposition (Figure 3.23B), and the manipulated showed initial signs of substrate damage, followed by erosion (Figure 3.23C). The movement of the substrate between being run over and the end of the experiment measurement is ~37 mm. Paradoxically the amount of deposition is similar ~40mm. There were also significant differences between sites (P<0.001) and species (P<0.001) (Appendix 3.8).

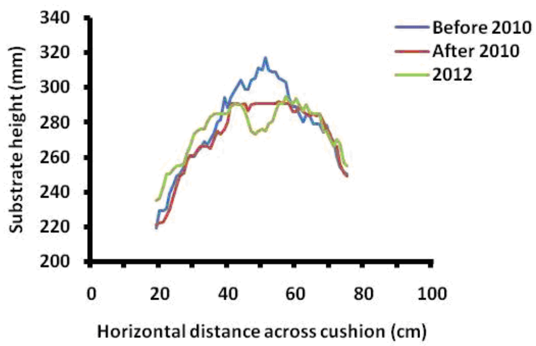
A



B



C



Cushion topography

Three treatments of *R. albo-sericea* from Shooting Box site:

Vehicle treatment shows signs of erosion over 15 months.
Control shows deposition over 15 months.

Manipulated treatment shows initial flattening after being compressed by a tyre followed by topography decrease (erosion) over the following 15 months.

Figure 3.23 Depiction of the substrate change to the micro topography over time with each treatment using *R. albo-sericea* at the Shooting Box site. A: The vehicle treatment, B: the control, C: the manipulated treatment. The blue line, January 2010 measurement was the topography at the beginning of the experiment. The “After 2010” line “C” shows the immediate change in topography after having a tyre pushed over it. The 2012 measurement was taken April 2012, at the end of the experiment.

3.5 Discussion

Three of the eight species were used to test the difference of a number of variables between the three sites, due to these three species being the species found at all three sites. There were considerable differences between sites with regard to the plant traits measured. For example, the percentage of live vegetation of *R. albo-sericea* was ~ 5 percent less at the Army Corner site compared to the other two sites, while there was a greater percentage of litter by ~ 2 percent at the Shooting Box site compared to the other two sites. These variances in site differences prevent extrapolation throughout the desert. However, this also indicates that different areas in the desert create different micro-habitats and plants respond differently within these areas. Vetaas (1992) investigated micro-site effects of trees and shrubs in dry savannas, and found that something as simple as the tree canopies modify the microclimate by interception of solar radiation and rainfall; this influenced the species' composition, and community diversity in his study. This suggests that what I interpreted as an open arid landscape is much more complex, and differences in micro-climates could be due to any number of biotic and abiotic features, such as sand dunes, tar-seal roads or periodic snowmelt river systems.

This information on spatial differences across a desert can be used in a positive way when looking at potential areas for restoration or protection of a particular plant species that does better in one area of the desert compared to another. Measurements of particular plant traits have been compared in different micro-habitats, using aspect and elevation gradients. Ackerly *et al.* (2002), found differences in leaf area at varying gradients and aspects. Murphy *et al*. (2012) also found differences in plant sizes of the same species; these vegetation patterns appear to be driven by rainfall and the stability of the fine, even-sized sand, not by altitude, suggesting that there are many factors that drive possible differences in plant size variation. Research has also been carried out on seedling survival and suitable microhabitat sites by Aerts *et al.* (2007). They concluded that microhabitats have significant effects on seedling survival, and in their study on restoration suggested that seedlings do better within certain microhabitats than others.

The species used in this experiment comprised of herbs, grasses, legumes, cushions, and woody shrubs. All eight species from all sites were compared, and showed significant differences to each other, including the two woody species *G. colensoi* and *P. prostrata*, indicating that the Desert species tested are different to each other. This result is not surprising, as the species used were from different genera with different growth forms and habits. *R. setifolia* has long tillers, being a tussock, so the shoot length would be longer for this species than what was measured for any other species; likewise the percentage of cover of live vegetation for *A. rupestris* is less than other species as it is only a small moss ball that sparsely populates small rocks or sandy substrates. However as different species, such as woody plants and herbaceous species cohabit in a particular area, thus creating a dynamic co-existence involving competitive interaction and complimentary processes (Vetaas 1992); it indicates that many species may be needed to produce a productive ecosystem and all are equally important. As with the differences in sites, we cannot extrapolate data to other species, but have a better understanding of how different species react to a crisis in arid environments.

As I had expected, there were significant differences among treatments. Even though species reacted differently to the treatments there were overall trends when comparing variables by treatments, i.e., shoot or tiller density, “other species” and percent of live material all showed a decreasing trend between the control and the vehicle treatments. The opposite trend was observed in the percentage of sand measured, as there was less sand at the control and more in the vehicle treatment where plant material had died back exposing more sand. There was also a reduction in dead cover percentage between the treatments and over time. There was less dead cover attached to the plant in the vehicle treatment compared to the control; a possible explanation for this is that dead cover is reduced because it becomes detached and blows away at a faster rate than it naturally would.

Although these treatment results looked as though vehicles can cause damage to plants, as anything ecological goes, it is complicated; the species reacted differently to the treatments. The sand cover of *R. setifolia,* for example, was greater in the vehicle treatment and lower in the control treatment as I would expect, as when the tussock was run over, it visually flattened out, and sand collected in the space. In contrast, some species such as *G. colensoi* had a greater percentage of sand in the control compared to the vehicle treatment, contrary to what I expected. Vollmer *et al.* (1976) found differences in plants' reaction to treatments; they pointed out in their experiment that one response of shrubs damaged by vehicles was to sprout from the base, which was not seen in the control or in any un-driven part of their test area. I did not see any statistically significant evidence of increased live vegetation in the woody shrubs after being run over by a vehicle in this study.

Some species are more vulnerable than others when run over by vehicles (Sun & Liddle 1993, Cole 1995, Pickering *et al.* 2010); woody species are less resistant than herbaceous plants, and intolerant compared to prostrate grasses and tussocks (Sun & Liddle 1993, Cole 1995b, Whinam & Chilcott 1999). I also found evidence that vehicle damage to vegetation varied significantly among species and different species were affected by different tested variables. Likewise Liddle & Greig-Smith (1975) noted that damage to shoots by vehicles was detrimental to plants when comparing vehicles driving over them to their control, both results suggesting that vehicles do detrimental damage to grasses. I also found in this study that *Rytidosperma setifolia*, a tussock, *and Raoulia albo-sericea,* a cushion, were more vulnerable to vehicle treatments than the other plants tested. *R. setifolia* showed a larger increase in sand in the vehicle treatment, compared to *R. albo-sericea, L. fraseri* (Figure 3.16b), and *R. albo-sericea* showed a deeper impact mark from tyres than *L. fraseri* (Figure 3.21). Here I have illustrated how differently species can react to the different variables tested and treatments, and how designing the experiment this way has allowed insight into how the different variables can be integrated.

At the initial set up we counted the number of species that were growing within the host plants' testable area. Annual plants in the process of germination are so sensitive that a single vehicle pass can destroy them and even mature plants are up-rooted and crushed at very low levels of Off Road Vehicle use (Wilshire 1983). Plants in the desert often have seedlings growing close to or within them; the host plants are often referred to as nurse plants (Flores & Jurado 2003, Gomez-Aparicio 2004). Seedling survival under nurse plants can more than double in comparison to open micro sites in arid landscapes (Gomez-Aparicio 2004).

R. albo-sericea is considered a nurse or facilitation plant, assisting in the restoration of other desert plants (Cockayne 1912), having an important role in its environment of creating micro habitats for seed germination*.* It is also one species that appears to be exposed and susceptible to the effect of vehicle movement. In my study I found a significant increase in species' abundance under most plants that have been run over. Possible reasons for this could be open sites, seed dispersal from tyres, where seed that has been picked up from other plants in the desert or from further afield has been deposited at the plant as it was being run over.

G. colensoi is a scrubby hardy bush type plant. It is possible that the woody limbs could have scraped the seeds off passing tyres, or the shrub has had limbs broken off allowing in resources, such as light, for the seeds to germinate. The woody shrubs were the most likely species to show an increase in species' abundance. It had more "other species" growing under the host plant in the vehicle treatment compared to the control, while *R. setifolia* had fewer. Hence, the reason for less sand under the vehicle treatment of *G. colensoi* could be due to the increase in other species growing in that site, or squashed, flattened stems after vehicle passage. The grasses and herbs had little change, and resource release is another possibility, as light is able to penetrate through the broken gaps of the damaged plant initiating the germination process. Whinam & Chilcott (1999) found that the shrubs break more after trampling than grasses or herbs, suggesting that it is plausible that the limbs of *G. colensoi* could have broken allowing resources to become available. This is plausible as the radius of *G. colensoi* is larger at time 2 (Figure 3.17).

More work would have to be done to determine why it appears that more seeds are deposited under the run over plants and follow these plants on through to maturity to observe if this is beneficial or not as a way to increase plants' biodiversity and abundance within the desert ecosystem and observe the fate of the plant that was run over.

Comparing plants between time 1 and 2 showed some significant growth differences. The overall shoot or tiller density decreased over time, as did the percentage of dead vegetation cover, but litter cover increased over time. A possible explanation for these results once again depends on the type of vegetation. Some plants lose dead vegetation, as it is removed from the parental plant by natural forces, wind etc. Other vegetation holds on and traps the dead plant material, increasing the litter cover. Hence the reduction in dead plant material is because the dead vegetation has either fallen off the plant and blown away in which case it cannot be recorded, or the dead material has fallen off the plant, become trapped as litter, increasing the litter percentage over time (Figure 3.12). No significant difference in live vegetation over time, as I found, could have more to do with natural growth rates being slow, but unnatural death being high (faster results).

Once again there was a lot of variation between species' growth over time. Shoot or tiller density decreased for *P. prostrata,* while there was little change in this variable for *L. fraseri and G. colensoi.* The shoot or tiller density did not show any significant sign of increase for any species between time one and time two.

