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Mt Grand Station – Wildlife Conservation

Conservation Biology (ECOL609) Project Reports

Nick Dickinson, Mike Bowie, Tom Maxwell

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Conservation Biology (ECOL609) Project Reports:

Mt Grand Station – Wildlife Conservation

Mt Grand Station
(Photo: Nick Dickinson)

Edited by Nick Nick Dickinson, Mike Bowie, Tom Maxwell

Department of Pest-Management & Conservation,
Lincoln University, PO Box 85084, Lincoln 7647

Email: Nicholas.Dickinson@lincoln.ac.nz

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Introduction

This document is a collection of reports from students of ECOL609 Conservation Biology (Semester 1, 2023). The aim of this course is to investigate the challenges and future options for nature conservation management within the agricultural and policy framework and the landscape mosaic of the New Zealand High Country. The focus of the course this year was a case study of the Lincoln University's High Country Station in Hawea, Central Otago. A 4-day residential field course was attended by more than 30 students with the support of five academic staff from the Faculty of Agriculture and Life Sciences and the Farm Manager.

This paper typically attracts students from several different disciplines and postgraduate study programmes, mostly Masters programmes. Overseas students accounted for a large proportion of the group, particularly from our Master of International Nature Conservation (MINC) joint programme with University of Gottingen in Germany, together with a good number of New Zealand students from various postgraduate study programmes including MINC. Overseas visitors were from a diverse range of countries including USA, Sweden and Kazakhstan.

Each student identified and developed their own research project that formed the practical component of the course. Although these were individual research projects, much value was placed on broader learning, sharing of knowledge, discussion, debate and teamwork. The breadth of research topics reflects the varied interests of the students, but all projects have a primary focus on some aspect of Conservation Biology at Mt Grand. These reports provide an original and unique contribution to knowledge of the agroecology of this beautiful landscape and, in our view, fully justify their collation.

We thank our colleagues Assoc. Prof. James Ross, Senior Tutor Jennifer Gillette and Mt. Grand Farm Manager Rick McNeilly for bringing their skills, supervision and enthusiasm to the fieldwork. We acknowledge the support of the Dean of the Faculty, Prof. Jim Morton, who encouraged the fieldwork and commissioned this report in the interests of further knowledge and research and teaching activity at this Lincoln University Farm. We are grateful to Fiona Bellinger for copy editing and collating the reports.

Nick Dickinson and Mike Bowie, Department of Pest Management and Conservation
Tom Maxwell, Department of Agricultural Science.
(August 2023)

Chapter 1: Native Species in Grazed Areas at Mount Grand Station

Katharina Schmidt

Abstract

Across New Zealand, stock animals graze upon native landscapes. The impact of this grazing on native species, including their survivorship and reproduction, as well as the impact on the overall health of the native landscape is not well studied. At Mt. Grand Station, merino sheep and cattle graze across a variety of habitats including managed meadows at lower elevations and native tall tussock grasslands at higher elevations. Our aim was therefore to determine the species composition at several grazed areas across the station and to determine the grazing pressure on specific species within the tussock grassland landscape. Across Mt. Grand Station, data was collected at three grazed areas of varying elevation. Native species percent cover was found to increase with elevation. Three 1m^2 quadrats were sampled in a managed meadow at 550m elevation which was dominated by exotic species and had no native plant cover. Two 30-meter transects were subsequently sampled, the first at 820m and the second at 1140m. 17% of cover at the first transect was made up of native species, and 87% of the second transect was native. A visual assessment of grazing damage to native species was conducted in the tussock grassland at 1140m. Varying degrees of damage to native species were found demonstrating a clear preference by sheep for specific species over others. Two threatened species were found to be impacted by grazing.

Key words: Grazing, Native Species, Tussock Grassland, Conservation

1.1: Introduction

Farming in the high country of New Zealand sees stock animals grazing on a variety of landscapes ranging from highly-managed meadows sown with exotic species to unaltered native habitat that is made available to stock. Because New Zealand ecosystems did not evolve alongside mammalian grazers, the impact of introduced grazers is not yet entirely understood. Biodiversity conservation in agricultural landscapes is generally understudied (Antonelli et al., 2010).

At Mt. Grand Station, fine merino sheep and cattle graze across a variety of habitats. At lower elevations managed meadows dominate while at higher elevations sheep graze in native tall tussock grasslands. Many tussock grasslands across New Zealand are degraded and have faced invasion by herbs in the *Hieracium* genus (Treskonova, 1991). This degradation has been attributed to vegetation clearing, burning, and high intensity grazing (Steer, 2012).

Although grazing is known to contribute to the degradation of tussock grasslands in New Zealand, conclusions derived from studies on this topic are not always straightforward. Some studies have shown that grazing contributed to the loss of tussock cover and the invasion by Hieracium or that tussock recovers after the pressure of grazing is removed (Lee et al., 1993; Rose & Platt, 1992) while others determined a more complex interaction of factors taking part (Meurk et al., 2002; Rose et al., 1995). The variable effects of grazing on tussock landscape that have been observed could be due to a variety of reasons including the unique conditions at the site such as the diversity of species present, the number of sheep stocked at the site, the number of rabbits and other herbivores present, and even variation in behavior between different sheep species and unique herds (Meurk et al., 2002; Oom et al., 2008; Steer, 2012).

Because the impact of grazing herds on tussock grassland can vary and alpine grasslands often experience an ecological time lag effect that makes it difficult to determine the immediate impact of stressors, it is best to approach the conservation of grazed tussock landscapes with caution as possible negative impacts may not be immediately felt (Steer, 2012). If an area is continuously overgrazed resulting in declines in threatened species or higher likelihood of invasion by exotic species interventions may come too late.
The aim in our assessment of Mt. Grand Station was to determine the species composition across various grazed areas at differing elevations with particular interest in determining the percent cover of native species and to determine grazing pressure on specific native species.

1.2: Materials and Methods

A mixed method approach was used to assess vegetation cover at various grazed areas at Mt. Grand Station over the course of two days. Data was collected at three 1m^2 quadrats as well as along two 30-meter transects (Figure 1.1). In addition to percent cover, a visual assessment of the impact of grazing on native plants was also carried out at the top of the ridgeline near Transect 2

Data were first collected on a highly managed, actively grazed meadow at 550m elevation (grazing intensity unknown). Three 1m^2 quadrats were laid out at random locations at the upper end of the meadow (given the preference of fine-wool merino sheep for higher elevation areas (Steer, 2012) and vegetation percent cover was visually assessed for each species.

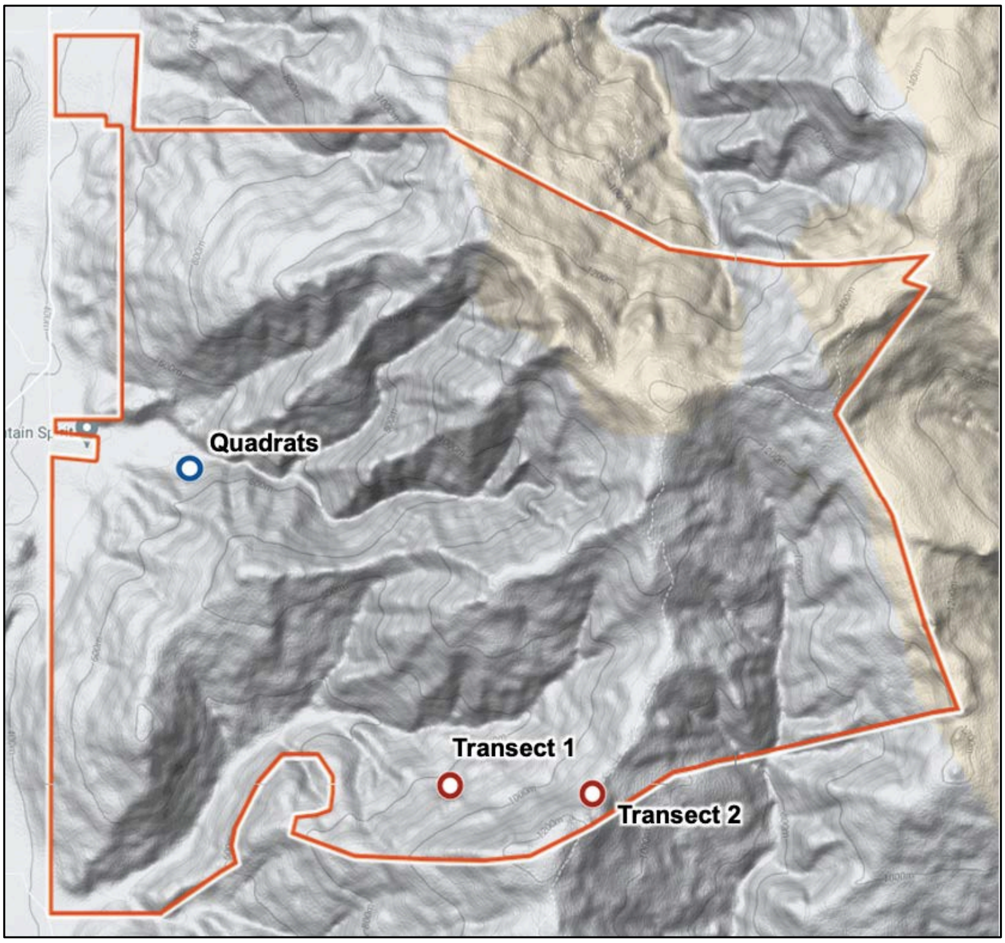

Figure 1.1: Data collection locations at Mt. Grand Station (perimeter shown in orange).
Three quadrats were sampled on a meadow near Hospital Creek (in blue) and two 30-meter transects were collected on the hillside and near the top of the ridgeline (in red).

Two 30-meter transects were sampled the following day. Transect 1 was located in an overgrown grassy clearing on a west-facing slope at 820m height surrounded by patches of Kānuka (*Kunzea ericoides*). Although this area did not seem to be actively grazed by stock, evidence of past grazing was observed. Transect 2 was located in a tall tussock grassland further up the same mountain on a west-facing slope right near the top of the ridgeline at 1140m. The area was actively grazed by 600 fine-wool merino sheep cycled through on a three-week interval. No stock were observed at any of the sites during data collection (Table 1.1).

After a meter tape was laid out along the path of the transect, data was recorded at 1m intervals starting at 0m and ending at 29m for a total of 30 points (Figure 1.2). A straight, long stick was used as a dowel and dropped at every sampling point along the transect. All plants that touched the dowel were recorded and photographed and ground cover was collected at every point.

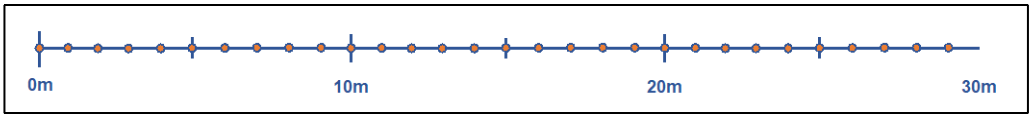

Figure 1.2: 30-meter transect sampling design.
Data was collected at 30 points along the transect starting at 0m and ending at 29m.

At the top of the ridgeline where Transect 2 was sampled a visual assessment of some of the native species was conducted to determine the variable impact of grazing. An area of roughly 1,000m^2 was searched and grazing damage to plants was photographed and noted down.

All species were subsequently identified with the help of iNaturalist. Photos of various parts of each plant were taken and then uploaded to the iNaturalist website and the automatic species identification function was used to assign a genus and species (iNaturalist). The identities of most species were confirmed by experts on iNaturalist and are considered “research grade” observations. Four grass species could not be identified due to the lack of reproductive structures and are collectively referred to as “unknown” species. The conservation status, functional groups, and whether or not a species is considered native or exotic was assigned using data available on the New Zealand Plant Conservation Network website (NZPCN).

For the transects, percent cover per species was calculated by dividing the number of hits per species by the number of points sampled (30). This means any given species can have a maximum percent cover of 100%. When these cover values by species are added to each other, a cumulative cover value of over 100% is obtained for each transect, which mirrors the natural overlapping way in which plants grow at the site. Rather than displaying cumulative cover values over 100% when visualizing and discussing the cover of native versus exotic plants, values were scaled so as to add up to 100 for more intuitive understanding.

1.3: Results

The lowest elevation, highly managed meadow that was sampled was found to be almost entirely dominated by exotic species and not very species rich. A total of only five named species were found in the three quadrats sampled: *Trifolium repens*, *Verbascum virgatum*, *Marrubium vulgare*, as well as a *Malva* species and a *Circium* species; all of which are exotic. One unknown grass species was observed and could not be identified, but is very likely also exotic.

The most common species observed was white clover (*Trifolium repens)*, which had an average percent cover of 42% over all three quadrats. The *Malva* species and the unknown grass were the next most common (Table 1.2).

The two transects sampled varied quite markedly in their vegetation cover although their species richness was similar. A total of 13 unique species were found at Transect 1, seven of which were exotic, three of which were native, and a further three of which were unknown grasses. Transect 2 consisted of 11 unique species, one of which was exotic, nine of which were native, and one of which was an unknown grass. There was no overlap in species between the two transects (Table 1.3).

Overall, Transect 1 was made up of more exotic species, with 41% of cumulative vegetation cover consisting of exotics. Native plants were 17% of total cover and 42% of the cover was made up by three unknown grasses (Figure 1.3). The exotic grass *Agrostis capillaris* had the highest cover of all exotic species observed, with 60%. Two species of unknown grass also had very high percent cover at this location, with 73.3% and 50%. The native species with the highest cover was the fern *Pteridium esculentum* at 23.3% (Table 1.3). Transect 1 was quite dense: all points sampled were covered by vegetation with a cumulative cover of 303.3%.

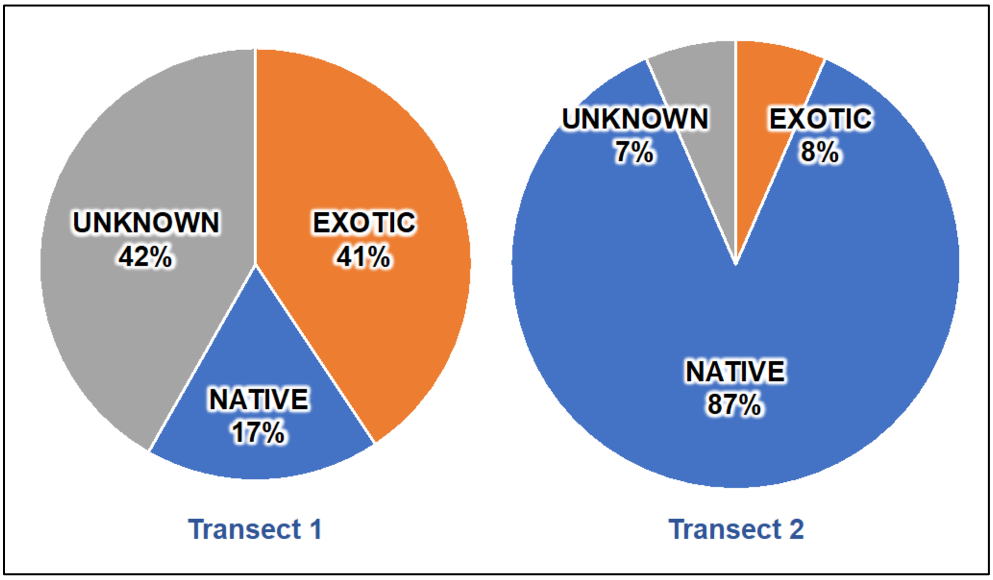

Figure 1.3: Percentage of transect cover represented by exotic species (in orange), native species (in blue), and unknown species (four unknown grass species, in grey) at the transects sampled at Mt. Grand Station.

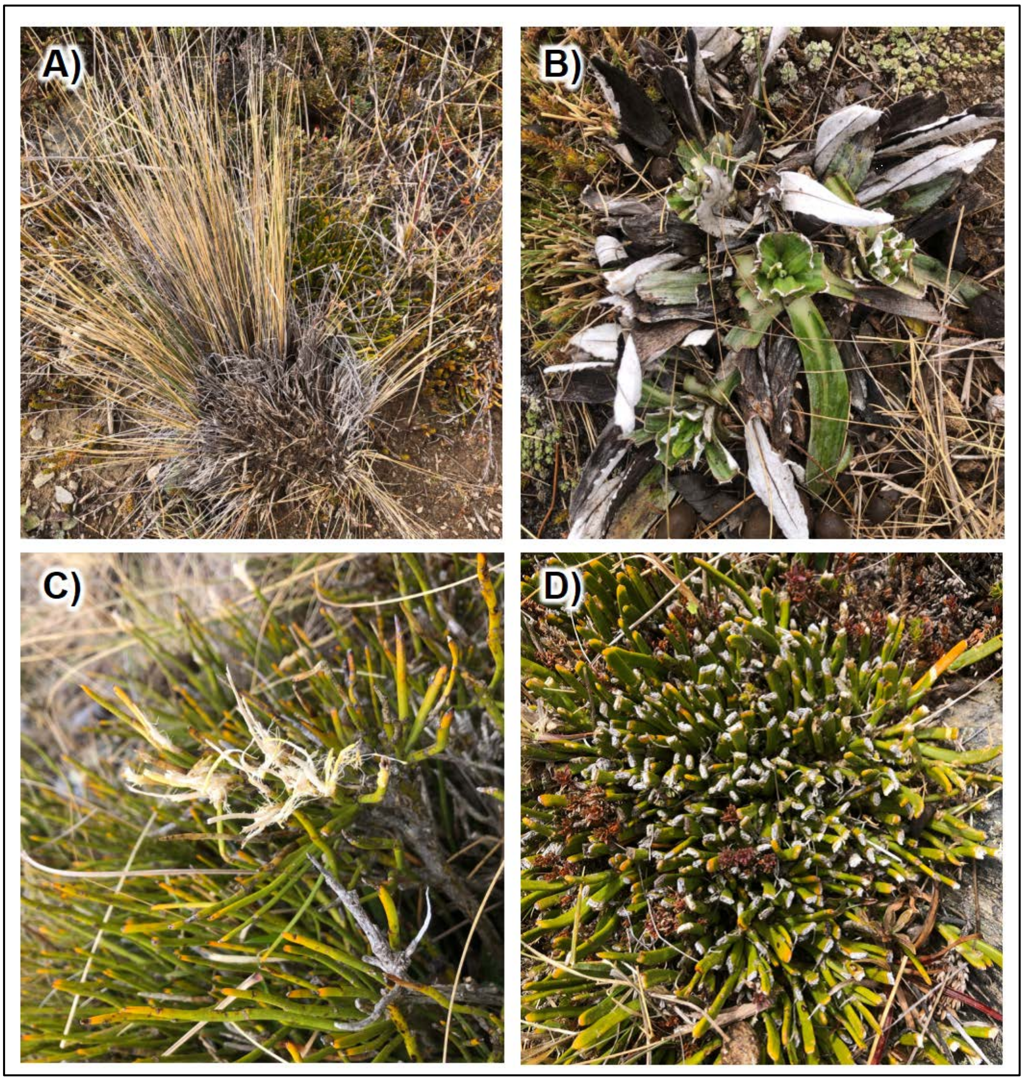

Figure 1.4: Grazing damage to various native species including A) Chionochloa rigida, B) Celmisia densiflora, C) Carmichaelia petriei, and D) Carmichaelia monroi.

The higher elevation tussock grassland area represented by Transect 2 had markedly more native species, with 87% of total cover made up of natives. 8% of cover comprised of exotic species while unknown plants contributed 7% (Figure 1.3). Most of the total cover was made up by the tussock grasses *Chionochloa rigida* with 36.7% cover and *Poa colensoi* with 33.3%. The low-growing shrub *Acrothamnus colensoi* was also quite common at 26.7% cover (Table 1.3). Vegetation at Transect 2 was significantly less dense than at Transect 1. 20% of points sampled were completely free of vegetation and cumulative cover was only 143.3%.

The visual assessment of grazing damage of the ridgeline near Transect 2 revealed a definite grazing preference for some species over others. Some species were not touched by the sheep such as *Acrothamnus colensoi* and *Aciphylla aurea* or rarely touched such as *Carmichaelia colensoi.* Some species seem to be preferred by the sheep and showed a lot of grazing damage. These include the tussocks *Chionochloa rigida* and *Poa colensoi*, and the shrub *Carmichaelia monroi*. Out of all species present, the herb *Celmisia densiflora* seemed most affected with all individuals sampled healvily impacted by grazing (Figure 1.4)

1.4: Discussion

Our results allow us to start to piece together some general trends regarding native species in grazed areas at Mt. Grand Station:

A high diversity of different types of grazed landscapes was observed at Mt. Grand Station. Generally, the percent cover of native species was found to increase with elevation at grazed areas across the station, which aligns with trends observed at other high country sites (Rose et al., 1995). At the lowest elevation managed meadows at 550m, only exotic species were found. At 820m the landscape started to incorporate more native species (17% of total cover was native) although the vegetation here was still dominated by exotic grasses such as *Agrostis capillaris.* Exotic species made up 41% of cover at this location while three unknown grass species made up the remaining 42% (Figure 1.3). Although these grass species could not be identified to genus level due to the lack of reproductive structues present, these species are most likely not native given their many stuctural similarities to other exotic grasses found on site and in New Zealand generally (Cosgrove et al., 2022). At 1140m, the landscape was dominated by tall tussock grasses and other alpine species – 87% of cover recorded here was made up of native species. The only exotic species found along Transect 2 was *Hieracium lepidulum* (which comprised 8% of total cover) although the unknown grass spotted here (7% of cover) was likely also exotic.

Although the tall tussock grassland ecosystem found near the highest elevations at Mt. Grand Station is fairly intact with a high percentage of native species and good amount of species diversity, the effects of grazing at this location are very apparent. At Transect 2, 20% of points sampled were entirely devoid of vegetation cover, which is at the upper end of the range of bare ground observed in other grazed tall tussock grasslands (Steer, 2012). There are also clear signs of sheep camping on the ridgeline at this location due to high amounts of droppings interspersed among the tussock grasses, which can negatively impact the habitat over time due to disruptions to the nutient cycle (O'Connor et al., 2000).

Sheep are known to graze selectively in comparison to larger stock animals such as cows, and will have varying impact on specific species in a given area (López et al., 2003). This effect was also observed at Mt. Grand, where certain species were left entirely untouched while others were heavily grazed. As expected, certain unpaletable, tougher species such as *Aciphylla aurea* and *Acrothamnus colensoi* were not observed to be impacted by sheep at all. Tussock grass species including *Chionochloa rigida* and *Poa colensoi* were generally quite heavily grazed, with many tussocks at the ridgeline significantly reduced in volume compared to tussocks found in ungrazed habitat. Because tussock grasses dominate this vegetation type (contributing 51% of total cover, Figure 1.5), the high amount of individuals present likely dilute the negative impact of grazing on these species overall. The most heavily impacted species at the ridgeline was *Celmisia densiflora*. Every single individual that was documented in the observational area was eaten down to about 1-3 cm off the ground (Figure 1.4). Although *Celmisia densiflora* is heavily grazed at this location, this particular species is neither endemic nor threatened (NZPCN), lessening the overall impact on the species. On the other hand, two further species found on the ridge, *Carmichaelia monroi* and *Carmichaelia petriei,* have been listed as at risk/declining since 2018 (NZPCN). Of these, *Carmichaelia petriei* was only found to be sparsely damaged by grazing while *Carmichaelia monroi* was moderately impacted. However, since these species are at risk, any grazing impact to them should perhaps be more carefully considered than that to plants that are comparatively more common.

High grazing pressure can have negative impacts on survivorship and reproduction of plant species, especially for species like *Chionochloa rigida* which rely on seed dispersal during mast years for reproduction (Jensen et al., 1997; Mark & Dickinson, 2003). Lower proportions of seedlings and juveniles have been observed in grazed compared to ungrazed areas (Rose et al., 1995). However, there is a lot of variation between studies showing grazing impact on particular species (Cockayne, 1920; Wraight, 1964). Different herds seem to have varying preferences in regards to plant species and grazing preference also depends on the overall availablilty of plants at a site (Steer, 2012). Although we can definitely conclude that there is clear variation in grazing pressure for certain species over others at this particular location, given the lack of data across time and locations it is diffcult to assess the true impact of varying grazing pressure on native species at Mt. Grand Station.

1.5: Conclusion

Mt. Grand Station was found to contain a diversity of different grazed areas. Overall, trends matched those observed at other high country sites with higher elevations found to have a higher percent cover of native plants than lower areas.

Grazing pressure by species was found to be variable at this highest elevation site, with sheep showing clear preference for certain species over others. Various native species including two species considered threatened in New Zealand are experiencing moderate to high impact.

However, due to the limited time frame of the study, no further locations could be sampled nor could data be collected over time which severely limits the conclusions we are able to make. Therefore although general trends can be hinted at, the effects of intense grazing on specific species and overall health and quality of tall tussock grassland remains unknown.

Given the extremely high grazing impact on specific native species as well as evidence of moderate to low grazing pressure to certain threatened species observed at Mt. Grand Station, a more in-depth monitoring effort is highly suggested. With careful monitoring we can determine if the amount of stock currently grazed at the highest-elevation areas is negatively impacting the native vegetation at the site and can adjust grazing schedules to balance out agricultural needs with conservation outcomes.

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1.7: Appendix

Table 1.1: Metadata for data collection locations at Mt. Grand Station.

DATE SAMPLED	ITEM NAME	COORDINATES		SLOPE	ASPECT	ELEVATION
dd/mm/yy	name	lat	long	degrees	degrees	meters
20/3/23	Quadrat 1	-44.65125	169.32327	Flat	NA	550
	Quadrat 2	-44.65146	169.32323	Flat	NA	550
	Quadrat 3	-44.65162	169.3232	Flat	NA	550
21/3/23	Transect 1	-44.66861	169.34364	32	300	820
	Transect 2	-44.66922	169.35417	28	267	1140

Table 1.2: Percent cover data from the three 1m^2 quadrats collected.

DATE SAMPLED	QUADRAT	SPECIES NAME	NATIVE OR EXOTIC	COVER
dd/mm/yy	Quad 1, 2, 3	scientific name	exotic, native, or unknown	in percent
20/3/23	Quadrat 1	Trifolium repens	exotic	25
		Circium species	exotic	3
		Verbascum virgatum	exotic	3
		Marrubium vulgare	exotic	1
		Unknown grass	unknown	0.01
		Malva species	exotic	0.01
20/3/23	Quadrat 2	Trifolium repens	exotic	55
		Unknown grass	unknown	25
		Malva species	exotic	1
20/3/23	Quadrat 3	Trifolium repens	exotic	45
		Malva species	exotic	20
		Unknown grass	unknown	6

Table 1.3: Percent cover data by species from the two 30-meter transects that were sampled. Cover is a percentage based on the number of hits per species divided by the total number of points sampled per transect.

DATE SAMPLED	TRANSECT	SPECIES NAME	NATIVE OR EXOTIC	COVER
dd/mm/yy	1 or 2	scientific name	exotic, native, or unknown	in percent
21/3/23	Transect 1	Agrostis capillaris	exotic	60.0
		Anthoxanthum odoratum	exotic	16.7
		Dactylis glomerata	exotic	30.0
		Lotus peduncultatus	exotic	3.3
		Rosa rubiginosa	exotic	6.7
		Trifolium repens	exotic	3.3
		Vicia satvia	exotic	3.3
		Discaria toumatou	native	13.3

		Muehlenbeckia australis	native	16.7
		Pteridium esculentum	native	23.3
		Unknown grass 1	unknown	50.0
		Unknown grass 2	unknown	3.3
		Unknown grass 3	unknown	73.3
21/3/23	Transect 2	Hieracium lepidulum	exotic	10.0
		Aciphylla aurea	native	3.3
		Acrothamnus colensoi	native	26.7
		Carmichaelia petriei	native	13.3
		Celmisia gracilenta	native	3.3
		Chionochloa rigida	native	36.7
		Coprosma petriei	native	3.3
		Pentachondra pumila	native	3.3
		Poa colensoi	native	33.3
		Styphelia nesophila	native	10.0
		Unknown grass 4	unknown	10.0

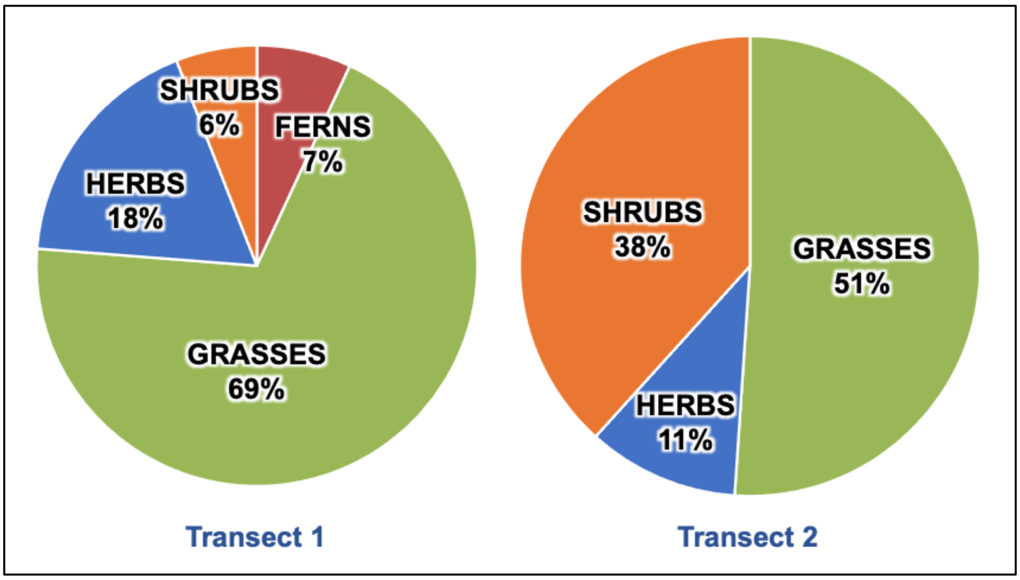

Figure 1.5: Breakdown of total percent cover sampled at Mt. Grand Station split up by functional group.

Chapter 2: Unique Flora of Conservation Status

Quinn O'Halloran

Abstract

New Zealand's high country environment has a unique flora which face significant threats, particularly from agricultural pressures. This report focuses on the presence and distribution of threatened plant species found at Mt Grand, while emphasizing the importance of protecting these species for conservation management and potential agricultural benefits. A number of Threatened and At Risk native species were identified throughout Mt Grand, many located within Hospital and Lagoon Creek which demonstrates the effectiveness of conserving areas of natural value. Some were also distributed throughout the wider pastoral land, suggesting Mt Grand is provides suitable habitats for threatened species. There is the potential to reintegrate these species throughout the wider farm area to improve overall ecological quality and farming practices of Mt Grand. Conservation can occur on agricultural landscapes if properly understood, through protecting threatened native plant populations there is the potential to provide mutually beneficial outcomes for both conservation and agriculture. This could be carried out through propagation or expansion of DOC managed land in order to protect vulnerable and endangered species such as *Olearia fimbriata* or *Hebe cupressoides*. Reintegration of the threatened species which are still relatively common, such as kanuka, matagouri, or *Carmachaelia* species would be advantageous to the Mt Grand agricultural system, due to their nitrogen-fixing properties. While simultaneously enhancing native biodiversity and potentially reducing threat status on a national scale. Through such practices, protection of threatened plant species at Mt Grand could not only enhance New Zealand's unique flora, but also allow conservation and agricultural needs to sustainably coexist.

Key words: Threatened, At Risk, Conservation, Agriculture.

2.1: Introduction

New Zealand has a highly unique flora. it is believed that of the 2,500 vascular indigenous plants, around 82% are endemic (de Lange *et al*., 2010; Ministry for the Environment, 2021). A significant proportion of these plants are under some form of threat, ranging from habitat loss particularly due to land conversion for agriculture, grazing, weed encroachment or lack of legal protection (Dopson *et al*., 1999). This high level of endemism and threat of extinction makes conservation management of New Zealand's plants critical.

Mt Grand, located in Central Otago, South Island, is a 2,127 ha high country pastoral farm operated by Lincoln University. The primarily west facing property is spread over altitudes from 400 to 1,400 metres above sea level, where the alpine environment extends into the high country environment (Kelly & Smith, 2012). Mt Grand underwent a tenure review process in 2005, which saw 530 ha of land transferred to the Department of Conservation due to its high conservation value. Surveys of the area found a number of rare and threatened plant species distributed throughout Hospital Creek, Lagoon Creek, Grandview Tops and Bluenose (Department of Conservation, 2006). With the intensification of threats to indigenous vascular plants, there has been an increase in the number of threatened or at-risk plants which can be found at Mt Grand today and were not previously listed in the tenure review; including those which are Nationally Endangered, Vulnerable or Declining.

The presence of these species indicates that Mt Grand offers a suitable habitat for the survival of nationally and local threatened indigenous plants (Wei & Maxwell, 2022). Many of the identified species are located within DOC managed land, suggesting the success of conserving areas of value. This raises further opportunities to protect the threatened flora throughout the adjacent pastoral land, or for restoration practices for reintegration of these plants to the wider Mt Grand area. The restoration of native plants, particularly those which are threatened, has been proven to increase biodiversity and provide many ecosystem services which may be mutually beneficial for agricultural landscapes and conservation of Mt Grand's unique flora (Franklin *et al.*, 2015). The aim of this report is to identify the presence of threatened or at risk plants in the Mt Grand area, while investigating the necessity and opportunity of protecting species of high conservation value.

2.2: Materials and Methods

During a two-day field course with the ECOL609 Conservation Biology class, observations of Mt Grand's flora and fauna were recorded and uploaded to iNaturalist. To begin the investigation of threatened plant species, the observations were filtered out by vascular plants within the Mt Grand area and entered into the NZTCS to determine threat status. The conservation status of New Zealand's indigenous vascular plants, 2017 report was additionally examined to assess the threat status (de Lange *et al*., 2017). Five species were classified as At-Risk – Declining, these included: *Discaria toumatou* (matagouri), *Leptospermum scoparium* (manuka), *Raoulia australis* (golden scabweed), *Carmachaelia petriei* and *Carmachaelia monroi*. Two were classified as Threatened – Nationally Vulnerable, including *Kunzea ericoides* (kanuka) and *Olearia fimbriata*. Lastly two were classified as Threatened – Nationally Endangered, including *Hebe cupressoides* and *Mazus novaezeelandiae* supsp. *Impolitus*. The coordinates of these observations were overlayed on Google Earth to produce 3D satellite maps of their distribution across Mt Grand. The observations were taken within Hospital Creek, Grandview Tops, Bluenose and Lagoon Creek, as this was the route taken during the field course. Therefore, the displayed points are a representative sample of where each of these species can be found but does not exemplify the full distribution. Hospital Creek and Lagoon Creek are managed by the Department of Conservation, Grandview Tops and Bluenose are located on the Lincoln

University owned pastoral land. Relevant scientific literature and resources have been reviewed as part of this desk study to understand specific properties of the listed species and how they could be further conserved or utilised to provide benefits to the Mt Grand agricultural system.

2.3: Results

Figure 2.1 shows the distribution of *Hebe cupressoides*, kanuka, *Olearia fimbriata,* and *Mazus novaezeelandiae* within the Mt grand area. Most of the observations were found on west to south-west facing slopes. *Hebe cupressoides* was found at an altitude of 593 metres within Hospital Creek and kanuka was found between 460-900 metres, both within Hospital Creek and surrounding pastoral land. The exact position of *Olearia fimbriata* and *Mazus novaezeelandiae* has been obscured on iNatualist due to the current threat statuses, however they have been included in the map to illustrate their presence at Mt Grand. Personal observations can locate *Olearia fimbriata* within Hospital Creek.

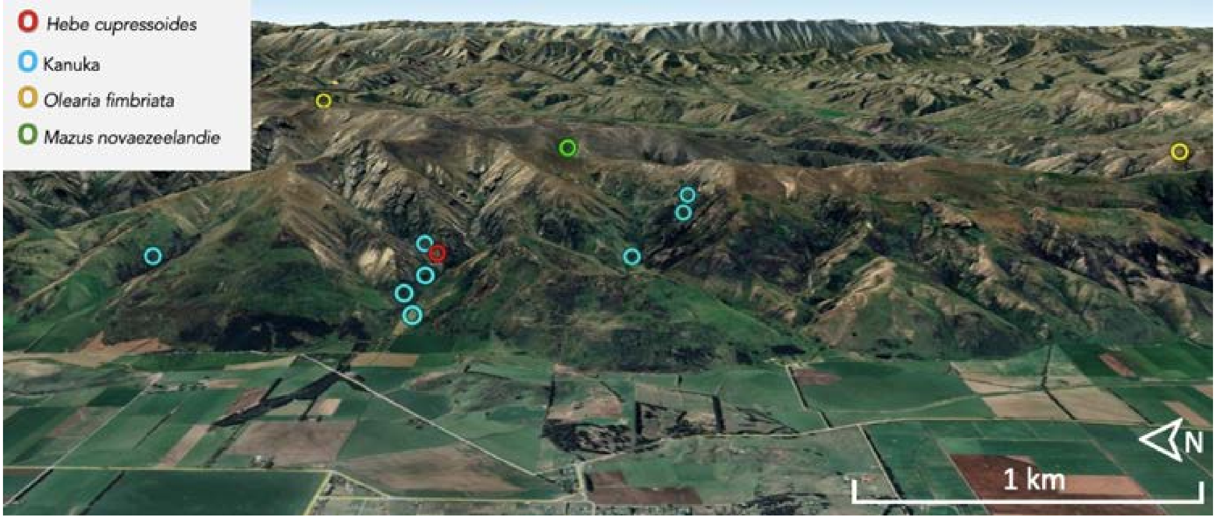

Figure 2.1. 3D satellite map showing the distribution of Threatened – Nationally Endangered species: Hebe cupressoides (red) and kanuka (blue) and Threatened – Nationally Vulnerable species: Olearia fimbriata (yellow) and Mazus novaezeelandiae (green) at Mt Grand Station, Central Otago, South island, NZ.