With regard to differences between time 1 and time 2, many of the significant results were produced from the Pylon site species*, R. albo-sericea, L. fraseri, R. setifolia* and *P. Prostrate*. This site had been set up 8 months before the Shooting Box and the Army Corner sites. There appeared to be more significant results over time, suggesting that damage is not instantaneous, but takes a while for damage to show. Although the experimental periods were different lengths, (8 months different), the plants had very similar growing seasons, there was ~ 1 or 2 months less growing time for the Army Corner and the Shooting Box sites. Since the growing seasons were similar, it is possible that the differences in change could be the result of when, throughout the growing season, the damage was done to the vegetation. There are papers that suggest the timing of the damage can make a difference to the plants' ability to cope with damage stress (Rowley 1970; Pickering *et al.* 2010). The Pylon site was set up in April. This was just before the dormancy of winter and the broken plants may not have had time to repair damage done to them before the onset of winter. The Army Corner and Shooting Box sites were set up in November or December and had one or two less growing months than the Pylon site, and produced very few significant results. It is possible that the plants damaged in summer may have used energy to repair damage done by vehicles and then recovered through the dormant winter period, so results do not show as significant for dead, as it has been repaired, or live as there has been no extra growth, as the plants traded off growth for repair. Other experiments on the timing of vegetation damage support this theory. An experiment on snow tussock, in Otago, found that for the snow tussock *Chionochloa rigida,* tiller and flowering responses differed when comparing the seasonal time they were burnt due to interactions of the carbohydrate storage with the growing season (Rowley 1970).

According to Pickering *et al.* (2010) the resistance and resilience of vegetation can vary seasonally, affecting the intensity of damage that may occur from a particular activity**.** The lack of significant results regarding treatment x time interactions could be due to the manipulation treatment lacking enough experimental time for plant growth, as plant growth is slower in arid environments (Noy-Meir 1973). It is possible that the manipulated treatment was not as aggressive on the plants as physically being run over by a vehicle. Maybe there was not enough torque to pull, rip and dislodge the plant roots, or maybe 6 passes with a tyre was just not sufficient to replicate a vehicle or I may have even created a different type of damage. It is also possible that the sample sizes might not be large enough, as individual plants react differently to tyre manipulation, so small changes within the species were not enough to statistically evaluate.

The site x species interaction was also significant suggesting that to achieve proper testing I should test the variable differences, and plant changes between time 1and time 2 using separate site and species. As already stated this is not a viable option in this experiment as once the experiment is separated down into sites and species the sample sizes are too small (N=1-3) for each treatment at each species at each site.

Erosion and compaction can lead to habitat fragmentation reducing the size of species' populations, and increases their isolation (Rathcke & Jules 1993). Habitat destruction and fragmentation are collectively the major cause of species' extinctions (Wilcove *et al*. 1998).

This study found that when a vehicle runs across a barren desert substrate the micro-topography change was instant. There was approximately 11mm difference between the substrate before and after it was run over, compared to no change in substrate where the substrate was not run over (Figure 3.22). Substrate changes when pressure is applied to the substrate. The changes consist of both substrate compaction and substrate breakage (Hegarty & Royle 1978, Priskin 2003, Affleck 2005). When the micro-topography is broken, wind can shear away at the larger surface area of substrate, increasing erosion. Soil compaction can create changes in hydrology and can prevent seedling emergence. As time passed I found that the micro-topography continued to change. The vehicle and manipulated treatment continued to erode (Figure 3.23) 37mm of substrate was removed from the tyre mark over a 15 month period. The control treatment built up sand deposits catching the sand and the nutrients that were attached, suggesting in absence of vehicle passes, a plant continues to accumulate sand, and/or grow. However when undamaged the erosion is negligible, and sand trap-ment or deposition which occurs naturally, builds up sand. These pockets of built-up sand could alter the ecosystem by producing microhabitats, or shelters from sun, heat or wind, encouraging seedling emergence, but more research would have to be done on this.

3.6 Conclusion

Vehicles damage plants although the results of the damage might not been seen for a long period of time after the initial impact. Different species react differently to treatments probably due to their growth habits. Coupled with the slow growth rates of plants it can be hard to determine plants' reactions to treatments. For these reasons testing plants for resistance to vehicle damage needs many variables to give clues on what part of the plant is affected. Some species are more resilient to vehicle damage than others; these species are the species that could persist within the environment (Pickering *et al.* 2010). Other species could become locally extinct, reducing plant diversity. The loss of less resistant species can result in a reduction of other specific fauna that rely on these plants, further lowering overall diversity affecting the entire ecosystem.

Vehicle tyre tracks change the topography of substrates, the changes consisting of both substrate compaction and substrate breakage. This can lead to erosion, loss of important organic material, and aeolian sand movement, which had the potential to bury plants, further reducing ecosystem functioning and ecosystem loss.

Vehicle passage does appear to increase species' diversity, within the host plant. However the long term status of these plants has not yet been tested. It is possible that these germinated seedlings have a short life expectancy as aeolian sands could bury the seedlings. We know that vehicles do increase erosion, and without fully understanding the role of sand deposition we have no way of knowing the benefits this has on the ecosystem. The benefits of deposition should be fully explored.

The results show that some sites appear to protect species by providing better niches for vegetation protection; certain plant species were larger at some sites than others. These sites could be used to protect species and help prevent species from localised extinction.

3.7 References

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3.8 Appendices

3.8.1 P values for the immediate change in micro topography between sites, and species.

Categorical values encountered during processing are:

Sites (3 levels) Army Corner, Pylon, Shooting Box
Species (3 levels) Leucopogon, Raoulia, Rytidispema
Time (2 levels) Before tyre treatment (1), After being run over with tyre (2)
Tyre (2 levels) No tyre impression, Tyre impression

Dep Var: MICROTOPGRAPHY N: 2301 Multiple R: 0.490 Squared multiple R: 0.240

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SITE	314883.472	1	57441.737	128.45	**0.000**
SPECIES	21800.06	2	10900.03	8.893	0.000
TIME	9925.557	1	9925.55	8.098	0.004
TYRE	33787.021	1	33787.02	27.566	0.000
SITE*SPECIES	129533.253	4	32383.31	26.421	0.000
SITE*TIME	557.288	2	278.644	0.227	0.797
SITE*TYRE	25308.048	2	12654.024	10.324	0.000
SPECIES*TIME	187.816	2	93.90	0.077	0.926
SPECIES*TYRE	19903.959	2	9951.979	8.120	0.000
TIME*TYRE	10958.526	1	10958.526	8.941	0.003
SITE*SPECIES*TIME	541.955	4	135.48	0.111	0.979
SITE*SPECIES*TYRE	26674.879	4	6668.720	5.441	0.000
SITE*TIME*TYRE	3181.905	2	1590.95	1.298	0.273
SPECIES*TIME*TYRE	687.419	2	343.71	0.280	0.755
SITE*SPECIES*TIME*TYRE	929.839	4	232.460	0.190	0.944
Error	2776174.474	2265	1225.684		

3.8.2 P values for the change in micro topography between sites, species and three treatments.

Categorical values encountered during processing are:

Sites	(3 levels)	Army Corner, Pylon, Shooting Box
Species	(3 levels)	Leucopogon, Raoulia, Rytidispema
Time	(2 levels)	Start of experiment (t1) end of experiment (t2)
Treatment	(3 levels)	Control, Manipulated, Vehicle

Dep Var: MEASUREMENT N: 5688 Multiple R: 0.564 Squared multiple R: 0.318

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SITE	973449.036	2	486724.518	396.260	0.000
SPECIES	51102.451	2	25551.226	20.802	0.000
TIME	120745.571	1	120745.571	98.303	0.000
TREATMENT	235493.331	2	117746.666	95.862	0.000
SITE$*SPECIES	165892.340	4	41473.085	33.765	0.000
SITE$*TIME	28831.856	2	14415.928	11.737	0.000
SITE$*TREATMENT	206965.573	4	51741.393	42.125	0.000
SPECIES$*TIME	9850.201	2	4925.101	4.010	0.018
SPECIES*TREATMENT	245318.598	4	61329.650	49.931	0.000
TIME*TREATMENT	12669.188	2	6334.594	5.157	0.006
SITE$*SPECIES*TIME	54743.435	4	13685.859	11.142	0.000
SITE$*SPECIES*TREATMENT	577574.481	8	72196.810	58.778	0.000
SITE$*TIME*TREATMENT	35763.874	4	8940.969	7.279	0.000
SPECIES$*TIME*TREATMENT	36832.720	4	9208.180	7.497	0.000
SITE$*SPECIES$*TIME*TREATMENT	44342.023	8	5542.753	4.513	0.000
Error	6920219.584	5634	1228.29		

Chapter 4

Erosion amplification; is it increased after substrate damage?

4.1 Abstract

Desert ecosystems are fragile and complex. Large areas of seemly bare substrates contain extremely fragile colonising biological organisms such as cyanobacteria, green algae, lichen and mosses, which have an important ecological role in soil stabilisation, and primary succession. Situated to a depth of ~3mm below the soils surface these micro-biotic crusts can be damaged through compression exposing a higher surface area to erosion from wind and rain.

The aim of this paper was to test if there were any differences in rates of erosion when comparing intact substrates with those that have been compressed by running a weighted tyre over the substrate. I tested both on pumice and bare sand, and on slopes of less than 5 degrees and flat land. I tested substrates that were both wet and dry before the onset of the tyre impact, and in three weather conditions, rain, wind and both rain and wind.

The findings supported the hypothesis that areas of substrate subjected to compression had significantly higher amounts of sediment movement compared to intact soil structures.

Damaged substrates had 2.2 times more substrate movement than intact substrates, while dry substrates were ~ twice as erodible as wet substrates. Bare ground that is wet is equally stable after wind for both broken and intact substrates; pumice after being wetted is equally stable after rain for both broken and intact substrate.

Vehicles running over a substrate can damage the crust and statistically increase erosion levels compared to an intact substrate, particularly in dry seasons.

KEYWORDS Wind, rain, crust, desert.

4.2 Introduction

The desert's ecosystem like any other ecosystem is complex (Polis 1991), non linear, and relationships are chaotic, rather than moving in one direction (Brown & Ernest 2002), and fragile (Vollmer *et al.* 1976). Biological soil crusts consist of cyanobacteria, green algae, lichens, and mosses (Belnap 2006). These crusts play an important ecological role in ground consolidation (Belnap & Large 2001) and stabilisation (Belnap & Gillette 1998). The organisms often have extremely slow biological colonization and growth rates (Belnap & Gillette 1997) but can extend by increasing in size and inhabiting open patches in discontinuous vascular plant vegetation. The slow growth rates are probably due to extreme temperatures, intense sun, high winds, limited moisture and the low fertility of the desert soils resulting in the natural recovery of a desert being very slow after disturbance (Bainbridge & Virginia 1990). Undisturbed, biological desert soil crusts are developed over hundreds or thousands of years and are often relatively stable (Lovich & Bainbridge 1999).

Crustal biomass is concentrated in the top 3mm of the soils, and a well-developed soil crust or desert pavement shields the soft, friable soil underneath from erosion by water (Wilshire & Nakata 1976) and wind (Belnap and Gillette 1998). The crust is very fragile; pressure applied to the crust can cause breakage and compaction altering topography (Figure 4.1), and creating other effects to the vegetation and ecosystem.

Once the crust is cracked from the force of impact the increased surface area creates larger, more accessible areas for the wind to shear sand particles from, the substrate surface strength lessens and the force of the wind more readily moves the surface increasing erosion occurrence. Soils disturbed by surface breakage are more noticeable in arid environments that develop such surface crusts (Belnap & Gillette 1997).

The Rangipo Desert ecosystem consists of open land and volcanic dunes, formed from raw acidic rock (Williams *et al.* 2007) scattered with sparsely placed vegetation. Micro-biotic crusts occur in almost all arid and semi arid ecosystems either colonizing bare soils after disturbance (Belnap 2006), or forming on raw substrates such as sand dunes (Karnieli & Tsoar 1995) and volcanic ash (Shields 1957).

Figure 4.1 Tyre marks on the Desert's surface showing the ability of vehicles to be able to both compact and break the substrate's surface changing the topography.

In desert ecosystems, where there is little organic matter or vegetation cover to protect soil surfaces, wind becomes a major erosive force (Belnap & Gillette 1997).

Sandblasting from wind can alter or destroy macro and micro vegetation elements. Wind can quickly remove the topsoil material, reducing seed quantity, Nitrogen (N) and Carbon (C) inputs from the soil, as well as exposing unprotected subsurface sediments to wind and water erosion. It only needs a small amount of surface loss to result in the loss of many organisms, reducing nutrients and site productivity (Belnap & Gillette 1998).

As well as displacement of vegetation, erosion can directly affect vegetation. The disturbance regimes and forces of erosion can affect vegetation at two extremes. Firstly there is an increased likelihood of roots becoming exposed; plants are unable to survive on eroding surfaces owing to desiccation of their root system (Maun

1994). Secondly large trees can become buried by an increase in aeolian sand movement (Figure 4.2) (*Pers ob.*). Aeolian winds also have the potential to fill in naturally occurring ditches and drains created through erosion by snowmelts, resulting in an altered landscape. While the vegetation may eventually recover from disturbances the protection afforded the desert pavement is, for all practical purposes, destroyed due to its slow rate of formation (Wilshire and Nakata 1976). Alternatively, along with a decrease in plant development there is a possibility of a shift in vegetation species from native plant communities to communities dominated by exotic species (Ayers 1994, Belnap & Gillette 1998, Lovich & Bainbridge 1999), following such disturbances.

The opposite of erosion is soil compaction. The pressure created causes the destruction of the soil crust's stabilizers. Compaction of soil structures can disrupt the adhesive bonds holding the substrate together (Lovich & Bainbridge 1999). Soil compaction occurs directly under the point of impact and can alter the soil by increasing bulk density, which can impede seedling emergence and survival. After compaction the porosity of the soil is decreased, resulting in a shortage of oxygen and changed water regime. Without the porous holes water penetration is prevented, increasing surface run off, and amplifying water borne erosion (Brainbridge & Virginia 1990; Kissling *et al.* 2009). Microbes may respond to these environmental stresses by changing their activity, growth or resource allocation (Schimel *et al.* 2007), potentially altering the production of the soil enzymes responsible for catalyzing Carbon, Nitrogen and Phosphorus cycling (Kissling *et al.* 2009). These enzymes play an important role in altering nutrients to a form more readily available for uptake by plants (Caldwell 2005).

Soil is compacted directly under the site of impact and the surface crust breaks around the edges of the compacted area. Hence both types of damage, can be simultaneously caused by passage of a vehicle. A combination of soil compaction and erosion can lend itself to a sorting of layered substrates; erosion from wind-blown dust infiltrates into loose, mutable sediment and contributes to the soils' structural development (Reheis 1999) and water erosion selectively removes the fine organic particles from the soil, leaving behind large particles and stones (Zuazo & Pleuezuelo 2008). When soils are compacted by external forces and this is followed by rain, a “slaking” of the soil aggregates results. Dispersion and change in orientation of the finer particles clog soil pores as these smaller particles are carried into larger pores by infiltrating water. All scenarios alter the soil surface and crust layers (Hegarty & Royal 1978), which can lead to physiological dysfunctions of plants such as reduced water uptake, a change in balances of growth hormone, and a decrease in the amount of photosynthesis. Seedling germination and growth is inhibited (Kozlowski 1999).

Humans and their activities are encroaching upon arid environments and altering the natural land cover (Gill, 1996). Anthropogenic activities increase susceptibility to wind erosion (Breed, 1999). Aeolian dust can also be harmful to humans, vegetation, and water bodies (Goudie, 1978), and sediment can harm traffic flow, fill in ditches, and decrease agricultural production (Bilbro & Fryrear 1994). Desert areas disturbed by human activities may take centuries to recover without active intervention.

Many authors have identified vehicle traffic as a main cause of crustal breakage and increased erosion. The aim of this section is to analysis the differences in substrate movement (erosion) between two substrate surfaces on the Rangipo Desert, sand and pumice, which have been identified as being driven over and compare it with areas that have not been driven on. Also I will identify any differences between driving on wet and dry substrates in three different weather conditions; rain, wind and the combination of both rain and wind within the lower altitudes of the Rangipo Desert, Tongariro National Park, New Zealand to see if erosion affects this area, possibly affecting vegetation.

Figure 4.2 Crowns of dead trees that have been partially buried by the erosion of substrate surface particles and the progression of burial as the sand accumulates around the trees.

4.3 Methods

Two different substrate types at Rangipo Desert that are typically run over by vehicles are pumice and sand. These two substrates were used to test erosion rates for this experiment. Bare substrate is classed as a sandy substrate without plants growing on it, and water or wind-blown pumice is situated on top of bare substrates. Each of six treatments compared the amount of substrate movement (erosion) between a damaged substrate that had a weighted tyre pushed over it, representing a vehicle transit, and an intact substrate that had no pressure applied to the testing area. The treatments consisted of running a tyre over a dry substrate then applying wind, running a tyre over a dry substrate then applying rain, running a tyre over a dry substrate and then applying wind and rain. These categories were then repeated for wet substrates. The differences in treatments were to help identify if weather variables had any influence on erosion rates, in relation to intact and broken substrates. Each of the treatments had a slightly different method of set up (detailed below) and testing. Each procedure was then repeated for the unbroken substrate by placing a stick into intact substrate and used as a reference to take measurements from. These methods were also repeated for pumice substrates.

1. **Dry substrate run over then wind applied**

A tyre was pushed over bare sand and a fine kebab stick was placed into the centre of the tyre print. The stick was measured from the top to the substrate surface. A box 41cm tall was placed 1.5 meters from the stick. A leaf blower (already going on idle) was placed on the box so the snout faced the stick. Left in a stationary position the blower was pushed to full throttle for 20 seconds, this equated to ~ 2 meters per second. The blower was turned off, and the stick was re-measured. The difference between the two measurements was the amount of erosion occurred.

2. **Dry substrate run over and watered**

A tyre was pushed over bare substrate and a fine kebab stick was placed into the centre of the tyre print. A 50cm X 50cm quadrat was placed over the stick so the stick was in the centre of the quadrat. The stick was measured. 1.5 litres of water was poured from a watering can evenly in a pattern into the quadrat. 1 minute was timed to allow the water soak in, and then the stick was re-measured. The difference in measurements was the amount of compaction of surface by water.

3. Dry substrate run over and water then wind applied

A tyre was pushed over bare substrate and a fine kebab stick was placed into the centre of the tyre print. The quadrat was centred over the stick. The stick was measured, and watered as above. A 1 minute time lapse occurred between putting on the water and applying wind. During that time extra water was placed between the leaf blower and the outside of the quadrat to prevent any dry substrate blowing into the quadrat. The quadrat was removed, and the leaf blower (on idle) was applied as above and the stick re-measured.

4. Wet substrate run over, then wind applied

The quadrat was placed on substrate and 1.5 litres of water was poured from a watering can evenly patterned into the quadrat. The quadrat was removed and 1 minute passed. Then a tyre was rolled over the wet sand and another 1 minute passed. A stick was placed into the centre of the tyre mark and measured. The leaf blower was set up on the box 1.5 m from the stick. It was set to full throttle and left on for 20 seconds. The stick was re-measured.

5. Wet substrate run over, then rain applied

The quadrat was placed on substrate and 1.5 litres of water was poured from a watering can evenly patterned into the quadrat. The quadrat was removed and 1 minute passed. Then a tyre was rolled over the wet sand. A stick was placed into the centre of the tyre mark and measured. Another 1.5 litres of water was poured over the area and another 1 minute passed. The stick was re-measured.