Figure 2.2 views Mt Grand Station from the west and shows the distribution of matagouri, manuka, golden scabweed, *Carmachaelia petriei* and *Carmachaelia monroi*. Most of the observations were located predominantly on west to south-west facing slopes, throughout Hospital Creek, Lagoon Creek and Bluenose with some distributed across the wider Mt Grand area. Matagouri was widespread across Mt Grand and was found between altitudes of 480-1,300 metres. Similarly, manuka was found between 500-1,000 metres. Golden scabweed was found between 900-1,000 metres, *Carmachaelia petriei* was found between 500-1,120 metres and *Carmachaelia monroi* was found around 1,100 metres.

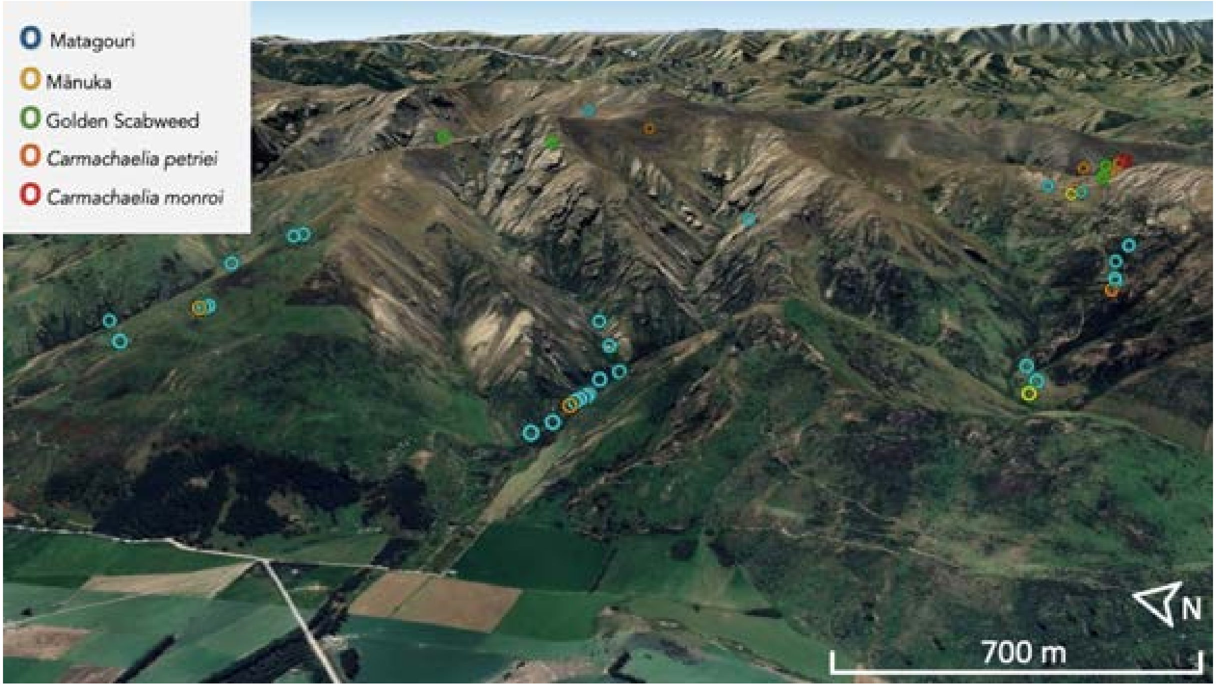

Figure 2.2. 3D satellite map showing the distribution of At Risk – Declining species: matagouri (blue), manuka (yellow), golden scabweed (green), Carmachaelia petriei (orange), Carmachaelia monroi (red) at Mt Grand Station, Central Otago, South Island, NZ.

2.4: Discussion

Mt Grand, like many high country landscapes, is constrained by soil infertility, low pH and dominated by exotic species which offer higher foraging value (Wei & Maxwell, 2022). The intensification of agricultural pressures in order to remain economically viable has disrupted the ecological quality, particularly through intense oversowing and topdressing of modified pastural land (Department of Conservation, 2006). Previous research has shown that native plant species are better adapted to these conditions and are efficient nitrogen fixers, which offers the potential of improving overall soil quality if reintroduced and appropriately managed (Franklin *et al.*, 2015; Wei & Maxwell, 2022). There are opportunities within the landscape of Mt Grand to reintegrate or conserve threatened native species, contributing to New Zealand's conservation management plans as well as providing benefits to the agricultural system.

The threatened and at-risk species identified at Mt Grand, suggests there is a degree of compatibility or tolerance of the specific ecology and habitat types of the area. The majority of the Threatened species were found within Hospital Creek, demonstrating the success of protecting areas of significant indigenous vegetation (Central Otago District Council, 2013). While kanuka appeared to be abundant and widespread throughout the farm, on a national scale it is vulnerable of extinction. The ecologically and economically important tree provides habitat, land stability, carbon sequestration and stock shelter (Heenan *et al*., 2022), showing the need for protection. Assisted planting of kanuka throughout Mt Grand as a conservation strategy, would not only provide shelter for sheep and increase the foraging availability of pollinators (Hart, 2007) but also create a more diverse landscape and prevent erosion in steep areas that are unproductive for farming. Thus, contributing to the conservation of indigenous biodiversity, while also supporting agricultural production services of Mt Grand. Similarly, there is the potential for propagation of *Olearia fimbriata* and *Hebe cupressoides* to provide similar benefits, being a research station owned by Lincoln University this is feasible.

The species listed as At Risk – Declining means the population numbers are dropping but the species is still moderately common (Townsend *et al*., 2008). The presence of the five at risk species at Mt Grand is reassuring that such plants are still present within the harsh alpine and intense agricultural conditions. Matagouri was abundant throughout all of Mt Grand although is commonly perceived as a weed and burned by farmers to create or maintain pasture. From an agricultural lens there are benefits to protecting matagouri, it is an efficient nitrogen fixing plant and can grow in relatively nutrient poor habitats. Thereby enriching the soils and facilitating the regeneration of other plant species which could potentially also be at risk (Department of Conservation, n.d.; Thomas & Spurway, 2001).

Carmachaelia are also among the few native nitrogen-fixing species and have likely contributed to natural succession processes by colonising open or disturbed sites, thus, providing benefits to coexisting plant species and ecosystem development (Bellingham *et al*., 2001). Although they appear to be preferentially grazed by stock and pest species, they could provide a valuable component to Mt Grands pastoral system if protected or reintegrated (Wei & Maxwell, 2022). Most of the At Risk species were distributed throughout the entirety of Mt Grand, suggesting the potential for such species to coexist with high country landscapes and systems. This knowledge provides opportunities for population establishment in similar habitats throughout New Zealand to expand their range and reduce current threat statuses.

2.5: Conclusion

Mt Grand has been found to provide a suitable habitat for a number of threatened indigenous plants, many of which are located within protected areas managed by the Department of Conservation. The successful preservation of areas of value, opens up opportunities to extend protection to threatened flora throughout the adjacent pastoral land and reintegrate these species into the wider Mt Grand area. Conservation of these Threatened and At Risk species can have mutually beneficial outcomes for both conservation and agriculture, which offers the possibility to establish populations in similar habitats throughout New Zealand. Overall, assisting in range expansion and reducing current threat statuses. Mt Grand has the potential to serve as a model for balancing the conservation of New Zealand’s unique flora with local agricultural needs.

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2.7: Appendix

Table 2.1. Threatened and At Risk plant species of Mt Grand, including threat status, scientific and common names, and where they were identified.

Threat classification	Species	Notes
Threatened – Nationally Endangered	Hebe cupressoides	Listed in the Tenure Review. Found in Hospital Creek.
	Mazus novaezeelandiae supsp. Impolitus	Exact location obscured.
Threatened – Nationally Vulnerable	Kunzea ericoides (Kanuka)	Common throughout Mt Grand (DOC and pastoral land).
	Olearia fimbriata	Listed in the Tenure Review. Exact location obscured, personal identification in Hospital Creek.
At Risk - Declining	Discaria toumatou (Matagouri)	Common throughout Mt Grand (DOC and pastoral land).
	Leptospermum scoparium (Manuka)	Found in Lagoon Creek. Potentially planted, not naturally established in the area.
	Raoulia australis (Golden Scabweed)	Found throughout Grandview Tops.
	Carmachaelia petriei	Common throughout Mt Grand (pastoral land).
	Carmachaelia monroi	Found in Bluenose.

Chapter 3: Hawkweeds at Mt Grand: Species and Environments Prone to Invasions

Ella Purvis

Abstract

Hawkweeds are a highly invasive plant group comprising the *Pilosella* (syn. *Hieracium*) genus. In New Zealand, hawkweeds dominate vegetation in the South Island, particularly in tussock grasslands, including Mount Grand. Although ten hawkweed species have been recorded and naturalised in New Zealand, *Pilosella officinarum* is the most concerning as it is responsible for the loss of native species, decreased productivity, and degradation of grasslands. *P. officinarum* forms dense, tight prostrate patches and mats of plants that exclude and outcompete other plant species, including both indigenous and adventive species. This research aims to evaluate and investigate the dominant species and environmental conditions typically found within the distribution range of hawkweeds at Mount Grand, and how these factors noticeably influence abundance. The research involved fieldwork using quadrat sampling, observational data on land use and environmental conditions, and online literature analysis. Results showed that high abundances of hawkweeds in Mount Grand tend to be associated with snow-tussock grasslands and disturbed environments, predominantly from grazing and soil disturbances. Although results were expected, it is interesting to recognise that hawkweeds remain a 'problem plant' prevalent across landscapes at Mount Grand, even though biocontrol strategies were initiated more than 20 years ago. Other control strategies for hawkweeds include agricultural development, herbicides, and grazing management, which are integral due to hawkweed's adverse effects on the conservation and agricultural values at Mount Grand.

Key words: Hawkweeds, Invasive, Species, Environment, Conservation, Agriculture, Abundances, Control.

3.1: Introduction

Hawkweeds are a diverse group of small herbs from the Asteraceae family, comprising the Pilosella (syn. Hieracium) genus. Hawkweeds are invasive to New Zealand, particularly the South Island tussock grasslands (French, 2021; Steer & Norton, 2012). In New Zealand, hawkweeds dominate the vegetation on more than 500,000 ha of the South Island (Williams & Holland, 2007). Appendix A shows ten hawkweed species recorded and naturalised in New Zealand (Webb et al., 1988; Williams & Holland, 2007). The four most widespread species include *Pilosella officinarum* (formerly *Hieracium pilosella*) (mouse-ear hawkweed), *Hieracium praealtum* (king devil), *Hieracium caespitosum* (field hawkweed), and *Hieracium lepidulum (H. lachenalii)* (tussock hawkweed) (Espie, 1994; Hunter, 1991). However, *Pilosella officinarum* is the most concerning.

P. officinarum, commonly known as the mouse-ear hawkweed, can be distinguished by the long hairs on its foliage and yellow flowers (Figure 3.1). *P. officinarum* is well-established and competitive in the South Island tussock grasslands due to being strongly stoloniferous, causing rapid spread through stolons and rhizomes (Espie, 1994; Williams & Holland, 2007). *P. officinarum,* alongside other hawkweed species, poses significant conservation issues as they are renowned for forming dense, tight prostrate patches and mats of plants that exclude and outcompete other plant species, such as indigenous and adventive grassland species (Craighead, 2018; Espie, 1994; Hunter, 1991; McMillan, 1991; Williams & Holland, 2007). The Mount Grand Pastoral Lease Tenure review has identified hawkweeds as a 'problem plant'. Hawkweeds have obtained this name due to their adverse threats to ecosystem services, conservation values, biodiversity, productivity, grasslands, pastoral industries, and native plant species richness.

Figure 3.1: Visual aid for identification of P. officinarum
Note. From Hieracium pilosella (Mouse-ear Hawkweed) by P. Bendle, n.d. CitSciHub*.*

Much literature alludes to the influence of environmental factors driving hawkweed invasions. In particular, hawkweed invasions are associated with soil disturbances (e.g. grazing, burning, and clearing), which can result from natural, agricultural, and anthropogenic activities (French, 2021; Hunter, 1991; Steer & Norton, 2013). Importantly, soil disturbances create space within a landscape for hawkweed establishment. For example, the tussock grasslands in the South Island high country are highly disturbed, thus highly susceptible to *P. officinarum* invasions. It is suggested that *P. officinarum* spreads faster when grassland disturbances increase, with disturbed shrub and tussock grasslands representing the highest invasion probabilities (French, 2021). However, there is limited information on species associations of hawkweeds, such as species often found in abundance with hawkweeds.

The four main options for control management of hawkweeds include agricultural development, herbicides, biological control, and grazing management (Espie, 1994). Although hawkweeds became naturalised in New Zealand in the mid-1800s, and these control strategies are readily available, their issues and presence are still highly prevalent today (Bay of Plenty Regional Council, n.d.). Therefore, to understand what is influencing these hawkweed invasions at Mount Grand, this study intends to answer the following investigative research aim:

Aim: "To evaluate/investigate the dominanting species of *Pilosella* and/or environmental conditions where they are typically found within the distribution range of hawkweeds

(*Hieracium spp.)* at Mount Grand, and how do these identify factors noticeably that influence the abundance of hawkweeds?"

3.2: Materials and Methods

The study was conducted at Mount Grand, Hawea, to investigate the research aim. The investigative question was addressed through fieldwork, observational studies, and desk-study.

- At Hospital Gully, within Mount Grand Station, fieldwork determined the research aim through quadrat analysis. A $1m^2$ round quadrat was used to estimate species abundance and spread along a 5m transect. Five samples were taken every 1m using a $1m^2$ quadrat, alternating placement on either side of the transect. In these samples, the ground cover percentages of hawkweeds, pasture species, exotic weeds, bare ground, and any native species were estimated and recorded.

- Observational data of the surrounding area was recorded, considering land use type (e.g., pasture, paddocks, grasslands, walkways, etc.) and environmental conditions (e.g., surrounding vegetation, soil state, grazing, etc.). These results were transferred to Excel for further statistical analysis. The data was consolidated to generate the mean percent cover for more accurate and reprehensive results.

- Extensive literature analysis was conducted to support and/or contract the information found. Information regarding hawkweeds was found from online accessible peer-reviewed journal articles, including Google Scholar, CitSciHub, and JSTOR. Other resources included the Mount Grand Tenure review report, iNaturalist, and regional council webpages.

3.3: Results

During field observations, identification was crucial to understanding to allow for reliable observations. Due to the time of year, many hawkweeds were not in flower. Instead, the hawkweeds were typically present as flat rosettes with foliage (Figure 3.2). Understanding these visual characteristics was essential for further analysis into quadrat studies.

Figure 3.2: A typical P. officinarum at Mount Grand, forming prostrate rosettes of foliage, with very few in flower

Figure 3.3 shows the mean percent cover of species in quadrats with *P. officinarum* across all quadrat samples. Snow tussock was the most common species found in abundance with *P. officinarum*, present in an average abundance of 78% across all quadrats. Following is hares-foot treefoil, present in an average abundance of 9% across all quadrats, then clovers in an average of 7%. Other species present occurred at insignificant abundances (≤ 2%), thus not of interest for further analysis.

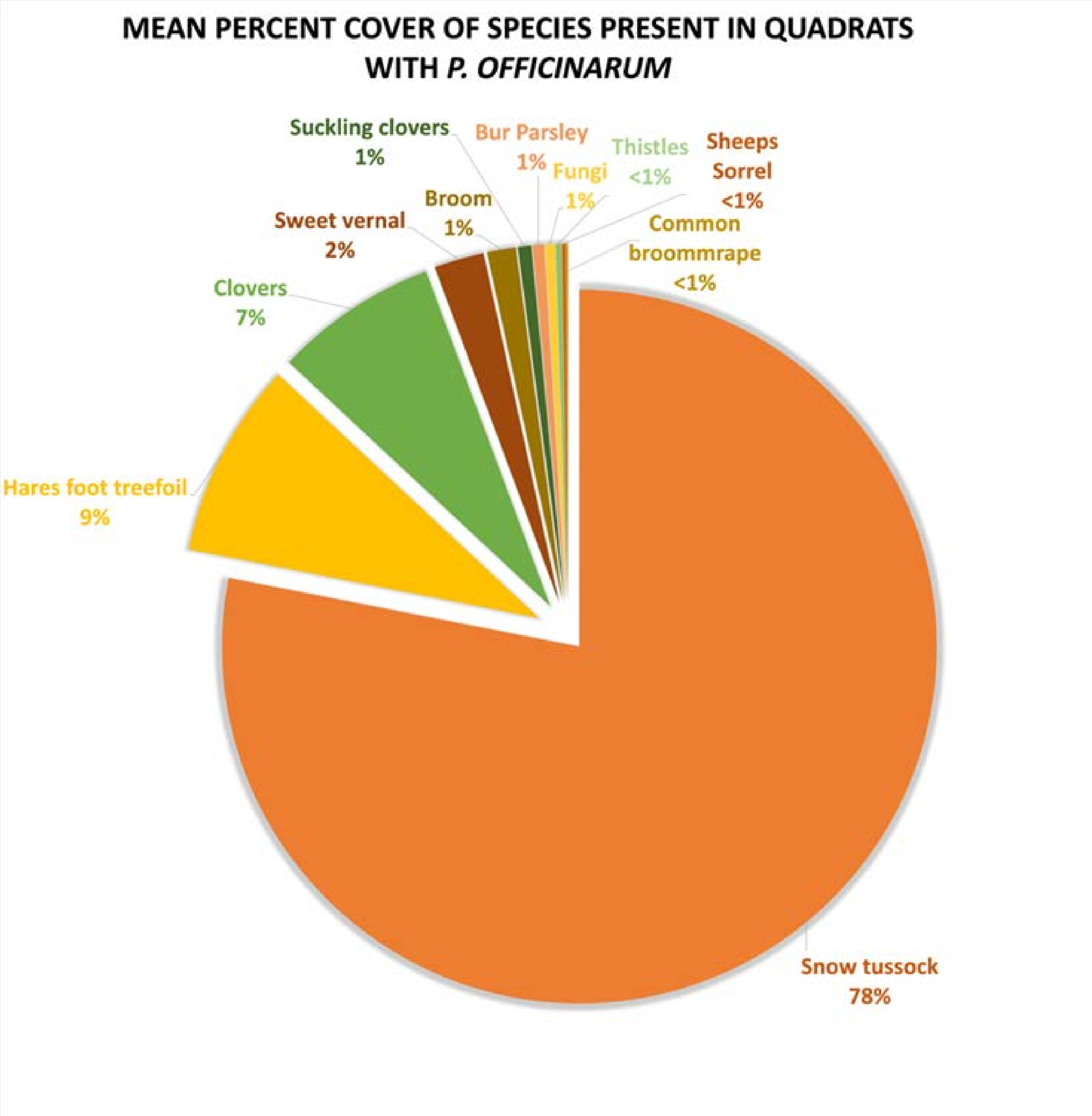

Figure 3.3: Mean % cover of species present in quadrats with P.

Table 3.1:The environmental conditions of the four sampling sites, presenting the land use, visual descriptions, and the generalised abundance of hawkweeds

Environmental conditions		
Land use:	Description of environment:	The abundance of hawkweeds:
Tracks/pathways	- Highly eroded soil	- High abundance
Bush	- Dominated by tall plant species and dense shrubs (native and invasive)	- Low abundance
Low altitude paddock	- Vast bare soil and low-stature vegetation	- Moderate abundance
High altitude paddock	- Highly grazed by sheep	- High abundance

Table 3.1 compiles information regarding the environmental conditions of the four sampling sites. Tracks/pathways and the high-altitude paddock presented the highest average abundance of hawkweeds.

The low-altitude paddock presented a moderate average abundance of hawkweeds, followed by the bush presenting a low average abundance of hawkweeds.

In addition to fieldwork and observational data, information concerning the research aim was consolidated from various online sources. These findings helped to strengthen and provide an understanding of what was observed in the field. From visually analysing areas within Hospital Gully, it was evident that hawkweeds were predominant across the landscape, consistently observed in abundance without the need to initiate deliberate search efforts. Due to the widespread distribution of hawkweeds, various plant communities were in association with the hawkweeds. This finding is consistent with observations in the 2006 Mount Grand Conservation Resources Report, claiming that:

“Hawkweeds occur throughout the property and all plant communities to some extent. Tussock hawkweed is the most widespread and prominent, with mouse-ear hawkweed common on the degraded lower and mid-altitude country with king devil hawkweed slightly less common.”

The review also stated that areas containing good snow tussock cover had high abundances of hawkweed present (Department of Conservation, 2006). Whilst grasslands composed of pasture grasses contained numerous introduced herbs, dry land grasses, clovers, and three species of hawkweeds (Department of Conservation, 2006). Although much older, these findings still present similar species and environmental conditions associated with the abundance and distribution of hawkweeds at Mount Grand today.

3.4: Discussion

Despite the short time in the field, the findings concerning hawkweed species relationships and distribution were as expected and consistent with abundant literature, making results easy to interpret and understand what was occurring. General observations were that hawkweed tended to predominate throughout the landscape. The majority of hawkweed observations were observed below 1000m above sea level. This finding is consistent with Hunter's publication in that this area is the central extent of hawkweed-dominant areas (1991). However, it is not uncommon to exceed this elevation, as observations were found much higher.

3.4.1: Species

Tussock grasslands represented areas of the highest hawkweed abundance, with snow tussock being the dominating species typically found within the distribution range of hawkweeds at Mount Grand. This result was expected as snow tussock occurs in tussock grasslands, in which *P. officinarum* is known to be well-established and competitive. Furthermore, several research papers allude to the fact that hawkweeds are a feature of tussock grasslands virtually everywhere (McMillan, 1991; Treskoova, 1991). For example, Day & Buckley found that hawkweed species were more likely to colonise and had higher rates of percent quadrat cover where short-tussock was more abundant (n.d.). Therefore, the presence of snow tussock obtaining the highest abundance of hawkweeds is expected.

3.4.2: Environment

It is well established that tussock grasslands are highly susceptible to hawkweed invasions and are the dominating environmental conditions influencing hawkweed abundance. Excluding tussock grassland, the dominating environmental conditions typically found within the distribution range of hawkweeds at Mount Grand were tracks/pathways and high-altitude paddocks. These two environments contained high levels of soil disturbances, thus, were expected to contain high hawkweed abundance, as hawkweed invasions are associated with disturbances (Day & Buckley, 2010; French, 2021; Steer & Norton, 2013). It is suggested that *P. officinarum* spreads faster when disturbances increase as the soil disturbances create space within a landscape for hawkweed establishment.

A high abundance of hawkweeds on the tracks/walkways was expected as they typically occur in areas of thin soil (Hunter, 1991). For example, the tracks/pathways were highly eroded by humans walking on them, disrupting the soil composition. This finding was consistent with Williams & Holland, as they found that sites colonised by *P. officinarum* in eastern Otago tended to be degraded, with a higher percent cover of bare ground and a lower cover of grass tussocks (2007).

On the other hand, the high-altitude paddock was currently highly grazed by sheep, and coincidentally, *P. officinarum* invasions are strongly associated with pastoral disturbances (grazing and burning) (Steer & Norton, 2012; Williams & Holland, 2007). Therefore, a high abundance of hawkweeds in the high-altitude paddock was expected as hawkweeds thrive in areas of depleted, open or hard-grazed unimproved grassland (Hunter, 1991). Grazing causes *P. officinarum* to increase the number and length of its stolons, thus aiding its spread (Day & Buckley, 2010). The ability to survive in these environments is linked to their adaptations. For example, *P. officinarum* can grow very low in heavily grazed areas, forming dense patches of prostrate rosettes. This adaptation makes it unobtainable for sheep, thus, avoiding sheep grazing (Treskonova, 1991). Therefore, *P. officinarum* survives and occupies the space provided as herbage becomes increasingly depleted.

The low-altitude paddock contained fewer hawkweeds and presented an average moderate abundance. This paddock was currently used for deferred grazing, with no grazing animals present, containing pasture with vast bare ground and low-stature vegetation. However, hawkweeds can take advantage of the altered disturbance regimen, allowing them to colonise the bare ground and explain the moderate abundance present.

The bush environment on either side of the tracks/pathways along the Hospital Gully track presented a low average abundance of hawkweeds. Either side of the track presented an extensive cover of tall tree species and large dense shrubs, native and invasives (e.g., matagouri, sweet briar, broom etc.). This result was expected but also unexpected. For example, *P. officinarum* is believed to remove moisture and nutrients from other plants, thereby choking out tussocks and taller vegetation (Treskonova, 1991). However, low-growing plant species, generally, are outcompeted by larger plant species through direct competition. For example, larger plants limit the amount of light available for the low-growing hawkweed species and nutrients due to extensive root systems (Steer & Norton, 2012). Therefore, adversely affecting the growth and survival of *P. officinarum.*

3.4.3: Relevance to conservation values at Mount Grand

Hawkweeds adversely affect the local environment, mainly by reducing the abundance of native species. Due to this, hawkweeds are a renowned nature conservation issue at Mount Grand and nationwide, as they are a conspicuous exotic element in areas trying to retain remnants of indigenous grassland ecosystems (McMillan, 1991). For example, in the South Island high country tussock grasslands, hawkweeds are present almost everywhere and are a severe problem to conservation values (Espie, 1994; Hunter, 1991); since many areas obtaining hawkweeds are conservation areas recommended for protection. Unfortunately, quantifying the environmental costs of tussock grassland degradation is difficult to estimate but can assume to be costly concerning costs relevant to the farming systems.

3.4.4: Relevance to farming systems at Mount Grand

Increasing hawkweed abundances impact conservation values at Mount Grand and the farming systems concerning economic, environmental, and ecological aspects. Over several decades, hawkweeds have caused concern among farmers, land management agencies, and conservation interests (McMillan, 1991). It is clear that grasslands face a decrease in productivity and are heavily degraded by hawkweed invasions (Hunter, 1991). Similarly, the ecology and diversity of Mount Grand are reduced, reducing native richness by forming dense mats to exclude other vegetation (Treskonova, 1991). Furthermore, hawkweeds can reduce pastoral production, adversely affecting local farm practices. For example, in 1994, the eventual cumulative gross annual revenue loss from pastoral production due to hawkweed invasions was estimated at $45 million (Espie, 1994). As a result, *P. officinarum* has been highly regarded as a threat, responsible for the loss of native species, the decrease in productivity, and the degradation of grasslands themselves.

Based on these environmental and ecological impacts, control is essential, such as agricultural development, herbicides, biological control, and grazing management (Espie, 1994). Biocontrol is the primary form of hawkweed control initiated in New Zealand. Several biocontrol agents were introduced to control hawkweeds in New Zealand, predominantly released between 1999 and 2002, which included the plume moth (*Oxyptilus pilosella*), gall wasp (*Aulacidea subterminalis*), gall midge (*Macrolabis pilosellae*), root-feeding hoverfly (*Cheilosia urbana*), crown-feeding hoverfly (*Cheilosia psilophthalma*), and Hieracium rust (*Puccinia hieracii* var. *piloselloidarum*) (Hayes, 2005; Landcare Research, 2020; Landcare Research, 2022). Appendix B provides additional detail regarding these biocontrol agents. However, it is crucial to recognise that these biocontrol agents all attack hawkweed species to varying degrees. Appendix C shows that the expected host range of agents can differ from preferred to least preferred host. Hayes's study found that the root hoverfly is the preferred host for all hawkweed species, including *P. officinarum* (2007). However, hawkweed biocontrol is less effective on the South Island than on the North Island. Therefore, for effectiveness, new control agents or new genotypes of the biocontrol agents already released or more significant releases of agents that failed to establish must be considered (Landcare Research, 2020).

Control raises economic impacts directly and indirectly. For example, in 1988, an economic evaluation of hawkweed biological control assessed the annual cost of lost production at up to $4.4m in 1988 dollar terms (McMillan, 1991). However, this estimate was conservative. Thus, the current economic impact of hawkweeds today would be astronomically more. Whereas managing reduced pastoral productivity, farmers may have to reduce stock numbers by as much as 30% to enable natural regeneration and more sustainable land use (McMillan, 1991). However, this faces extensive indirect costs from the loss of farming production. On the other hand, hawkweeds can be managed using sulphur fertiliser, as sulphur encourages legume growth, resulting in longer-term pastoral growth and providing competition for hawkweeds (Craighead, 2018). A 1992-2006 study found that pasture top-dressed with 56 kgS/ha every three years gradually reduced hawkweed cover over time when pasture was mown.

In the South Island, hawkweed densities have been reduced by 10%, predominantly attributed to changes in land management practices, such as irrigation, cultivation, and reduced grazing pressure, rather than biocontrol (Landcare Research, 2020). Coincidentally, grazing management is the most feasible control strategy for hawkweeds, which slows spread on low-input land and can be immediately implemented at a low cost (Espie, 1994). In addition to this, physical control, such as removing small patches of hawkweeds (disposing of rhizomes) and maintaining dense groundcovers such as shrubs, grasses, and clovers, can help prevent hawkweed from establishing (Environment Southland Regional Council, n.d.).

3.4.5: Limitations of the study

The study's primary limitation was the short duration of fieldwork and observations due to only obtaining one day in the field. Thus, the amount of information gathered is limited. Future studies can conduct more extensive analysis concerning abundances at different altitudinal gradients. Due to the limited amount of findings, literature analysis has provided helpful information to answer these knowledge gaps; however, it needs to be more of direct relevance to the unique environment at Mount Grand.

3.4.6: Value of findings and suggestions for future work

The value of these findings is significant, as despite most research being from over 20 years ago, this shows that hawkweeds are still an issue at Mount Grand today. From understanding what species and environments favour hawkweed invasions, local farmers can use this information to focus control strategies on reducing hawkweed abundance and, for example, focusing efforts on areas requiring control before other areas ranked in hawkweed abundance.

Although the value of findings is of little importance due to being consistent with serval publications, this study provides an updated analysis of hawkweeds at Mount Grand rather than the old version from the 20^{th} century. These findings provide a good starting point for more up-to-date research concerning hawkweeds at Mount Grand, allowing great potential for further essential work. For example, investigating deeper into invasion influences to strengthen the ability to control hawkweed populations successfully is significant; as Pat Garden said, “Unless we contain *Hieracium,* high country pastoralism is doomed” (Treskonova, 1991).

3.5: Conclusion

Based on extensive research in the field and literature analysis, high abundances of hawkweeds in Mount Grand tend to be associated with snow-tussock grasslands and more disturbed environments due to soil erosion and grazing. The results were expected due to consistency with reports in the literature. However, it is interesting to recognise that hawkweeds remain a 'problem plant' prevalent across landscapes at Mount Grand, even though biocontrol strategies were initiated more than 20 years ago. The snow-tussock grasslands and more disturbed environments prone to hawkweed invasions can be highly monitored and prioritised for control mechanisms at Mount Grand to reduce hawkweed abundance. In addition, these results can be used to establish a data inventory regarding hawkweed status as an invasive pest at Mount Grand and as a foundation for future research.

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3.7: Appendices

3.7.1: Appendix A

Table 3.2:The ten hawkweed species found in New Zealand, including their distribution and potential to be a significant weed problem.

Species	Distribution	Potential major weed problem?
Hieracium argillaceum (previously sometimes known as *H. praecox*)	Canterbury (Mt Torlesse and Lake Pukaki) Central Otago Roadsides, rocky places, waste land, in scrub, grassland and forest	Unlikely (rarely noted during map compilation)
H. aurntiacum orange hawkweed	Manawatu (Fielding), Nelson, Canterbury, Westland (Otira), Otago, Southland; Stewart Island (Halfmoon Bay) Wasteland, grassland, scrub, tussock grassland, roadsides, lawns, gardens, pastures	Unlikely (rarely noted during map compilation)
H. caespitosum field hawkweed (previously sometimes known as *H. pratense* and *H. piloselloides*)	Marlborough, Canterbury, Otago (Old Main Range) Grassland, scrub, tracksides, riverbanks, forest margins, roadsides, pasture	Yes (extensively recorded during map compilation, especially in Marlborough, Otago)
H. lepidulum tussock hawkweed (previously sometimes known as *H. lachenalii*)	Taranaki (Mt Egmont), Nelson, Marlborough, Canterbury, Otago	Yes (extensively noted during map compilation, especially in Marlborough and Otago)
H. murorum	Southern Ruahine Range, Canterbury (Hanmer Forest), Otago (Dunedin)	Unlikely (note noted during map compilation
H. pilosella mouse-ear hawkweed (previously sometimes known as *Pilosella officinarum*)	Rotorua, Volcanic Plateau, Lake Waikaremoana, Kaimanawa and Ruahine Ranges, Hawke's Bay, Marlborough, Canterbury, Westland (Douglas River), Otago, Southland Tussock grasslands, lawns, waste land, river terraces, roadsides, rock outcrops, pasture	Yes b far the worst species (very extensively noted during map compilation)
H. pollichiae spotted hawkweed	Marlborough (Dillon Stream), Canterbury (Hanmer Forest) Under beech and manuka/kanuka forest and exotic conifer plantations	Unlikely (not noted during map compilation
H. praealtum king devil hawkweed	Volcanic Plateau (between Tokoroa and Taupo), Nelson (Glenhope), Marlborough (Mt Richmond), Canterbury, Westland, Otago Grassland, scrub, stony sites, waste land, roadsides, pasture, occasionally in wet sites	Yes (extensively noted during map compilation, especially in South Canterbury, Otago)
H. sabaudum	Otago (Wanaka and Queenstown) Garden weed, waste land	Unlikely

Source: Names and distributions from Webb *et al.*, 1988.

Note. Retrieved from "The distribution of hawkweeds (Hieracium spp.) in the South Island, indicating problem status" by G.G. Hunter, 1991. Journal of the New Zealand Mountain Lands Institute, 48.

3.7.2: Appendix B

Table 3.3: List of weed biocontrol agents under investigation at Manaaki Whenua Landcare Research New Zealand suitable for controlling hawkweeds.

Hieracium crown hover fly (*Cheilosia psilophthalma*)	Crown feeder, released at limited sites as difficult to rear, thought unlikely to have established.
Hieracium gall midge (*Macrolabis pilosellae*)	Gall former, established but spreading slowly in the SI, common near Waiouru, where it has reduced host by 18% over 6 years, very damaging in laboratory trials.
Hieracium gall wasp (*Aulacidea subterminalis*)	Gall former, established and spreading well in the SI but more slowly in the NI, appears to be having minimal impact although it reduced stolon length in laboratory trials.
Hieracium plume moth (*Oxyptilus pilosellae*)	Foliage feeder, only released at one site due to rearing difficulties, did not establish.
Hieracium root hover fly (*Cheilosia urbana*)	Root feeder, released at limited sites as difficult to rear, thought unlikely to have established.
Hieracium rust (*Puccinia hieracii* var. *piloselloidarum)*	Leaf rust fungus, self-introduced?, common, causes slight damage to some mouse-ear hawkweed, plants vary in susceptibility.

Note. Adapted from “Who’s Who in the Biological Control of Weeds” by Landcare Research, 2022.

3.7.3: Appendix C

Table 3.4:The status of six weed biological control agents for hawkweeds (Hieracium spp.) in Southland, New Zealand and their expected host range.

5.3 Hawkweeds (*Hieracium* spp.)

The six hawkweed agents covered below are expected to attack the weedy hawkweed species to varying degrees (Table 8).

Table 8 Expected host range of hawkweed biocontrol agents (**preferred host, *less preferred host).

Hawkweed species	Crown hover fly	Gall midge	Gall wasp	Plume moth	Root hover fly	Rust
H. pilosella	**	**	**	**	**	**
H. praealtum	**	*		*	**	
H. caespitosum	**	*		**	**	
H. aurantiacum	**		**	*	**	
H. lepidulum	*			*	**	

Note. The root hover fly is the preferred host for all hawkweed species examined in the study, followed by the crown hover fly. However, all biocontrol agents examined are equally preferred hosts to target *H. pilosella* (mouse-ear hawkweed), the most concerning hawkweed in the South Island, including Mount Grand. Table retrieved from “Status of Weed Biological Control Agents in Southland” by L. Hayes, 2007*. Landcare Research New Zealand*.