6. Wet substrate run over, rain applied followed by wind application

The quadrat was placed on substrate and 1.5 litres of water was poured from a watering can patterned evenly into the quadrat. The quadrat was removed and 1 minute passed. Then a tyre was rolled over the wet sand. A stick was placed into the centre of the tyre mark and measured. Another 1.5 litres of water was poured over the area and another 1 minute passed. The leaf blower box was set up 1.5 m from the stick and the blower sitting on its box was set to full throttle and left on for 20 seconds. The stick was re-measured.

I tested to observe any differences in substrate movement between unbroken and broken substrates. The statistical software package SYSTAT 8.0. Analysis of Variance was used to test erosion differences between categorical variables consisting of: Sites either flat or slope; Subtypes either bare or pumice; Damage either damaged or intact; Substrate conditions either dry or wet; and Weather conditions either rain, wind or rain & wind (Appendix 4.8). Three repetitions from slopes and four repetitions on the flat substrates were tested.

4.4 Results

Although there were no statistical differences between flat and sloping sites (Appendix B 4.7.2), there is evidence that many factors affect substrate movement, including substrate type, the integrity of the substrate, the substrates' saturation state and weather conditions (Table 4.1).

There were no significant between differences between pumice and bare substrate; see appendix B 4.7.2. There were significant differences in substrate movement between damaged and intact substrates ($P<0.001$) and substrate conditions being wet or dry before it was run over ($P<0.001$).

There are statistically significant differences between the amount of substrate movement when comparing substrate integrity, i.e., damaged and intact. A substrate that has been damaged erodes ~ 2.2 times faster than an intact substrate (Table 4.2). There are also significant differences in substrate movement depending on the saturation levels, wet or dry, before vehicle impacts ($P<0.001$) and the weather conditions after vehicle impacts ($P=0.008$). Dry substrates erode ~1.6 times faster than wet substrates, and substrates in wet weather conditions are more stable than in windy conditions or in a rain- wind combination.

Table 4.1 ANOVA to show significant differences in erosion between intact and broken substrates. P=<0.005, in bold P=<0.10 in italics. N=168
Conditions in the table refer to the weather conditions.
For site and other non significant results see appendix B 4.7.2.

Source	Sum Squares	D.f	Mean Square	F ratio	P value
Damage	67.175	1	67.175	15.910	**0.000**
Wet or Dry	59.383	1	59.383	14.064	**0.000**
Subtype & Conditions	67.610	2	33.805	8.006	**0.001**
Wet or Dry & Conditions	66.543	2	33.271	7.880	**0.001**
Site & Damage	32.508	1	32.508	7.699	**0.006**
Weather Conditions	42.430	2	21.215	5.025	**0.008**
Sites, Subtypes & Wet/Dry	26.240	1	26.240	6.215	**0.014**
Subtypes, Wet/Dry & Conditions	33.858	2	16.929	4.010	**0.021**
Subtypes, Damage, Wet/Dry & Conditions	29.537	2	14.768	3.498	**0.033**
Sites, Subtype, Wet/Dry & Conditions	25.120	2	12.560	2.975	*0.055*
Site, Wet/Dry & Conditions	21.805	2	10.902	2.582	*0.080*

There were significant interactions between substrate type and the weather conditions (P=0.001). In dry conditions there was a similar amount of substrate movement between pumice and sand; in wet conditions bare sandy substrates move more than pumice (Table 4.2).

There are significant differences of erosion with levels of saturation and weather conditions (P=0.001). Wind shifts ~ 2-6 times more substrate when the substrate is dry compared to when it is wet.

Rain also shifts ~2 times more "dry" substrate after rain than wet substrate. Wind can move ~5 times more dry bare substrate compared to wind eroding wet substrates. Alternatively when there was a rain and wind combination the substrate movement was about equal for both wet and dry soils if not slightly higher for wet soils, i.e., 38mm movement compared to 58mm respectively.

Although there were no significant differences in substrate movement between flat and slopes or between pumice and bare sand, there are significant differences when other factors are taken into consideration. Flat sites tend to have significantly (P=0.006) more erosion than slopes when they have been driven on, while slopes tend to have an increased amount of erosion when they are intact. Flat areas that are driven on are less stable than sloping areas. However when the surface area is intact, the flat area is more stable than slope.

There are significant interactions between flat and sloped area, between pumice and bare lands and between saturation levels (P=0.014). When the lands bare surface was wet the slope was more stable than the flat land. When the land was bare sand and dry, the flat surface was more stable than the slope. However the opposite was found with that of the pumice. Pumice on dry slopes was more stable than pumice on dry flat surfaces. Pumice on wet surfaces whether dry or sloped was equally stable.

There were also interactions between flat and sloped area, wet and dry soils, and weather conditions (P=0.080) to 10%. In dry conditions, rain and wind resulted in more erosion on the slopes; in wet conditions rain and wind resulted in more erosion on the flat.

Pumice and sandy substrates react differently to different weather conditions and this is also affected by the different conditions of the substrate before it is compressed. There are significant differences between the movement of pumice and sand and soil saturation and weather conditions (P=0.021). On both wet and dry substrate conditions sand has greater movement in wind and rain combined than pumice. If the substrate is dry before rain pumice will move more than sand, however if the substrate was wet before the rain begin i.e. “rain showers”, then sand will move more than pumice. There is no difference in substrate movement between pumice and sand when it has been dry and then is exposed to wind; however pumice moves more than bare sand when the substrate has been wet and the wind blows.

Table 4.2 Substrate movement (mm) for each category, Bare = sand, Pumice = pumice, the two substrate types. Dry and Wet are the substrate conditions before being run over with a tyre, and wind, rain and wind & rain combined, are the weather conditions created, with a watering can and leaf blower after the tyre was run over a substrate variable. (Averages in brackets)

	Damaged substrate	**Intact substrate**
Bare/Dry/Wind	36 (5.1)	12 (1.7)
Bare/Dry/Wind & rain	24 (3.4)	19 (2.7)
Bare/Dry/Rain	6 (0.8)	4 (0.5)
Total (mm) substrate movement Bare/Dry	**66 (9.4)**	**35 (5)**
Pumice/Dry/Wind	31 (4.4)	21 (3)
Pumice/Dry/Wind & rain	14 (2)	0 (0)
Pumice/Dry/Rain	20 (2.8)	13 (1.8)
Total (mm) substrate movement Pumice/Dry	**65 (9.2)**	**34 (4.8)**
Bare/Wet/Wind	0 (0)	0 (0)
Bare/Wet/Wind & rain	44 (6.2)	7 (1)
Bare/Wet/Rain	13 (1.8)	4 (0.5)
Total (mm) substrate movement Bare/Wet	**57 (8.1)**	**11 (1.5)**
Pumice/Wet/Wind	13 (1.8)	6 (0.8)
Pumice/Wet/Wind & rain	10 (1.4)	7 (1)
Pumice/Wet/ Rain	0 (0)	0 (0)
Total (mm) substrate movement Pumice/Wet	**23 (3.2)**	**13 (1.8)**

There are also significant differences between subtypes and damage, wet or dry and weather conditions (P=0.033). A representation of the difference in stability between broken and intact substrates and the tested variables is shown in Figure 4.3.

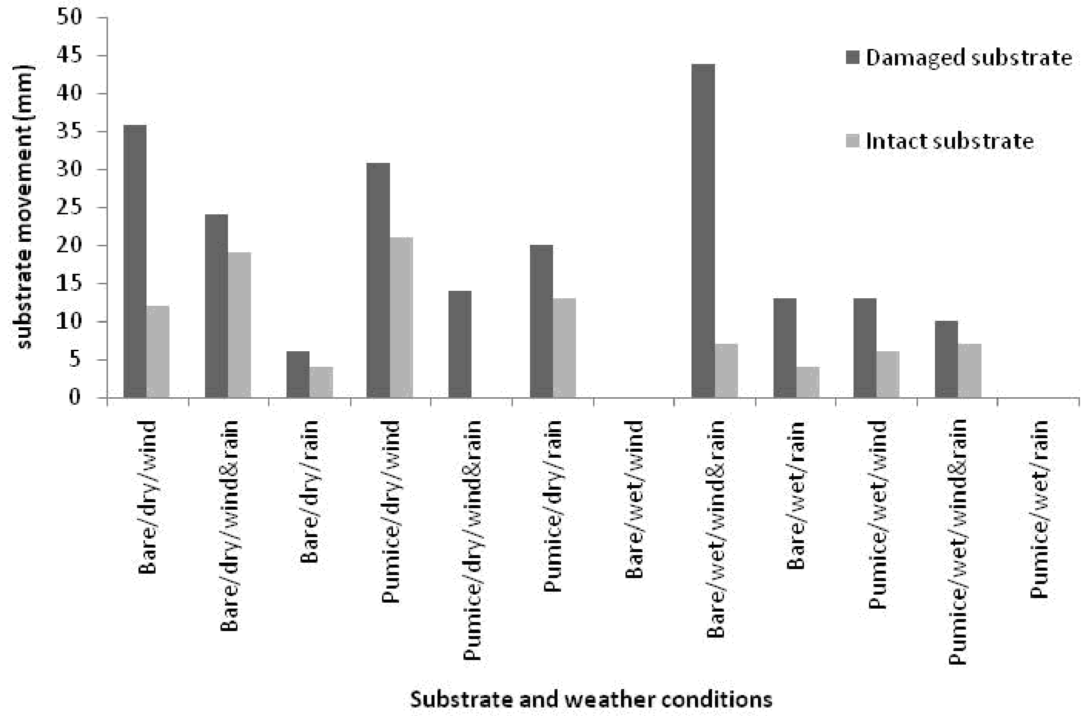

Figure 4.3 Graphical representation of substrate movement (Table 4.2).

4.5 Discussion

This study found that vehicles driving over substrates, especially when they are dry, increase the amount of substrate movement or erosion. Flat sites tended to have significantly more erosion than slopes following vehicle use. My finding that erosion was more rapid on slopes with intact soil was supported by Weaver & Dale (1978). However Brooks & Lair (2005) found that sediment yield can be 10-20 fold higher on slopes during rainfall following vehicle use, which my findings did not support.

Results show vehicles diving on substrates do damage and the consequences of soil damage are multiple. The topsoil cracks up when it is dry, a larger surface area to become exposed to weathering from environmental forces such as wind and rain increasing the rate of erosion (Belnap & Gillette 1997), and the movement of soil particles can damage plants. Soil can become undrained, and compaction of soils impedes seedling emergence (Hegarty & Royle 1978), and the ability to support natural vegetation (Webb *et al.* 1978). This can result in loss of vegetation, cyclic severe soil erosion, alluvial fan formation, and increased sediment discharge (Griggs & Walsh 1981). Off road vehicles can therefore change the basic properties of soil and these property changes can have adverse effects on the soils' stability (erosion), and plant longevity and recruitment. Wind erosion rates increase with decreasing percentage of vegetation and crust cover (Li *et al.* 2004).

Wind is an erosive force on deserts (Belnap & Gillette 1998). My study supported that wind and wind/rain combinations moved more surface substrate than rain alone. The removal of soil has many important implications for the desert ecosystem, as very little surface loss can remove most soil organisms, reducing site productivity (Belnap & Gillette 1998). It also increases spatial heterogeneity of soil resources which is considered to be characteristic of the process of desertification (Abrahams *et al.* 1995).

Increased soil movement can have a direct impact on plants. Sand blast can cause abrasive flux on stems and leaves of seedling and adult plants**.** Blowing sand can rupture plant cells, dry out the exposed tissue, and expose the damaged seedlings to diseases and insects, causing death or slowing plant growth rates (Fryrear *et al.* 1973). Increased soil movement can also result in a gradient of decline in germination correlated with increased depth of seed burial by aeolian sands, possibly owing to seed dormancy mediated by higher soil moisture, a decrease in soil temperature, and lower oxygen content at greater depths (Harper 1977). But then that might depend on how deep they are buried as Maun & Lepierre (1986) suggested from his experiment that germination of surface seeds was lower than buried seeds as seeds lying on the soil surface became desiccated, thus inhibiting germination. Bayfield (1974) found from burial experiments where erosion debris had covered vegetation, such as mosses, herbs, grasses and shrubs, recovery at best took several years, and with depths above 7cm recovery was negligible.

Unfortunately wind erosion has a cyclic effect, as wind erosion rates increase with decreasing vegetation cover (Li *et al.* 2004), and the resulting bare soil is susceptible to greater temperature and moisture fluctuations (Althoff *et al.* 2009). Bare soils, without the protection of plants, have an increased risk of raindrop impact, which increase soil detachment resulting in increased sediment transport (Abrahams *et al.* 1995).

Increase in runoff could occur with compaction of the soil surface, creating channels for rain water to pool, which enhances soil detachment and sediment transport (Abrahams *et al.* 1995). Studies by Loch (2000) suggest that vegetative cover reduces runoff and erosion, and found that erosion from storms was greatly reduced by vegetative cover. Frost action might also greatly increase soil erosion as a result of the freeze-thaw effect destabilising substrates (Affleck 2005). Soil surface was observed to be more fluffed up and loosened by frost action (Abrahams *et al.* 1995), leaving an easily erodible substrate. A greater vegetation cover could also protect from frost damage and alleviate erosion as plants with their diverse root systems, anchor soils on slopes and prevent erosion (Korner 2004).

Even if off road vehicle and hiking activities do not directly remove surface material they still can have a profound impact on soil resources and nutrient cycles (Webb and Wilshire 1983). Walkers cause vegetation damage and reduction of the plant surface profile potentially causing erosion (Whinam & Chilcott 1999). Vehicles can increase levels of nitrogen (N) in the soil affecting plant communities up to 200m away and routes with dirt surfaces can be a significant source of dust (Brooks & Lair 2005).

Desert areas that are disturbed by human activities may take centuries to recover (Lovich & Bainbridge 1999), and the full extent of damage to soils may not be evident until years or even decades after the original disturbance (Vollmer *et al.* 1976).

The Desert Road is situated in a mountainous area. A single mountain may host a series of climatically different life zones over short elevational distances, making mountains hot spots of biodiversity and priority regions for conservation (Korner 2004). In desert regions where vegetation is sparse, it is apparent that the ecosystem is easier to access by off road vehicles, leading to wind and water erosion that are very difficult or impossible to control without very high investments in material and labour (Lovich & Brainbridge 1999).

Management policies of arid and semi arid regions should take into consideration that desert pavement along with vegetation cover shields the loose friable soils beneath from erosion by both wind and water (Vollmer *et al*. 1976). Crusts play an important role in soil surface stability; crust disturbance should be reduced whenever possible (Belnap & Gillette 1997). A well developed soil crusts can be highly effective at controlling wind erosion (Belnap & Gillette 1998, Li *et al.* 2004). Having increased vegetative areas within the desert might be a deterrent to drivers. Higher density vegetated ecosystems may create impenetrable barriers preventing off road travel (Brooks & Lair 2005) thwarting soil crust and vegetation damage.

On areas such as Tukino Skifield Road and Pylon service tracks there should be a limit to the extent and intensity of impacts as much as possible**,** as these are the main entry points into the Desert. Present studies demonstrate that one-time passes of an off-road motorcycle on an area cause immediate but temporary changes in the plants and to a lesser degree on the soil. Since repeated impacts appear to have cumulative negative effects on the soil and the vegetation, it is better to minimize unavoidable impacts by restricting traffic to fixed trails (Kutiel *et al.* 2000). Rickard *et al.* (1994), also suggests that where vehicles are permitted to travel, they should avoid steep gradients and sharp turns as the substrate will shear under the torque of the tyres and become wind borne aeolian sand erosion.

Management policies of arid and semi arid regions should reflect that crusts play an important role in soil surface stability, and as such disturbance should be reduced to these crusts whenever possible.

4.6 Conclusion

The widespread use of off road vehicles is now recognised as having a significant impact on the land, water, native plants and animals (Sheridan 1979, Anders & Leatherman 1987). Vehicles driving on arid substrates damage surface crusts which in turn increases erosion which has serious implications to desert ecosystems. Movement of soil has the potential to bury plants, and expose roots, prevent seed germination, reduce recruitment of plant species and increase areas of bare substrate, further escalating the erosion processes.

The Desert Road at Tongariro National Park is a mountainous hot spot worth preserving. Management policies should take into account the functioning ecosystem, the importance and sensitivity of surface crusts and attempt to prevent traffic driving into the Desert ecosystem.

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4.8 Appendix

4.8.1 Appendix A: P values of categorical values tested in erosion experiment.

Categorical values:

Site	(2 levels)	Flat, Slope.
Subtype	(2 levels)	Bare, Pumice.
Damage	(2 levels)	Driven, Intact.
Conditions	(2 levels)	Dry, Wet.
Weather	(3 levels)	Rain, RainWind, Wind.

Dep Var: DIFF N: 168 Multiple R: 0.747 Squared multiple R: 0.559

Analysis of Variance

Source	Sum-of-Square	df	Mean-Square	F-ratio	P
SITE	0.127	1	0.127	0.030	0.863
SUBTYPE	8.643	1	8.643	2.047	0.155
DAMAGE	67.175	1	67.175	15.910	**0.000**
CONDITIONS	59.383	1	59.383	14.064	**0.000**
WEATHER	42.430	2	21.215	5.025	**0.008**
SITE*SUBTYPE	5.786	1	5.786	1.370	0.244
SITE*DAMAGE	32.508	1	32.508	7.699	**0.006**
SITE*CONDITIONS	6.907	1	6.907	1.636	0.203
SITE*WEATHER	3.882	2	1.941	0.460	0.633
SUBTYPE*DAMAGE	5.365	1	5.365	1.271	0.262
SUBTYPE*CONDITION	2.431	1	2.431	0.576	0.450
SUBTYPE*WEATHER	67.610	2	33.805	8.006	**0.001**
DAMAGE*CONDITIONS	0.335	1	0.335	0.079	0.779
DAMAGE*WEATHER	11.715	2	5.858	1.387	0.254
CONDITIONS*WEATHER	66.543	2	33.271	7.880	**0.001**
SITE*SUBTYPE*DAMAGE	9.175	1	9.175	2.173	0.143
SITE*SUBTYPE*CONDITIONS	26.240	1	26.240	6.215	**0.014**
SITE*SUBTYPE*WEATHER	8.396	2	4.198	0.994	0.373
SITE*DAMAGE*CONDITIONS	0.716	1	0.716	0.170	0.681
SITE*DAMAGE*WEATHER	8.882	2	4.441	1.052	0.353
SITE*CONDITIONS*WEATHER	21.805	2	10.902	2.582	**0.080**
SUBTYPE*DAMAGE*CONDITIONS	8.383	1	8.383	1.985	0.161
SUBTYPE*DAMAGE*WEATHER	3.257	2	1.628	0.386	0.681
SUBTYPE*CONDITIONS*WEATHER	33.858	2	16.929	4.010	**0.021**
DAMAGE*CONDITIONS*WEATHER	19.019	2	9.509	2.252	0.110
SITE*SUBTYPE*DAMAGE*CONDITIONS	1.050	1	1.050	0.249	0.619
SITE*SUBTYPE*DAMAGE*WEATHER	6.233	2	3.117	0.738	0.480
SITE*SUBTYPE*CONDITIONS*WEATHER	25.120	2	12.560	2.975	**0.055**
SITE*DAMAGE*CONDITIONS*WEATHER	1.995	2	0.998	0.236	0.790
SUBTYPE*DAMAGE*CONDITIONS*WEATHER	29.537	2	14.768	3.498	**0.033**
SITE*SUBTYPE*DAMAGE*CONDITIONS*WEATHER	15.37	2	7.685	1.820	0.166
Error	506.667	120	4.222		

Chapter 5
Vehicles can alter ecosystems.