Chapter 4: Kānuka Communities

Eva Saison

Abstract

Kānuka (*Kunzea ericoides*) is existent across Mount Grand station, on both farming land and land owned by the Department of Conservation. However, it is not fully understood how its presence influences the surrounding environment, or of the advantages kānuka communities may have for conservation and farming. This report aims to address this gap using knowledge from iNaturalist data and the literature. The results demonstrated multiple impacts of kānuka communities on the land affecting plants, wildlife, and livestock. Part of those effects acts positively toward the land purpose, whereas some others may be detrimental. On one hand, kānuka communities act against erosion and heat stress while being a habitat for wildlife and livestock. On the other hand, kānuka competes with and shades both production and conservation species. The observations in this report demonstrate the importance of the presence of kānuka communities in the Mount Grand station. Kānuka presence should thus be encouraged on DOC lands. Further research should also be pursued to determine the appropriate density of kānuka on farming land ensuring improved land management decisions in the future.

Key words: agriculture, conservation, kānuka, kanuka, *Kunza ericoides*, *Kunzea serotina*, communities, Mount Grand, Mt Grand

4.1: Introduction

Kānuka is an endemic tree species of New Zealand known worldwide for the therapeutic honey it produces (K. L. Allen et al., 1991; Brady et al., 2004; Chan-Zapata & Segura-Campos, 2021; Fingleton et al., 2014; Holt et al., 2015). Regarding kānuka scientific name, some papers refer to it as *Kunzea serotina* (*K. serotina*) whereas others refer to kānuka as *Kunzea ericoides* (*K. ericoides*). In 2014, de Lange divided the *K. ericoides* (Myrtaceae) complex into 10 species, including *K. serotina* and *K. ericoides*. The different species' names were then used in the literature, until 2023, when Heenan *et al.* re-evaluated the *K. ericoides* (Myrtaceae) complex based on genetic analysis. Their results re-established the presence of a unique species of kānuka: *K. ericoides* (Heenan et al., 2023). All 10 species described by de Lange were *K. ericoides* organisms; their observed differences were due to environmental pressure (Heenan et al., 2023).

K. ericoides is transitional vegetation from open land to native forest (Harris et al., 2004; Lloyd, 1960; Mirams, 1957; Pook, 1978; Ross et al., 2009). During that time, various species are thus in contact and navigate around kānuka. They will form a community around each kānuka, creating kānuka communities in the environment. As a matter of fact, a community is described as "all of the organisms in a prescribed area" (Roughgarden & Diamond, 1986). These communities may have an impact on the ecology of that area and the conservation of the species belonging to them. Thus, it is crucial to study kānuka communities.
At Mount Grand, understanding the impacts of kānuka communities on the environment would be beneficial for both farming and conservation lands. This would facilitate future decision-making on kānuka for projects aimed at achieving the respective objectives of these lands. The present study aims to determine the influence of kānuka communities on their surrounding environment and their potential roles in conservation and farming.

4.2: Materials and Methods

Mount Grand Sstation, the study area, contains both land owned by the Department of Conservation (DOC) and land used for farming (Katzenberger, 2016). Since 2016, students from Lincoln University (Canterbury, New Zealand) regularly visited Mount Grand during field trips. However, I was unable to visit the site. Over the years, numerous photographs of observed organisms were taken and uploaded to iNaturalist (*Mt Grand Biodiversity*, 2023) to be identified. Although kānuka observations were registered to iNaturalist, there was no observation of other species in the direct surroundings of kānuka. It was therefore impossible to determine kānuka community's composition via this method. The use of iNaturalist data for this study was hence limited. In addition to evaluating these data, a review of relevant literature has been conducted. The websites of DOC and Landcare research were consulted. Although, as they are more dedicated to the public, access to precise scientific information was difficult and no relevant information was retrieved from those websites. Therefore, the bibliographic work was conducted using the University of Lincoln's collection of print reports and online collection, along with Google Scholar. Both iNaturalist and bibliographic information are used in this report.

4.3: Results and discussion

Table 4.1: Advantages and disadvantages of kānuka communities on soil, plants, wildlife, and livestock.

	Advantages	Disadvantages
Soil	Acts against erosion Higher phosphorus, nitrogen, and water concentration	
Plants	Heat stress protection	Increased competition
Wildlife	Procures habitat and food source	Other shrubs species may be more suitable
Livestock	Provides shelter	Reduces grazing surface Unpalatable for livestock

K. ericoides, the kānuka tree, is the nucleus of a kānuka community. This essential component of Kānuka communities is described as a tall shrub or tree (R. B. Allen et al., 1992; Harris et al., 2004; Williams & Karl, 2002) that grows quickly as it colonises open ground (R. B. Allen et al., 1992; Esler & Astridge, 1974; Molloy, 1975) or disturbed land (Harris et al., 2004; Ronghua et al., 1984; Ross et al., 2009; Wardle, 1991). In addition to this, kānuka presence procures stability against erosion threats (Table 4.1) (Heenan et al., 2023; Stephens et al., 2005).

Once kānuka trees are established, kānuka communities appear under its dense canopy (Ross et al., 2009; Trotter et al., 2005; Williams & Karl, 2002). Kānuka communities' influence begins with its impact on abiotic factors (Table 4.1). As a matter of fact, the soil composition under the kānuka canopy differs from the surrounding open grassland soil (Camara, 2022). Ross et al. (2009) recorded a higher concentration of phosphorus and nitrogen under the kānuka canopy. Likewise, the water content was found higher under *K. ericoides* canopy, reducing the risk of suffering from hydric stress for the plants living within kānuka communities (Camara, 2022). Furthermore, the canopy procures protection against heat stress (Table 4.1), as it reduces by 70% the amount of photosynthetically active radiation (PAR) (Camara, 2022). Light with a wavelength between 400 and 700 nanometres is recognized as PAR (Krizek, 2004). Some authors even reported the absence of sunny patches under the canopy (Harris et al., 2004). However, soil conditions granted by the kānuka community may have influenced the plant diversity present underneath its canopy. A higher diversity of herbaceous species was found under the kānuka canopy compared to the surrounding open grassland (Camara, 2022).

For animals, kānuka communities procure habitat (Heenan et al., 2023) and food sources (Table 4.1). The nectar-rich flowers (McCaskill, 1965; Molloy, 1975; Ross et al., 2009; Stephens et al., 2005; Wardle, 1991; Williams & Karl, 2002) and seeds (McCaskill, 1965) of kānuka trees attract birds and insects, the latter attracting supplementary insectivorous birds (Williams & Karl, 2002). Dugdale & Hutcheson (1997) recorded an increase in invertebrates' biodiversity when kānuka trees were older, even surpassing native forests. More than 100 species of butterflies (*Lepidoptera*) were indexed in older kānuka communities (Dugdale & Hutcheson, 1997). Moreover, endemic species of birds showed a preference towards kānuka communities rather than the exotic bush gorse (*Ulex europeaus*) (Williams & Karl, 2002). In contrast, the introduced mice subsist in smaller numbers within kānuka communities than in gorse bushes (Williams & Karl, 2002). Finally, kānuka is used by livestock for shelter (Heenan et al., 2023), wild pigs or deer may also benefit from it (Table 4.1).

The previous results present kānuka communities as a habitat and food source for wildlife, impacting in parallel abiotic factors under its canopy. However, the dense canopy can limit the benefits of kānuka communities' presence. Under that dense canopy, the quantity of light is limited (Camara, 2022) and some species cannot establish (Table 4.1). Indeed, plant species richness is lower under the kānuka canopy than in the surrounding grassland (Camara, 2022). Kānuka consistently competes with and overtops manuka (*Leptospermum scoparium*) when the two species develop together in the same area (McCaskill, 1965). Furtherly, no canopy tree can grow and survive before the natural decline of kānuka (R. B. Allen et al., 1992; Esler & Astridge, 1974; Molloy, 1975) around 100 years after its implantation in the area (Heenan et al., 2023; Williams & Karl, 2002). This time frame might be problematic in restoration projects and other shrubs might be considered more efficient. Gorse can is a candidate that already replaces kānuka (Blaschke et al., 1981; Harris et al., 2004; Williams & Karl, 2002). Gorse is a successional plant that persists for an average of 30 years before native forests take over (Druce, 1957; Lee et al., 1986; McQueen, 1993; Wilson, 1994). Additionally, gorse is also a suitable habitat for native species (Table 4.1). The same number of invertebrate native species were recorded in kānuka and gorse shrubs by Harris et al. (2004). Another advantage of gorse over kānuka is its ability to fix nitrogen (Williams & Karl, 2002). As a result, a large quantity of nitrogen is naturally introduced into the ecosystem thanks to gorse litter (Reid, 1973). Other characteristics of kānuka make them less attractive on farming lands. The leaves are indeed not eaten by sheep (Ross et al., 2009) thus reducing the grazing surface available (Table 4.1).

The distribution of kānuka across Mount Grand was observed on the iNaturalist data (*Mt Grand Biodiversity*, 2023) recorded during the consecutive field trips at Mount Grand over the years and by Katzenberger (2016). *K. ericoides* is existent on both farming and DOC-owned lands. Kānuka communities bring numerous benefits to the lands that are used towards their respective goals: farming or conservation. It is imperative to preserve the kānuka and their communities already present on DOC land, as they are non-negligible actors in conservation. Resources must be committed to increasing the number of kānuka, particularly where the objectives of native forests restoration and native biodiversity protection are to be achieved. Preservation of kānuka presence on farming lands is equally important. As a matter of fact, kānuka communities dispatched across the farmed area may be used by native biodiversity to travel more easily between DOC-owned lands. Nonetheless, further research is needed to define the optimal density of kānuka on grazed land, assuring that livestock has sufficient shelter without drastically reducing the surface available for grazing. On top of that, monitoring and regulating the presence of wild pigs and deer that use kānuka as shelter will be necessary as both species negatively impact farming. Finally, all lands from Mount Grand benefit in the long term from kānuka presence from its action for soil improvement and against erosion.

4.4: Conclusion

Through this study, it was demonstrated that kānuka communities harbours multiple benefits for wildlife. They are both a habitat and a food source for numerous species, including native ones. The benefit of kānuka communities further expands towards the soil: its composition is modified, and erosion is limited. Considering all factors, kānuka and their communities have long-term importance for both conservation and farming at Mount Grand. As kānuka cover decreased in the last four decades (Katzenberger, 2016), maintaining and restoring their presence is crucial. Considering that the short-term advantages of kānuka presence on farming lands are fewer, it would be justified to determine the optimal kānuka density on these lands in a further research project. This density would preserve advantages for wildlife and livestock, without suffering from any detrimental effects on the farming lands.

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Chapter 5: Distribution of Kānuka *(Kunzea ericoides)* and its Conservation Value

Rose Sketcher

Abstract

This study investigates Kānuka (Kunzea ericoides) cover on Mount Grand and its conservation status. This study aims to contribute to an inventory of species composition associated with Kānuka on Mount Grand and ascertain the conservation value Kānuka holds to contribute to sustainably managing this high-country station. Research was conducted using a vehicle to travel up and down the west facing sides of the Mountain (400m-1200m). At roughly every 100-metre rise in altitude a landscape photograph was taken to capture Kānuka cover. Findings show Kānuka abundance and species composition within Kānuka communities decreases with elevation. Kānuka density was significantly higher in the gulley and sparser on the exposed face. Kānuka was found in similar areas as in a 2005 inventory, although density is hard to compare. Kānuka is the dominant woody shrub on Mount Grand with the invasive Sweet Briar (Rosa rubiginosa) also prominent. A desk study revealed Kānuka does have value in aiding conservation efforts by enhancing biodiversity, restoring native forests, and providing protection against soil erosion and landslides. This study successfully encapsulated Kānuka distribution on Mount Grand and reveals how Kānuka can aid in conservation efforts by increasing biodiversity, retaining soil composition and nursing native forests.

Key words: Kānuka, Conservation, tool, Mount Grand, cover, management, Sweet Briar, altitude, distribution, inventory

5.1: Introduction

Mount Grand has a rich history of forest clearance, burning and grazing since the late 1800's. Due to this history, much of the alpine zone vegetation now extends to below the treeline (i.e., snow tussocks (*Chionochloa))*. The make-up of the landscape today is comprised of shrublands, pastured land, eroded mountain slopes and snow tussock areas. Diversity is evident across Mount Grand, from the flora, fauna, and ecosystems to the many natives, as well as invasive species. It is important to understand the pattern of these distributions and develop a species inventory, particularly amongst natives and invasives to facilitate eradication and restoration efforts. In a system such as this, it is imperative to address conservation issues, as invasive species can have significant impacts on productivity and revenue as well as the unique biodiversity within the area (Pyšek et al., 2020).

Kānuka is an endemic woody tree found commonly throughout New Zealand, particularly on lowlands and mountain scrub (Department of Conservation, n.d.). Size can vary from small shrubs to taller trees (up to 18m) (De Lange, 2023). Kānuka has dark green needle-like leaves and clusters of small white flowers while its' trunk is made of flaky bark. Its life cycle is conducive to its seeds being dispersed by wind and possibly water (Thorsen et al., 2009). It is very tolerant and has been found up to 1800 meters above sea level and near geothermal systems (Department of Conservation, n.d.). It can withstand high winds, drought and frost and tends to thrive in less waterlogged soils (Department of Conservation, n.d.). It is listed as "nationally vulnerable" as it is at risk from clearance for farmland and felling for firewood (De Lange, 2023). This native also holds medicinal value (Chen et al., 2016) and is of importance to Māori namely for these healing properties.

Figure 5.1: Kanuka at Mount Grand

As the literature suggests, Kānuka on Mount Grand will be found on drier areas with shallow soils (Tane's Tree Trust & Barton, n.d., Wardle, 2001) and present at relatively high altitudes (<1800m) (Department of Conservation, n.d.). McQueen (1954) indicated that relative distribution of Kānuka may be influenced by climate which may contradict the Department of Conservation (n.d) if climatic conditions differ between altitudes significantly. The Tenure review of Mount Grand (Department of Conservation, 2006) also states that Kānuka was a significant feature of the original landscape before human influence and subsequent burning and pasture conversion. The review also mentioned several invasive plant species present and although Kānuka is extremely tolerant, it will be interesting to see if any of these species have since outcompeted Kānuka in places. I therefore expect my results to show Kānuka present throughout all of Mount Grand, lessening around pastured areas and potentially varying in abundance levels in areas with strong invasive species presence and differing climatic conditions.
As Kānuka is one of the dominant, original natives on Mount Grand, generating an inventory of its current distribution will divulge its success within a high-country station. The properties of Kānuka can also be explored to potentially aid in the restoration of other natives and eradication of invasives on Mount Grand. This report aims to improve our understanding of Kānuka *(Kunzea ericoides)* distribution, and to identify its value in facilitating conservation efforts on Mount Grand.

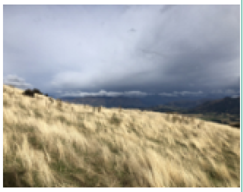
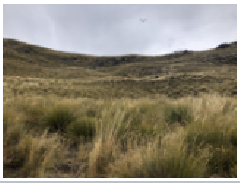
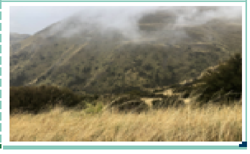
5.2: Materials and Methods

This research comprised field work and a desk study of relevant literature. Field research was conducted on the 20th of March 2023 on Mount Grand. The relationship between altitude and Kānuka abundance was explored to generate an inventory of Kānuka presence throughout the property. Considering it is a functional high-country farm, operations occur on more of an elevational system, this approach also gives rise to further research to be explored (i.e., grazing and abundance, or climate and abundance). A car was used to drive up the exposed, west facing side of the mountain to its peak (1200m) before coming down the sheltered "Lagoon Gulley", also facing the west. Altitude was measured using an altimeter, starting at 400m, and stopping roughly every 100m to assess Kānuka coverage. Kānuka presence and absence as well as size and species composition within Kānuka patches was recorded using a camera on an iPhone. General descriptions were also noted at each altitudinal stop (iI.e., location, weather, dominant species). The images along with corresponding altitudes and notes were uploaded to a table in a word document to undergo comparison. Literature research was also undertaken to determine what previous research had been done on Kānuka abundance in the High Country but more so to gather information on what Kānuka can provide regarding conservation efforts.

5.3: Results

Kānuka varied in its abundance and community make-up throughout the area. From comparing the images on the table (Table:5.1), my results indicated at lower altitudes (400-600 meters) Kānuka communities commonly included other shrub species such as the invasive exotic, Sweet Briar (*Rosa rubiginosa)* and native Matagouri *(Discaria toumatou)* and consisted of relatively sparse community hubs. As altitude increased up the west, exposed face, those species became less common and the Kānuka existed as the sole species within the community. There is a general abundance pattern present, as elevation increases Kānuka abundance becomes less, and trees become sparser before completely dying out. Kānuka were found up to 990 metres above sea level before snow tussocks began to dominate. Also interesting to note, was the density of Kānuka coming down the Gulley compared to the exposed face. As is evident (Table 5.1), at 870m in the Gulley, Kānuka was very dense, while at a similar altitude on the ascent, Kānuka had very small groupings and was relatively sparce. Kānuka also grew at higher altitudes (1100m) in the gulley in comparison to the exposed mountain face.

Table 5.1: Compiled re sults of Kānuka distribution at varying altitudes on Mount Grand.

Location	Altitude (metres)	Description	Photo
Ascent-Lowlands/pasture	400m	Starting out driving up West facing side. Groupings of Kanuka communities and Matagouri and sweet briar surrounding grazed, pasture lands.	
Ascent-West face	500m	Exposed, west facing mountain side, sparsley dotted Kanuka.	
Ascent-West face	600m	Larger spacing between Kanuka communities, also less mixing of species within each community.	
Ascent-West face	700m-800m	Very small and sparse pockets of Kanuka, mostly dry, hay dominating landscape.	
Peak elevation	900m-1200m	No Kanuka, shrub land and tussock varieties dominating.	
Descent-Lagoon Gulley	1100m	Coming down Lagoon gulley (west facing side still) Kanuka alot more prevalent on this side, communities close together.	
Descent-Lagoon Gulley	1000m	Kanuka growing, populating tussock.	
Descent-Lagoon Gulley	870m	Kanuka very dense, dominant species covering landscape.	
Descent-Lagoon Gulley	580m	Kanuka starts sparsing out and other species mix in.	

5.4: Discussion

5.4.1: Abundance

The findings of this study are supported in the current literature, although it is said that Kānuka can be found as high as 1800m, this may not be the case on Mt Grand due to increased soil moisture at higher altitudes, species competition, changes in soil composition or general changes in climate (McQueen, 1954), more research would be needed to determine this. An explanation as to why Kānuka was denser in the gulley could be due to the warmth and shelter it provides, along with softer soils, allowing for easier growing conditions for a tree that does not do so well on wet sites with harder clays (Tane's Tree Trust & Barton, n.d.). The results also indicate a potential species association between Sweet Briar and Kānuka. It would be interesting to further explore this as they were often grouped together, particularly Sweet Briar growing mostly next to Kānuka and rarely alone. Understanding this association is important as it is between an invasive exotic (Sweet Briar) and a native (Kānuka), a competitive or dependent relationship could be detrimental to Kānuka.

Looking at landscape changes over time, site inspections for the Tenure review (conducted in 2005), show a consistency with my results regarding Kānuka cover. The review states, patches of Kānuka shrubland are the dominant vegetation types on areas below 900m, extensive low Kānuka forest is present through the 4WD track (Department of Conservation, 2006) (coming down lagoon gulley, where I also noted dense Kānuka cover). The review does include some pictures, although the low quality makes it difficult to distinguish species cover, thus hard to compare Kānuka cover between results and the review. The review does note that Kānuka was found above 1000m on Bluenose and beneath Grandview Mountain, which differ from my results, noting no Kānuka sightings above 990m. This could be due to a limitation of the study, only two west-facing slopes were explored as well as the weather was extremely foggy, reducing visibility. Overall, the consistency in comparisons show there has been minor change overtime in terms of Kānuka abundance. As the DOC (Department of Conservation) land has been protected since this review (2006) it also indicates that grazing does not influence Kānuka abundance.

5.4.2: Other limitations

Aside from the weather impacting visibility as well as the extent of area covered, the duration of data gathering, and lack of robust methodology were also limiting factors. There was a lack of controls around data gathering (I.e., how to point and capture areas of Kānuka, how far away, how far to look etc.). As well as all data was collected over two west-facing slopes and only as high as 1200m (the farm extends to 1400m), resulting in possible unrealistic representations of Kānuka-cover over the whole of Mount Grand. Conducting this study again over a few days, in finer weather to allow for more accessibility as well as having transects or defined boundaries to measure Kānuka abundance would further generate a holistic representation. This study is a great building block in contributing to the entirety of species composition on Mount Grand.

5.4.3: Conservation qualities

The literature suggests that aside from being an endemic native plant with valued properties that should be protected, it may also help other conservation efforts. Kānuka can enhance biodiversity by providing a habitat for native invertebrate communities (J.Harris et al., 2004). Therefore, increasing or decreasing the abundance of Kānuka is likely to affect the diversity of these invertebrate communities. J.Harris et al., (2004) found other woody shrub species could also host invertebrates but adds, Kānuka had the largest species richness, hosting rare and threatened invertebrates when compared to other woody shrubs.

Kānuka can be used as a tool for re-vegetating eroded slopes, also known as a 'nursing tree' (Department of Conservation, n.d.). Kānuka creates shade and shelter within its understory, providing an ideal habitat for slower growing natives. Once the understory natives grow large enough and out-compete Kānuka for light, the Kānuka dies off and thus successfully nurses the younglings (Department of Conservation, n.d.). There has been recognition that this is a lengthy process and may not be the most effective for growing native forests (Ogden, 1985). It has been found that Kānuka provides a prominent level of protection for reducing landslides after heavy rain, aiding in the protection of soil erosion (Bergin et al., 1995). Soil erosion is detrimental to this landscape regarding conservation and agriculture as it can affect flora growth and survival and allow for harmful gas emissions and water pollution (Lal, 1998). Kānuka are also not usually eaten by sheep or cattle, further enforcing their suitability for restoration projects within this type of environment (Department of Conservation, n.d.).

5.5: Conclusion

This research has improved our understanding of Kānuka distribution on Mount Grand by revealing, Lagoon Gulley hosts the densest Kānuka communities while the West-facing, exposed slopes host communities that are smaller and sparser. Kānuka may also be less dispersed at higher altitudes (compared with a 2005 report). As mentioned, Kānuka is listed as vulnerable due to felling for timber and clearing for pasture. Mount Grand can protect this native as its farming system does not rely heavily on clearing for pasture. Therefore, strong stands of Kānuka at Mount Grand should be protected to account for the loss of others around the country. This protection can be done through further investigation of invasive species interactions with Kānuka and potential eradication of them, as well as ensuring no felling of Kānuka occurs. Kānuka cover should also be increased (planting of younglings), particularly on eroded, bare slopes to help with further erosion and recovery. Considering this farming environment, Kānuka's best value lies within this soil protection and landslide prevention to ensure palatable plant species remain productive and water and nutrient cycling is optimal, thus improving yield and revenue. Kānuka plantings will also be valuable to enhance biodiversity, ecosystem services and restoration of other natives, further contributing positively to the conservation and economic properties of the landscape.

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Chapter 6: Rocky Outcrop Flora

Amelia Agranovich

Abstract

This study examines rocky outcrop floral biodiversity found on rocky outcrops of Mt. Grand. From data gathered on one research day in Autumn of 2023, primarily endemic species were found, including Desert Broom (*Carmichaelia petriei*), Colenso's Mingimingi (*Acrothamnus colensoi*) and Narrow- leaved snow tussock (*Chionochloa rigida*). Evidence of grazing highly affecting Narrow-leaved snow tussock was found. The invasive species Great mullein *Verbascum thapsus* and Mouseeared hawkweed (*Pilosella officinarum*) were also observed. Further research on rocky outcrops in Mt. Grand is recommended.

Key words: Agriculture, Conservation, Rocky Outcrops, Biodiversity, Flora, New Zealand, High Country, Mt. Grand

6.1: Introduction

Aotearoa New Zealand is known for its distinctive biodiversity. Due to its geological isolation for millions of years, the island nation has flightless birds that have evolved without the threat of mammalian predators, and many distinctive plants. The alpine region of Aotearoa New Zealand today has over 700 species, of which 93% are endemic (Mark & Galloway 2012). Rocky outcrops are a distinctive feature of Aotearoa New Zealand's highland landscape, and provide habitat for both flora and fauna. As part of the Conservation Biology course at Lincoln University, I chose to research the biodiversity found around rocky outcrops at the Research Station of Mt. Grand, an area of 2,131 hectares.

6.2: Materials and Methods

This study was carried out on Monday the 20th of March, the purpose of which was to assess the biodiversity found around rocky outcrops at Mt. Grand, New Zealand. Due to the heavy rain and wind conditions, the initial study plan had be adapted as to ensure personal safety, as at higher elevations and near larger rocky outcrops - the researcher team would be more exposed to the elements.

Materials used for data collection include measuring tape, a circular 1-meter quadrat, a camera and personal phone device.

At -44.409 S° 169.2116 E° at the elevation of 1,143 meters - a rocky outcrop was found around which the researcher could assess the biodiversity without risk to personal security. Using a rocky outcrop with a height of 1.2 meters (Figure 6.1) as a center point – the researcher laid out a 5 by 5-meter quadrat – an area of 25 meters. Within this area the easily identifiable flora was visually assessed and counted. A circular quadrat was laid down 6 times randomly throughout the area – with photos taken to later assess what species were found within each quadrat (Figure 6.2).

Figure 6.1: Rocky Outcrop located at -44.409 S° 169.2116 E°, Mt. Grand. The biodiversity study took place around this outcrop.

Photos taken of the species in the area were then uploaded to iNaturalist – a platform created by the California Academy of Sciences and the National Geographic Society to upload and share natural observations around the world (Ueda 2023). Species were then identified by volunteer experts in the field of biodiversity of Aotearoa New Zealand. Lichens were identified down to the family level using the publication *Lichens of New Zealand: An Introductory Illustrated Guide* by Allison Knight (2014).

6.3: Results

Within the 5x5 meter quadrat, 30 specimens of   waswere countedrecorded. This shrub species is identifiable by its leafless thin branches varying from green, yellow green, and bronze green in color (Kirk 1899). Colenso's Mingimingi *Acrothamnus colensoi*, a sprawling shrub with sessile or subsessile leaves that range from pinkish green to a red-brown coloration, with a slightly glaucous appearance (Quinn et al. 2005) and Carpet Heath *Pentachondra pumila*, a shrub with oblong to elliptical leaves crowded near branch ends was also identified in the area (Forst & Forst 1810). 4 small bushes entirely covered in a bearded lichen were also observed. Sheep scat too was observed all around the area - with evidence of grazing of Narrow leaved snow tussock *Chionochloa rigida*.
Within the 1 meter quadrats (Fig. 2) the species Narrow leaved snow tussock *Chionochloa rigida*, Golden Spaniard *Aciphylla aurea* which is also known as speargrass for its sharp and spiky leaves, Lichen of the Rhizocarpaceae family and the invasive plants Great Mullein *Verbascum thapsus* and Mouse eared Hawkweed *Pilosella officinarum* were observed.

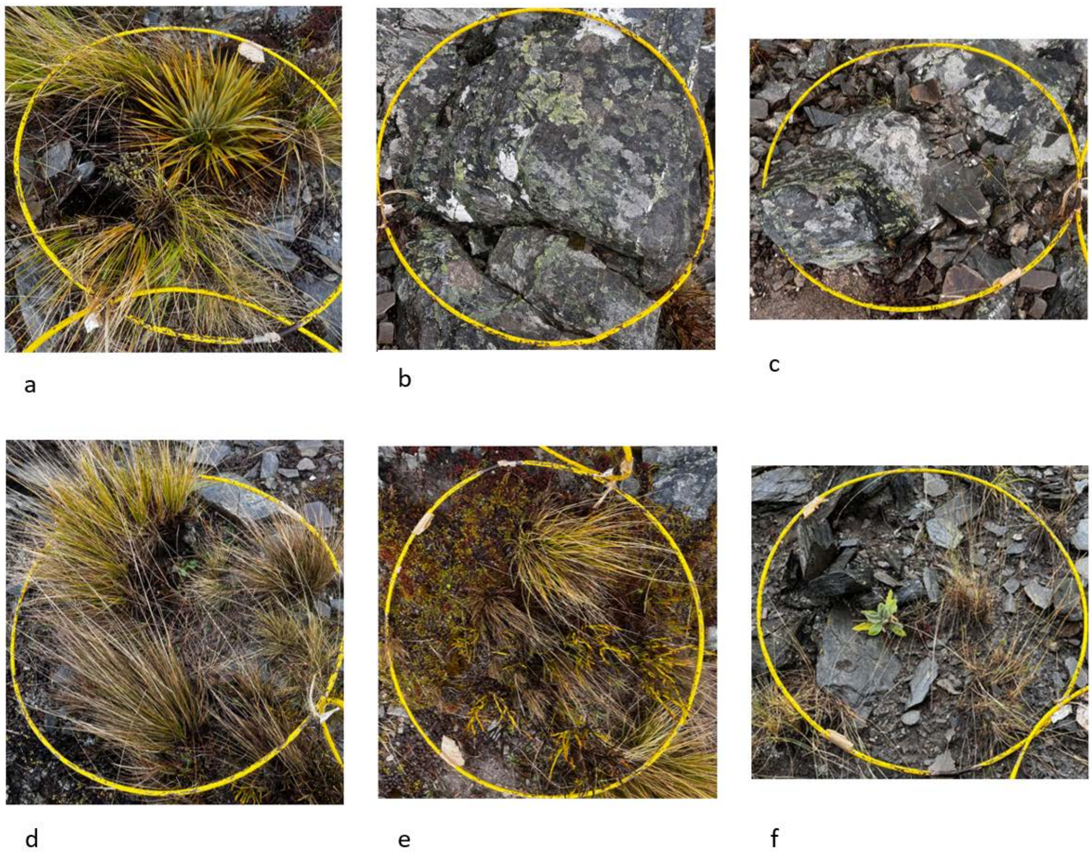

Figure 6.2: Circular quadrats showing the floral biodiversity found around the rocky outcrop – including Narrow-leaved snow tussock Chionochloa rigida rigida (a, d, e, f), Golden Spaniard Aciphylla aurea (a), Lichen of the Rhizocarpaceae family (b, c), Great Mullein Verbascum thapsus (f), and Mouse eared Hawkweed Pilosella officinarum (d).

Golden Spaniard did not have evidence of grazing, which is logical considering its very sharp texture.

6.4: Discussion

Mostly indigenous species were found around this rocky outcrop. However, that invasives observed in just the 1-meter quadrats of the area around the rocky outcrop in question shows the effect that European colonization has had on the highlands of Aotearoa New Zealand. Heavy grazing has also damaged many of the snow-tussocks found in the area – which are not adapted to mammalian predation. To gather a better understanding of rocky outcrops it would be recommended to return to Mount Grand during better weather conditions – as well as during the spring and summer seasons. This would allow for better observations of flora at higher grounds – where the heavy rain and windfall made research quite difficult. Researchers would also be more likely to observe interactions of fauna with the rocky outcrops – such as lizards hiding from the sun (Hitchmough et. al 2016). It is difficult to draw any conclusions from one sole site, but there are already good indicators of how rocky outcrop provide habitat for a large variety of endemic species. It would be useful to research the ratio of invasive to endemic species found around outcrops in Mt. Grand – as well as how artificially planted rocks are influencing fauna behaviour. Therefore, it is most important to return to Mt. Grand in better weather conditions – and to research the biodiversity found at multiple sites.

Lichen should also be studied with better methodology, including chemical spot tests to better understand which exact species can be found.

6.5: Conclusion

As seen by the results of this study, rocky outcrops provide habitat for a large variety of highland biodiversity and are also an area that introduced and farmed species like to habituate. Rocky outcrops are seen throughout Mt. Grand, providing not only a majestic view but an important landscape for the overall ecology. Ensuring the health of the overall eco-system of Mt. Grand means protecting the natural landscape from large changes – like removing outcrops for agricultural purposes.

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Chapter 7: Iconic Tussock Landscapes: What has Changed, and What is the Best Way Forward?

Catherine Priemer

Abstract

The aim of this study was to gain a better understanding of vegetation cover and land-use change in tussock grassland, and to discuss influential management factors at Mt Grand. This was supported by a desk study and iNaturalist inventory. Our findings underscored the conservation value and high biodiversity in the alpine regions of Mt. Grand (roughly 1000m and over), but also brought attention to the widespread presence of Hawkweeds (*Hieracium*) and sweet brier (*Rosa rubiginosa*). Previous studies have found that the retirement from grazing can be a double-edged sword; it can be beneficial for the growth of snow tussocks (*Chionochloa* spp.), but reduced herbivory can also promote the growth of weeds. The implications of Tenure Review are not clear cut. Areas with conservation tenure continue to be grazed by introduced pests, and within pastoral tenure there are areas that are no longer grazed (Day, 2008). This considered, future conservation strategies should consider a wide range of factors, such as soil chemistry, climate, and management.

Key words: Tussock Grassland, *Chinochloa*, High-Country, Management, Restoration

7.1: Introduction

Mt. Grand Station is a 1974 ha pastoral farm, located in the Central Otago Eco Region (Katzenberger, 2016). After undergoing a process of tenure review, about 500 ha of the property were retained as public conservation land managed by the Department of Conservation (DOC), while the surrounding land is now owned by Lincoln University, and is mainly used for merino sheep grazing (DOC, 2006; Katzenberger, 2016). The vegetation at Mt. Grand varies greatly with elevation. The lower and intermediate altitudes consists mainly of introduced grasses and herbs, due to high management intensity by oversowing and topdressing (DOC, 2006; Katzenberger, 2016). The higher elevations, in contrast, are still largely made up of native plants such as snow tussock, and is considered of high conservation value (DOC, 2006). Tussock grasslands play a vital role in retaining water (Mark et al., 2013). Not only do they store and effectively produce water, tussock grasslands also help to prevent soil erosion and sequester carbon (Mark et al., 2013). Native alpine plants that often appear in these grassland habitats, such as Mountain Daisies (*Celmisia sessiliflora*), are important to pollinators as well (Bischoff, 2008).

Tussock grasses can be identified by their arrangement of stems and leaves which forms a tuft of vegetation (Stupples, 2003). Much of the low alpine zone is dominated by Snow tussock, a name given to several alpine species of *Chinochloa*. Narrow leaved snow tussock (*C. rigida*) is found in the south-western South Island, but is more widespread east of the main divide, along with slim snow tussock (*C. macra*) (Mark, 2007). Blue tussock (*Poa colensoi*) is also commonly found in the alpine zone, occupying a wide range of habitats including grassland, shrubland, herbfield and rocky places (Talbot & Prendergast, 1984). Although palatable, Blue Tussock's grazing tolerance has allowed it to persist and increase where pressure has been heavy (Talbot & Prendergast, 1984). Silver tussock (*Poa cita*, synonyms *Poa caespitosa, Poa laevis*) can also be found in lowland to montane grassland, as well as shrubland and bouldery ground (Talbot & Prendergast, 1984).

The tussock grasslands of the Otago high-country are dynamic ecosystems, that have been heavily influenced through various pastoral and conservation methods. Considering the lessons that have been learned from past management strategies, this study aims to gain a better understanding of the current vegetation cover at Mt. Grand, while proposing possible management factors and approaches that can be applied to tussock grassland ecosystems now and in the future.

7.2: Materials and Methods

This study consists of both a field-based iNaturalist inventory, and a literature review. The species inventory was taken at Mt. Grand on March 20th and 21st, using the iNaturalist mobile App - a crowdsourced species identification system and organism occurrence recording tool (iNaturalist NZ, 2022). Photos were taken at Hospital Gully (~450m-600m), as well as along the ATV track leading up to Grandview Ridge, and the surrounding tussock grassland (≥1000m). These were then uploaded onto the "Mount Grand Biodiversity" iNaturalist project page. To supplement the iNaturalist data, a literature review was undertaken to get a bigger picture of the vegetation distribution and change at Mt. Grand. This study also drew upon existing restoration research, to explore management impacts, such as grazing.

Figure 7.1:Locations where observations were gathered using iNaturalist

7.3: Results

7.3.1: How has tussock grassland changed?

The tussock grasslands of New Zealand's South Island have been greatly shaped and modified through human activities, such as burning, grazing, and the introduction of exotic plants for pastoralism (Day, 2008). Before the arrival of humans, montane and subalpine regions had variable cover of beech/montane podocarps and broadleaves, as well as subalpine scrub and tall tussock grassland (McGlone, 2004). Drier areas of Central Otago and the Mackenzie Basin were home to scrub conifers, small-leaved shrubland, kōwhai and kānuka, with grassland or herb fields being found on the driest soils (McGlone, 2004). Wetter areas on the higher slopes of mountains within the semi-arid regions, supported extensive forests of Mountain tōtara, silver beech and celery pine (McGlone, 2004). The first wave of colonization by Māori settlers approximately 800 years ago, led to the widespread clearing and burning of fire-sensitive woody vegetation (McGlone, 2001). This led to the destruction of roughly 75% of the forest and tall scrub cover in the eastern South Island (McGlone, 2004). In drier, eastern areas and low elevations, tall forests were replaced by tall tussock (which had migrated downslope from its alpine and subalpine habitat), short tussock grasslands, scrub and fern, as well as patchy, low forest (McGlone, 2004). Historically, a shrubland element was much more prominent over much of the area that is now regarded as pure tussock grassland (McGlone, 2004).

European pastoralists brought in new grazers, using fire to stimulate fresh palatable grass foliage and to open up scrubland for grazing (McGlone, 2004). The high stocking rates of sheep and cyclical rabbit outbreaks, led to a reduction in palatable shrubs, native herbs and grasses (McGlone, 2004). Many heavily grazed areas also suffered a decline in the stature, vigour, and cover of the main tussock species (McGlone, 2004). Aggressive introduced weeds, pasture grasses and forbs, began to dramatically alter the functioning of native plant communities (McGlone, 2004).

The invasion of *Hieracium* (Hawkweed), particularly *H. pilosella* (Mouse-ear Hawkweed), has resulted in large scale changes in the composition and structure of lower-elevation grasslands, to the point that many areas that were previously dominated by native short tussocks (especially *Festuca novae-zelandiae*) are now *H. pilosella*-dominated herbfields (Scott et al.,1990; Duncan et al., 1997; Rose et al.,1998; Norton et al., 2006; Steer & Norton, 2013). One of the factors that may contribute to the increase of this invasive herb, regardless of grazing and environmental conditions, could be its ability to efficiently sequester nitrogen from the soil (Scott et al. 2001; Treskonova 1991, Scott 1993, Jensen et al. 1997, Rose et al. 1998, Rose and Frampton 1999, Duncan et al. 2001).

Sweet -brier (*Rosa rubiginosa*) is another invasive species that has set foot in a variety of habitats. This woody weed has adapted to the dry environment of the inland South Island and, once established, can grow rapidly and persist for long periods of time (Sage et al., 2009). It appears to have increased quickly after significant reductions in rabbit numbers in the early 1950s in several parts of the South Island (Molloy, 1976).

In addition to the spread of invasive species, soil erosion became an issue in pastoral landscapes. As a management measure, the government provided subsidies to farmers between the 1960s and the 1980s to fertilize and oversow land in pastoral tenure to prevent soil erosion (O'Connor 2003). However, this action led to the further degradation of tussock grasslands (Mark & McLennan, 2005). The process of Ttenure review Review was then introduced as a means of reversing degradation. It aimed to promote ecologically sustainable management of high-country farms and retain areas with high conservation or cultural values in Crown ownership (Land Information New Zealand 2003). More recent studies, however, have found that management in the broad sense (i.e. Ttenure) has not influenced changes in species composition (Day, 2008).

7.3.2: What is the current vegetation cover?

According to the iNaturalist survey, many more non-native species were recorded at lower elevations (450m-600m), than areas of higher elevation (≥1000m) (see Tables 7.1 and 7.2). Some of the frequently observed non-native species, (particularly at lower elevations) on the "Mt Grand Biodiversity" iNaturalist project page include Butterfly Bush (*Buddleja davidii*), Sweet-Brier (*Rosa rubiginosa*), Mouse-eared Hawkweed (*Pilosella officinarum*), Common Vetch (*Vicia Sativa*), Red Clover (*Trifolium pratense*), Scotch Broom (*Cytisus scoparius*), Orchard Grass (*Dactylis glomerata*), Mallows (Genus *Malva*) and Great Mullein (*Verbascum thapsus*). Frequently observed native species include Tutu (Genus *Coriaria*), Matagouri (*Discaria toumatou*), Colenso's Mingimingi (*Acrothamnus colensoi*), Niniao (*Helichrysum lanceolatum*), Prickly Shield Fern (*Polystichum vestimum*), and Kānuka (*Kunzea serotina*). Based on iNaturalist observations, species diversity appeared to be greater at Grandview Ridge. Many native species were found at higher elevations, including Mountain Daisy (*Celmisia densiflora*), False Spaniard (*Celmisia lyallii*) Golden Spaniard (*Aciphylla aurea*), *Anisotome flexuosa*, Colenso's Mingimingi (*Acrothamnus colensoi*), Blue Tussock (*Poa colensoi*), Narrow-leaved snow tussock (*Chionochloa rigida*), Blue tussock (*Poa cita*), Porcupine Shrub (*Melicytus alpinus*), Pātōtara (*Styphelia nesophila*), *Brachyglottis haastii*, South-Island Edelweiss (*Leucogenus grandiceps*), *Veronica buchananii*, Slender Chickweed (*Stellaria gracilenta*) and Coprosma (Genus *Coprosma*). Non-native plants found at higher elevations include Tussock Hawkweed (*Hieracium lepidulum*), Sheep's sorrel (*Rumex acetosella*), and Sweet Brier (*Rosa rubiginosa*).

Table 7.1: Vegetation at Lower Elevation (~450m – 600m)

Native	Non-Native
Genus Coriaria	Buddleja davidii
Discaria toumatou	Rosa rubiginosa
Acrothamnus colensoi	Pilosella officinarum
Helichrysum lanceolatum	Vicia Sativa
Polystichum vestimum	Trifolium pratense
Kunzea serotina	Cytisus scoparius
	Dactylis glomerata
	Genus *Malva*
	Verbascum thapsus

Table 7.2: Vegetation at Higher Elevation (≥1000m)

Native	Non-Native
Celmisia densiflora	Hieracium lepidulum
Aciphylla aurea	Rumex acetosella
Anisotome flexuosa	Rosa rubiginosa
Acrothamnus colensoi	
Poa colensoi	
Chionochloa rigida	
Poa cita	
Melicytus alpinus	
Styphelia nesophila	
Brachyglottis haastii	
Leucogenus grandiceps	

Veronica buchananii
Stellaria gracilenta
Genus Coprosma
Celmisia lyallii

These observations are consistent with the Land Cover Database, (LCDB, version 4.1), which classifies much of Mt. Grand as low producing grassland, with the upper reaches classified mainly as tall tussock grassland (Katzenberger, 2016). The LCBD (which is based on satellite imagery), does not indicate any change of land cover type between the years 1996, 2001, 2008 and 2012 (Katzenberger, 2016). However, the New Zealand Land Resource Inventory (NZLRI), which contains data from 1973-1979, reveals substantial differences in vegetation cover over the past four decades. As Katzenberg (2016) points out, the cover of kanuka *Kunzea* and snow tussocks *Chionochloa* seems to have shrunk substantially at Mt. Grand compared to what has been observed in the LCBD.

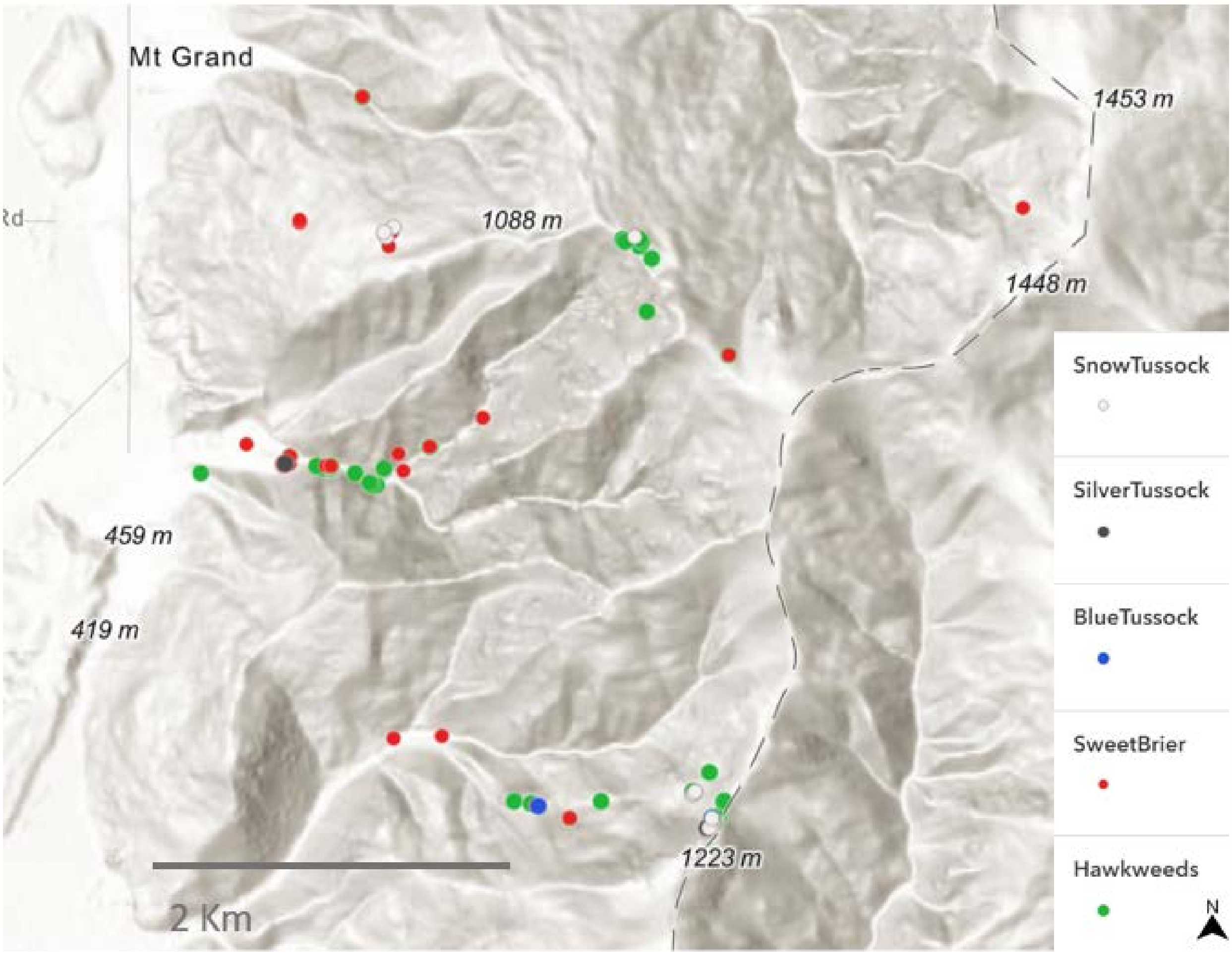

Figure 7.2: Map of iNaturalist observations, created by Catherine Priemer, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 7.3: Top Left: Snow tussock, Top Right: Diverse alpine plant community, Bottom Left: Golden Spaniard, Bottom Right: Veronica Buchanani

7.4: Discussion

These findings highlight the high biodiversity and unique alpine plant communities found in the tussock grassland ecosystem at Mt. Grand Station. At the same time, the iNaturalist observations point to the widespread abundance of invasive species, such as Sweet-brier and Hawkweed. To allow this important high-country ecosystem to thrive, management options might need to be considered to keep the spread of invasive species in-check. After the process of tenure review, about 500 ha of the Mt. Grand Station property have been retained as public conservation land managed by the Department of Conservation (DOC). However, questions remain as to the best management of these protected areas.

Grazing effects might be an important factor to consider, when looking at conservation strategies for tussock grassland at Mt. Grand. The removal of sheep grazing from areas that have been greatly modified and grazed for over a century, can result in dramatic impacts on vegetation dynamics (Day, 2008). Several studies have shown that snow tussock populations can recover significantly after grazing has stopped (Meurk et al., 2002; Lee et al., 1993; Dickinson et al, 1992). Research has also found that an increase in *Chionochloa* spp. may be caused by the growth of existing plants or recruitment (Scott et al., 1988), and that recruitment is required for the continuation of the community (Rose & Platt, 1992).

On the other hand, other studies have documented increases in exotic species as a result of these fast-growing invasives no longer being suppressed by herbivory (Norton 1988, Meurk et al. 1989, Lord 1990, Walker 2000). A study by Sage et al. (2009) investigating the effects of the removal of sheep grazing on Sweet-brier (*Rosa rubiginosa*) in montane short-tussock grassland, for example, found that Sweet-brier was significantly taller and had higher cover and densities in the ungrazed sites.

When it comes to the implications of tenure review, findings by Day (2008) indicate that management in the broad sense (tenure) has not influenced changes in species composition. However, her study suggests that management at the property-scale may be important. As she points out, this could be because tenure may not accurately represent differences in grazing.

Areas within conservation tenure continue to be grazed by introduced pests, and within pastoral tenure there are areas that are no longer grazed (Day, 2008). During our inventory at Mt. Grand, evidence of grazing was indeed observed in the alpine areas (see fig. 2). This could have a negative effect on palatable native plants, such as Mountain Daisy (*Celmisia densiflora*). However, as Day's (2008) study reveals, changes in community structure are influenced by a large combination of factors, such as soil chemistry, climate, and management. Future monitoring could use standardized methods to further investigate and compare species richness and composition over intervals of 10 years or less (Day, 2008).

Figure 7.4: Evidence of grazing. Photo by Katharina Schmidt SS

7.5: Conclusion

This study looked investigated vegetation cover and land-use change in tussock grassland, and investigated factors that are relevant to the future management of these iconic landscapes. Our observations highlighted the rich diversity of native vegetation in the alpine reaches of Mt. Grand Station. At the same time, it brought attention to the widespread presence of invasive species, such as Hawkweed and Sweet- brier. Factors to be considered in future management include the positive and negative impacts of grazing (such as limiting the spread of invasives and reducing plant growth), and the influence of other factors such as soil chemistry, and climate. By learning more about these complex relationships, we can contribute to the well-being of this unique high-country ecosystem.

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Chapter 8: Alpine Tussock Grasslands of Mt Grand

Nicola Wegmayr

Abstract

High Country tussock grasslands are an iconic cultural landscape of New Zealand, valued for its unique aesthetics, rich biodiversity and use as extensive pastureland. In elevations above the climatic treeline, these grasslands are part of the alpine zone, the habitat of many unique species that may be sensitive to disturbance and climate change, For decades, the native vegetation in these areas has felt the rising pressures of human use and the introduction of invasive species. At Mt. Grand station, Tenure RGood Introeview (2006) identified a stable alpine community in the upland pastures. This report aims to review the current situation based on empirical data gathered in March 2023, supported by a desk study of the literature. This report further aims to advocate the need to protect this iconic alpine landscape and provides suggestions for measures that could reduce the tension between conservation and agriculture.

Key words: Agriculture, Conservation, Alpine Zone, High Country, Tussock grassland, Alpine plants, Native Vegetation

8.1: Introduction

The extensive upland pastoral grasslands of the New Zealand South Island High Country are an iconic landscape that is intrinsically connected to Aotearoa's cultural sense of identity and heritage (Brower and Swaffield 2009). They form the mid-altitude zone of the High Country, which is the land above 700 m that includes a large portion of New Zealand's mountainous regions, reaching from sprawling low-altitude foothills and intermontane basins to the high peaks of the Southern Alps (Swaffield and Hughey 2001).

Reaching above the treeline into the alpine zone, the grasslands are comprised of a high degree of native vegetation and provide habitats for the sensitive mountain flora that grows at this altitude (Clarke et al. 2018). Characterized by an especially high degree of biodiversity and endemism, New Zealand's alpine ecosystems have high conservation values (O'Connor 2003). The abundance of native flora such as *Chionochloa rigida* (snow tussock), herbaceous flowering plants like *Aciphylla aurea* (golden spaniard), as well as shrubs like *Discaria toumatou* (matagouri) (Land Information New Zealand 2006), form the iconic beautiful and rugged aesthetic of the High Country's upland pastures that have invoked strong spiritual and aesthetic responses since their first occupation. A classic example of a "traditional continuing cultural landscape" (Brower and Swaffield 2009, p.162) that is symbolically important to both colonial and modern New Zealand culture, the High Country grasslands are classified by the World Heritage Convention as worthy of protection. Their unique scenery also becomes increasingly important economically in terms of recreational use and tourism (O'Connor 2003; Brower and Swaffield 2009).

The landscape has a long history of being altered by humans. Māori burning practices caused the transition from native beech forest to tussock-dominated grasslands (Mark and Dickinson 2008), European pastoralism further decreased the vegetation in density and stature, grazing-overpressure depleting the soil of nutrients. A multitude of exotic flora was introduced and especially lower areas were converted to farmland covered with cultivated crops and sown pastures (O'Connor 2003; Pollock and Scott 1993). The traditional form of tenure pattern management of the "natural" tussock grasslands has since become that of extensive rangeland for grazing sheep (Brower and Swaffield 2009). The area having both significant values for nature conservation as well as pastoral land, its management and purpose-of-use have caused a decade-long debate. The dichotomy was perhaps accentuated by the Resource Management Act of 1991 which called into question the "sustainable management" of the High Country landscape, addressing ecological, social and economic objectives (O'Connor 2003).

This report will investigates the composition and distribution of the vegetation community in the upland pastures of the High Country, with a special focus on the areas of higher elevation and the presence of alpine plants. This is done based on observations collected at Mt. Grand Station, a typical example of a High Country farm managed partially as extensive rangeland under the tenure process (Land Information New Zealand 2006). The implications of the empirical findings in the context of conservation value and farming will be discussed in light of insights provided by a desk study of the literature. This report aims to provide suggestions for measures that may reduce the tension between conservation and agriculture in this landscape.

8.2: Materials and Methods

The empirical data for this report was gathered at Mt. Grand Station in March 2023. This High Country farm is located in the central Otago region of the South Island, adjacent to the Hawea Flat. The station ranges in altitude from approximately 400 to 1400 m above sea level, in total 1974 ha of pastoral lease run by Lincoln University. The last tenure review in 2006 (Land Information New Zealand 2006) describes Mt. Grand mostly as an intermediate agriculture-scrub ecosystem. At lower altitudes, the land is cultivated with pasture crops and lucerne, the pastures oversewn and top-dressed, also hosting *Rosa rubiginosa* (sweet briar), *Discaria toumatou* (matagouri), *Kunzea ericoides* (kānuka), and *Rosa rubiginosa* (short tussock). Surrounded by steep, eroded mountain slopes, the tussock grassland at higher altitudes is also oversewn and top-dressed, but includes a range of indigenous grasses, herbs, and shrubs.

For two days, photographic materials of flora and fauna was were taken at different locations across the station, recording the geographical position of each observation. These photos were uploaded into a group project on the INaturalist platform (INaturalist n.d.), called “Mt. Grand Biodiversity”, where the identity of recorded species was validated with the help of AI and user identification. From the generated database, all plant observations were filtered and exported as a .xlsx-file to be analysed for this report. Using the geographical coordinates attached to the observations, the details of elevation were retrieved from a digital elevation model (DEM) (Landcare Research n.d.) using QGIS (QGIS Development Team, n.d.). Further data analysis was conducted in R (R Core Team, n.d.) using simple descriptive statistics (i.e. bar charts) to explore and graphically visualize the observations in the context of the research objectives. For the analysis, observations with elevations below 400 m were excluded, as well as those missing elevation data (some photos did not include geographical coordinates).

The fieldwork further included the conduction of 30 m-long transects at two different elevations of the High Country pasture below Grandview Ridge. The exact locations of the transects were chosen due to easy accessibility in the scope of the trip. T1 (the first transect) was conducted at a slope below the climatic treeline (44'40.1254'S, 169'20.5972'E), at an elevation from 818 to 821 m (Figure 8.1, top). Above the climatic treeline that was estimated at around 900 m, T2 (the second transect) was taken in the alpine zone near the Grandview Ridge (44'40.1463'S, 169'21.2421'S) at 1124 to 1140 m elevation (Figure 8.1, bottom). The locations of the transects are shown below in Figure 8.2. Along the transects, a stick was placed perpendicular to the line (a tape measure) at every meter, recording the species and groundcover type that it touched. The recorded species were again identified in INaturalist and additional information (i.e. structural class, current conservation status, habitat, etc.) was taken from the homepage of the New Zealand Plant Conservation Network (NZPCN, n.d.). The transect data were analysed in R. The access to the data files and the R-code used for the analysis can be found in Appendix 3.

Figure 8.1:Transect sites (T1: top, T2: bottom)

Figure 8.2: Locations of transects below Grandview Ridge (Map source: Google (2023)).

8.3: Results

8.3.1: Transect Data

The transect data indicates little similarity between the vegetation composition of the two sampled locations. The only shared component is "non-native grass", which is a description based on the expertise of the transect collectors (the exact species of grass could not be identified).

At T1, the lower-altitude transect, the majority of observed species were exotic. The most prevalent functional groups of vegetation in terms of cover were "grass" (57%) and "groundcover" (25%; mostly thatch, some stems (Appendix 2, Figure 8.9)). A lower portion was herbs (7%), ferns (6%) and shrubs (5%). A graphical visualization of the functional groups is located in Appendix 1 (Figure 8.7). The abundance of species recorded at T1 is shown below in Figure 8.3. Ten taxa could be identified at the species level. A large portion (18%) was of the grasses genus *Festuca* (called "Festuca species"), which could not be identified at the species level, and "non-native grass" (12%). The most abundant species were the exotic grasses *Agrostis capillaris* (browntop; 15%) and *Dactylis glomerata* (cat grass; 8%), and the native alpine fern *Ptertidium esculentum* (bracken fern; 6%). The native vegetation present further included the alpine herb *Muehlenbeckia* australis (pohuehue), as well as the threatened shrub *Discaria toumatou* (matagouri).

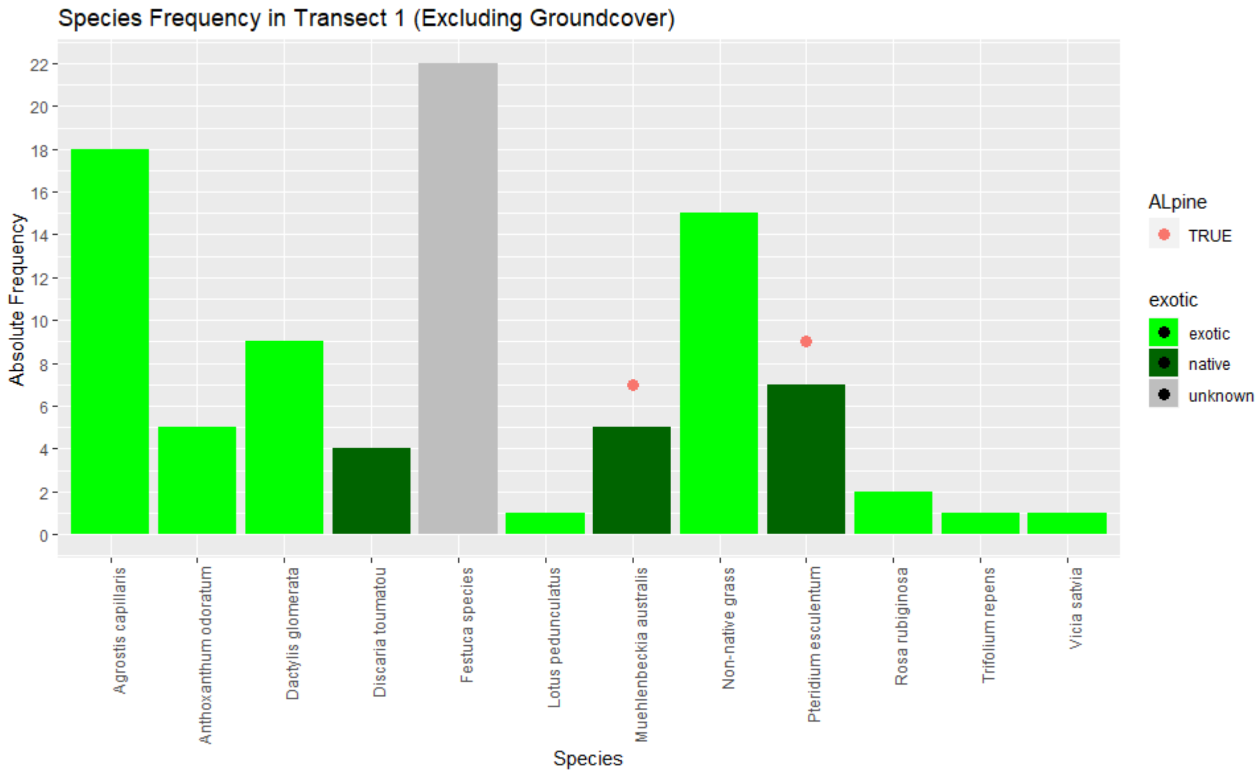


Figure 8.3: Plant species community at T1 (red dot = "alpine" species).

At T2, the transect in the alpine zone, the majority of observed species were native. The abundance of functional groups was more balanced than at T1, with a distribution of "groundcover" (39%; bare ground, with some litter, rock, stems and thatch (Appendix 2, Figure 8.10)), "grass" (32%) and "shrub" (22%) and "herb" (7%) occurring least. The category "ferns" was not recorded. A graphical visualization of the functional groups is located in Appendix 1 (Figure 8.8).The abundance of species identified at T2 is depicted below in Figure 8.4. Ten taxa could be identified at the species level at the second transect. In percentage cover, the most abundant species at T2 were the native grasses *Chionochloa rigida* (narrow-leaved tussock; 14%), *Poa Colensoi* (blue tussock; 13%), and the native alpine shrub *Acrothamnus colensoi* (Colensos mingimingi; 11%). *Hieracium lepidulum* (Tussock hawkweed; 4%) and "non-native grass" (4%) were the only recorded exotics. The vegetation further encompassed several alpine plants such as the herbs *Aciphylla aurea* (golden spaniard), *Celmisia gracilenta* (common mountain daisy), and the shrubs *Pentachondra pumila* (epacris pumila), S*typhelia nesophila (*dwarf mingimingi) and *Coprosma petriei (*turfy coprosma). The threatened native shrub *Carmichaelia petriei* (desert broom*)* was also present.

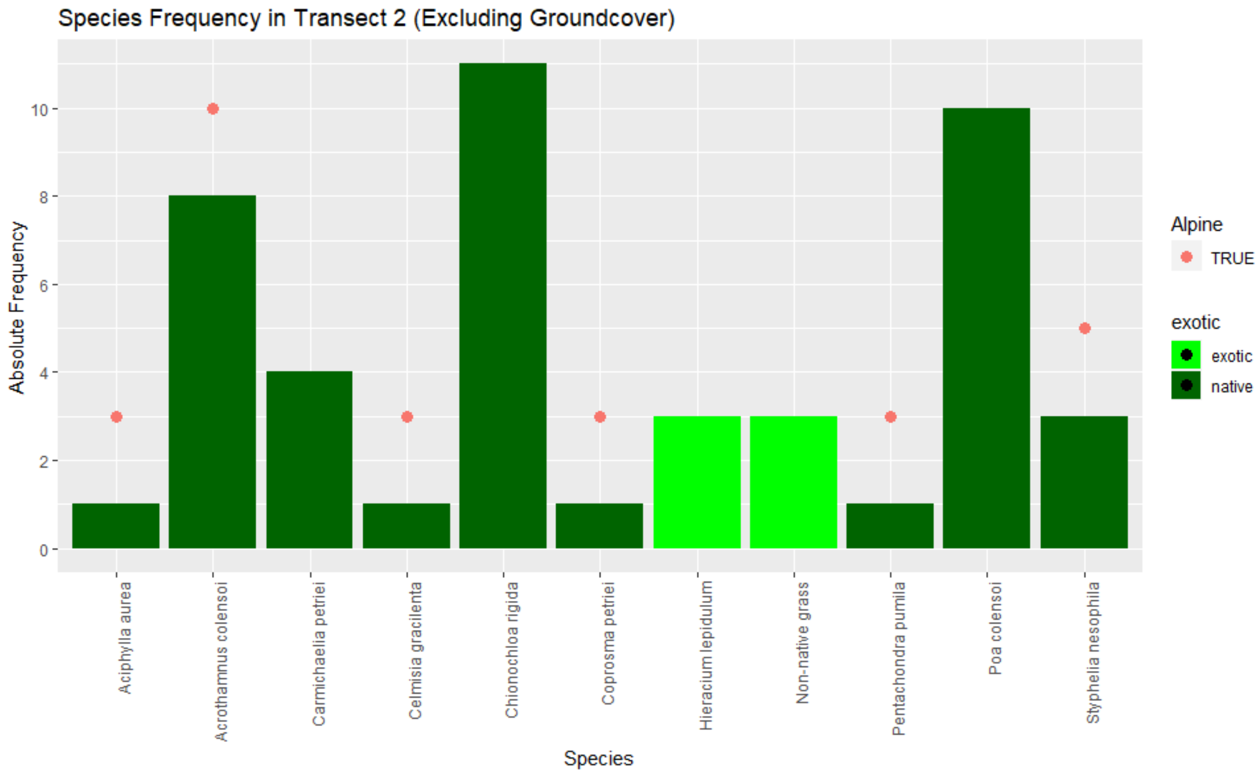


Figure 8.4: Plant species community at T2 (red dot = "alpine" species).

8.3.2: INaturalist Data

The data exported from INaturalist comprises a total of 1355 plant observations across an elevational range of 400 – 1447 m. 671 sightings are in the lowland area (< 700m), 211 in the range mid-zone of the High Country (700-900 m), and 471 in the alpine zone (> 900m). The observations show a similar pattern to the transects, with the fraction of natives increasing in altitude. Below 700 m, the number of observations of native and exotic vegetation is approximately equal, with a slightly lower fraction of native plants (48%), while in the mid-zone, most observations are of native vegetation (74%). In the alpine area, the fraction of native plant observations is even higher (88%).

The observations depict a higher species richness above the treeline in comparison to the mid-zone range. Depicted below in Figures 8.5 and 8.6 are the frequency of sightings per species in the mid- and alpine zone (only depicting species that were recorded more than twice). The mid-zone observations comprised in total of 22 exotic and 72 native species. The most commonly observed plants were the endangered native shrub *Discaria toumatou* (matagouri), the invasive shrub *Rosa rubiginosa* (sweet briar) and the native alpine shrub *Styphelia nesophila* (dwarf mingimingi). The alpine zone had a total of 23 exotic plant species and 118 natives. The most commonly observed plants were the native alpine shrub *Acrothamnus colensoi (*Colensos mingimingi), the native alpine herbs *Aciphylla aurea* (golden spaniard), and *Celmisia densiflora* (mountain daisy).

Figure 8.5: INaturalist species observations (mid-zone)

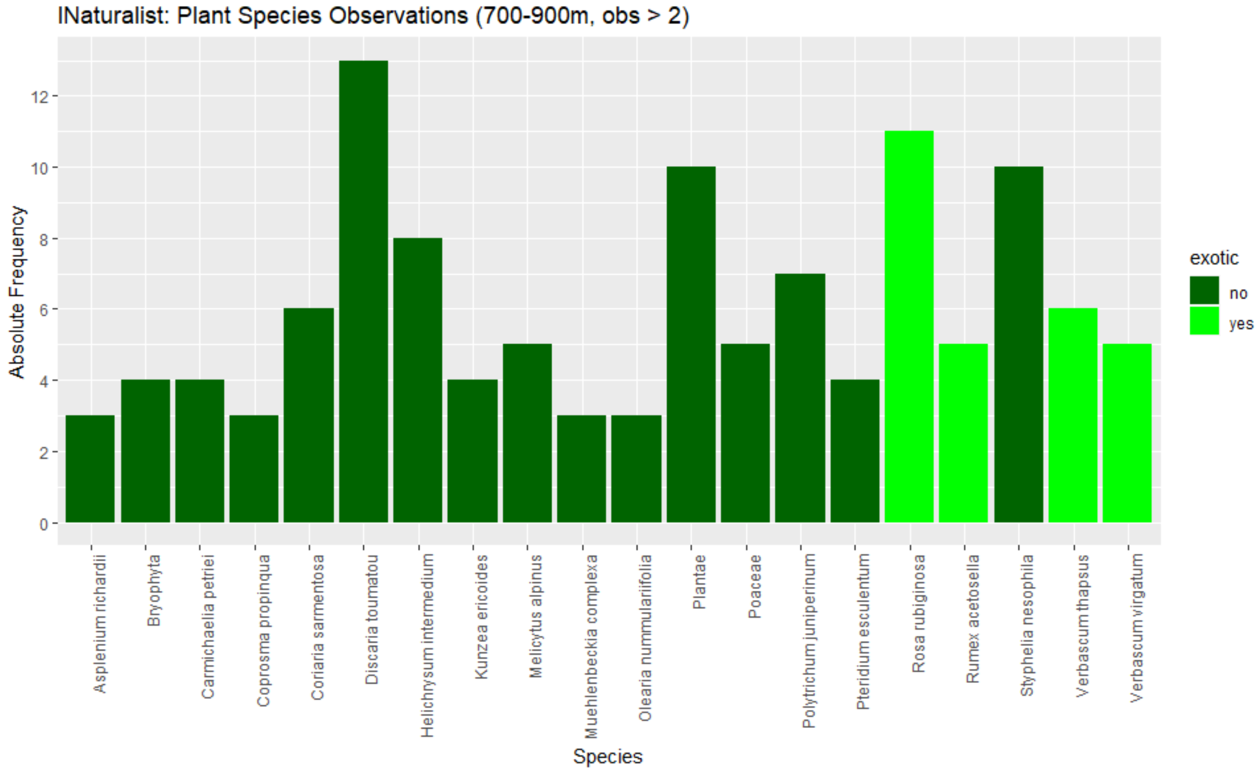
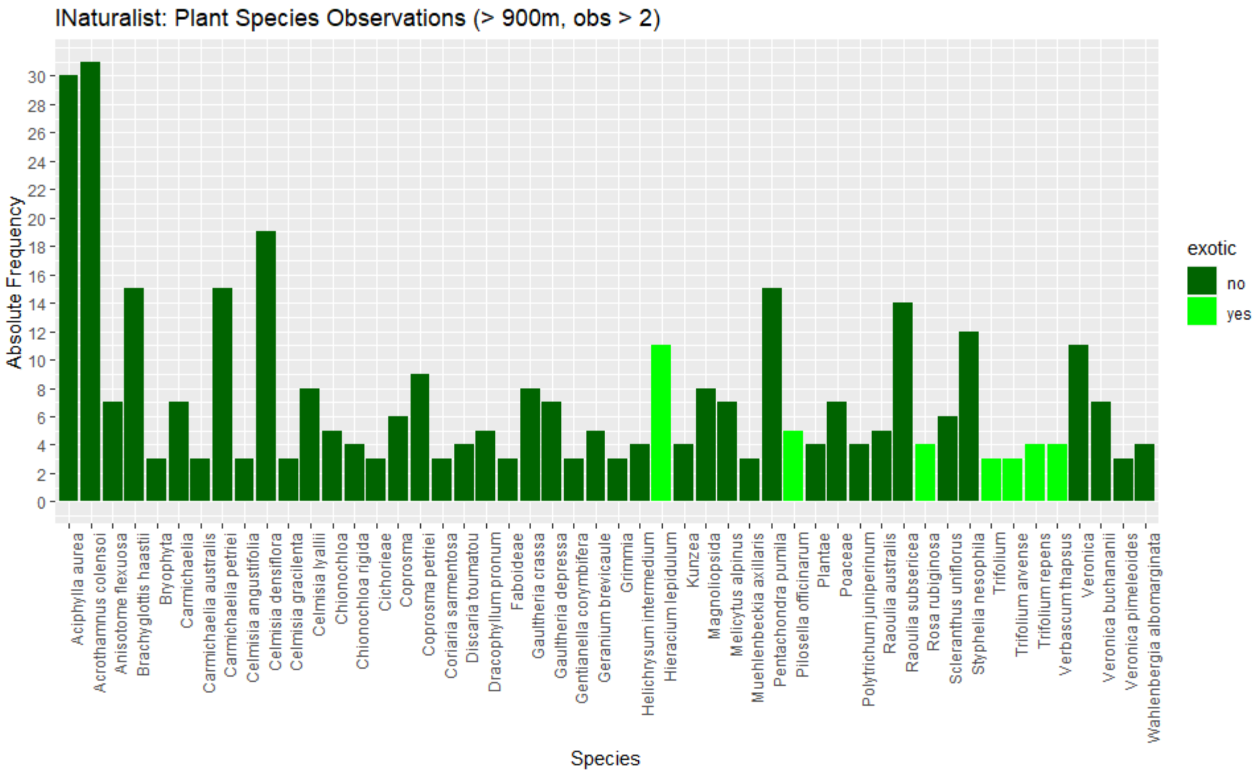


Figure 8.6: INaturalist species observations (alpine zone)



8.4: Discussion

The results from the data that was obtained demonstrate the increase of native plants with altitude in the upland pasture landscape at Mt. Grand, both in terms of species diversity, as in their relative abundance. The transects do not show a difference in alpha diversity (richness), as ten different species were identified at both locations, although the distribution of functional groups was more even at the second transect. However, the transects indicate a high turnover rate of species across elevation, as no identified species was found to occur at both locations (except for the unspecified “non-native grass”). At T1, the transect taken at the lower range of the High County (~ 820m), the largest fraction of cover was exotic grass. Only two species classified as “alpine” (NZPCN, n.d.) were recorded there. The second transect T2, conducted in the alpine zone (~1130 m) was covered mostly by native grasses and different alpine herbs and shrubs, with a comparatively low abundance of the invasive hawkweed (*Hieracium spp.*) and exotic grass.