5.1 General discussion

The Rangipo Desert, Tongariro National Park, is a unique area within the New Zealand landscape. The vast areas of open volcanic plain and mountainous peaks contain many distinctive floral species which people have the opportunity to observe and are vastly different from many other species they have probably encountered.

Being New Zealand's first National Park, and only North Island ski area, many visitors are attracted to this park annually and tramping and camping is encouraged. As well as skiing in winter, many other activities are available throughout the Tongariro National Park in summer. There are many walks ranging from the famous one day Tongariro Crossing, to longer walks such as the Tongariro Northern Circuit. There are annual one day events such as the Tussock transverse (a one day across the park run), and a scenic flight is a popular activity allowing a unique view of the park.

All these activities are encouraging greater tourist numbers to the park elevating acoustic disturbances (chapter 1) and increasing the number of vehicles entering the area. The increased foot traffic has disadvantages for the Desert. Exotic seeds can be brought in on footwear, and footprints can also break surface crusts if the contestants of the tussock transverse enter the Desert. The increase in visitor numbers also puts extra pressure on natural resources through the deterioration in air and water quality, increasing noise levels, and impacts on the visual environment, seriously diminishing the natural values of a national park, as well as the physical impacts of all these visitors in terms of wear and tear on tracks and facilities, space consumption, parking and even sewerage disposal. This places the Park in precarious position of losing such unique ecosystems as the Rangipo Desert as we know it, due to increased demand of vehicles driving through the Desert.

Of the vehicles I noted in the Rangipo Desert area over 16 days (chapter 2.4.4) 48% were off road vehicles, which have the potential to drive over bare substrates, and low lying vegetation. This act can drastically alter an ecosystem by changing plant species, and increasing soil erosion within the Desert.

Figure 5.1 shows the cycle of how the Rangipo Desert ecosystem could be changed and it is discussed more fully throughout this chapter. Vehicle operators operating off-road constantly make choices while driving their vehicles. Off-road drivers steer through terrain by visually differentiating between traversable and untraversable pathways (Hadsell *et al.* 2009). I found that vehicle operations within this Desert were over bare substrates between sparsely vegetated areas (Table 2.5), suggesting these are the preferred pathways of drivers who drive over this Desert ecosystem. These vehicle manoeuvres can alter ecosystems. There have been many scientific papers written on how destructive vehicles can be. These papers discuss damaging contaminants that can affect ecosystems, such as noise pollution, exhaust emissions and heavy metal toxins. Vehicles can also physically damage plants that are small enough to drive over, by breaking branches and dislodging roots, hindering xylem and phloem processes, resulting in dehydration and die back. Vehicles also disturb soils by either compaction or by breaking substrate surfaces, leading to increased soil erosion, impeding germination and/or seedling emergence. Vehicles also are carriers of exotic seed that can be brought in from kilometres away and be deposited within the areas driven over. In short vehicles have the potential to alter entire ecosystems. This thesis covers some of the potential damage that other papers have suggested vehicles can do and I have tested these ideas *in situ* at the Rangipo Desert.

The Rangipo Desert consists of an arid environment with low statue vegetation and a vast area of bare substrate, which is a fun and accessible place for drivers to manoeuvre off road vehicles. In this thesis I looked at what type and what number of vehicles left the main road and how far vehicles travelled into the Desert. I looked at vegetation densities and the type of substrate drivers preferred to drive over. I experimented with the damage done to plants and how driving affects them over time, and how vehicle pressure can alter the micro-topography, and the number of seedling recruits under damaged plants compared with undamaged plants. Finally I looked at whether vehicles can increase wind and rain erosion processes.

I found forty eight percent of all vehicles entering into the Desert were off-road vehicles consisting of both cars and motorbikes (Table 2.4). All three roads, Tukino Skifield Road, State Highway One, and the Pylon Track were used to either enter or exit the Desert. There is evidence that a vehicle travelled up to 1.8km into the Desert from State Highway One. Drivers preferred to drive over bare or patchy land where there is low stature vegetation in comparison to denser vegetated areas with taller vegetation.

Figure 5.1, (Step1); The Rangipo Desert ecosystem once was uncontaminated by human interference and contained only native species. Historically we could look back in time and assess if the most vulnerable vegetation has all ready been removed from the Desert and only robust vegetation has remained. There are large bare patches of land that may have contained other species. This vegetation loss may have been the result of natural events such as volcanic eruptions or fires, or the loss could be due to influences by early settlers. However it is hard to assess if we have already lost vegetative species without documentation of vegetation before human arrival. What we can do is preserve what is left, as has been documented by Atkinson (1981) as a base line vegetation map of the Tongariro National Park.

Today the Desert contains native, endemic, and exotic species with a height and density gradient running from tall vegetation, which is densely populated, to low stature, sparsely placed vegetation (Table 2.1). All vegetation within the Rangipo Desert is under threat by vehicle damage, whether by being directly driven over, or indirectly by burial by erosion, or other indirect acts such as habitat fragmentation and associated actions. The lower stature patchy vegetation that is easier to drive over show signs of tyre marks across the vegetation.

Figure 5.1, (Step 2), I noted most vehicle marks were found in sparsely populated areas with vegetation of low stature (Figure 2.7). Drivers prefer to utilise areas such as these due to the suitable, easy access route for their vehicles (Brooks and Liar 2005). Vehicles manoeuvring through low stature vegetation can damage the plants as they are run over (Chapter 3).

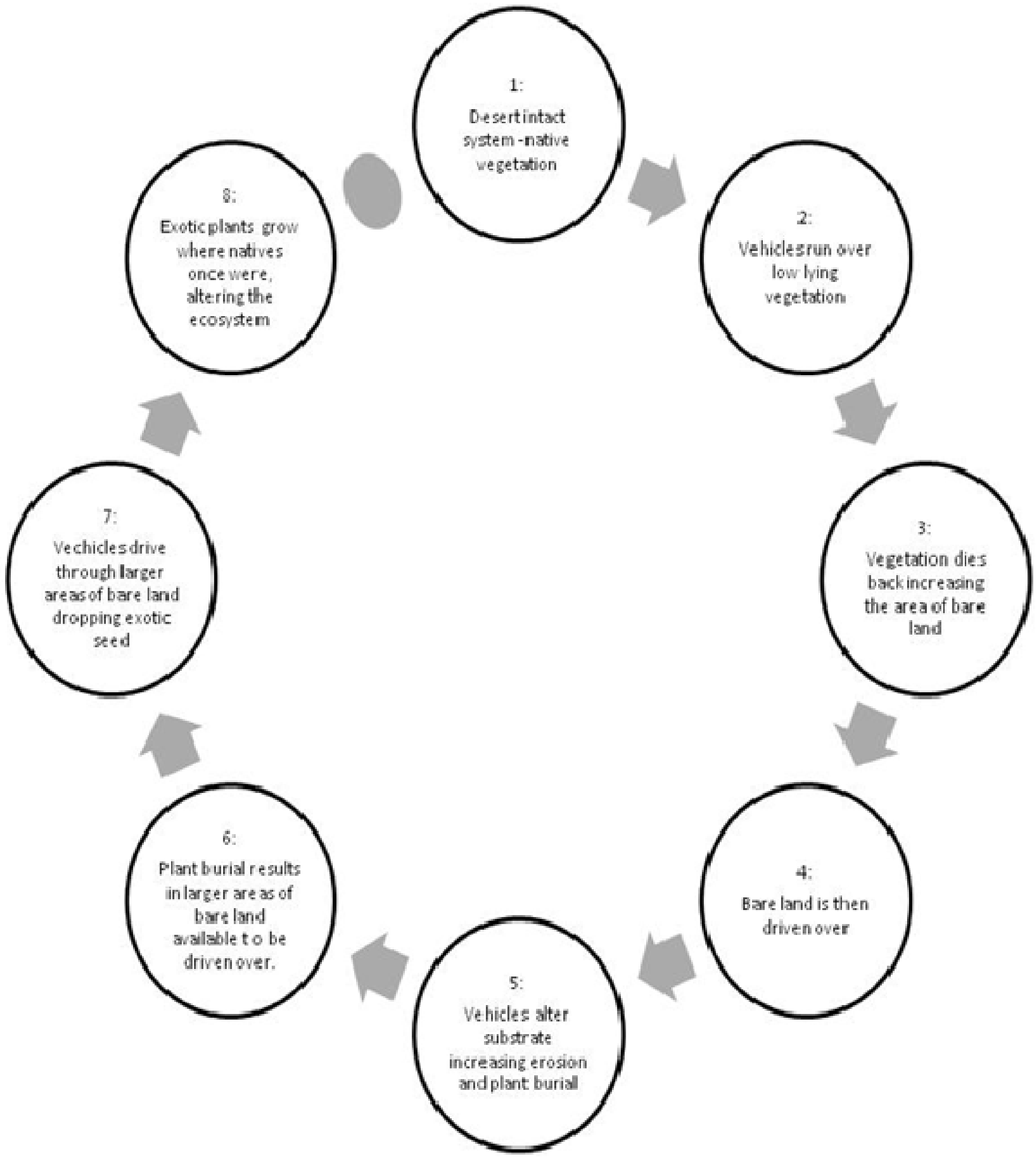

Figure 5.1 (Steps 1-8) Changes made to vegetation within an ecosystem being run over by vehicles, in eight steps, as discussed in text.

There was evidence of limb damage to the more woody species after passing the tyre over plants (*Pers. obs;* Chapter 3, Sun & Liddle 1993, Rickard *et al.* 1994). Other researchers also suggest driving over the plants results in immediate broken vegetative limbs, and dislodged root systems (Wilshire 1983, Rickard *et al.* 1994), while months later there were signs of die back (Rickard *et al.* 1994).

One pass of either an automobile (Rickard *et al.* 1994) or motorbike (Kutiel *et al.* 2000) through vegetation results in visual signs of passage by either tyre marks (Lovich & Brainbridge 1999), broken limbs of vegetation (Rickard *et al.* 1994), plant roots becoming dislodged (Wilshire 1983), or the mean height of the plant being reduced (Kutiel *et al.* 2000). Working on this thesis I did see visual signs of the vehicle prints, in the substrate and over plants. The plants were flattened, limbs were broken and roots became visible above the substrate as they were dislodged. Although I did not measure any differences between height, limb breakage and root dislodgment before and after vehicle passage the changes were noticeable (Chapter 3, *Pers. obs*).

Figure 5.1, (Step 3); Damage to plants and a decrease in photosynthetic material can increase plant dieback. This dieback can decrease the biomass of leaf litter produced which in turn reduces nutrient turnover and alters enzyme activity which can impede a successful re-establishment and growth of plants (Kissling *et al.* 2009).

Not all plants die back equally; some plants are more resistant than others and sometimes recover slowly, which I discussed it throughout Chapter 3, and Sun & Liddle (2003) and others found similar results. The plants that are less resistant, have less chance to recover and therefore are more susceptible to die back and death. All the species I tested for vehicle damage showed different tolerance levels depending on what variable was being tested. *Raoulia albo-sericea* showed less resistance than other species, noted by the greater amount of sand and reduction of live material in the vehicle treatment. When comparing the small woody shrubs *Pimelea prostrata* and *Gaultheria colensoi*, *G. colensoi*, appeared more resistant as *P.prostrata* had less shoot tiller density and more sand at the end of the experiment, compared to the beginning. However this result could be influenced by the season when the species were manipulated with the tyre. *P.prostrata* was run over in November just before summer while *G. colensoi* was run over in April just before winter suggesting timing of the damage could play a part in vegetation recovery (Chapter 2), as suggested by Pickering (2010). Espie & Barratt (2006) stated that during the spring the tussock contained more water, so did not burn as hot as in the summer when a tussock was less likely to survive the burns. The differences in moisture status at the time of burning tussocks have an effect on plant response. The differing responses of plant species after a disturbance are caused by many complex factors.

Temperature and rainfall have a major role in plant succession after disturbance (Leathwick & Rogers 1996). Other factors, for instance, the distance from intact forest, (or largely vegetated areas of species specific to a particular area), topography, slope and solar radiation can affect how plant species respond (Leathwick & Rogers 1996), as do differences in altitude, and habitat variability, e.g. pockets of densely vegetated sites compared to sparsely vegetated sites (Espie & Barratt 2006). Considering all these factors it is not surprising that management of ecosystems, such as the Desert, is hampered by a lack of reliable information on ecology of these ecosystems (Rogers 1991). It is only with an understanding of ecological responses related to disturbance that we can start to interpret ecosystem dynamics (Espie & Barratt 2006). The three sites used in Chapter 3 showed differences in experimental responses. The Shooting Box had larger plants compared to the other two sites; this is possibly because this site was sheltered by taller vegetation and sand banks which were a contrast from the open sites of the Army Corner and the Pylon sites. The Army Corner site was positioned beside the Tukino Skifield Road which was not the case with the other two sites. The site position beside the road more than likely had an increase in dust and sand deposits, which the other sites were unlikely to been exposed to. More pumice was visible at the Pylon site compared to the other two sites which may have affected soil temperatures while pumice was acting as a barrier between the sun and the substrate. All sites had un-vegetated areas surrounded by bare substrates.

Plant die-back can result in increasingly larger areas of bare land becoming exposed. As these areas of bare land become larger the once continuous plant habitat becomes smaller and more isolated. Habitat fragmentation immediately reduces the size of species' populations, and increases their isolation (Rathcke & Jules 1993). The chance of inbreeding is increased in smaller population fragments (Severns 2003), and these pockets of vegetation have higher extinction rates than the larger patches of flora that were originally there (Groom 1998).

Figure 5.1, (Step 4); the bare substrates that occur between flora patches develop surface crusts which take many years to form. These crusts then help stabilise soils and prevent erosion (Belnap & Gillette 1997). The soil crusts at Rangipo are continually under threat by being driven over, preventing soil stability. These crusts are extremely vulnerable and highly susceptible to disturbance (Belnap & Gillette 1997). I found soils were compacted or broken from tyres as the plants are driven over and changes to substrate surfaces and the micro-topography happened instantly (Chapter 3.4.6). Under the tyre the substrate became compacted, while the substrate at either side of the tyre was pushed up and broken, increasing the effective surface area. I found the soil crust broke and the substrate under the hand pushed tyre compacted up to 32mm compared with the previously measured intact substrate. There was an increased amount of erosion from both the compacted and broken substrates compared to the intact substrate. The intact substrate was flat and compactly crusted together. The broken substrate had a larger broken surface area for the wind to erode away, while the compacted substrate had particles dislodged which water was subsequently able to move. Compacted soils become less well drained, the droplets from rainwater enhance soil detachment, and water pools build up. The built-up water starts flowing, creating channels, increasing sediment transfer and movement of organic matter (Abrahams *et al.* 1995). This can clearly be seen in the aerial photographs where pumice collected in "snow melt channels" and as the water subsides the pumice settles in a similar pattern to river flow. Compacted soil can impede seedling emergence (Hegarty & Royle 1978) when vegetation has not evolved in an environment containing impacted soil. When soil surfaces break, soil erosion is increased and vegetation and surface crust cover is reduced (Li *et al*. 2004). I found that the rate of erosion on broken substrates was almost double to that of intact soils. The removal of soil has many implications for a desert ecosystem; a small amount of surface lost can remove most soil micro-organisms, reducing site productivity (Belnap & Gillette 1998) and increase spatial heterogeneity of soil resources which is considered to be a characteristic of the process of desertification (Abrahams *et al.* 1995), i.e., the process where vegetation is lost from the area resulting in barren substrate. High proportions of bare ground in desert environments are prone to losses of soil particles, seeds, nutrients, and organic matter (Pohl *et al.* 2009). Cracked topsoil is prone to erosion by wind. Soils at the Rangipo Desert are notably drier in summer; this is evident due to the “wet land” areas in the desert drying out over the summer months. All damaged sites had a greater amount of erosion compared to the intact substrate, except when the substrate was wet and the conditions were windy; in these conditions substrate movement in both intact and damaged soils was negligible. Damaged dry substrate lost a greater amount of substrate under the experimental wind conditions, than wet substrates under the same conditions. Wet substrates in windy conditions were relatively stable and rain after windy conditions on broken substrate slowed any erosion process. This indicates that when the soils are wet there is less erosion; therefore, summer driving is more damaging to the Rangipo Desert than winter driving.

Figure 5.1, (Step 5); any vegetation still present on the Desert after vehicle damage becomes threatened by aeolian sands that are increased due to the larger area of bare substrate present. Stems and leaves of plants become damaged with increased soil movement (Hegarty & Royle 1978); abrasive movements by sand and substrate particles expose plant tissue, retarding plant growth (Fryrear *et al.* 1973). The abrasive aeolian particles not only cause the slow death of plants by rupturing plant cells, but can also bury plants under sediment deposits (Wilshire 1983). Aeolian soil particles that result in plant burial and damage to vegetation further increase the size of the patches of bare sand. The potential for wind erosion to bury vegetation is increased, especially after a trampling episode has broken the substrate. Wind eroded and moved more than double the amount of surface sand in a broken substrate compared to the intact substrates in my experiment (Table 4.2). Wind erosion has a cyclic effect; the wind erosion rate and area eroded increases with decreasing vegetation cover (Li *et al.* 2004). The resulting increased area of bare land becomes suitable for vehicles to drive over, exacerbating the entire erosion processes. These larger bare areas of land further isolate plants; this is followed by a decrease in pollinator services, further reducing plant recruitment.

Figure 5.1, (Step 5); alee affects may be experienced by plants when populations are too small or isolated to receive sufficient pollinator services (Groom 1998) or species are too far from each other for wind-carried pollen to be collected by another of its species, resulting in decreased plant fitness. This has further complications as genetic drift in small populations can lead to the rapid fixation of alleles which decreases genetic variation preventing adaptation to environmental change (Fischer *et al.* 2000).

Figure 5.1, (Step 6); these effects result in habitat destruction and fragmentation, which are collectively the major cause of species' extinctions (Wilcove *et al*. 1998) and ecosystem alterations; while not examined in my work, these are potential threats to the Desert's flora and is one of the eight steps in the cycle of change (Figure 5.1).

Figure 5.1, (Step 7); vehicle impact can also be indirect. Vehicles are operated over large areas of bare land within the Rangipo Desert, which, by being the primary pathway for plant invasion into arid and semi arid ecosystems (Amor & Stevens 1976), has the potential to alter the ecosystems. Vehicles serve as dispersal vectors for alien plant propagules (Brooks & Lair 2005) and weed imports (Priskin 2003), and have the ability to spread weeds and seeds into a desert. Vehicles can disperse seed over hundreds of kilometres; these distances are several orders of magnitude greater than most other dispersal mechanisms (Hodkinson & Thompson 1997).

Figure 5.1, (Step 8); exotic seeds germinating in the Desert can displace natives and change ecosystems, in my experiment (Chapter 3) there was a greater number of plants germinating within the tyre imprints from within the vehicle treatment compared with the control (Figure 3.17). Both exotic and native seedlings were found under the vehicle treatments; however the difference between native and exotic species abundance was non-significant. Of the 40 plots I ground-truthed, for the substrate categories used in the aerial survey (Chapter 2), only two plots were found with an exotic species present. Vehicles have the potential to spread heather, *Culluna vulgaris,* an aggressive exotic weed growing on the Desert roadsides of State Highway One, further into the Desert at a faster rate than heather would naturally spread. This poses serious threats to the conservation of natural values (Dickinson *et al.* 1992), as the effects of invasive plants are great threat to ecosystem function and indigenous biodiversity (Williams & west 2000).