In contrast, the INaturalist data does suggest that the species richness is especially high in the alpine zone (> 900 m), as the observations include 141 distinct species, while in the mid-altitude zone, only 94 were recorded. The proportion of native plants is highest in the alpine zone, both in terms of the species count (84% of identified species are native), as well as the overall number of observations (88% of observations are of native species). However, it must be noted that the number of photos taken within the mid-elevational range is lower, likely a result of students having spent less time there during the field course. Therefore, while this data is useful for getting a gross picture of the vegetation found across the upland pasture's altitudinal range, the focus of research on the higher-elevated areas brings in a degree of distortion. The transect data may be more accurate in this sense.

The Conservation Resources Report of the Crown Pastoral Land Tenure Review (Land Information New Zealand 2006) describes the state of the high-altitude tussock grasslands as having a rich and stable alpine plant community, with good species diversity and only a minor component of exotic flora. Several uncommon species were present in 2006, especially within the proximity of rocky outcrops. The data collected during the 2023 field course captures a similar picture, although it is difficult to determine whether the condition of the alpine community is still as “good” as it was at the time. Especially at the location of the second transect, the pressures of herbivorous grazing were highly visible during the field course, in the form of intensely chewed-on vegetation and droppings. The abundance of “bare ground” along the transect T2 could indicate enhanced soil erosion in the area. The presence of problem plants such as hawkweeds (*Hieracium spp.*) that were identified on-site poses a threat to the native alpine plants, as they are often more resilient to grazing (Land Information New Zealand 2006).

From the agricultural perspective, there is a considerable economic incentive to increase the productivity rates of these upland pastures, which are low due to the limited nutrient availability of the soil, especially lacking nitrogen (N) (Pollock and Scott 1993; Maxwell, Moir, and Edwards 2016). Historically, native shrubs such as *Carmichaelia petriei* (broom), *Sophora prostrata* (kowhai), *Discaria toumoutu* (matagouri) and *Coriaria arborea* (tutu) were important N-fixers, their abundance much reduced after the introduction of European pastoralism (Boswell, Lowther, and Agresearch 2001). The current composition of the tussock grassland vegetation is often referred to as “unimproved”, in contrast to the “improved” lowland, which is covered in exotic pasture crops with an enhanced ability to fix nitrogen. Applying fertilizer, as well as increasing the abundance of different "improved" exotic grasses and legumes have long been explored approaches in an attempt to raise the quality of tussock grassland as pasture resources (Boswell, Lowther, and Agresearch 2001; O’Connor 2003; Pollock and Scott 1993; Maxwell, Moir, and Edwards 2016). Native grasses like Poa collensoi (blue tussock), *Festuca novae zelandiea, and Chionochloa rigida* (snow tussock), are acknowledged to have “*some potential for use in pastoral agricultural systems*” (Scott, Keoghan, and Allan 1996, 504), however their presence in pastures shall not exceed the extent of rejuvenation measures applied for soil, landscape and native flora conservation.

From a conservation viewpoint, it seems that while the introduction of exotic species may raise the “quality” of pastures in terms of higher productivity, demeaning the native vegetation to the status “unimproved” disregards the natural ecosystem’s values in terms of ecosystem services provision, cultural heritage and preserving the country’s biodiversity. For the Mt. Grand Station, many of these attributes and values have been described and discussed in detail in the past reports of the ECOL609 Conservation Biology course, such as Sutton (2019), Brown (2016) and (2019).

8.5: Conclusion

In the context of preserving the functional integrity of one of New Zealand’s most iconic cultural landscapes, the High Country tussock grasslands, several measures could be considered to preserve conserve it as a habitat for a range of native plants, among them sensitive alpine species. These could include the purposeful re-introduction of native shrubs that have been identified as historically important fixers of nitrogen, which, besides increasing the structural diversity of the ecosystem, could positively impact the soil-nutrient availability and benefit the pasture productivity rate. Lowering the stocking rates could enhance the stability of the pastureland, decreasing the rate of soil erosion and weed expansion, which could support the recovery of native flora. Measures to prevent grazing around the proximity of rocky outcrops could provide refuges for the alpine plants occurring there. Many of these measures have been described in the literature, and the before-mentioned ECOL609 student reports.

As the Mt. Grand Station tussock grassland is openly available to be studied by Lincoln University, they provide an ideal setting for further research in terms of testing approaches (like those mentioned above) that could potentially harmonize the conflict between agricultural interests and conservation concerns. This could provide valuable insights for increasing the sustainability of management practices in the upland pastures of the High Country.

8.6: References

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8.7: Appendices

8.7.1: Appendix 1: Distribution of functional group at transects

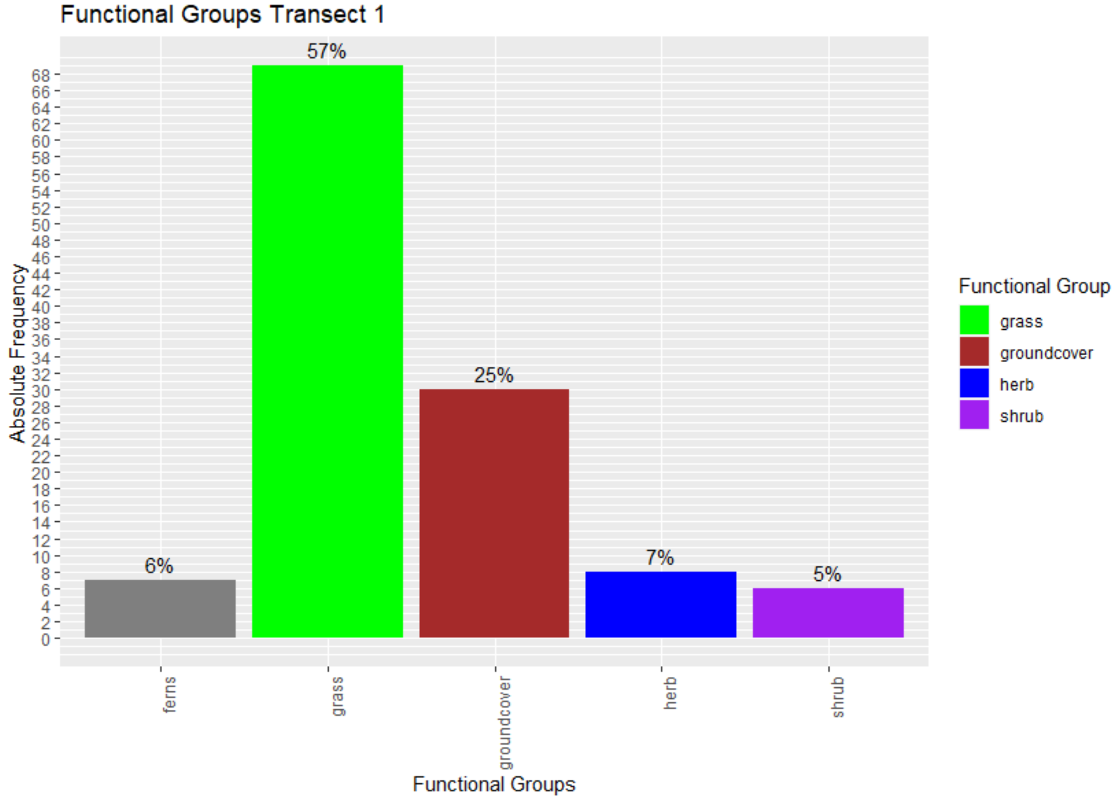

Figure 8.7: Functional groups at T1 (mid-zone)

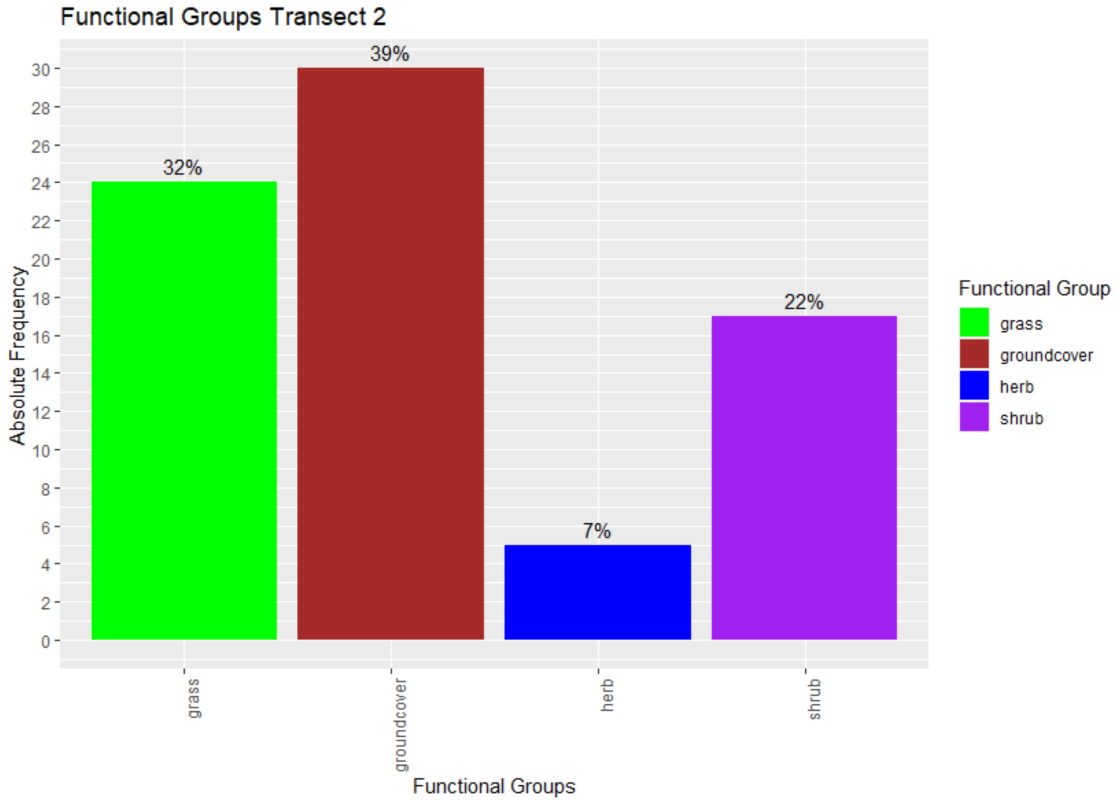

Figure 8.8: Functional groups at T2 (alpine zone)

8.7.2: Appendix 2: Functional group “groundcover” at transects

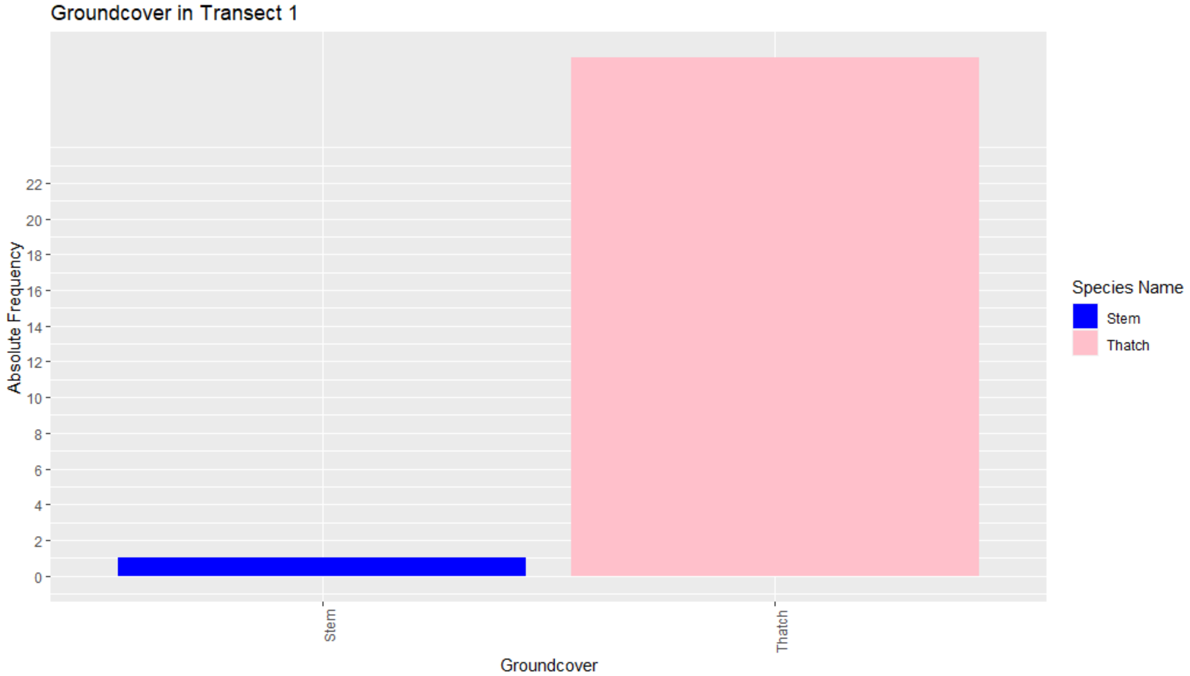

Figure 8.9: Functional group “groundcover” at T1 (mid-zone)

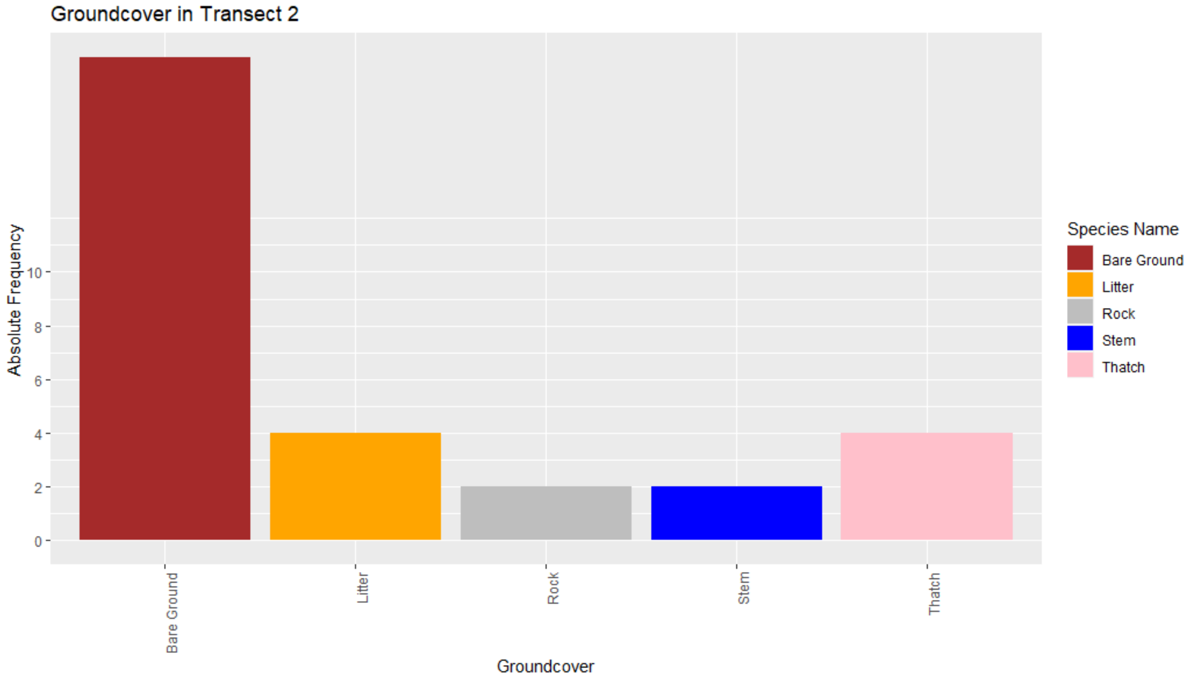

Figure 8.10: Functional group “groundcover” at T2 (alpine zone)

8.7.3: Appendix 3: R- Code (data analysis in R)

The supporting data (xlsx. format) can be accessed at:
https://drive.google.com/drive/folders/1eDtyGnLBivnWbTlkpye2dUT6uyrb3dei?usp=sharing

```
rm(list=ls())
setwd("…")
library(ggplot2)
library(dplyr)

#load data
plant_obs <- read.csv("all_samples_clean_exotic.csv")
# all plant observations, elevations below 400 removed (not part of Mt. G station,
#as well as obs without elevation(NAs); 58 obs removed, 7 (all native) taxon removed)

#count exotics and native observation
# Changing the column name
names(plant_obs)[names(plant_obs) == "Exotic"] <- "exotic"
names(plant_obs)[names(plant_obs) == "waitaki_25"] <- "altitude"

'---------------------------------------------------------------------------'
summary(plant_obs$altitude)
# Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
# 400.6   520.0   706.3   799.2  1105.4  1447.1

# count exotic:native in all obs
sum(plant_obs$exotic == "yes")
sum(plant_obs$exotic == "no")

'details (n= all observations:'
# 1355 obs
# exotic: 457
# native: 898

'---------------------------------------------------------------------------'
#subset elevational zones
obs_below700 <- subset(plant_obs, altitude < 700) # 671
length(unique(obs_below700$scientific)) #141

obs_700 <- subset(plant_obs, altitude > 700 & altitude < 900) # 211
length(unique(obs_700$scientific)) #94

obs_900 <- subset(plant_obs, altitude > 900) # 471
length(unique(obs_900$scientific)) #140

'---------------------------------------------------------------------------'
# > 700m: native/exotic fractions:
obs_ex_below700 <- subset(obs_below700, exotic == "yes") #348
obs_nat_below700 <- subset(obs_below700, exotic == "no") # 323

length(unique(obs_ex_below700$scientific))#60 species
length(unique(obs_nat_below700$scientific))#84

# > 700m: native/exotic fractions:
obs_ex_700 <- subset(obs_700, exotic == "yes") #54
obs_nat_700 <- subset(obs_700, exotic == "no") # 157
```

```
length(unique(obs_ex_700$scientific))#22 species
length(unique(obs_nat_700$scientific))#72

# > 900m: native/exotic fractions:
obs_ex_900 <- subset(obs_900, exotic == "yes") #55
obs_nat_900 <- subset(obs_900, exotic == "no") # 416
length(unique(obs_ex_900$scientific))#23 species
length(unique(obs_nat_900$scientific))#118

'----------------------------------------------------------------------------'
# common taxa
length(common_tax <- intersect(obs_ex_700$scientific, obs_ex_900$scientific))
length(common_tax2 <- intersect(obs_nat_700$scientific, obs_nat_900$scientific))

length(common_tax <- intersect(obs_ex_700$scientific, obs_ex_900$scientific))
length(common_tax2 <- intersect(obs_nat_700$scientific, obs_nat_900$scientific))

'----------------------------------------------------------------------------'
#creating taxon dataframe
#700.900m
species_700 <- obs_700 %>%
  group_by(`scientific`, exotic) %>%
  summarise(frequency = n()) %>%
  ungroup()

#>900m
species_900 <- obs_900 %>%
  group_by(`scientific`, exotic) %>%
  summarise(frequency = n()) %>%
  ungroup()

# Calculate the total frequency
freq_700 <- sum(species_700$frequency)

# Calculate the frequency percentages
species_700$percentage <- (species_700$frequency / freq_700) * 100 ;
sum(species_700$percentage)
species_700$percentage <- paste0(round(species_700$percentage), "%")
#T2
# Calculate the total frequency
freq_900 <- sum(species_900$frequency)

# Calculate the frequency percentages
species_900$percentage <- (species_900$frequency / freq_900) * 100 ;
sum(species_900$percentage)
species_900$percentage <- paste0(round(species_900$percentage), "%")


'----------------------------------------------------------------------------'
# taxon 700 - 900m
species_700_abundant <- subset(species_700, frequency > 2) # only species observed
more than once

ggplot(species_700_abundant, aes(x = `scientific`, y = frequency, fill = exotic)) +
  geom_bar(stat = "identity") +
```

```
  xlab("Species") +
  ylab("Absolute Frequency") +
  ggtitle("INaturalist: Plant Species Observations (700-900m, obs > 2)") +
  scale_fill_manual(values = c("yes" = "green", "no" = "darkgreen")) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(species_700_abundant$frequency), by = 2))

# taxon >900 m
species_900_abundant <- subset(species_900, frequency > 2) # only species observed
more than once

ggplot(species_900_abundant, aes(x = `scientific`, y = frequency, fill = exotic)) +
  geom_bar(stat = "identity") +
  xlab("Species") +
  ylab("Absolute Frequency") +
  ggtitle("INaturalist: Plant Species Observations (> 900m, obs > 2)") +
  scale_fill_manual(values = c("yes" = "green", "no" = "darkgreen")) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(species_900_abundant$frequency), by = 2))

# library(writexl)
# write_xlsx(species_900, "~/_EDUCATION/_STUDIUM/BOKU/NARMEE_Master/SS23
(exchange)/ecol609/Final Report/Data/INaturalist data/created in R/species_900.xlsx")

################################################################################
#########
# TRANSECT DATA
rm(list=ls())
setwd("…")
library("readxl")
library(dplyr)
library(ggplot2)
library(tidyverse)
library(tidyr)

trans <- read_excel("transects_prepared_2.xlsx")

# clean
# Remove a column using subset
trans <- subset(trans, select = -Notes) # removed Notes column, as it was empty
trans <- trans[!grepl("Dead", trans$`Species Name`), ] # I removed all observation with
"Dead"
trans <- trans[!grepl("dead", trans$`Species Name`), ]
trans <- trans[!grepl("NOT IDENTIFIED", trans$`Species Name`), ]
names(trans)[names(trans) == "Exotic or Native"] <- "exotic"

# subset transects
t1 <- trans[trans$Transect_Name == "Transect 1", ]
t2 <- trans[trans$Transect_Name == "Transect 2", ]

# data exploration
'DETAILS'
#T1
# obs: 120
# unique tax: 12 (groundcover excluded)
```

```
#T2
# obs: 76
'lower coverage'
# unique tax: 11 (ground cove excluded)

# which species do transects have in common?
common_species <- intersect(t1$`Species Name`, t2$`Species Name`) # no specific species
in common, only ground cover classes


# frequency plots
# summary statistics (total number of species in transects)
sum(trans$Transect_Name == "Transect 1")
sum(trans$Transect_Name == "Transect 2")

#species frequency (all data, including groundcover functional groups)

species_freq_t1 <- trans %>%
  filter(Transect_Name == "Transect 1") %>%
  group_by(`Species Name`, `Functional Group`, exotic, Alpine) %>%
  summarise(frequency = n()) %>%
  ungroup()

species_freq_t2 <- trans %>%
  filter(Transect_Name == "Transect 2") %>%
  group_by(`Species Name`, `Functional Group`, exotic, Alpine) %>%
  summarise(frequency = n()) %>%
  ungroup()

# add percentage
#T1
# Calculate the total frequency
freq_t1 <- sum(species_freq_t1$frequency)

# Calculate the frequency percentages
species_freq_t1$percentage <- (species_freq_t1$frequency / freq_t1) * 100 ;
sum(species_freq_t1$percentage)
species_freq_t1$percentage <- paste0(round(species_freq_t1$percentage), "%")
#T2
freq_t2 <- sum(species_freq_t2$frequency)

# Calculate the frequency percentages
species_freq_t2$percentage <- (species_freq_t2$frequency / freq_t2) * 100 ;
sum(species_freq_t2$percentage)
species_freq_t2$percentage <- paste0(round(species_freq_t2$percentage), "%")

'---------------------------------------------------------------------------'
# funcitonal group distribution

func_t1 <- trans %>%
  filter(Transect_Name == "Transect 1") %>%
  group_by(`Functional Group`) %>%
  summarise(frequency = n()) %>%
  ungroup()
```

```
func_t2 <- trans %>%
  filter(Transect_Name == "Transect 2") %>%
  group_by(`Functional Group`) %>%
  summarise(frequency = n()) %>%
  ungroup()

# add percentage
#T1
# Calculate the total frequency
funcper_t1 <- sum(func_t1$frequency)

# Calculate the frequency percentages
func_t1$percentage <- (func_t1$frequency / funcper_t1) * 100 ; sum(func_t1$percentage)
func_t1$percentage <- paste0(round(func_t1$percentage), "%") # round and add % sign

#T2
funcper_t2 <- sum(func_t2$frequency)

# Calculate the frequency percentages
func_t2$percentage <- (func_t2$frequency / funcper_t2) * 100 ; sum(func_t2$percentage)
func_t2$percentage <- paste0(round(func_t2$percentage), "%") # round and add % sign

#plot
ggplot(func_t1, aes(x = `Functional Group`, y = frequency, fill =`Functional Group` )) +
  geom_bar(stat = "identity") +
  xlab("Functional Groups") +
  ylab("Absolute Frequency") +
  ggtitle("Functional Groups Transect 1") +
  #scale_fill_manual(values = c("exotic" = "green", "native" = "darkgreen", "unknown" =
"red")) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(func_t1$frequency), by = 2))+
  geom_text(aes(label = percentage), vjust = -0.5)+
  scale_fill_manual(values = c("grass" = "green", "groundcover" = "brown", "herb" = "blue",
"shrub" = "purple", "fern" = "pink"))


ggplot(func_t2, aes(x = `Functional Group`, y = frequency, fill =`Functional Group` )) +
  geom_bar(stat = "identity") +
  xlab("Functional Groups") +
  ylab("Absolute Frequency") +
  ggtitle("Functional Groups Transect 2") +
  #scale_fill_manual(values = c("exotic" = "green", "native" = "darkgreen", "unknown" =
"red")) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(func_t2$frequency), by = 2))+
  geom_text(aes(label = percentage), vjust = -0.5)+
  scale_fill_manual(values = c("grass" = "green", "groundcover" = "brown", "herb" = "blue",
"shrub" = "purple", "fern" = "pink"))


'-----------------------------------------------------------------------------'
# excluding functional group ground cover (overview of identified species)
newspecies_freq_t1 <- trans %>%
```

```
  filter(Transect_Name == "Transect 1", `Functional Group` != "groundcover") %>%
  group_by(`Species Name`, exotic, `Functional Group`, Alpine) %>%
  summarise(frequency = n()) %>%
  ungroup()

newspecies_freq_t2 <- trans %>%
  filter(Transect_Name == "Transect 2", `Functional Group` != "groundcover") %>%
  group_by(`Species Name`, `Functional Group`, exotic, Alpine) %>%
  summarise(frequency = n()) %>%
  ungroup()

# add percentage
#T1
# Calculate the total frequency
total_freq_t1 <- sum(newspecies_freq_t1$frequency)

# Calculate the frequency percentages
newspecies_freq_t1$percentage <- (newspecies_freq_t1$frequency / total_freq_t1) * 100 ;
sum(newspecies_freq_t1$percentage)
newspecies_freq_t1$percentage <- paste0(round(newspecies_freq_t1$percentage), "%") #
round and add % sign

#T2
total_freq_t2 <- sum(newspecies_freq_t2$frequency)

# Calculate the frequency percentages
newspecies_freq_t2$percentage <- (newspecies_freq_t2$frequency / total_freq_t2) * 100 ;
sum(newspecies_freq_t2$percentage)
newspecies_freq_t2$percentage <- paste0(round(newspecies_freq_t2$percentage), "%")


# color coded barplots
ggplot(newspecies_freq_t1, aes(x = `Species Name`, y = frequency, fill = exotic)) +
  geom_bar(stat = "identity") +
  xlab("Species") +
  ylab("Absolute Frequency") +
  ggtitle("Species Frequency in Transect 1 (Excluding Groundcover)") +
  scale_fill_manual(values = c("exotic" = "green", "native" = "darkgreen", "unknown" =
"gray")) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(newspecies_freq_t1$frequency), by = 2))+
  geom_point(data = subset(newspecies_freq_t1, Alpine != "NA"),
             aes(x = `Species Name`, y = frequency + 2, color = Alpine != "NA"),
             size = 3) +
  labs(color = "Alpine")

ggplot(newspecies_freq_t2, aes(x = `Species Name`, y = frequency, fill = exotic)) +
  geom_bar(stat = "identity") +
  xlab("Species") +
  ylab("Absolute Frequency") +
  ggtitle("Species Frequency in Transect 2 (Excluding Groundcover)") +
  scale_fill_manual(values = c("exotic" = "green", "native" = "darkgreen", "unknown" =
"gray")) +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(newspecies_freq_t2$frequency), by = 2))+
```

```
  geom_point(data = subset(newspecies_freq_t2, Alpine != "NA"),
             aes(x = `Species Name`, y = frequency + 2, color = Alpine != "NA"),
             size = 3) +
  labs(color = "Alpine")


'---------------------------------------------------------------------------'
#groundcover

#new try
groundcover_freq_t1 <- trans %>%
  filter(Transect_Name == "Transect 1", `Functional Group` == "groundcover") %>%
  group_by(`Species Name`, exotic) %>%
  summarise(frequency = n()) %>%
  ungroup()

groundcover_freq_t2 <- trans %>%
  filter(Transect_Name == "Transect 2", `Functional Group` == "groundcover") %>%
  group_by(`Species Name`, exotic) %>%
  summarise(frequency = n()) %>%
  ungroup()

#frequency plots

ggplot(groundcover_freq_t1, aes(x = `Species Name`, y = frequency, fill = `Species Name` ))
+
  geom_bar(stat = "identity") +
  xlab("Groundcover") +
  ylab("Absolute Frequency") +
  ggtitle("Groundcover in Transect 1") +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(newspecies_freq_t1$frequency), by = 2))+
  scale_fill_manual(values = c("Bare Ground" = "brown", "Litter" = "orange", "Rock" = "gray",
"Stem" = "blue", "Thatch" = "pink"))

ggplot(groundcover_freq_t2, aes(x = `Species Name`, y = frequency, fill = `Species Name` ))
+
  geom_bar(stat = "identity") +
  xlab("Groundcover") +
  ylab("Absolute Frequency") +
  ggtitle("Groundcover in Transect 2") +
  theme(axis.text.x = element_text(angle = 90, hjust = 1))+
  scale_y_continuous(breaks = seq(0, max(newspecies_freq_t2$frequency), by = 2))+
  scale_fill_manual(values = c("Bare Ground" = "brown", "Litter" = "orange", "Rock" = "gray",
"Stem" = "blue", "Thatch" = "pink"))
```

Chapter 9: The Lichen Community in a Rotationally Grazed High Country Tussock Grassland

Julia Criscuolo

Abstract

Lichen are a symbiotic relationship between a fungus and an algae or cyanobacteria found all over the world. They cover an estimated seven percent of the Earth's surface and perform a variety of vital ecosystem functions. Lichen are highly influenced by anthropogenic activities. Livestock grazing typically increases soil nitrogen levels due to manure. Mt Grand is a working farm with rotational sheep and cattle grazing in a high country tussock grassland in Otago, New Zealand in which the lichen community was assessed. Students collected observational data on lichen at several locations in proximity to the farm roads and along the trail of Hospital Gully. Given the challenges of identifying lichens, samples were identified down to the scientific family. A total of 131 samples were identified from 15 families. The majority of observations occurred on rocks, which is representative of the available substrate in a high country grassland. The family with the most identifications was *Parmeliaceae*, followed by *Teloschistaceae,* then *Cladoniaceae*. This is generally representative of relative nitrogen-tolerances according to previous studies, as well as sun-tolerance, diversity, and specializations for altitude and habitat. Within families, there are species-specific abilities to acclimate to nitrogen inputs over time. However, other factors such as competitive interactions, humidity, and nitrogen form also influence nitrogen enrichment acclimation ability. Individual species responses are based on many factors and are difficult to predict. More research is needed on how lichens are influenced by nitrogen inputs in soil from livestock. Long-term lichen monitoring should be conducted at Mt Grand.

Key words: High country; lichen; livestock; nitrogen enrichment; rotational grazing; substrate.

9.1: Introduction

Lichens are a symbiotic relationship between a fungus and an algae or cyanobacteria to form a mutualistic relationship that is so efficient and successful, it has likely evolved multiple times (Malcolm & Malcolm, 2000; Nash III, 2008). Lichens are found all over the world, covering an estimated seven percent of the Earth's surface (Nash III, 2008) and are essential early colonizers in primary succession (Lepp, 2011). Many can grow on bare rock, and some can even grow up to eight millimeters into it (Grzelewski, 2011). This leads to the biodeterioration of stone, an essential process for freeing up locked nutrients (Nash III, 2008). The ability of lichen to grow where others can't plays a vital role in early ecosystem transformation, such as catching and trapping dust and dirt particles to form a layer of soil where flora, such as mosses, can grow (Grzelewski, 2011).

Beyond primary succession, lichens have essential chemical ecosystem functions, including nitrogen fixation and nutrient cycling (Nash III, 2008). Lichens also provide food and habitat for a variety of species, and some birds use lichen to camouflage their nests (Malcolm & Malcolm, 2000). Beyond their ecosystem functions, they also have important cultural and medicinal roles for humans (Martin & Child, 1978). For example, the beard lichens (*Usnea spp.*) are believed to be the inspiration for tinsel on Christmas trees, have been used as nappies by Mauri people, and they have antiseptic properties (Grzelewski, 2011). Lichens are also important bioindicators, with some being quite sensitive to air pollutants (Malcolm & Malcolm, 2000; Nash III, 2008), pollution in soils (Nash III, 2008), and changes in nutrients and chemical composition in substrate (Johansson et al., 2012). Some lichen are more tolerant of specific nutrient inputs than others (Munzi et al., 2013), so changes in atmospheric and substrate nutrients may cause noticeable changes in lichen communities. Despite their ecological importance, they have been incredibly understudied both around the world and in New Zealand, where they are especially diverse. New Zealand has 1/500th of the world's land, but hosts 1/10th of the world's lichen species (Malcolm & Malcolm, 2000). Over 2,100 species that have been identified in New Zealand, over half of which are data deficient, and more are constantly being discovered (de Lange et al., 2012).

Livestock grazing can intensely alter flora community structure (He et al., 2021; Li et al., 2022; Zhang et al., 2023). Grazed plants that would otherwise grow taller and more dominant are kept in check, which opens up room for other species that would otherwise be shaded out (Armstrong & Welch, 2007). This influences available food and habitat for other species living in the community, and alters light availability (Li et al., 2022). Grazing can also influence flora morphology, nutrient cycling, soil density, and water runoff (Centeri, 2022), all of which influence lichen. Soil nitrogen levels typically increase with livestock grazing due to manure (Dymond et al., 2013), although the extent of which depends on the intensity of the grazing. Many lichen species thrive in low-nutrient, low-competition environments (Armstrong, 2017). Therefore, soil nitrogen elevation from grazing could lead to localized declines in lichen diversity and density due to intolerance of nitrogen enrichment, as well as increased competition with the likely increase in plant biomass that typically comes with more eutrophic environments (Sullivan & Sullivan, 2017). The effects of soil nitrogen enrichment on lichen communities is believed to be negative. Most studies show that lichen biodiversity declines with excess nitrogen inputs (Briton & Fisher, 2007; Kantelinen et al., 2022; Rönnqvist, 2013), however, studies have demonstrated that slow and low nitrogen inputs into an environment can maintain the same lichen diversity (Frati et al., 2007) or even increase lichen diversity (Zarabska-Bożejewicz, 2020). Mt Grand is a subalpine active farm with rotational grazing in the high country tussock grasslands of Otago, New Zealand. This paper aims to generally assess the lichen community in Mt Grand through livestock grazing and soil nitrogen enrichment from manure. Notes on the conservation and management efforts and their impacts on lichen are included.

9.2: Methods

On two consecutive days, 20 March and 21 March 2023, lichen photos were taken at Mt Grand Station. At three locations around Mt Grand Station on 20 March 2023, researchers conducted observational research in proximity to the dirt roads that run through the farm. The locations were at the following GPS coordinates: (1) -44.6835800, 169.3247700, (2) -44.650310, 169.334410, and (3) -44.6698100, 169.3452900. Researchers made observations within a 100 meter radius from the GPS coordinates. Due to weather conditions, researchers did not go up for general data collection on 21 March 2023, however there were some detection methods that were deployed on 20 March that had to be retrieved on 21 March. During the retrieval researchers collected photographic data as they saw it. Lichen observations were also made along the trail during a hike up Hospital Gully on both days. Observations occurred between 297 and 1447 meters.

Lichen are notoriously hard to identify (Malcom & Malcolm, 2000). The following features are utilized for identification: photobiont type, growth form, thallus and medulla color, sterile features, fertile structures, vegetative propagules, substrate, and habitat (Hutchison & Ford, n.d.). However, many are visually indistinguishable and are identified using chemical spot tests in the field (Bergamini et al., 2005; Malcom & Malcolm, 2000). Crustose lichens were generally not identified, because chemical field testing is often required. Even with tools for chemical identification, some researchers still only identify down to the genus (Bergamini et al., 2005; Roca-Valiente et al., 2016). Given the author's lack of expertise on lichens and limited tools for identification, samples were keyed out to the scientific family for highest confidence in accuracy. Lichens were identified with only photographs, using a variety of clues including photobiont type, thallus shape and color, substrate, and environmental clues, including general altitude and habitat preferences. A variety of tools were used for this process including Malcolm and Malcolm's New Zealand Lichens (2000), New Zealand Plant Conservation Network, Martin and Child's New Zealand Lichens (1972), Hutchison and Ford's (n.d.) guide for lichen field collection and identification, and iNaturalist. Melissa Hutchison was also a valuable resource for identification for this project.

9.3: Results

One hundred thirty-one observations were identified in 15 different families. The family with the most observations was *Parmeliaceae*, followed by *Teloschistaceae* and then *Cladoniaceae* (Table 9.1). Some could be identified to genus, most frequently *Usnea spp.* (*Parmeliaceae*), *Xanthoparmelia spp.* (*Parmeliaceae*), *Xanthoria spp.* (*Teloschistaceae*), *Teloschistes spp.* (*Teloschistaceae*), and *Cladonia spp.* (*Cladoniaceae*). The majority, 69 percent, were observed on rocks, with 20 percent on trees, eight percent on soil, and two percent unknown (Table 9.1). Unknown substrate occurred only a few times with photographs posted on iNaturalist that were too zoomed in on the observation to determine what the substrate was. Lichens were identified with best attempt at accuracy, but it is possible that there are some misidentifications included in the results.

Thirty-two observations could not be identified. With few exceptions, crustose lichens are generally best identified via chemical testing (Folk, 2018; Malcolm & Malcolm, 2000) and were mostly not identified. Otherwise, photographs may not have been clear enough for a confident identification.

Table 9.1: Lichen observations organized by scientific family and substrate on Mt Grand, New Zealand.

	Family	Rock	Bark	Soil/earth	Unknown	Total
1	Parmeliaceae	38	10	2	2	52
2	Teloschistaceae	22	10	0	0	32
3	Cladoniaceae	3	2	4	0	9
4	Rhizocarpaceae	8	0	0	0	8
5	Lecanoraceae	4	0	3	0	7
6	Agyriaceae	4	0	0	0	4
7	Icmadophilaceae	2	0	1	1	4
8	Candelariaceae	3	0	0	0	3
9	Lecideacaea	3	0	0	0	3
10	Physciaceae	2	1	0	0	3
11	Collemataceae	0	2	0	0	2
12	Chrysothricaceae	1	0	0	0	1
13	Lobariaceae	0	0	1	0	1
14	Ramalinaceae	0	1	0	0	1
15	Peltulaceae	1	0	0	0	1
		91	26	11	3	131
	Percent	0.69	0.20	0.08	0.02	

9.4: Discussion

In rotationally grazed land, there are usually slightly elevated levels of nitrogen in the soil due to livestock manure (McGuire, 2020). Changes in nutrient and chemical composition can have many impacts on the ecosystem, both direct and indirect (Malone & Newton, 2020). Directly, some lichens may be very specialized to particular nutrient needs (Nash III, 2008), and specialized species will be influenced by soil nutrient changes. Indirectly, Flora, fungi, and lichen communities are all impacted by soil nutrient composition (Gadd et al., 2001; Morgan & Connolly, 2013; Zarabska-Bożejewicz, 2020). Not only do individual species directly respond to the nutrient changes, but this can lead to changes in community-level interaction as well, including animals and insects. For example, nitrogen encourages the growth of a variety of flora species, which would change the amount of sunlight that reaches various substrates (Cung et al., 2021), changing the dynamics of light competition, ultimately influencing the ability of lichen to grow. While lichens generally require some level of sun so the algae partner can perform photosynthesis, different genera and species tend to tolerate different levels of sun (Nash III, 2008).

During only two days of observation and data collection, species from 15 lichen families were observed. This is a high level of diversity, and may be representative of a diverse and thriving lichen community. However, lichen are slow-growing and take time to adjust to environmental and ecological changes (Nelsen et al., 2022). The *Parmeliaceae* family was the top performer. This is unsurprising given that *Parmeliaceae* is the most diverse lichen family in New Zealand with over 200 identified species (de Lange et al., 2012). At least in part because of its diversity, there are a wide range of habitat, substrate, and nutrient adaptations among the species in *Parmeliaceae* (de Lange et al., 2012). *Teloschistaceae* and *Cladoniaceae* are also diverse families (de Lange et al., 2012).

9.4.1: Elevated nitrogen in soil

Figure 9.1: Cladonia spp, in soil at Mt Grand, New Zealand

Cladoniaceae had the third-most number of observations (Table 9.1), and is the fourth most diverse family in New Zealand (de Lange et al., 2012). The family is terricolous, which tends to be nitrophobic, (Ardelean et al., 2015; Johansson et al., 2012). Additionally, being terricolous puts the species in more direct competition with plants (Armstrong & Welch, 2007). As *Cladonia spp.* is nitrophobic, it is plausible that the genus could have declined since grazing was introduced into Mt Grand. However, a recent study found that long-term low exposure of *Cladonia rangiferina* to nitrogen led to nitrogen acclimation (Morillas et al., 2022), indicating that at least some species may be more resilient than previously believed.

Despite these results, it is important to understand the ecosystem functions of species that are believed to be influenced by nitrogen enrichment. For example, the small cups of trumpet lichen (*Cladonia fimbriata*) (Figure 9.1), which is a nitrophobic species (Ardelean et al., 2015; Johansson et al., 2012), provide cover and perhaps a slightly different microclimate than the surrounding area, which could be important habitat for small insects or arachnids, who could therefore be impacted by a decline of this species. However, no literature was found on the topic. There is extremely limited information on species-specific interaction with lichen.

The *Telochistaceae* family contains the *Xanthoria* genus, or the sunburst lichens, some of which tend to be able to tolerate moderate levels of increased nitrogen in soils if it occurs slowly (Munzi et al*.*, 2013). Long-term slow additions gives the species time to make adjustments and tolerate elevated soil nitrogen (Munzi et al. 2013). With moderate rotational grazing, this could give them an advantage. However, it is difficult to make generalizations about lichen, and lichen responses to chemical and nutrient changes, even at the genus level, due to species specialization. For example, *Usnea spp.* is a diverse genus of lichens with some species being relatively nitrophilic (Wang et al., 2019) and others being fairly nitrophobic (Woltyńska et al., 2023).

Soil enrichment also impacts lichen at both a community level and individual level (Carter et al. 2017). There are four primary ways in which nitrogen enrichment has been found to impact lichens: direct toxicity, changes to lichen-plant interactions, soil acidification impacts, greater susceptibility to secondary stressors (Bobbink et al., 2010). Carter et al. (2017) discusses the various ways lichen are impacted by soil nitrogen enrichment. Lichens have been anecdotally classified as oligotrophic, mesotrophic, and eutrophic regarding nitrogen deposition (Geiser et al., 2010; Jovan, 2008), but community and individual responses are impacted by other factors, including the form and amount of nitrogen input (Carter et al., 2017). Beyond species-specific responses, a variety of factors influence lichen responses to nitrogen enrichment, such as precipitation and humidity (Geiser et al., 2010), competitive interactions (Johansson et al., 2012), nutrient supplies (Gaio-Oliveira et al., 2005), phosphorus limitation (Pilkington et al., 2007) and timing (Carter et al., 2017). It is also important to note that lichens respond to multiple types of nitrogen enrichment, including atmospheric nitrogen (Carter et al., 2017). Additionally, there is not one single species responding to nitrogen enrichment, but two in a symbiotic relationship who may do so differently (Carter et al., 2017). Overall, eutrophic lichens are found to have the greatest tolerance to nitrogen increases (Carter et al., 2017), but community-level and species-specific responses to soil nitrogen enrichment are incredibly complicated and the specifics are poorly understood.

9.4.2: Substrate

There are a variety of factors that influence substrate preference of lichen, including microclimate (Nuzzo et al., 2022), substrate characteristics (Lamit et al., 2015), chemical relationships with substrate (Nash III, 2008), and competition (Herrera et al., 2021). The most common substrates for lichen are rocks, trees, and soil (Aprile et al., 2011), which were the three lichen substrates observed on Mt Grand. The vast majority of the observations in this study occurred on rocks (Table 9.1). In a subalpine tussock grassland environment, there is more rock substrate available to lichens than tree substrate (Department of Conservation, 2006). Often, especially in eutrophic environments, lichens are outcompeted by plants and shrubs (Reinhardt et al., 2022). Lichens typically move from a generalist to specialist direction, rather than the other way around (Resl et al., 2018), which perhaps may have led to relatively greater rock substrate specializations, particularly among subalpine and alpine lichens, and other lichens that live in challenging environments. For example, *Parmelia sulcata* is a species in *Parmeliaceae* that was observed on Mt Grand that is very generalist for elevation and habitat preferences, found from the coast to 2000 meters (Galloway, 2007). However, it is specialist in its saxicolous substrate preference (Galloway, 2007). *P. Sulcata* has rhizines, which are specialized rootlike structures that provide grip on rocks and can extract nutrients (Galloway, 2007). Most lichens have specializations for substrate (Brodo, 1973).

Indirectly influencing lichen, trees have also been found to be sensitive to nitrogen enrichment (Carter et al., 2017). Trees have negative growth responses in areas with excess nitrogen (Thomas et al., 2010). As trees are a vital substrate for lichen (Aprile et al., 2011), excess nitrogen could also impact the availability of substrate for epiphytic lichens if tree growth is inhibited. Additionally, in more extreme cases, if nitrogen enrichment is excessive enough to cause tree die-back or influence seedling recruitment, it could lead to dominance of different tree species or community structure. This could drive the lichen community towards different species as many epiphytic lichens have particular host tree species preferences (Rosabal et al., 2013).

9.4.3: Conservation and invasive species management

Lichen relationships with other species are poorly understood. Lichen relationships with native species are vital to understand for conservation and land management best practices, but the relationship between lichen species and nonnative species should not be overlooked. Nonnative species in New Zealand play a large role in current ecosystem relationships. For example, the nonnative common chaffinch (*Fringilla coelebs*) uses lichen species, including tube lichen (*Hypogymnia physodes*), to camouflage nests (Nash III, 2008; Tolpysheva, 2019). This, however, is quite a visible relationship and more easily documented and studied. Other relationships are less obvious and often poorly understood.

Invasive species control is active on Mt Grand, as it is in much of New Zealand. As lichens do play a vital role in the ecosystems, it is important to preserve native-native interactions, but the importance of lichen interactions with invasive species should not be overlooked. Much of New Zealand's pest management involves culling invasive pests (Russel *et al.,* 2015). There is widespread evidence around the world that mammals browse on various lichen species (Lepp, 2011; Rickbeil et al., 2017). In an environment where all terrestrial mammalian grazers are introduced (Antonelli et al., 2011), grazing could have a very profound impact on the lichen communities. However, moderate levels of generalist grazing can help prevent a monolithic lichen community (Derner et al., 2014). There is a concern that introduced grazers can lead to declines in native species (Gough et al., 2008), although whether or not this is happening at Mt Grand is unclear. *Usnea spp*. is a genus that is known around the world to be grazed on by mammals (Lepp, 2011). Yet, even with many introduced grazers in New Zealand, the *Usnea* genus was one of the more common observations in the *Parmeliaceae* family in this study. Grazing also opens up more substrate available to lichen, and it also changes the amount of sunlight that reaches the substrate. In the *Teloschistaceae* family, *Xanthoria spp.* are generally relatively sun-tolerant (Nash III, 2008). Like other brightly-colored lichens, they produce anthraquinones, which are chemical compounds that block harmful UV rays, while still allowing enough sunlight for the algae to undergo photosynthesis (Nash III, 2008; Cung et al., 2021; McGrath, 2023). This is especially advantageous in a moderately grazed ecosystem with more sunlight.

There is also plenty of evidence that mammals play a role in lichen spore dispersal (Wang et al., 2021; Borgmann-Winter et al., 2023), so the relationships between lichens and introduced mammals in New Zealand are not entirely one-sided. New Zealand has a lofty goal of eradicating rats, stoats, and possums by 2050 (Office of the Minister of Conservation, 2016). There are likely indirect impacts on lichens with the eradication of these species. While the removal of stoats would have large benefits for the ecosystem, such as increased survivability of bird eggs, stoats are also an important predator for introduced hares. They also prey on hedgehogs, which also prey on bird eggs (Taylor, 2005), so the removal of this predator could lead to increased predation by the hedgehogs on ground-nesting birds which could eat lichen or use it for nest-building. No stoats could lead to an increase in rabbit populations, which graze on lichen and could increase pressure on lichen communities (Carter et al., 2017). Rabbits also graze on grass, which could open up substrate and sunlight for the lichen community. While this doesn't mean that the goal of rat, stoat, and possum eradication should be abandoned, it is important to understand the possible releases that could occur from this type of conservation initiative across all components of the ecosystem, rather than just the most clear and direct.

9.5: Conclusion

The lichen community at Mt Grand is very diverse. While soil nitrogen enrichment can impact lichen communities and species present, the specifics are poorly understood. *Parmeleaceae* may continue to be the most diverse family on Mt Grand due to its diversity and array of adaptations and specializations. *Telochistaceae* may do well because the sunburst lichens can acclimate to nitrogen enrichment when done slowly, and the genus is also sun-tolerant (Nash III, 2008), which may be advantageous in a grazed environment as more sun reaches the substrate. Surprisingly, some research has found that *Cladoniaceae* species may have the capacity to acclimate to nitrogen enrichment over a long period of time (Morillas et al., 2022). However, many environmental and chemical factors also influence species ability to adapt to soil nitrogen enrichment (Gaio-Oliveira et al., 2005; Geiser et al., 2010; Johansson et al., 2012; Pilkington et al., 2007), and soil is not the only form nitrogen enrichment can take (Carter et al. 2017).

Studies of nitrogen enrichment impacts on lichens have demonstrated conflicting results. For example, Zarabaska-Bożejewicz (2020) found that nitrogen inputs at a slow and low level can actually increase lichen biodiversity by increasing landscape diversity and fostering more complex environments, welcoming a greater variety of lichens from different trophic levels. It does need to occur slowly, giving species enough time to adjust (Morillas et al., 2022; Munzi et al., 2013), as well as at a moderate enough level, so that there is not the consequence of completely transforming the ecosystem towards eutrophy, which can reduce overall community diversity (Lai et al., 2018; Wang et al., 2021). Carter et al. (2017)

discusses a more complicated picture with individual specializations being influenced by other environmental factors. Lichen also tend to be specialists regarding substrate preference (Brodo, 1973), changes in soil nutrient composition also influence substrate availability for lichen. A subalpine tussock grassland already has relatively limited substrate-diversity, but movement towards a more eutrophic environment could cause this to easily decline even more, as it could lead to an increase in competition with plants (Reinhardt et al., 2022). Additionally, total nitrogen canopy throughfall is considered to be a better measurement and predictor for abundance of eutrophic species (Giordani & Malaspina, 2016; Jovan et al., 2012), rather than isolating it to soil enrichment.

Beyond nitrogen inputs into the soil, another important factor in a rotationally grazed environment is the alteration in the level of sunlight that reaches the lichen, which could shift the lichen community towards more sun-tolerant species. Additionally, shade-tolerant species are typically found in oligotrophic environments and may struggle to respond to eutrophication (Hauck & Wirth, 2010), further challenging their survival. These factors further influence lichen communities, which have broader implications for the ecosystem, such as nutrient cycling and interactions with insects and birds.

Lichen interactions, both with native and non-native species, have been very understudied but are a crucial piece to understanding lichen ecosystem roles and functions. Researchers and decision-makers should not overlook lichen relationships in communities. Lichens are difficult to make generalizations about because even within genera, different species often have different specializations and a variety of very specific factors influence the ability of lichen to grow. Consequently, both individual and community lichen responses are very hard to predict even with very modest environmental changes. Rotational grazing, designated conservation areas, and invasive species management all occur on Mt Grand. The management of this working farm provides a unique opportunity to study grazing and soil nitrogen enrichment on lichen communities. Given that lichens are highly influenced by anthropogenic activities and ecosystem changes. long-term research should be conducted at Mt Grand to assess the current community and changes over time.

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Chapter 10: Clovers in Conservation

Marcus Bjors

Abstract

The landscape of New Zealand has a long history of anthropogenically induced land-changes through fire to make space for farming and introduced species used in agricultural land. Several species of clovers have been introduced to increase productivity of pastoral land and some of these have become naturalised. This study investigated the abundance of clovers on Mt. Grand station, a high country farm close to Hawea Flat. Several locations along a farm track going up to the top of Mt. Grand and one location on Department of Conservation land was sampled. Clover abundance differed according to elevation, aspect and related plant communities. A literature study was conducted and discussed to appraise the role of clovers in conservation. Clovers could play a role by increasing the rate of succession in degraded or erosion- prone soils but further research is warranted to further clarify whether using introduced clovers could have a negative impact on native biodiversity.

Key words: Clovers, legumes, nitrogen, conservation, pasture

10.1: Introduction

The landscapes of New Zealand have changed dramatically over time due to human influence. What met the first Polynesian settlers would have been dense forests of beech, podocarps and manuka. Through fires, these forests started being cleared to ease hunting, and continued through early Māori settlements to make way for kumara plantations. Indigenous forest cover reduced from an estimated 85% down to about 55% from first colonisation until the start if European settlement in early 1800s (Taylor & Smith, 1997). Deforestation quickly continued as European settlement intensified during the 1800s to make room for a mosaic of pastures and agricultural land. These lands were populated with exotic grasses, shrubs and herbaceous plants from the settlers' home ranges. By 1925, the landscape had changed from native forests and bushes bushland to be more akin to the lowland ranges of Europe (Daly, 1990).

Introduction of clovers into New Zealand was done early in the 20th century was a response to decreasing pastoral productivity. White clover (*Trifolium repens* L.) was introduced in the 1920's as a response to deteriorating pasture production rates. Little attention had previously been given to improving pastures but following a guarantee of cheap phosphate through the British Phosphate Commission, which was necessary for nitrogen fixation, white clovers began to be sown in pastures (Brock et al., 1989). Early imported shipments of white clover seed was often impure due to imperfect sorting of seeds. This led to the introduction of annual clover species such as suckling clover (*Trifolium dubium* Sibth), cluster clover (*T. glomeratum* L.), striated clover (*T. striatum* L.), and haresfoot clover (*T. arvense* L.). (R.Lucas, pers.comm.).

Subterranean clover (*Trifolium subterraneum* L.*)* was introduced at roughly the same time as white clover and quickly grew in popularity. Initially believed to have been inadvertently introduced with imported sheep and regarded as a weed until the mid-1920's, sowing began in the 1930's on low to rolling country. However, popularity decreased after grazed lucerne was introduced in the 1960's (Smetham, 2003). Another species of legume introduced was Greater Bird's-foot-trefoil (*Lotus pedunculatus* Cav.) that has been commonly sown in the hill country where soils are too moist, acidic or infertile to support white clover (Armstrong, 1974).

Nitrogen, N, is the main limiting nutrient in South Island High-country soils (White, 1990). Perennial clovers are able to fix between 34 kg N ha^{-1} in the hill sites with low clover cover to 342 kg N ha^{-1} in warm and humid Northland conditions (Hoglund et al., 1979) and growing mixtures of legumes and grasses increases total dry matter yield compared to monocultures (Sturludóttir et al., 2014). However, red clover (*Trifolium pratense* L.) dominated hill pastures at one summer-moist farm in Canterbury showed 40% higher annual dry matter production compared to conventional grass-dominated hill pastures (Chapman et al., 2021).

Despite nitrogen limitations, abundance of sown clovers remain limited. One cause may be that they have high nutrient demands requiring additional phosphate, sulphur and sometimes lime to stimulate growth (Maxwell et al., 2014; Moir et al., 1997). In addition, conditions on the sunny, north-facing aspects of South Island high-country are unfavourable for the sown clovers. A study by Power et al. (2006) showed that white clover was only dominant on the southern aspect of Mt. Grand station despite being sown over the whole property. This was further attributed to decreased drought stress due to lower evaporation during summer months.

Annual, unintentionally introduced covers show a higher affinity for the sunny, north-facing aspects and have become naturalised there. Lower temperature threshold of naturalised, annual clovers allows for life-cycle completion in dry hill-country before early summer moisture stress inhibits growth (Maxwell et al., 2010). Lower thermal time requirement for germination of naturalised, annual clovers (Lonati et al., 2009) allows germination earlier than perennial white clovers allowing the annuals to complete their lifecycle before summer droughts typical for the sunny, north-facing aspects of Mt Grand station (Maxwell et al., 2014). Suckling clover is more adapted to the moister, shady southern aspect. In unirrigated pastures, suckling clover can outcompete white clover due to being more adapted to microsites of higher moisture (Boswell et al., 2003). This was also shown by Power et al. (2006) who found that suckling clover was the only adventive, annual clover on the northern aspect.

The naturalisation has been deemed positive as their contribution to pastoral land productivity through nitrogen fixation could be significant (Maxwell et al., 2010), yet little is known about the possible impact of clovers on conservation land. Conservation land that is often right next to and has a history as pastoral land (O'Connor, 2003). Tenure review was a process wherein farms in New Zealand were given the option to buy the land that they currently were leaseholders of in exchange for giving up the rights to land considered important for conservation (Brower, 2008). Mt. Grand station also underwent this process in 2005 and two areas were recommended for protection, Hospital Creek (which is sampled in this study) and Grandview Tops. Both have a history of grazing and a mix of both native and introduced species (New Zealand Department of Conservation, 2006).

Naturalisation of clovers thus pose the question of how this might impact conservation or restoration work. Problems such as invasive introduced plants are important to manage to prevent a loss of native biodiversity. Considering the low amount of native nitrogen fixers on New Zealand and their woody nature compared to the introduced legumes herbaceous nature could cause issues of compatibility between native and introduced plants in taking advantage of the fixed nitrogen. This could mean that initial establishment of clovers in degraded soils could alter the native succession to increase the abundance of introduced plants that can better take advantage of available nitrogen. The complementarity in rhizobial interactions shown by Wei et al. (2023) could be such a pathway.

Conversely could the quick establishment and high nitrogen fixation lead to faster plant coverage in degraded soils. Nitrogen fixation in clovers is high in the first years, until soil organic matter increased and clovers could make use of that resource instead (Scott, 2003). However, once nitrogen is more abundant in the soil introduced plants such as grasses will increase in relative abundance and is usually managed through grazing and spraying to halt the natural succession (Chapman et al., 2021). On conservation land, grazing is not present and it is likely that this land will move towards developing a dominant shrub layer as has happened at other high-country farms (Young et al., 2016).

Investigating clovers impact on conservation requires knowledge of environmental niches and their interactions with other plants. Especially comparison between native and introduced plants. Mt. Grand station poses the opportunity to do just that and a rudimentary study on this subject has been conducted through observations of clovers and their immediate neighbours. Coupled with a literature study, this paper aims to explore the potential impact of clovers in conservation in the South Island hill/high-country.

10.2: Methods

Sampling of Mt. Grand station was done over two days. Clovers were located using a subjective search among commonly found species at four different locations at different altitudes along the four-wheel drive track going from the Mt. Grand station woolshed to the Lagoon Valley on the 20th of March 2023, see Table 10.1. The same search methodology was used on the following day walking along the path in Hospital Gulley. Observations were photographed with location data automatically included. Further data was included from the "Mt Grand Biodiversity" project on iNaturalist (*Mt Grand Biodiversity*, n.d.) with observations made during the same time. Both observations considered research-grade and not have been included due to limited observations.

A literature study was conducted on topics regarding conservation and clovers in the New Zealand South Island high-country. Personal communication from Richard Lucas, senior lecturer at Lincoln University, has been included in the literature study due to his expert knowledge on clovers on Mt. Grand station.

Table 10.1 Stopping locations where sampling was done on Mt. Grand station

Location	Altitude	Aspect	General description
1. Pastoral land	800-950 m	NW	Commonly grazed land, lightly sloping. Vegetation dominated by introduced grasses and shrubs. Low, grazed grass with plenty of patches with tall, ungrazed grass.
2. Tussock grassland	1200 m	Flat top	Tussock dominated landscape with low-growing vegetation or bare ground between tussocks. Several rocky outcrops dotted around. Some signs of grazing on tussocks.
3. 4WD track	800-1000 m	N	Gravel track going back and forth down a steep hill. Shrubs dominate the slopes, whereas grasses and clovers can be found lining the track.
4. Lagoon Valley	550 m	Valley	Heavily grazed paddock dominated by low grass swards. On one side a slope down to a stream, where the vegetation changes to shrubs.
5. Hospital Gulley	450-600 m	Valley	Conservation land since 20 years. Has had no significant grazing during this time. Ground moist and vegetation dominated by shrubs. Valley sides also dominated by shrubs on scree slopes.

10.3: Results

A total of seven species were identified on Mt. Grand station. These were Hare's foot trefoil, White clover, Red clover, Suckling clover, Subterranean clover, Clustered clover and Striated clover. Across all species, 42 observations were made and uploaded to iNaturalist along with 13 observations of unidentified clover species. The distributions of observations across species can be seen in Table 10.2.

Table 10.2 Distribution of clover species observations at Mt. Grand station using data from iNaturalist.

Location	Clover species	Observations
1. Pastoral land	Unidentified	5
	White clover	4
	Red clover	1
2. Tussock grassland	Hare's foot trefoil	1
	White clover	2
	Unidentified	2
3. 4WD track	Hare's foot trefoil	4
	Unidentified	1
	White clover	1
	Striated clover	1
4. Lagoon Valley	Red clover	1
	Unidentified	2
	Subterranean clover	1
5. Hospital Gulley	Hare's foot trefoil	15
	Red clover	6
	Unidentified	3
	Suckling clover	2
	White clover	2
	Clustered clover	1
	Total	55

Occurrence of clovers was widespread in lower altitudes growing in swards of exotic grasses and exhibiting high ground cover where grazing pressure was high. All identified clovers, except the observation of Knotted clover, were found at this altitude. These were mainly growing in and among exotic grasses such as Rye grasses (Genus *Lolium*) and Cock's-Foot (*Dactylis glomerata* L.). Early germination of suckling clover as identified on site (but remaining unidentified on iNaturalist) was growing within the base of Cock's foot, see Figure 10.1.

In the Tussock grassland at higher altitudes (>1200 m), only white clover was identified. There were a further two observations of unidentified clover species at this altitude. These observations were exclusively found growing within native Tussock grasses, see Figure 10.3, and Golden Spaniard (*Aciphylla aurea* W.R.B.Oliv.), see Figure 10.2.

The four-wheel drive track going down into Lagoon Valley from Grandview ridge exhibited predominantly Hare's foot trefoil, a naturalised annual, which is expected on the north-facing aspect the road is located on. On the bottom of Lagoon Valley were few observations, compared to Hospital Gulley which had the greatest observations of any location. Predominantly naturalised, annual clovers were found in Hospital Gulley. These were found close to the walking track with the vegetation dominated by shrubs further from the track. A few observations were also found in the scree slopes further into Hospital Gulley where little other vegetation was found.

Figure 10.1 Suckling clover (Trifolium dubium) growing within the base of Cock's 9foot grass (Dactylis glomerata) (Marcus Björs CC BY-NC 4.0)

Figure 10.2 White clover (Trifolium repens) growing at the base of a Golden Spaniard (Aciphylla aurea) (Marcus Björs CC BY-NC 4.0)

Figure 10.3 Unidentified clover growing in tussock grass (Marcus Björs CC BY-NC 4.0)

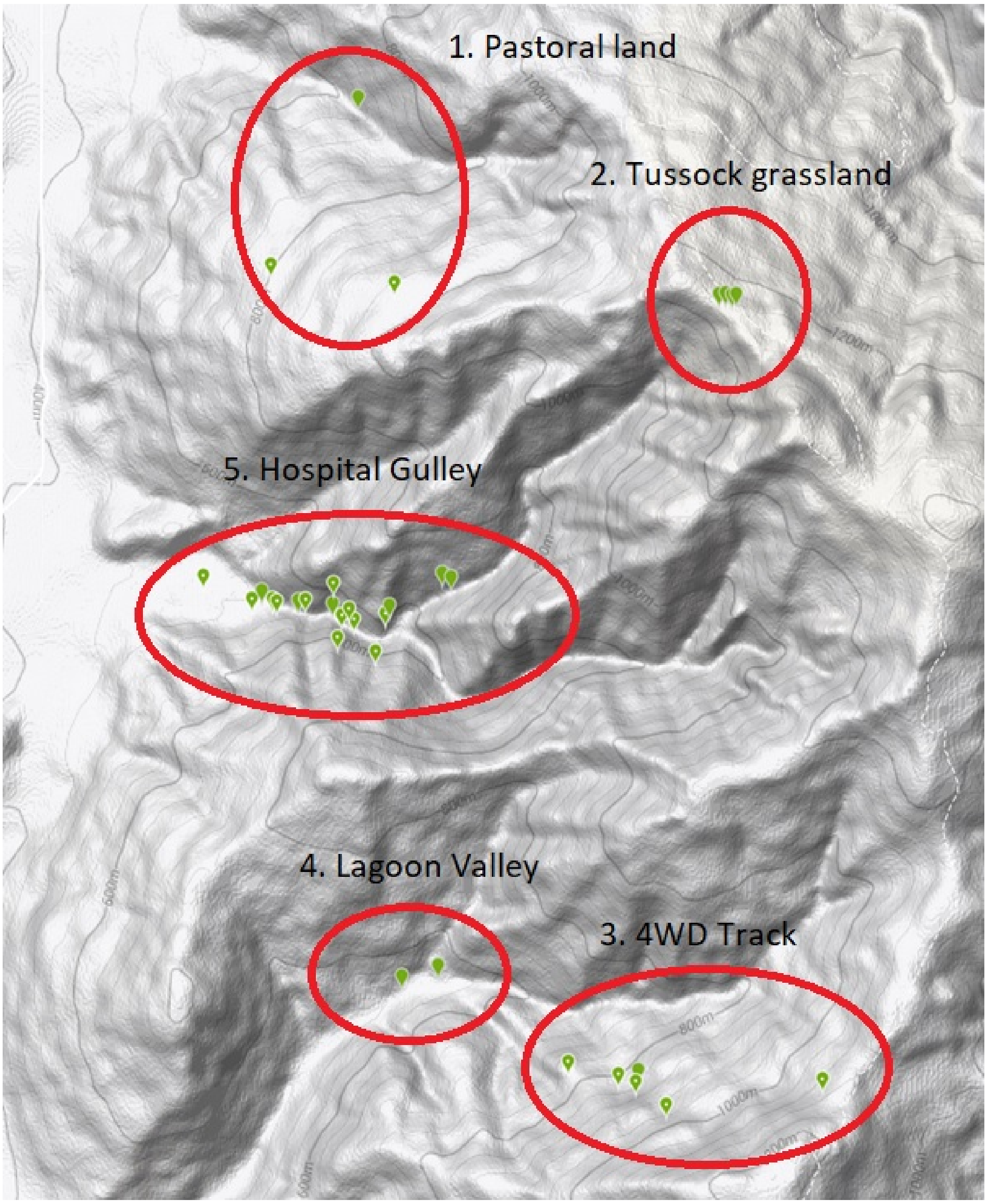

Figure 10.4 Mount Grand showing Hospital Gully and Lagoon Valley. Altitude and aspect.
Green pins show observations, location of pins is approximate and pins can denote several observations in close proximity. Pins with a white dot denote observations considered research grade on iNaturalist (iNaturalist.nz).

10.4: Discussion

10.4.1: General discussion

Observations from the sampling at Mt. Grand Station generally follow the expected distribution from previous studies. Sown clovers dominated in pastures, where they have likely been top-sown and fertilised. Grazing and fertiliser application in these areas could also promote growth of these species. Further up, the clovers were less abundant and a greater percentage of naturalised, annual clovers were found on the mainly sunny, north-facing aspects that were sampled.

In the tussock grasslands there was a very low abundance of clovers that were growing only within the tussock grasses or at the base of Golden Spaniard. These observations were either unidentified or identified as white clover, however these could be misidentified for *L. pedunculatus* that have been previously located growing within the base of Golden Spaniard in a study by Wei et al. (2023) and that has a history of being sown at these altitudes (Armstrong, 1974). The study by Wei et al. (2023) further identified a higher concentration of seven nutrients (N, P, K, Ca, S, Mn, Zn) in *L. pedunculatus* when growing with Golden Spaniard indicating mutualism between the species which could explain the establishment of *L. pedunculatus* here. Another factor indicated in the study was grazing preference affecting the distribution of legumes, as Golden Spaniard can shield the *L. pedunculatus* from grazing animals.

On the 4WD track going down into Lagoon Valley was predominantly bare soil with the hill-side lined by shrubs. The general inaccessibility and shrubby vegetation indicates little grazing which could explain the higher amount of clovers, especially Hare's foot trefoil observed here. Hare's foot trefoil has previously been found at the driest sites (Boswell et al., 2003), which is expected on the bare-soil track traversing the north-facing, sunny slope of Lagoon Valley. A few grasses, unidentified, were also growing on the side of the track and the other observed species were found here. Finding white clover here is unexpected and could be due to misidentification.
Few observations were made in Lagoon Valley. However, number of observations is not directly tied to actual abundance and ground cover. This is exemplified by one observation of ground cover of subterranean clover in Lagoon Valley, see Figure 10.5, showing high ground cover whereas only one observation has been noted on iNaturalist. As there were signs of intensive grazing in Lagoon Valley, subterranean clover may have been over sown and the pasture top-dressed which would explain a high ground cover of subterranean clover here.

Figure 10.5 Circle (1x1m) showing ground cover of subterranean clover in Lagoon Valley (Nicola Wegmayr CC BY-NC).

Observations in Hospital Gulley account for 53% of total observations and shows the highest species diversity of all locations which is unexpected given the lack of grazing there in the last 20 years. However, Hospital Gulley features a diversity of locales from grass tracks featuring introduced grasses to scree slopes with bare soil giving opportunities for many species to find their niche. The high amount of observations may also be due to increased amount of people sampling the area as it was sampled across two days whereas only location 3 and 4 were sampled twice on Mt. Grand track due to poor weather the second day. This is supported by Hospital Gulley noting 11 observers on iNaturalist whereas the second highest has 4 observers, which is the 4WD track.

Observations would also have been affected by weather the first day. During the first day of sampling there was rough weather with rain and wind at the top making sampling difficult. Another contributing factor is also my own inexperience in recognizing clovers, which may have led to more identifications during the second day as I got more used to it. The time for data collection was also low at all stopping locations, about 30 minutes to an hour, except for Hospital Gulley where the whole day was spent. Taken together, this could skew the data in favour of Hospital Gulley.

Time of data collection also influences results. Sampling was done in March, at a time when annual clovers may not have germinated yet and those that have are still small with few easily recognizable identifiers. This was especially prevalent for clovers growing within the tussock grasses and introduced grasses, see Figure 10.1. 24% of observations could not be identified. Difficulty in identification was also a factor in the tussock grassland where the clovers had a higher percentage of dead parts of leaves, see Figure 10.2. Despite these limitations, there is clear evidence of clovers growing in all locations. Thus there is cause to investigate whether this may influence conservation land.

10.4.2: Clovers in conservation

Legumes are generally pioneer species, growing well in soils lacking nitrogen. Sturludóttir et al. (2014) found the highest effects of growing mixtures of legumes and grasses in Icelandic Vitric Andosols low in organic matter. This is further supported by Scott (2003) that found highest nitrogen fixation in soils with low soil organic matter. Once soil N is more abundant, other plants will outcompete the legumes as nitrogen fixation is an expensive function (Keddy, 2017). Utilising naturalised, annual clovers for the purpose of increasing nitrogen abundance in degraded soils could speed up the natural succession (Vetter et al., 2018) or allow for planting other plants that help stabilise the soil against soil erosion.
There are examples of nitrogen fixers aiding in restoring severely eroded landscapes. In Iceland, nitrogen fixing lupines have been sown in areas to increase nitrogen availability in the soil before planting of trees. The trees subsequently grow above and shade out the lupines, effectively outcompeting the lupines. Further, grazing by sheep can be used to keep down the lupines after tree establishment due to grazing preference on lupines by sheep (Brown et al., n.d.).

Similarities exist between the Icelandic and New Zealand conditions with erosion prone soils, sheep grazing and historic forest cover suggesting possible use of legumes as a restoration tool. No research was found on the topic during the literature review part of this study. However, given the benefits in Iceland it could be a viable tool in New Zealand as well. Hospital Gully, that hasn’t been grazed for 20 years (Lucas priv. comm.), is dominated by shrubs. Clovers were only found near paths with short grass or in bare soil indicating that clovers will be growing outcompeted by other plants if not grazed.