An increase in visitor numbers has been positively correlated with an increase of weeds and in Kadadu National Park tourist's four-wheel drive vehicles were important vectors of introduced species (Priskin 2003). More adaptable weeds adapt easier to different environments. Weeds such as *Hypochaeris radicata*, *Holcus* *lanatus*, and *Pilosella officinarum* have been observed in the Desert by myself and also documented by Chapman & Bannister (1990), Dickinson *et al.* (1992), and many others. These weeds were possibly brought into the Desert as seeds via vehicles travelling along State Highway One. Ruderal exotic plants are able to establish within a desert ecosystem due to their high adaptability to freshly disturbed ground, and to different environments. These weeds have the potential to use the ecosystem niches that were once filled by native plants that have died back due to vehicular traffic.

This concludes the idea of the Rangipo Desert ecosystem change from an indigenous ecosystem to one that has the potential to be quite different as a result of vehicular traffic.

Impact of my work

Forty eight percent of the vehicles driving off State Highway One were off road vehicles. This is not illegal in itself when vehicles stick to the Tukino Skifield Road, but these vehicles do have the potential to drive some distance over the Desert ecosystem. There is evidence that some do drive off-road as seen by tyre marks left behind on substrate surfaces.

Vehicles have the potential to import and disperse exotic seed (Lonsdale & Lane 1994) while roaming the Desert. Any seed which is genetically plastic enough to adapt easily in the new environment will germinate, and fill the bare patches which once housed native vegetation therefore drastically changing the native landscape at the Rangipo Desert to a homogeneous mass of exotic weedy plants.

Vehicles are doing damage to this unique environment and the damage is significant. Such destruction is particularly serious in desert areas, generally because of the fragility of these ecosystems (Vollmer *et al.* 1976). The same applies at the Rangipo Desert, even though it is not a true desert, it has friable soils that become stabilised under a fragile surface crust, which is easily broken with little impact. The damage done is not evident until long after the perpetrator has left (Vollmer *et al.* 1976) leading to a false sense of belief in the driver that no damage is done at all. The reality is that, the impact on plants alone creates bigger issues than just plant breakage and dieback, such as reduced plant fitness, increased erosion, loss of fauna which decreases both native biodiversity and conservation value of the landscape (Olesen & Jain 1994), to one of a more exotic nature. With the increasing number of visitors there is an increase in vehicle traffic, a higher potential for vehicles to drive off-road, increasing plant dieback and spatial distance between vegetated areas. Continuing to drive on the resulting bare patches will increase erosion, plant burial and importation of exotic weeds; which, when these impacts are combined, result in a shift in the ecosystem dynamics of the Desert.

Current management at Tongariro National Park

One of the relevant objectives of the Tongariro Management Plan (Tongariro/Taupō Conservancy 2006) is to manage Tongariro National Park's formed and maintained roads in a way which provides for existing public access but avoids adverse effects on the environment. The current management policy also states no-one is allowed to drive a vehicle on any area that is not a public road, camping site, or car park. In saying this, the Plan also acknowledges in that the ongoing maintenance of the Tukino Skifeild access road provides the opportunity to extensive illegal off-road access into the park by motorised vehicles (Page167). Consequently the Park managers, have reminded drivers to adhere to the legal road through signage close to the Tukino Skifield Road and State Highway One intersection (Figure 5.2). While most do in fact adhere to these instructions, a number of vehicles do infringe, and with impunity. The Department of Conservation does not recognise an obligation to assist in the recovery of stuck vehicles (page 167) and may close the road if they feel it is unsafe to the public. If the Ski area is permanently closed the departments will remove the access road and restore the area.

Figure 5.2 Signage requesting that drivers stay on marked roads, and warning it is an offence to take any type of vehicle off-road. The signs on the left do not mention “marked roads”. The information about vehicles not being permitted off road is situated in an inappropriate position if drivers are expected to read that information.

Management implications of my work

There is a negative correlation between the number of cars going in the Desert and distance travelled, suggesting that many of the cars stay close to the road (within 150m Chapter 2.4.1). It is well documented that a higher number of passes by vehicle over vegetation is positively correlated with the intensity of the damage done to plants (Cole 1995). Since most of the vehicles stay relatively close to the road, road margins are one area where traffic load is intensified. Hence it would be highly beneficial to this Desert ecosystem and also to the vegetation succession if vehicles were prevented from driving off road onto this fragile environment. More signs are the cheapest option, particularly around easy exit points. However fences and barriers could also be used to deter vehicles. On State Highway One, when the roads were re-surfaced in November 2010, a barrier bund of substrate was dropped on the road-side, which then prevented vehicles driving into the Desert via a seasonal stream system where frequent vehicle marks had been previously seen. Although this only temporarily prevented vehicles (two years passed before vehicle marks were seen there again), it did prove effective as a barrier in the short term, when it was raw. Thus this represents a suitable mechanism for isolating the Desert from traffic at simple access points. Along the Tukino Skifield Road, where there is much barren substrate, a simple chain and post fence running along either side of the road, where access to the desert is easily gained, and extra “no entry” signs, can be put at intersections of the Tukino Skifield Road and other “off roads” such as the pylon tracks, and these tracks can be utilised by authorised personal such as Pylon maintenance workers, or Department of Conservation staff. Most off-road drivers would not attempt to cut into a chain type fence to gain access to the park for a joy ride; drivers would more likely find an alternative area to drive off-road. The chain and post fences would be a temporary measure until plants alongside the roads become established to prevent traffic flow on to the desert.

Restoration efforts could be adopted behind the barriers; if the planting is dense enough, it may be enough to prevent vehicle manoeuvres. A full restoration alongside the Tukino road, as has been attempted alongside the “Desert Road” (State Highway One) might be all that is required to prevent vehicles driving off the Tukino Skifield Road. Restoration work could also be adopted at high productivity sites. This study suggested that some plants grow larger at the Shooting Box site than at other sites. Larger plants have more potential to reproduce (Samson & Werk 1986), and are more effective as a barrier. It is possible that the Shooting Box have bigger plants because there is less vehicle traffic at this site, the traffic frequency was further reduced when the accessible river system was blocked in November 2010 State Highway One reseal. So restoration work along the Tukino Skifield roadsides could prevent ecosystem damage and initiate growth in plants that reach larger sizes than in the previous damaged areas.

An “adopt a friend” program in conjunction with the Department of Conservation could be set up, where community groups and schools from Waiouru and the Central North Island can donate an annual subscription to the program for restoration work. Schools could combine ecology restoration and conservation within their curriculum based around the Rangipo Desert. An education program in the effort to explain about the long term consequences to this fragile environment, and the conservation value of the land could also be adopted with the hopes that people might show an interest in the value of this landscape and think twice about driving over the Desert.

Future work

This project produced many questions that still need be answered to give a better understanding of the processes in action and if vehicles are harmful or beneficial to the environment. Understanding the choices and responses the driver makes between driveable and un-driveable routes, as an alternative to fencing can provide information on how best deal with driver route choices (Hussein 2002), Gao & Wang (2010) explain how models and simulating methods based on Decision Field Theory and Bayesian Theory can help assist in understanding driver choice. Understanding the outcomes of the choices drivers make in desert environments can assist in management practises that aid in preventing off-road traffic.

The experiment processes explained in this paper could be modified by altering the experimental design to only a manipulated and a control, and setting up experiments for longer periods of time which would possibly give greater statistical power if the slow growth time of the vegetation is a factor in the results gained, as I suspect. A paired experiment could be set up consisting of a manipulated and control plants, but with larger replicate sizes.

The use of site-specific plants, (*Pimelea prostrata* are specific to the Pylon site), would allow for the differences in species' responses to variable differences that were tested in Chapter 3.3.2 of this thesis. Testing the change of vegetation abundance under the manipulated and vehicle treatments (Chapter 3.4.5) could be investigated further, posing questions such as: do vehicles initiate resource release which facilitates seedling germination? Or do vehicles drop seed? Since plant growth form influences plant responses, the paired experiments could include species with differing growth forms, to improve our understanding of the reactions of these plants.

It is possible that micro-climates played a part in the results, the Shooting Box was less exposed to wind as it was sheltered on one side by taller vegetation, and a sand hill on the other, this could have prevented wind and chill factors. More information on the environmental conditions in different parts of the Desert could deepen our understanding on how plants react within these environments, explaining the differences between the sites observed here, and how this can be affected by vehicular damage.

Seeds germinating under the tyre treatments could be followed from germination to death, focusing on the survival process, asking questions such as do small germinated seedlings get covered by eroded sands, how far can seeds be washed away due to change in hydrology regimes and could seed movement benefit the Desert? Exotic weed seeds can also spread using water flow, however it is hoped that further weed seed invasions are limited as vehicles are prevented from travelling through the Desert, and native plants grow in denser patches preventing the germination of weed seeds.

Disturbance-induced changes in vegetation composition have important implications for biodiversity management as plant diversity drives terrestrial ecosystems and any small population is vulnerable to extinction, especially through habitat modification or loss (Rogers 1991, Espie & Barratt 2006).

5.2 Conclusion

The Rangipo Desert is New Zealand's only desert-like environment. This unique habitat is under threat from vehicles driving over the National Park and not adhering to signs put up by the Department of Conservation asking drivers to keep to the legal roads. The drivers who drive off-road prefer open areas of substrate and low stature vegetation. Although different species react differently to vehicle damage, overall results suggest that a plant's growth is compromised once it is driven over. Vehicles also change the micro-topography of substrate and increase both wind and water erosion. Although it is possible that one of the benefits of having vehicles drive over vegetation is an increase of species' diversity, how persistent these germinated native plant species are, has not yet been tested. Neither has the percentage of exotic species that might be introduced to the area, and this should also be considered for future research to obtain further information on whether, at least for some species, some damage is beneficial to the restoration of the area. To preserve the Rangipo Desert landscape it is desirable to prevent vehicles from manoeuvring over the Desert landscape. Barriers along the road-sides could prevent vehicles moving into the Desert; acting as an impenetrable barrier between the road and the National Park and the Desert ecosystem which could include barricading the roadside of State Highway One.

5.3 References

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