However, using introduced species to promote native regeneration is controversial. Lupine use on Iceland is not only seen as positive as it also changes the characteristic look of Iceland’s volcanic landscapes (Brown et al., n.d.) and decreases biodiversity in sites where it is planted (Brown et al., n.d.). The time needed from lupine planting until they are permanently removed is around 20-30 years (Brown et al., n.d.). Using clovers that are less apparent and less invasive may prove useful in restoration works in New Zealand high-country. However, management techniques would be needed for effective application such as topdressing and grazing. The question of non-native bushy plants is also a concern. Hospital Gully contained a high amount of introduced shrubby plants such as Sweet Briar and Buddleia growing among the native plants.

There is inconclusive evidence showing the effect of clovers on future species composition. Studies have clearly shown that legumes and other plants have reciprocal effects on nutrient acquisition (Wei et al., 2022a, 2022c, 2022b, 2023) but have shown no clear preference for native versus introduced species. A study by Young et al. (2016) investigating the vegetation change at Cass, located in the upper Waimakariri Basin, where light grazing and no evidence of over sowing or top-dressing exist was at the time of the study’s publication dominated by native shrubs. According to the study, this was possible due to elimination of fire, limitation of grazing and control of introduced woody species. However, the lower levels of Cass was dominated by exotic grassland and gorse shrubland which may be due to the species structuring according to slope and elevation as found in the study. This suggests that environmental adaptation may play a larger role than species sharing a native range having a higher complementarity. The case study on Cass also shows the need for active management in conservation. Without over sowing and top-dressing, introduced shrubs are able to grow with the native shrubs and management through grazing and mechanical or chemical removal might be needed.

10.5: Conclusion

Clovers may have a role to play in conservation in the South Island high-country. Problems such as soil erosion may benefit from the quicker succession brought by legumes and potentially clovers in stabilising the soil. Annual clovers such as striated clover, hare’s foot trefoil, suckling clover and clustered clover that have become naturalised could be potential candidates for such use due to their lower nutrient limitations and better adaptability to sunny, drier aspects. However, more research is needed on how this might affect future species composition particularly with regards to native versus introduced species. Future topics might include more conclusive data on species nutrient complementarity as has been shown by Wei et al. (2023) and clover species driving co-invasiveness with plants from the same native range. If the goal of conservation is on maintaining or increasing native biodiversity, these considerations must be made as it is clear from these results that clovers have found a place in the high-country.

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Chapter 11: Does the Spread of Sweet Briar Pose a Threat to Mount Grand Station?

Emma Lloyd

Abstract

This study investigates the spread of Sweet Briar (*Rosa rubiginosa)* at Mt Grand station. The aim wa to determine whether the spread of Sweet Briar poses a threat to this high-country station and, if so, what can be done to reduce the abundance. This study was conducted using a vehicle to travel up and down the west facing slopes of the Mountain. An altimeter was used to record the altitude, at approximately every 100m gain in elevation, landscape photographs were used to evaluate the spread of Sweet Briar. The study was conducted between 400m – 1200m. The finding show that the spread and size of the Sweet Briar decreased with elevation, with the highest density between 500-600m. From 900m Sweet briar became sparse and native species such as kānuka and matagouri dominated. In conclusion, sweet briar is an invasive weed that does pose a threat to Mt Grand station. Once established it can prevent the growth of native species and reduce the value of the grazed pasture.

Key words: *Rosa rubiginosa,* threat, abundance, high country, Mount Grand Station, pasture

Figure 11.1: Sweet Briar at Mount Grand by Emma Lloyd

11.1: Introduction

Sweet Briar was originally introduced in the 19th century as an ornamental rose by European settlers, it soon spread outside the gardens and was classified as a noxious weed (Hura et al., 2022). By the 1950's it had spread to areas of the South Island high country, where it tends to adapt very well to dry conditions, particularly in tussock grasslands and unimproved grazed pastures where competition is low (Hunter, 1983). New plants are highly susceptible to competition, and do not do well in competitive pastures. However, once they are well established, they are highly competitive. Sweet Briar can be identified as a woody shrub, usually growing up to 3-5 meters tall, with pink flowers followed by bright red or orange rose hips. From an ecological perspective, the concern of sweet briar is the threat they pose to the ecosystem as their growth and establishment may contribute to the displacement of native plant species (Gadzinowska et al., 2019).

Another concern at Mount Grand Station is the fact that it can significantly reduce the value of the grazed pasture, limiting the area of which where the stock can graze.
Sweet Briar is mainly spread by suckers and seeds being dispersed by birds and other mammals (AgResearch). First understanding the weed and in what conditions it becomes dominant is the starting point at where to understand how we can bring it under control at Mount Grand.

This study was carried out at Mount Grand for the purposewith the aim of exploring the spread of Sweet Briar and whether it should be of a growing concern to the station. And if so, what management practicses can be undertaken to reduce the abundance of this invasive weed.

11.2: Materials and Methods

Research was conducted using a vehicle, traveling up and down the west sloping side of the station.

An altimeter was used, a device that records the distance of a point above sea level. Starting from 400m in altitude, I stopped roughly every 100m and took a picture to capture the spread of the sweet briar. The maximum altitude reached was 1200m. This was to gain an idea of the spread, find any areas of particular concern and whether I could find any trends. I also took note on any other well-established vegetation, particularly any native species. The information collected on the spread of Sweet Briar at Mount Grand Station was limited due to time sensitivity and weather conditions.

11.3: Results

I found that the Sweet Briar was the most densely populated and largest in size at an elevation of 500 – 600m. As attitude increased to 700m, the Sweet Briar significantly reduced in size, while maintaining moderate dispersion. It was interesting to find that around 900m Sweet Briar became extremely sparse and the native species; Matagouri and Kanuka, were dominating. No sweet briar observed past an altitude of 1000m. This information is valuable as it showed that Sweet Briar may not establish itself well in areas with Matagouri *(Discaria toumatou)*.

Figure 11.2: Mt Grand at 500m above

Figure 11.4: Mt Grand at 900m above sea levell

Figure 11.3: Mt Grand at 1000m above sea level

11.4: Discussion

It has become clear that Sweet Briar is a major invasive weed at Mount Grand, with potential to spread further around the Station. Although the sweet briar is found everywhere up to 900m in elevation, the density is highest is around the 500–600-meter mark, this is the focus area for managing the spread.

There are a number of methods to control the spread of Sweet Briar, some of which are more practical and economically feasible that others. Options include chemical control, digging it out, planting competition, and grazing management. I am more interested in the two latter options as I think they are more in line with both agricultural practises and conservation efforts; the use of planting native trees to introduce more competition and managing grazing effectively.

From my investigation I have found that the sweet briar does not seem to establish well in areas where there is competition from the native Matagouri tree. Matagouri, also known as Wild Irishman, is native to New Zealand and is known to be an important associate of tussock grasslands. Matagouri plays an important role in the high country as it is a nitrogen fixing species, meaning it can grow well in nutrient poor soils, enriching soils for other plant species to regenerate (Thomas & Spurway, 2001). Planting sites of Matagouri will introduce more competition to the sweet briar by minimising their seedling regrowth, while also integrating conservation efforts for native species.

I found that there are currently no biological control options in New Zealand for controlling the spread of sweet briar. According to Gadzinowska (2019) the last known efforts of biological control of this invasive weed occurred in the 1960s, where an attempt was made using rose-seed megastigmus *(Megastigmus aculeatus).* It is said that approximately only 8% of the rose seeds were infested and destroyed due to concerns impacted other species in the rose family. Gadzinowska (2019) also mentioned there were plans to use another insect; *Diplolepis rosae,* a gall wasp which causes a growth called 'rose bedeguar gall', but the project was withdrawn.

As a part of my investigation, I also researched any experiments involving the spread of Sweet Briar in relation to grazing management. I found a study based at the Otematata Station, a hill country farm in the Waitaki district of the South Island. The conditions are like Mount Grand station, as it grazed sheep in a low rainfall area with grassland as the dominant vegetation type.

The study (Sage et al., 2009) looked at the impact sheep grazing had on the spread and size of Sweet Briar, they tracked the spread on multiple sites; some with continued sheep grazing and others where sheep grazing had been excluded for 15 years. The results indicated that the density of sweet briar was significantly higher where sheep grazing was excluded. If we are to apply these finding to Mount Grand, it is likely that any reductions in grazing will result in the expansion of sweet briar across the station. The sheep graze on the young seedlings of the sweet briar, which prevents their establishment and therefore can be an effective management for this weed.

11.5: Conclusion

In conclusion, sweet briar is a growing concern at Mount Grand Station, it is an invasive weed which poses a threat to the farm. It is competitive once well established, preventing the growth of native species and reduces the value of the grazed pasture as it deters the stock from potential forage areas. Management practises to control the spread need to be investigated and implemented at Mount Grand. Possible options to slow the spread include planting sites of native matagouri and avoid any reduction in grazing in the high-density areas, (perhaps increase the grazing in areas that are at risk of sweet briar establishing).

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Chapter 12: Sweet Briar and Climate Change

Julia Eggert

Abstract

The invasive species sweet briar, *Rosa rubiginosa,* was introduced by the early settlers and has become established in the high country in New Zealand, particularly in the tussock grasslands. Although its impact in terms of production losses and conservation concerns is difficult to estimate, there could be serious ramifications for native species and agricultural production, should it continue to spread. Climate change is likely to contribute to an increase in its distribution range as it is anticipated to reduce temperature limitations. Additionally, as a pioneer plant sweet briar, has been found to have a high adaptive potential making it likely more competitive than native species. This project i) aimed to evaluate sweet briar's distribution around Mount Grand Station and how it might develop in the context of climate change and ii) to review the implications for native species in addition to providing an overview of knowledge and data gaps.

Key words: Sweet briar, invasive species, climate change, distribution

12.1: Introduction

Invasive species in Aotearoa New Zealand have been a long standing problem, severely impacting the country's biodiversity and threatening native species. Due to its high endemism and isolated location, these impacts are particularly pronounced and pose unique challenges (Norton, 2009). Additionally, since over half of the rare ecosystems in New Zealand are under threat of functional extinction due to multiple causes, climate change, which has been shown to impact island ecosystems especially harshly, will likely exacerbate present conditions (Macinnis-Ng et al., 2021). Thus, it is important to understand how climate change effects will interact with other ecologically influential processes and resulting species reactions (Macinnis-Ng et al., 2021). Especially in alpine regions where range shifts of plants are geographically limited and pressures from invasive species add to climate change stressors it is crucial to understand species relationships, responses and interactions to make informed conservation decisions (Halloy & Mark, 2003). The aim of this project is to analyse sweet briar's potential changes in distribution in light of climate change and the implications that poses for native species at Mt Grand through a systematic literature review and observations collected during a field study. Additionally, it has the objective to contextualise the existing research and provide an overview of knowledge gaps that are pertinent to conservation efforts.

Understanding how sweet briar will respond to climate change is imperative for its control. It was deliberately introduced to Aotearoa New Zealand by the early settlers, likely for decorative purposes, in 1865. It fairly quickly colonised dry open grasslands and was subsequently declared a noxious weed in the 1900s (Hunter, 1983). As a pioneer plant, often first to colonise areas that had been degraded by livestock grazing, it turned into an increasingly aggressive scrub weed, particularly on dry tussock grassland country. Thus, its main infestations can be found predominantly in the high-country pastoral farms of the South island (Hunter, 1983; Hura et al., 2022). Its distribution seems to be mostly facilitated by birds and possums, among others, with livestock like sheep or goats putting grazing pressure on not established plants. Also other species like rabbits have an impact on its abundance, as evidenced by its increase during the 1950s when rabbit numbers declined and the growth of seedlings and young plants was no longer kept in check (Glen et al., 2012; Hatton, 1989; Hunter, 1983; Syrett et al., 1985). So far at Mt Grand Station no specific steps were taken to curb its spread and the costs it causes for example in terms of production losses are not clear or easily estimated (Grundy, 1989)

12.2: Methodology

As research questions analysing the changing distribution of species through the influence of climate change require substantial datasets, the data collection during the field trip was not sufficient in providing enough information that could be extrapolated upon in an analysis. Thus, to supplement the overview of the site characteristics and the observations during the field trip pertinent to sweet briar's abundance, a literature review was conducted. In order to find existing studies on sweet briar's distribution in New Zealand, the approach was to set narrow search parameters on Google Scholar at first using the following key words: "sweet briar", "New Zealand", "climate change", "distribution", "Mt Grand" and "high country" or "alpine". After that initial search the parameters were no longer confined to just the high country in New Zealand, but other parts of the world as well. Additionally, the literature on expected impacts of climate change in the high country in New Zealand was researched, attempting to draw out the effects on specific ecosystem characteristics like soil or climate that would have a link to sweet briar's distribution.

12.2.1: Observations and site information

Mount Grand Station is mainly used for pastoralism containing a merino sheep farm and a small herd of beef cattle on about 2136 ha (Provost, 2018). Biophysical factors like microclimates, soil and biodiversity vary greatly spatially. Soils, especially, present a constraint for plants, as they are light and prone to erosion after the loss of vegetation (Wei et al., 2023). Another potential limiting factor to pasture production is a soil moisture deficit, which could be of consequence, if the annual rainfall of about 690 - 800 mm shifts with climate change

Figure 12.1: Mt Grand Station (Simtih et al., 2022)

Although pastoralism is the main land use, native vegetation like kānuka and matagouri, among others, can still be found. Sweet briar, in addition to other invasive species, also occur widespread throughout the station (Provost, 2018). The full extent of its distribution in the area is unknown, as mentions and observations are mainly anecdotal. During the fieldwork it was noted that the presence of native species increased with altitude while sweet briar declined in numbers, but the species composition was not recorded. A difference in distribution between grazed and non-grazed areas was not noted, but on a south facing slope it was observed that the presence of permafrost prevented sweet briar and other shrubs from growing.

12.3: Results and Discussion

12.3.1: Climate change at Mt Grand Station

Climate change projections in Aotearoa New Zealand indicate that the temperature increase will be fairly uniform with rainfall increasing in the west and the east becoming drier (Lundquist et al., 2011; Macinnis-Ng et al., 2021). The temperature increase is likely to have a far-reaching impact on species composition and sweet briar's distribution. The permafrost that presently poses a limitation for shrubs is likely to disappear potentially allowing for sweet briar's expansion. Similarly, non-native species may shift their range upwards increasing competition for native species and presenting new conservation concerns. Furthermore, soil functionality of the already erosion prone soils is also likely to be detrimentally impacted by climate change, as nutrient cycles may be changed and the increased rainfall is likely to exacerbate erosion rates (Smith et al., 2022). The extent of these changes and impacts in the high country is unclear and also how sweet briar's distribution may adjust. However, in light of existing pressures through competition, predation and human activity in addition to climate change, the adaptive potential of species is likely to be a crucial factor regarding their survival, dispersal and abundance (Halloy & Mark, 2003).

12.3.2: Adaptation potential by Sweet Briar

As a pioneer plant, that can colonise habitats under stressful conditions, sweet briar is likely to be able to adapt to these climatic changes a lot more easily than the native plants. Research shows that especially invasive populations of *Rosa rubiginosa* have more effective mechanisms to cope with arid environments, as they can recover better from soil drought, see Figure 12.2. This also translates to dry habitats of the Southern Hemisphere and may have positive implications for the plants as temperatures increase (Hura et al.,2022; Macinnis-Ng et al., 2021). Additionally, its adaptive potential is high, as it uses nutrients, water and light very efficiently (Gadzinowska et al., 2019).

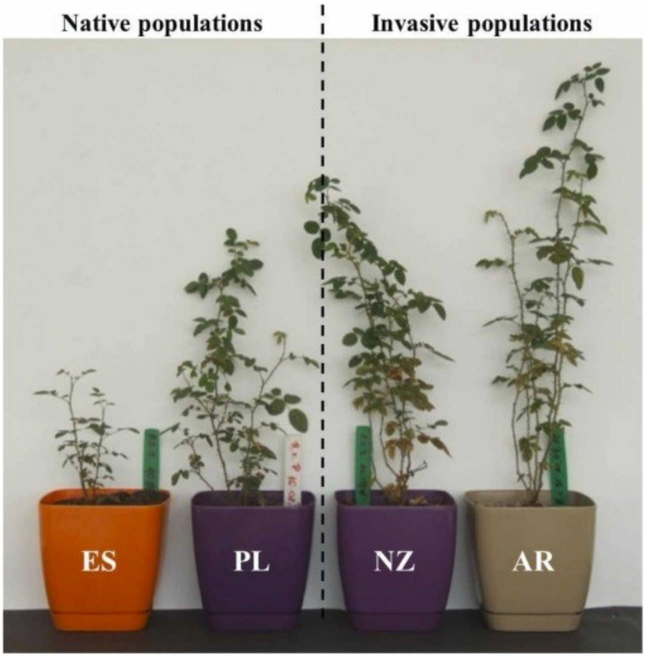

Figure 12.2: Comparison of growth dynamics between native (ES – Spanish; PL – Polish) and invasive (AR – Argentinian, NZ - New Zealand) populations (Hura et al., 2022)

The ability of invasive species to successfully colonise and become established in a new area due to greater tolerance or adaptability to sudden environmental changes points to a likely greater resilience towards climate change as well (Macinnis-Ng et al., 2021). A growing body of research provides evidence for comparatively rapid evolutionary changes of these invasive species in their introduced range which can be observed through their increased dispersal and changes in phenology or morphology (Macinnis-Ng et al., 2021). Based on existing research sweet briar's future distribution cannot be estimated with certainty, but it is likely that its range may expand towards higher altitudes and that it will be able to cope with the detrimental impacts more easily.

12.3.3: Species composition and relationships

Other important factors in sweet briar's distribution are the interactions and relationships with other species that facilitate its dispersal or curb its spread. As Hunter (1983) showed, a decline in rabbit numbers reduced grazing pressure on young plants and allowed it to spread more quickly. Native birds, on the other hand, have aided sweet briar's dispersal, since the fruits provide a food source. Consequently, an increase or decrease in either one's abundance is likely to have an impact on the other's. Studies on the removal and management of invasive species in New Zealand have shown that significant changes in a species' population numbers may have inadvertent consequences for native and invasive species alike (Norbury, 1996; Zavaleta et al., 2001). It has been postulated, that climate change will affect species interactions and relationships, but the extent and nature of these impacts are unclear (Macinnis-Ng et al., 2021). Arguably, sweet briar's adaptive potential makes it more competitive to the detriment of native species potentially resulting in a more urgent need for intervention.

12.3.4: Data and knowledge gaps

The literature review highlighted that there are many knowledge gaps regarding sweet briar and a statistically relevant estimation of how it might react to climate change is not possible based on currently available research and data. The observations and available literature do, however, point to a likely increase in its abundance and distribution, which may pose issues for conservation as well as economically. Since there is limited understanding of the ecological impacts of climate change across ecosystems and taxa due to study duration and lack of comprehensive data coverage, it is difficult to assess and estimate the implications (Lundquist et al., 2011; Macinnis-Ng et al., 2021). Data deficiency was recognised as a major challenge in quantifying the effects of climate change on New Zealand's ecosystems by the IPCC in both their Fourth and Fifth assessment reports (Macinnis-Ng et al., 2021). This also extends to studies on the species relationships and interactions on a community level (O'Donnell et al., 2017), making it difficult to assess the sustainability of conservation gains from controlling invasive species, like sweet briar, since there are already many unknowns and climate change is thought to further alter species interactions (Macinnis-Ng et al., 2021). Although no definitive conclusions about sweet briar's distribution could be drawn, there are clear indications that it may present a risk in the future. There is a lack of recent research that is needed to fill these knowledge gaps. Mapping sweet briar's distribution against the biophysical conditions and their predicted changes could provide an important baseline for effective and sustainable management and conservation decisions.

12.4: Conclusion

As restricted elevation ranges and habitat fragmentation act as barriers to geographical range shifts in alpine ecosystems (Macinnis-Ng et al., 2021), shifts in distribution of invasive species are likely to present a particular conservation concern in the future. Due to the complexity of climate change and the interactions and relationships between species in alpine ecosystems, the implications of these changes are not immediately visible, but may present hidden costs for both conservation and agriculture (Grundy, 1989; Macinnis-Ng et al., 2021; Zavaleta et al., 2001). In conclusion, the data and research that are currently available are not sufficient for estimating changes in the distribution of sweet briar or how it may impact native species, but due to its high adaptive potential it is likely to become a pervasive problem in the future necessitating both more studies and possibly interventions that control its spread at Mount Grand station.

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Chapter 13: How Sweet Briars (*Rosa rubiginosa*) are Changing the Indigenous Woody Shrub Communities

Mariana Pires Barboza

Abstract

Native to Europe, sweet briar (*Rosa rubiginosa* L.) has been a highly expansive weed in New Zealand since the 1800s. It has quickly spread beyond gardens and now occurs in the tussock grasslands of South Island, impacting conservation and restoration projects. This study evaluated the distribution and ecology of woody shrubs to understand the biological invasion of sweet briars and how they may affect the native biodiversity of Mount Grand Station. *Rosa rubiginosa* is highly adapted to dry environments where it easily establishes, competing with indigenous plants, such as matagouri (*Discaria toumatou).* Long-term monitoring of this competition is required because physical control of invasive species is difficult, and chances of reinvasion are high.

Key words: biodiversity, conservation, woody shrubs, matagouri, sweet briar, invasive, control

13.1: Introduction

Fragmentation of ecosystems, along with a decrease in fauna and flora abundance, are major concerns threatening biodiversity. They are frequently resulting from land-use change and intensification, invasive weeds and pests, fire, climate change, and exploitative industries (Allen et al., 2013). Currently, in New Zealand, denative forestation exceeds cover is 70% less than itsof the pre-human state, and the current cover of indigenous forests and shrublands represents only 23% and 10%, respectively, of the 27 million hectares of land surface (Wiser et al., 2011).

Following a relatively common trend, areas once occupied by structural dominants, such as trees, are now dominated by woodlands and shrublands, representing succession to secondary vegetation; however, a new ecosystem has been created, which is a blend of indigenous and exotic woody shrubs and small trees (Allen et al., 2013; Walker et al., 2014). Since invasive species can have severe deleterious effects on native biodiversity and significantly impact farm activities in New Zealand South Island hills and high country pastoral landscapes, it is critical to understand the complex interactions of indigenous and exotic species, and how these interactions play out in the landscape to manage biodiversity (Allen et al., 2013; Sage et al., 2009).

According to the Crown Pastoral Land Tenure Review of Mount Grand (2006), released by the Department of Conservation of New Zealand (DOC), the shrubland of Mount Grand Station changes at different altitudes. Below 900m where the vegetative cover is primarily dominated by introduced grasses and herbs, the shrubs are dispersed, and there are patches of sweet briar (*Rosa rubiginosa*), an exotic woody shrub co-occurring with native onesshrubs, such as matagouri (*Discaria toumatou*). In contrast, native grasses and indigenous shrubs are more abundant at higher altitudes.

It is unquestionable that Mount Grand Station holds significant conservation value, and the elevated areas of the property are dominated by native plants with a diverse range of species, however, exotic plants are prominent in most communities and might threaten indigenous individuals. As the establishment of invasive plants is often related to the destruction of socially valued aspects of ecosystems, the present project aimed to document the distribution and ecology of woody shrubs and understand biological invasion of sweet briars at Mount Grand Station.

13.2: Materials and Methods

The study was conducted at Mount Grand Station, a research area owned by Lincoln University, during two days of March, this year. It is a merino farm situated in Hāwea, Central Otago, New Zealand. On the first day, the investigation was conducted at Hospital Gully, around Hospital Creek, and on the second day in the Lagoon Creek region. Both native and invasive woody shrubs were observed, and several photos were taken from different individuals of the shrublands, as well as details of their leaves, flowers, and fruits, when available. Photos were used to illustrate this project and uploaded onto iNaturalist© in the "Mt Grand Biodiversity" project.

Additionally, a literature review of articles and books was carried out. The studies related to the research goals were searched on the Learning, Teaching and Library portal of Lincoln University using specific Key words relevant to the question: *"How sweet briars are affecting flora biodiversity and farm productivity at Mount Grand Station?"* Moreover, the search was completed selecting recent publications and cited studies in the articles that were already selected.

13.3: Results

Shrublands at Mount Grand are abundant, indicating that the area, once devastated by fire, intensive grazing, or deforestation, started its regeneration, as these plants are considered nurse plants and are the first ones in the natural process of succession. In both areas explored, I saw numerous dispersed native woody shrubs (Figure 13.1), such as: porcupine shrub (*Melicytus alpinus*), matagouri (*Discaria toumatou*), mountain wineberry (*Ariostelia fruticosa*), and miki (*Coporosma propinqua*).

Figure 1a: *Melicytus alpinus* and *Discaria toumatou* (from left to right).

Figure 1b: *Ariostelia fruticosa* and *Coporosma propinqua* (from left to right).

Figure 13.1: Native Woody Shrubs at Mount Grand Station

At lower altitudes, the vegetation is dominated by grasses, herbs and weeds. Coexisting with the documented native shrubs, I identified several sweet briars, *Rosa rubiginosa,* (Figure 13.2) predominantly present in exposed and unsheltered areas, where the plant can grow, spread, and establish without competition. Furthermore, it is important to report that the abundance of sweet briars decreases with increasing altitude.

Figure 13.2: Rosa rubiginosa - Sweet Briar

It was evident that the remaining forests and shrublands of Mount Grand Station continue to be affected by invasive species, and the establishment of sweet briar may pose a threat to the biodiversity of the farm, contributing to the displacement and extinction of valuable species of indigenous plants, especially woody shrubs, as there is competition for the same space.

13.4: Discussion

At Mount Grand, the presence of matagouri is noticeable at lower levels and could be interpreted as a problem for farmers, and be considered a weed. Because these shrubs have the ability to invade and form self-sustaining populations in pastures and impact various ways of productivity by reducing pastoral output and adding to the costs of production (Bourdôt et al., 2007). However, matagouri is an indigenous plant of New Zealand that participates in secondary woody communities and adds value to biodiversity conservation, since ecological integrity maintenance is based on the enhancement of three elements: indigenous dominance, species occupancy, and environmental representation (Lee et al., 2005)

Walker, et al. (2014) predicted that the development of secondary shrublands would be beneficial for the conservation of the indigenous dryland flora of New Zealand because secondary succession might promote species occupancy and indigenous dominance. The prediction was tested at three sites in Central Otago, where Mount Grand is located. Moreover, the mixed indigenous-exotic shrublands studied emerged in the presence of pastoral grazing, herbivores, and with any intervention, as well as the place studied in this project. In summary, these shrublands appeared to have positive effects on plant biodiversity, supporting indigenous species complementary to those in grasslands and increasing the variety of indigenous plant species. Furthermore, they may provide refuges for indigenous plant species that are vulnerable to human-induced disturbances in grasslands.

In addition, matagouri, along with other native plants, such as broom (*Carmichaelia petriei*), kowhai (*Sophora prostrata*), and tutu (*Coriaria arborea*), are important nitrogen fixers, that influence the sustainability of dry and semi-arid tussock grasslands (Boswell et al., 2001). Considering that deforestation has reduced N-fixing plants in the grasslands and grazing will be unsustainable without fertiliser nutrient inputs, I conclude that the presence of the woody shrubland is crucial not only for biodiversity conservation but also for farming productivity. However, the new design of these shrublands, where there are exotic plants coexisting with the native ones, presents concerns about threats to biodiversity in high country environments.

Although noneany of the native woody shrubs documented in this project were considered threatened plants in accordance with the Tenure Review of Mount Grand Pastoral Lease (DOC, 2006), I believe that they are at risk. Lange, et al (2010), in their book, described "at risk" species as those ones that have declined in abundance but are not considered threatened or reduced from their historical range. A mix of factors, such as habitat loss, predation, competition, reproductive failure, and ignorance, might drive a species to an extreme reduction that leads to extinction (Lange et al, 2010). In summary, conservation management is the key to protecting these plants, as they continue to be impacted by invasive species, fire, and herbivory.

Given my observations and the context of Mount Grand, sweet briar, an exotic woody shrub previously identified as a problem plant (DOC, 2006), might be considered a threat to matagouri and other native woody plants in the near future because of intensive competition. These shrubs grew in disturbed areas, dispersed, and often gaps in the vegetation were spotted on the sites analysed. Sweet briar, as an invasive plant, can quickly occupy these disturbance gaps in forests, competing with the native ones by smothering adult plants to the exclusion of seedlings and regeneration of native plants (Lange et al, 2010). Furthermore, invasive plant species tend to grow at higher densities than indigenous ones, and there is also evidence that exotic species tolerate adverse environmental conditions, such as water deficit, deficiency of minerals in soil, or soil salinity, because they often possess traits that help with the establishment of these specific areas (Hura et al., 2022; Zimmermann et al., 2012).

Sweet briars most likely comprise some of these mechanisms that make them highly adaptable to the Mount Grand environment, since based on my observations and review of literature, this plant is not only well established at the station but also in many other dry areas of the southern hemisphere. Sweet briar has developed physiological and molecular traits that translate into more effective mechanisms of colonisation of arid envi-ronments, pollution, poorer soils, frosts, and diseases (Gadzinowska et al., 2019; Hura et al., 2022). As previously mentioned, the effective adaptive strategy of survival and dispersion is noticeable, however, information about the physiology and biochemistry of these possible traits in the literature is scarce.

Although there is not much data about the biomechanics behind this phenomenon, there are two recent studies that touch on the adaptive mechanisms of sweet briar in the dryer southern hemisphere. In 2019, Gadzinowska, et al. investigated the response of young sweet briars to a soil water deficit, assuming the photosynthetic activity was related to water availability. As a result, researchers have suggested that the sweet briar response involves adaptation mechanisms for water deficit tolerance and effective water management, including: limited transpiration and stomatal conductance, higher levels of soluble sugars, lower levels of chlorophyll, and other photosynthesis optimisation during water stress for growth processes. The second study performed by Hura, et al. (2022) was a comparison between native sweet briars from the Northern Hemisphere to the invasive ones from the South exposed to soil drought. As expected, contrary to the native population, the invasive population showed specific responses to maintain a high water potential in the leaves, greater content of soluble carbohydrates, and higher osmotic potential.

As successional shrublands, native woody shrubs require disturbed sites for regeneration (Lange et al., 2010), and the high country system represents this place, combining low rainfall, large diurnal and seasonal temperature ranges, high potential for evaporation for much part of the year, strong winds, and many years of mammalian herbivory (Sage et al., 2009). However, the same characteristics make it easy to be highly invaded and today, these sites are frequently occupied by exotic plants, impacting on ecosystem processes (Allen et al., 2013; Lange et al, 2010). Therefore, the physiological traits that make sweet briar a tolerator plant in this situation make it even more competitive with the native species of Mount Grand Station.

Under these circumstances, sweet briar might not only limit economic production across pastoral lands but also offer severe deleterious effects on native biodiversity. Since its introduction to New Zealand in the 1800s, it has been treated as a truly parasitic species. As an alternative to deal with this well established, highly adept, exotic plant is to reduce the population of this shrub. In 1960, New Zealand tried to apply biological methods to control invasive varieties of sweet briar, using *Megastigmus aculeatus* (of the order Hymenoptera), but only about 8% of the plant seeds were infected and destroyed, after it was plans to use another insect but the project was withdrawn (Gadzinowska et al., 2019). Physical or chemical control can be conducted in the area, however, the use of herbicides can affect native plants that coexist with sweet briars. Also, physical control of invasive species can be very difficult, and the chances of reinvasion are very high (Lange et al, 2010). On the other hand, a regular grazing regime by domestic stock as well as rabbits appears to limit its establishment (Sage et al., 2009).

13.5: Conclusion

Rosa rubiginosa has an enormous ability to rapidly colonise new and unfavourable environments due to physiological traits that improve plant tolerance and it is competing for space with native woody shrubs at Mount Grand Station. In contrast to habitat loss and predation, competition is harder to manage, and physical control can be difficult with high chances of reinvasion. For the present scenario, long-term monitoring is recommended, as native and invasive woody shrub interactions may change in direction and intensity, and there is not much information about the distribution and ecology of many of these species. Furthermore, this monitoring will aid in the development of new strategies for controlling sweet briar abundance. As a bonus, sweet briar may be a valuable source of genes that probably encompass unique and effective adaptation mechanisms and is still not fully studied, offering new opportunities to the topic.

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Chapter 14: Protecting Native New Zealand Pollinators while Supporting Agricultural Production

Kat Douglas

Abstract

Pollinator systems are very important to the health of ecosystems and should be given a high level of conservation attention and priority. This has not been the case in New Zealand, with the focus instead going towards introduced species such as cover crops for pasture and honey bees. The alpine zone is particularly understudied for the effects of introduced species and landscape changes. With a high diversity of species, including endemic pollinators, it is crucially important to study, both culturally and environmentally. In March 2023, a two-day field study was carried out at Mount Grand Station in Central Otago. Mt Grand is a classic example of a High Country pastoral station, used for the production of goods such as meat, wool, and honey. This fieldwork was followed up with an in-depth literature review. High rates of introduced flora and fauna were observed while at Mt Grand. Previous studies have shown the detrimental impacts of introduced species on native pollinator ecosystems, while others have found the potential for positive ramifications with an increased abundance of flowering plants. In New Zealand, pollinator assemblages are resilient to change so could adapt to semi-pristine conditions, allowing for less-intensive farming practices to remain productive. Therefore it is critical to gain an understanding of pollination networks to provide the best protection of the native landscape as well as to promote economically viable production. Without diverse pollinator ecosystems, this will not be possible. This paper investigates the available research to begin the journey towards finding answers and inspiring important research to further understanding. It provides recommendations for how High Country farming stations such as Mt Grand can integrate pollinator conservation into management practices and achieve the best outcomes for farm productivity.

Key words: pollination, pollination networks, alpine, conservation, native bees, honey bees

14.1: Introduction

Isolation can do incredibly interesting things to the natural world. New Zealand (NZ) is no exception. Far removed from the rest of the world after the split from Gwandanaland millions of years ago, unique birds and unusual ecosystems began to evolve, resulting in a fascinating biological concoction like no other place. Prior to human settlement, 85% of the land was covered in forest. The flowers were mostly small, white or pale, and freely available for all pollinators. The pollinators evolved alongside them, a diverse unspecialised group dominated by flies, beetles, and solitary bees. Today, 27 of the bees are endemic (Knowles et al., 2022). The native moths and butterflies are similarly special with 94% only found in NZ (Patrick, 2004). When it comes to our alpine habitats, fascinating endemism occurs, regional as well as national. To put this into context, the alpine zone only covers 20% of the country, yet it supports 40% of all moth fauna (Patrick, 2004). NZ prides itself on its conservation success with incredible work being done, particularly for birds. Yet invertebrates are not given the same amount of attention. With such a unique set of pollinators, we must give them the attention they deserve to protect them, rather than replace them with exotics.

With the introduction of humans, our landscape began to change. Forests disappeared at a rapid rate. But the most drastic change came with the Europeans, the shift towards pasture. Sheep and cattle were introduced to provide food, but our ground was not adapted to this form of farming. Red clover (*Trifolium pratense*), lucerne (*Medicago sativa*), and other flora were brought in to add nitrogen, phosphorus, and sulphur needed for crop and pasture conversion (Knowles et al., 2022). But introductions didn't stop there. This new flora was too much for our small natives to tackle, even with their generalist proclivities. So beginning in 1839, pollinators were brought in to solve the problem, including the honey bee (*Apis mellifera)*, and several bumble bee species (for example *Bombus terrestris* and *Bombus Hortorum)* (Donovan, 1980). Since then, over 2000 exotic invertebrates have been introduced with new species arriving at a steady rate (Brockerhoff et al., 2010).

NZ has a higher proportion of unspecialised pollinators than most places in the world, owing to our high latitudes and oceanic climate (Newstrom & Robertson, 2005). All normal orders are represented, yet there are a few important families which are either low in abundance or absent. Butterflies are relatively rare in the alpine zone, instead replaced by day-flying moths (Bischoff, 2008). But the biggest of these differences can be seen in the complete lack of large social bees, hence the decision to import them in the 1800s (Newstrom & Robertson, 2005). These are more efficient pollinators, requiring nectar and pollen to feed their brood and overwinter, and can access a greater diversity of flowers with their longer tongues (Iwasaki et al., 2018). These introduced social bees have become critical for the agricultural success of NZ. The beekeeping industry has grown to be an important part of the national economy, not only through the sales of honey but also through their pollination services (Murphy & Robertson, 2000). Yet globally, introduced pollinators have been found to be one of the biggest threats to global diversity, habitat loss, and climate change (Johanson et al., 2019; Valido et al., 2019; Prendergast & Ollerton, 2022; Lazaro et al., 2021).

Similarly, exotic flora has become naturalised and important, with 50% of NZ's wild vascular plants introduced (Miller et al., 2018). Introduced flora, including weeds, are an important source of nectar and pollen for honey bees. With the increase in beekeeping services, there could be the potential to encourage their spread (Murphy & Robertson, 2000). This could encourage invasive mutualism (Newstrom & Robertson, 2005). However, with the generalist nature of native pollinators, an increase in potential floral resources could be beneficial with some arguing that there are no negative implications (Primack, 1978; Primack, 1983; Donovan, 1980). Yet when we take a closer look at how these new pollination connections affect our alpine native flora which rely on small bee pollination, this could be detrimental to their survival (Bischoff et al., 2012).

Alpine flora sexual systems in NZ have not been comprehensively studied so the importance of faunal pollinators is not fully understood (Bischoff, 2008). Yet in work from Bischoff (2008) analysing pollination systems in montane flowering networks in New Zealand, 87% of the analysed species depended on pollination services, much higher than was previously thought. Only three species (13%) were found to be fully independent of insect pollination. This is in contrast to angiosperms throughout the rest of the country which have high rates of independence (Newstrom & Robertson, 2005). This suggests that the alpine zone has higher rates of insect dependence for angiosperms than at lower elevations in NZ.

Very few studies have effectively looked at the effects of introduced species with native pollinator assemblages in NZ and even fewer in the alpine zone (Iwasaki et al., 2018; Murphy and Robertson, 2000; Miller et al., 2018). Much of the data in current use was collected between 1954-1972 when NZ was predominantly a sheep-farming nation. However, there has been a marked shift towards forestry and dairy, changing the use of the land and the plant assemblages (Knowles et al., 2022). This is even more important with the tenure review which began in 1998, with much of the alpine area going through major changes with the move away from Crown Land (Patrick, 2004). With so much change over the last 50 years, it is important that we consider the impacts this has had on our smaller, often forgotten natives. Therefore it is critical to understand the complex pollination networks to balance the success of the country's primary industries with the protection of our native invertebrates.

In the context of Mt Grand Station in Central Otago, there have been significant changes in the landscape, both in farming practices and with the passing over of land to the Department of Conservation (DOC) following the tenure review. The land has been utilised for merino sheep with cows introduced later. It is also used by beekeepers with some managed hives on the property. Minimal hives were observed during field research but this could be due to changing of sites in preparation to overwinter as the study dates were in late autumn. Mount Grand is a classic example of High Country farming, with introduced species slowly climbing into higher altitudes.

The aim of this study is to analyse all current understandings and provide recommendations for how High Country farming stations such as Mt Grand can integrate pollinator conservation into their practices.

14.2: Materials and Methods

During a two-day field study at Mt Grand Station in March 2023, two different locations were analysed to acquire a complete overview of the general ecology of the station. A trip over the top of the ridgeline and past the DOC-owned land, known as Bluenose, was travelled on the first day. This provided insight into the alpine zone as well as the impact of DOC-managed land in comparison to the rest of the farm. The second day remained at lower elevations and journeyed through Hospital Gully.

The method was to take stock of the flora and fauna observed, both native and non-native. While multiple species of non-interest were observed to aid in the research of others (for example lichens, non-flowering flora, non-pollinating insects), done via an area scan, a specific focus was placed on recording flying insects, particularly those on flowers. Flowering plants were also a focus. To aid in the survey of flying insect diversity and species, 8 pan traps were laid out in Hospital Gully at increased elevations, mixing water with a small amount of detergent in a yellow container. 3 Malaise traps were also set up, 1 at a low elevation in Hospital Gully, and 2 at higher elevations going into the alpine zone.

These observations were photographed and input into iNaturalist to ensure correct identification, thanks to the many enthusiastic contributors to the platform. From these general observations, a broader understanding of abundance and the general ecological makeup could be drawn, identifying trends, patterns, and interactions between various species.

Following this study, a literature review of current and historical information was compiled and analysed to gain a more complete understanding of pollination networks in NZ in general as well as in the alpine region. Information was sourced with searches through Google Scholar and the Lincoln University research databases. General information and statistics to understand the wider New Zealand context (ie. tenure review and tourism statistics) were found through government sources such as websites and reports.

14.3: Results and Discussion

During the field study, extensive issues with introduced weeds were observed at Mt Grand such as buddleia (*Buddleja davidii*), sweet briar (*Rosa rubiginosa*), and Hawkweed (*Pilosella spp*., Asteraceae). These were seen prominently throughout the lower elevations but in the case of some such as sweet briar, also at higher elevations. An abundance of introduced pollinators such as bumble bees (*Bombus terrestris*) and honey bees (*Apis mellifera*) were also observed pollinating flowers, particularly at lower altitudes. Unfortunately, due to rainy weather conditions, very few native pollinators were observed as conditions were not appropriate. The pan traps and Malaise traps did not return interesting results, with a very small number of insects found, mainly flies (*Anthomyia punctipennis, Calliphora vicina*), bumble bees (*Bombus terrestris),* and Common grass moths (*Orocrambus flexuosellus*), an unsurprising result considering the weather. However, a number of native bees, moths, flies, and butterflies have been observed in past excursions.

Numerous native species that are known to require faunal pollination were observed including kanuka (*Kunzea ericoides*), Matagouri (*Discaria toumatou*), mountain daisy (*Celmisia densiflora*), brooms (*Carmichaelia*), golden Spaniard (*Aciphylla aurea*), porcupine shrub (*Melicytus alpinus*), and false Spaniard (*Celmisia lyallii*) (see Table 14.1 in Appendix for comprehensive list). Some of these species, such as kanuka and matagouri, were seen in high abundance, perhaps owing to their use for the farm and therefore being prioritised for conservation. Other species such as the mountain daisy and native brooms were sighted very rarely. At higher altitudes, although multiple introduced species were observed, native flora was the most prevalent. In many cases, the native angiosperms do not have known sexual systems, so their reliance on insect pollinators is unknown. However, considering the work done by Bischoff (2008) on alpine pollination systems, we can assume it would be high. Therefore, it should be a priority to protect more of these species, regardless of their importance to farming.

A diverse number of introduced flora was observed (see Table 14.1). Examples of introduced angiosperms that require faunal pollination include clover species (*Trifolium*), sweet briar (*Rosa rubiginosa*), moth mullein (*Verbascum blattaria*), broom (*Cytisus*), and viper's-bugloss (*Echium vulgare*). Examples of angiosperms that do not require faunal pollination include buddleia (*Buddleja davidii*), Hawkweed species, sheep's sorrel (*Rumex acetosella*), Cock's foot (*Dactylis glomerata*), and thistles (*Asteraceae*). These species utilise other pollination techniques, such as wind, but can still provide a food source for insect pollinators. Many of these species are doing very well, notably buddleia, sweet briar, Hawkweed, and thistles, particularly at lower altitudes. It is unclear how big a problem this is as they still provide food sources for pollinator species even though they may be overtaking native flora.

Overall, the current literature has mixed conclusions on whether introduced flora and fauna is detrimental to native pollinator communities. It seems that more recent research is more cautious when in it comes to downplaying the negative impacts (Iwasaki, et al., 2018; Johanson, et al., 2019; Murphy, et al., 2000), whereas older studies generally find no competition, particularly when comparing with native bees (Primack, 1978; Primack, 1983; Donovan, 1980). This suggests that with more research the closer we become to understanding the complicated pollinator networks and how they could be negatively impacted.

Finding negative impacts does not mean we need to eliminate introduced species. On the contrary, many studies have found that introduced species of flora are important as an extra foraging source (Johanson et al., 2019; Newstrom et al., 2005; Patrick, 2004; Miller, et al. 2018). Therefore, some changes which include a combination of introduced and native flora could be beneficial to native pollinators. Land conversion has been seen to be a significant factor when it comes to species loss, so it is difficult to properly assess the impacts of non-native flora and fauna (Newstrom et al., 2005). Yet the native survivors have proven to be very resilient, able to survive in semi-pristine conditions (Patrick, 2004). Therefore, we can deduce that as long as we protect the remaining areas from further land intensification and ensure native flora is not completely eradicated through the spread of exotics, there is a possibility that both native pollinators and primary industry can be preserved.

When it comes to analysing the effects of land change in the alpine zone, the limited research makes it particularly difficult to draw conclusions. We have seen that at lower elevations in areas with higher levels of development, such as the Canterbury Plains which have been almost entirely converted into food production, native bee nesting sites have been destroyed, in some areas causing localised extinctions or significant drops in population size (Donovan et al., 2010). Such intensive development has not occurred in the alpine zone, yet still, it has seen growing intensification in High Country stations to ensure maximum productivity. Crop pollination, pasture pollination, as well as honey, is crucially important to the export economy as well as for feeding the nation (Ministry for Primary Industries, 2022). Yet this should not come at the cost of native species.

Analysing pollination systems in the High Country and in NZ in general, there is currently not enough information to make a decisive conclusion as to best practices. It is therefore critical that we complete more in-depth research on the topic. This should include an analysis of floral makeup in comparison to native abundance and diversity. Without this understanding, we are blind to what is going on. If introduced species, of either flora or fauna, are causing natives to decline this should be of paramount concern.

This is of particular importance for the High Country where intensive farming has occurred but is now changing tact with the changes through the tenure review. With a greater push to protect conservation areas of note, this is the perfect time to begin to find a way to tie in conservation with production throughout the rest of the farm. With such high diversities in the alpine zones, this is a crucial step to finding the balance between these two important issues and ensuring any detrimental trophic cascades do not occur. Mt Grand Station, with its ties to Lincoln University, is perfectly placed to lead the movement towards a more sustainable system of High Country farming that supports native pollination rather than works against it. As the iconic Barry Donovan, a leader in NZ native bee research, said, "If any organism at all becomes extinct, it's an unstitching of the ecological web that supports all of us. To lose one bee species would be a tragedy from a human point of view. So we do need to know whether there is an impact – from a purely selfish, survival of the human species view" (Macdonald, 2008).

14.4: Conclusion

We need to understand our native pollination networks and pay head to the native flora, not allowing introduced species to completely take over. Otherwise, there could be trophic cascades we have not accounted for. As pollination networks are some of the most important, this could be devastating. This is particularly true for the farming industry which relies on pollination services, albeit mainly introduced, to pollinate flora such as cover crops which are crucial to the success of the farm. Starting this journey in a High Country farming ecosystem such as Mt Grand Station is perfect, as the land has not been as heavily transformed as they have at lower elevations and tenure review has encouraged the protection of conservation hotspots. Native pollinators do not appear to be too fussy and can survive semi-pristine conditions (Patrick, 2004). With this in mind, it should be possible to shift practices to support both productivity on the farm as well as protection of native species. Therefore it should be a priority to find a balance between an introduced, productive landscape and one which is inclusive of conservation needs. NZ pollinators have already withstood intensive changes in their landscape. With some thought and care, we can surely find common ground between their needs and our primary industries. The next step should begin research to understand pollinator makeup and abundance as well as floral preferences. Then work can be placed into ensuring these ecosystems are incorporated into farm planning practices. In the meantime, care should be made into controlling the spread of non-native flora to ensure it does not take over.

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14.6: Appendix

Pollinator and Angiosperm Observations at Mt Grand 2023			
Native Fauna	**Introduced Fauna**	**Native Angiosperms**	**Introduced Angiosperms**
Allograpta	Plutella xylostella	Aciphylla aurea	Achillea millefolium
Archichauliodes diversus	Helicoverpa armigera	Acrothamnus colensoi	Agrostis capillaris
Argyrophenga antipodum	Epiphyas postvittana	Anaphalioides bellidioides	Anthriscus caucalis
Asaphodes abrogata	Clepsis divulsana	Anisotome aromatica	Buddleja davidii
Austrevylaeus	Calliphora vicina	Anisotome brevistylis	Carduus acanthoides
Capua semiferana	Bombus terrestris	Anisotome flexuosa	Carduus nutans
Crocidosema plebejana	Apis mellifera	Brachyglottis haastii	Celmisia densiflora
Dasyuris partheniata	Anthomyia punctipennis	Bulbinella angustifolia	Centaurium erythraea
Eudonia leptalaea	Anthidium manicatum	Carmichaelia australis	Cirsium arvense
Eudonia philerga	Achyra affinitalis	Carmichaelia crassicaulis	Cirsium vulgare
Eudonia sabulosella		Carmichaelia petriei	Crataegus monogyna
Eudonia submarginalis		Carmichaelia vexillata	Crepis capillaris
Hepialidae		Celmisia angustifolia	Cytisus scoparius
Ichneutica atristriga		Celmisia densiflora	Dactylis glomerata
Ichneutica lignana		Celmisia densiflora	Digitalis purpurea
Ichneutica mutans		Celmisia gracilenta	Echium vulgare
Ichneutica nullifera		Coprosma crassifolia	Erodium cicutarium
Ichneutica propria		Coprosma propinqua	Galium aparine
Leioproctus		Coprosma virescens	Hieracium lepidulum
Lycaena boldenarum		Cordyline australis	Holcus lanatus
Melangyna novaezelandiae		Coriaria arborea	Hypericum perforatum
Metacrias		Discaria toumatou	Hypochaeris radicata
Meterana ochthistis		Dracophyllum pronum	Juncus articulatus
Neoitamus melanopogon		Dracophyllum rosmarinifolium	Leucanthemum vulgare
Odontria		Epilobium melanocaulon	Lotus corniculatus
Orocrambus flexuosellus		Gaultheria antipoda	Lotus pedunculatus
Orocrambus ramosellus		Gaultheria crassa	Malva sylvestris
Orocrambus vittellus		Gaultheria depressa	Marrubium vulgare
Phaeosaces apocrypta		Gentianella corymbifera	Mycelis muralis
Phasia campbelli		Geranium brevicaule	Navarretia squarrosa
Physetica phricias		Helichrysum lanceolatum	Orobanche minor
Physetica sequens		Kunzea ericoides	Pilosella officinarum
Pison spinolae		Leptospermum scoparium	Populus nigra
Pyronota		Leucogenes grandiceps	Prunella vulgaris
Rhyparochromidae		Linum	Rosa rubiginosa
Scopula rubraria		Melicytus alpinus	Rumex acetosella
Tephritidae		Muehlenbeckia axillaris	Salix
Triplectides		Muehlenbeckia complexa	Sonchus oleraceus
Vanessa gonerilla		Myrsine nummularia	Tilia
Vanessa itea		Olearia avicenniifolia	Trifolium arvense
Zizina oxleyi		Olearia fimbriata	Trifolium dubium
		Olearia nummulariifolia	Trifolium glomeratum
		Ozothamnus leptophyllus	Trifolium pratense
		Parsonsia capsularis	Trifolium striatum
		Pentachondra pumila	Trifolium subterraneum

Table 14.1: All observations of native and introduced species of pollinator fauna and angiosperms.
Most observations are recorded at the species level, but occasionally the genus is recorded if the species remains unknown. Note that the species collected is by no means complete and was recorded over two days of field observations

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Chapter 15: Insect Sampling to Monitor the Distribution of Insects in Different Sites and Different Trees, and the Presence and Status of Pest Species in Mt Grand

Albert Salemgareyev

Abstract

Insect sampling plays a crucial role in monitoring the distribution and abundance of insects, as well as identifying pest species within specific ecosystems. This study focuses on the application of beating trees and shrubs as a method for insect sampling to assess insect diversity and the presence of pest species at Mt Grand Station.

The study was conducted in multiple sites across Mt Grand, encompassing various tree species and vegetation types. Beating trees and shrubs involved gently striking the foliage with a beating tray or net, causing the dislodgement of insects, which were then collected and identified. The collected insects were categorized into different taxonomic groups and further analyzed to determine species richness, abundance, and diversity.

Preliminary results indicate a diverse insect fauna in the Mt Grand region, with a wide range of species identified across the sampled sites. The beating method effectively captured a broad spectrum of insect taxa, including both beneficial insects and potential pests. Additionally, the presence and status of known pest species were assessed, providing valuable information for pest management strategies.

The data collected through this study will contribute to the understanding of insect distribution patterns within Mt Grand and provide insights into the potential impacts of pests on local ecosystems. This information will aid in developing targeted pest control measures and conservation strategies for the region.

Key words: Mt Grand, pest management, conservation, environmental changes, ecological and economic impacts

15.1: Introduction

Insect sampling plays a crucial role in monitoring and understanding the distribution patterns of insects within various ecological settings. By conducting insect sampling in different sites and trees, we can gain valuable insights into the diversity, abundance, and behavior of insect populations. Additionally, monitoring the presence and status of pest species is particularly important for effective pest management strategies.

In this context, our study focuses on insect sampling and monitoring efforts in Mt Grand. Mt Grand, a region of ecological significance, is known for its diverse plant and animal communities. However, the impact of insects, especially pest species, on the ecosystem remains a concern. Therefore, our objective is to assess the distribution of insects across different sites and trees within Mt Grand, as well as to evaluate the presence and status of pest species.

By conducting systematic insect sampling, we aim to address several key questions. Firstly, we seek to identify the insect species present in the area and determine their relative abundance. This information will enable us to create a comprehensive inventory of insect diversity within the study area. Secondly, we aim to examine the distribution patterns of insects across different sites and trees. This will help us understand how insect populations vary spatially within Mt Grand and identify potential hotspots of insect activity.

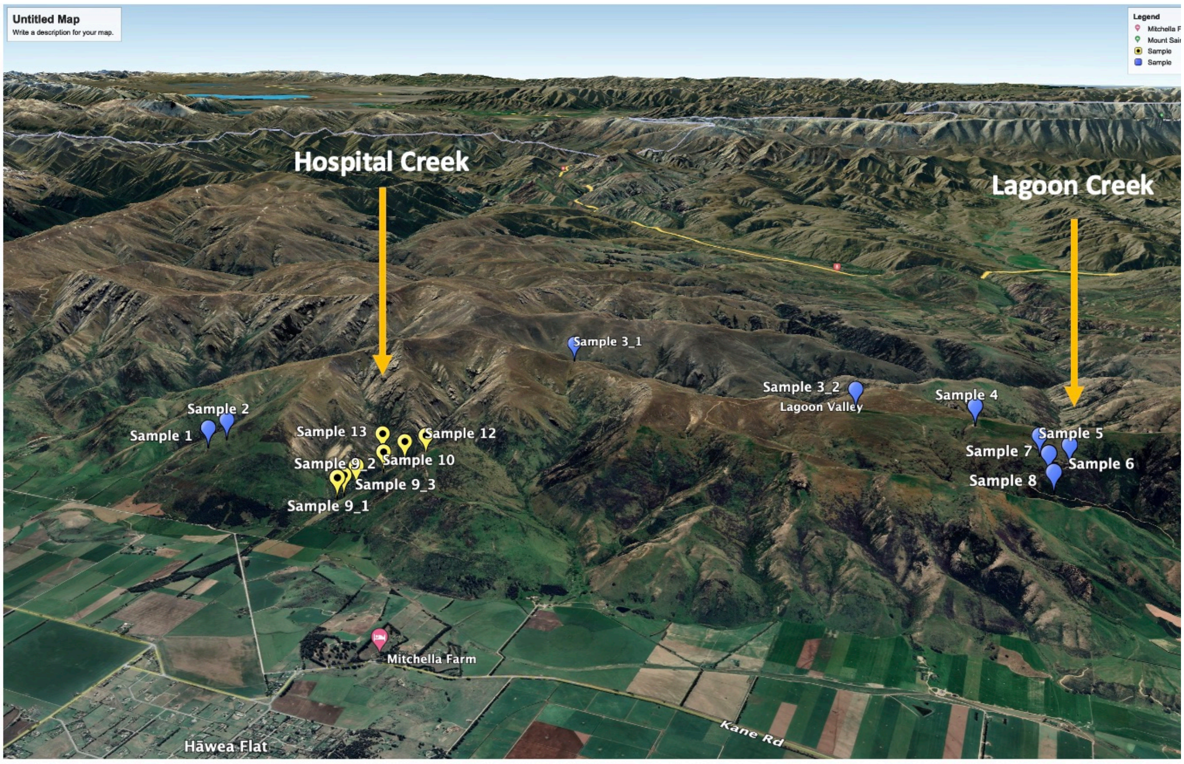

Figure 15.1: Project area and the main data collection sites

Furthermore, our study places particular emphasis on monitoring pest species. Pest insects can cause significant damage to both natural and agricultural ecosystems, affecting plant health and productivity. By monitoring the presence and status of pest species, we can gather valuable data to inform pest management strategies and mitigate potential ecological and economic impacts.

To achieve our objectives, we will employ various insect sampling techniques, including trapping, visual surveys, and collection methods. These methods will allow us to capture a broad spectrum of insect taxa and provide a comprehensive overview of insect populations in Mt Grand.

In conclusion, our study aims to contribute to the understanding of insect distribution, diversity, and pest species status within Mt Grand. The data obtained from this research will not only enhance our knowledge of the local ecosystem but also assist in developing effective strategies for insect pest management. Ultimately, our findings may have broader implications for the conservation and sustainable management of natural resources in the region.

15.2: Materials and Methods

Mt Grand, located in New Zealand, is a diverse and ecologically rich region known for its unique flora and fauna. This mountainous area is characterized by a variety of shrubs and trees, making it an ideal location for studying insect biodiversity. The study aims to monitor the distribution of insects in different sites and different trees, and the presence and status of pest species. This chapter outlines the materials and methods used for beating shrubs and trees to collect insects in Mt Grand.

15.2.1: Beating Tools

To effectively collect insects from shrubs and trees, several tools are required:

a) Beating Sheet: A large white sheet made of a lightweight, durable material (cotton), measuring approximately 1 meter by 1 meter.
b) Beating Stick: A long, flexible stick made of lightweight material, approximately 1.5 to 2 meters long. The beating stick strikes the shrubs and trees to dislodge the insects.
c) Collecting Containers: Various containers were used vials with lids, which are needed to collect and store the captured insects.
d) Field Guides: Comprehensive field guides specific to the insect species are needed, but in my case, I used internet resources such as iNaturalist and picture insects for accurate identification after the collection process.

After capturing the insects on the whipping sheet, the following steps have been taken to collect and save the specimens:

a) Using tweezers, insects were transferred from the whipping sheet to collection containers. Ensuring that each container is labeled with the sampling location and date.
b) If possible, separate the collected insects by species or taxonomic groups to facilitate subsequent identification and analysis.
c) A small piece of cotton wool or soft paper is placed in each container to prevent damage to the samples during transport.

Figure 15.2: Project site (Hospital Creek)

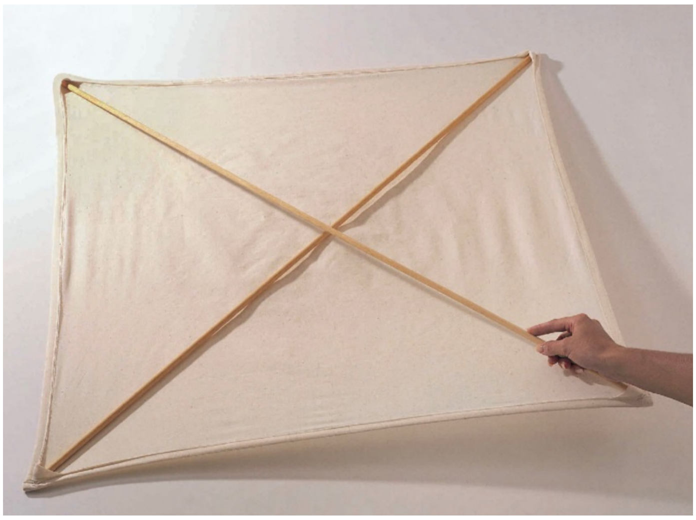

Figure 15.3: Beating sheet

15.2.2: Data recording and analysis

To keep accurate records and facilitate analysis of the data, basic information during the collection process has been documented.

a) The location, date and time of each sampling as well as geographical coordinates were recorded. These data are essential for understanding seasonal changes and spatial patterns in insect diversity.
b) A record was made of the vegetation type, including common plant species encountered during the sampling process.

15.3: Results

Based on data collected from four main trees (Kanuka, Matagouri, Miki, Manuka), a total of 28 specimens were collectedcollections were made. A total of 12 species from 21 genera were identified. These species belong to 10 orders and 2 classes.

Among the insects and spiders collected, approximately 44% of the total number can be attributed to the four main trees. This indicates that these trees support a significant portion of the insect and spider populations in the study area.

The order Diptera, which includes flies and mosquitoes, accounted for 23% of the total collected specimens. This suggests that Diptera is a relatively abundant group in the study area.

Hemiptera, which includes true bugs and aphids, made up 12% of the collected specimens. This indicates that Hemiptera is less abundant compared to Diptera but still represents a notable proportion of the insect and spider populations.

Furthermore, it is observed that Kanuka, one of the four main trees, exhibited higher species richness and abundance compared to the other trees. This implies that Kanuka provides a favorable habitat for a diverse range of insect and spider species.

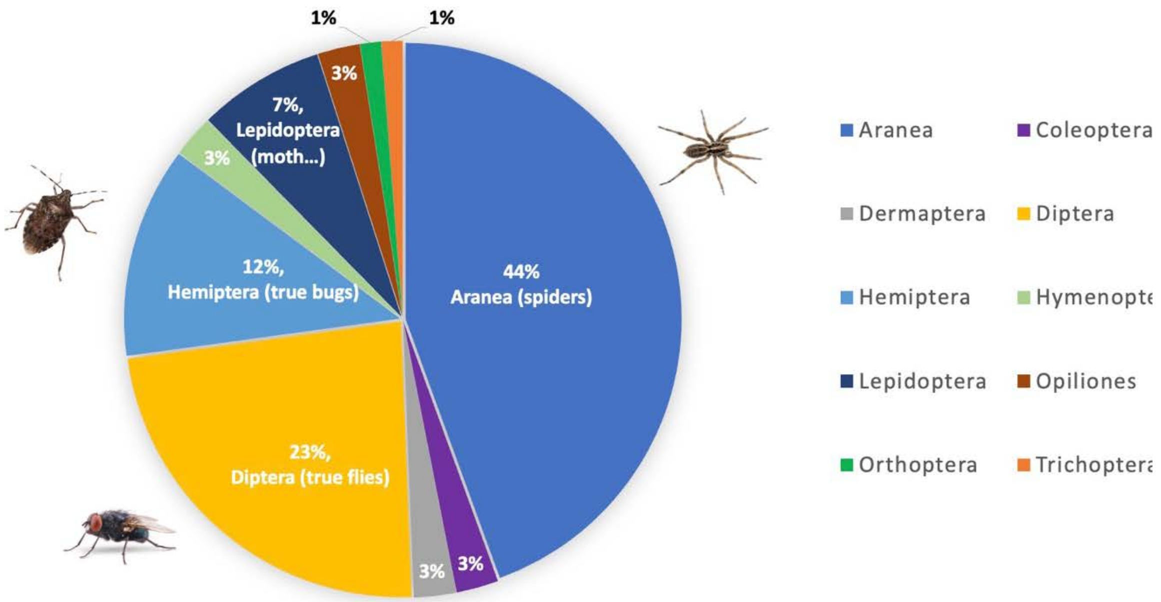

Figure 15.4: Proportional occurrence of arthropod orders across all sampling points

Overall, these findings provide insights into the insect and spider diversity associated with the four main trees and highlight the significance of Kanuka in supporting a rich and abundant insect and spider community. No pest species were found as a result of the samples collected.

15.4: Discussion

Insect sampling is an important tool used to monitor the distribution and abundance of insects in various ecosystems. It provides valuable insights into the dynamics of insect populations, their interactions with other organisms, and the overall health of ecosystems. Monitoring insects is particularly crucial when it comes to identifying and managing pest species, as their presence and status can have significant impacts on both natural and agricultural systems.

When monitoring insect populations in different sites and trees, it is essential to use appropriate sampling techniques that capture a representative sample of the insect community. Various methods can be employed, depending on the specific objectives and resources available. Common sampling techniques include sweep netting, sticky traps, pitfall traps, and visual surveys.

In the case of Mt Grand, insect sampling can provide valuable information about the diversity and abundance of insect species in the area. By comparing data from different sites and trees, researchers can assess how insect communities vary across the landscape and identify any patterns or trends. This information can be useful for understanding the ecological dynamics of Mt Grand and assessing its overall biodiversity.

Moreover, insect sampling can help detect the presence and status of pest species in Mt Grand. Pest species are organisms that can cause harm or damage to ecosystems, crops, or human health. By monitoring insect populations, researchers can identify any increases or outbreaks of pest species, allowing for timely intervention and management strategies. This may include implementing targeted control measures or adjusting land management practices to mitigate pest impacts.

Insect sampling should be conducted over time to capture seasonal variations and long-term trends. Long-term monitoring efforts enable researchers to track changes in insect populations and detect any shifts in community composition. These changes may be influenced by various factors, such as climate change, habitat degradation, or the introduction of invasive species. By monitoring insect populations regularly, scientists can assess the effectiveness of conservation efforts and develop strategies for maintaining healthy ecosystems.

In summary, insect sampling plays a crucial role in monitoring the distribution of insects, identifying pest species, and assessing the overall health of ecosystems. By conducting systematic sampling in different sites and trees, researchers can gain valuable insights into the dynamics of insect communities in Mt Grand and make informed decisions regarding pest management and conservation strategies.

15.5: Conclusion

In conclusion, insect sampling is an invaluable tool for monitoring the distribution of insects in various sites and trees, as well as assessing the presence and status of pest species in specific regions such as Mt Grand. This monitoring technique allows researchers and environmentalists to gather critical data on insect populations, which is essential for understanding ecological dynamics and implementing effective pest management strategies. By conducting systematic insect sampling in different sites and trees within Mt Grandt, researchers can gain insights into the diversity and abundance of insect species. This information aids in establishing baseline data, detecting changes in insect populations over time, and identifying potential areas of concern. Through regular monitoring, it becomes possible to track shifts in insect distribution patterns, which can be indicative of environmental changes or the spread of invasive species.

Furthermore, insect sampling provides a means to identify and monitor pest species within the Mt Grandt ecosystem. Pests can have significant impacts on the health and vitality of trees and other organisms within the ecosystem. By monitoring their presence and status, researchers can develop targeted pest management strategies to mitigate potential damage and preserve the ecological balance.

Insect sampling techniques can vary depending on the specific objectives and requirements of the study. Common methods include sweep netting, pitfall trapping, and insect traps. These methods enable researchers to capture and identify insects in a standardized and efficient manner. Additionally, advances in DNA barcoding and molecular techniques have further enhanced our ability to accurately identify and classify insect species, even at the larval or microscopic stages.

Overall, insect sampling serves as a critical tool for monitoring the distribution of insects in different sites and trees, and for assessing the presence and status of pest species in Mt Grand. It allows researchers to gather valuable data on insect populations, contributing to our understanding of ecosystem dynamics and facilitating informed decision-making in pest management efforts. Continued monitoring and research in this field are crucial for preserving the biodiversity and ecological integrity of Mt Grand and other natural environments.

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15.7: Appendix

Table 15.1:Data Sample table

Sample #	Data	Time	Lat_dec	long_dec	Latin name (tree)	Scientific name (tree)	Num_ species	Total_ number
1	20.03.2023	11:21	-44,636669	169,323844	Discaria toumatou	Matagouri	5	9
2	20.03.2023	11:33	-44,637873	169,325379	Discaria toumatou	Matagouri	4	11
3_1	20.03.2023	11:55	-44,660993	169,360062	Olearia nummulariifolia	Tree daisy	5	8
3_2	20.03.2023	12:07	-44,689699	169,356708	Leptospermum scoparium	Manuka	6	9
4	20.03.2023	13:20	-44,699923	169,35973	Kunzea ericoides	Kanuka	5	11
5	20.03.2023	14:13	-44,705474	169,356712	Leptospermum scoparium	Manuka	5	8
6	20.03.2023	14:27	-44,707912	169,356425	Kunzea ericoides	Kanuka	6	9
7	20.03.2023	15:01	-44,706341	169,354037	Kunzea ericoides	Kanuka	4	4
8	20.03.2023	15:10	-44,706856	169,351302	Coprosma propinqua propinqua	Miki	3	5
9_1	21.03.2023	10:46	-44,650674	169,32277	Coprosma propinqua propinqua	Miki	5	6
9_2	21.03.2023	11:16	-44,650971	169,323528	Coprosma propinqua propinqua	Miki	6	5
9_3	21.03.2023	11:27	-44,65118	169,325679	Coprosma propinqua propinqua	Miki	4	7
10	21.03.2023	11:52	-44,652076	169,329724	Leptospermum scoparium	Manuka	5	6
11	21.03.2023	12:26	-44,652758	169,333082	Leptospermum scoparium	Manuka	5	9
12	21.03.2023	14:06	-44,654955	169,333192	Buddleja davidii		6	8
13	21.03.2023	14:13	-44,65041	169,333195	Kunzea ericoides	Kanuka	4	11

Chapter 16: Ground Dwelling Invertebrates

Colleen Buchanan

Abstract

Soil surface invertebrates are good bioindicators of ecosystem health. On Mt. Grand, the alpine region is divided into private land and Department of Conservation (DOC) land. With different land management processes present between the private and DOC owned land, invertebrates respond accordingly. Through field observations, iNaturalist data, georeferencing, and previous publications; ground dwelling invertebrates within the study area were identified and compiled into this analysis. A wide-ranging diversity of invertebrates were found within the study area including more than 55 species present spanning over 13 invertebrate orders. The most abundant orders include Aranea (spiders), Hymenoptera (ants, wasps & bees), Coleoptera (beetles), and Orthoptera (grasshoppers & weta) which may be attributed to these orders including species that are more conspicuous compared to other species like mites or earthworms. Nonetheless, studying the abundance and diversity of surface invertebrates is ideal due to their relatively small body size, short generational turnover, and generally abundant presence. Overall, this report adds to the greater scientific discussion of a better understanding of the impacts that land disturbance has on ecosystem health at Mt. Grand.

Key words: Invertebrates, Surface-soil, Alpine, Conservation, Bioindicators

16.1: Introduction

Soil-surface invertebrates are one of the most diverse groups found throughout the survey area on Mount Grand. They can be used as soil bioindicators and respond to human disturbance of the land (Paoletti et al., 2010). Within the context of conservation, soil invertebrates can offer insight into the soil health and thus overall health of an ecosystem (Onipchenko & Zhakova, 1997; Paoletti et al., 2010). Furthermore, they are indicators of ecosystem response to climate change. And with temperatures rising and altered rates of nutrient mineralization, ground dwelling invertebrates found in alpine ecosystems will be especially susceptible (Paler et al. 2021). This applies to the soil invertebrates found within the alpine region at Mt. Grand living within the 400-1445m above sea level range.

Invertebrates are of fundamental importance in terrestrial ecosystems. Depending on the habitat structure, soil nutrient availability, and elevation; the specific composition of soil invertebrate communities can vary greatly (Onipchenko & Zhakova, 1997). A paper published in the European Journal of Soil Biology postulates elevation influences the habitat structure and therefore abundance of soil macro-invertebrates dwelling in the European Alps. It found that certain insect larvae, particularly some flies (Brachycera and Nematocera) increase in biomass and abundance while other invertebrates like earthworms (Lumbricidae) and millipedes (Diplopoda) become less common due to poor nutrient availability. Additionally, low intensity grazing of sheep actually enhances the nutrient content of the soil with the sheep's feces thus enabling invertebrates to thrive in the upper elevational limit of the alpine region (Steinwandter et al., 2018).

Additional studies have been conducted showcasing the difference in soil invertebrate communities between managed and abandoned alpine pasturelands. Centipedes (Chilopoda), millipedes, beetles (Coleoptera) and some flies were either exclusively found or more abundant on the abandoned sites, whereas earthworms were largely more common on the managed sites (Steinwandter et al., 2017; Gerlach, et al., 2013). There is still little known of the geographic biodiversity patterns across managed alpine land in relation to soil invertebrates; thus, this survey adds to the growing understanding of soil invertebrate biodiversity in alpine regions.

Within Mt. Grand, the NZ Department of Conservation (DOC) owns over 110 ha of land (DOC Conservation Resources Report 2006). The ecosystems vary across land owned and not owned by DOC. This study aims to address the differences in biodiversity of soil surface invertebrates between land belonging to Mt. Grand vs. DOC land to better understand their role as bioindicators in land management and conservation applications.

16.2: Materials and Methods

Field surveys took place over March 20th – 21st 2023 on Mt. Grand Station, Hawea Back Road, Lake Hawea. Survey efforts commenced at approximately 10:30 and concluded before 16:00. The weather included occasional showers, wind 4-6 m/s and temperatures ranging from 8-15° over both days (OpenWeatherMap & Light Inform Ltd © Weather-Forecast.nz, 2023). Groups of around 15 people stopped at occasional locations throughout Mt. Grand chosen by course instructors. To observe soil invertebrates, a ~10cm spade shovel was used to dig a cubic hole. This would allow visibility of soil surface invertebrates (Sherley & Evans, 2016). The dirt taken from the hole was placed over a white tarp to ease the spotting of tiny invertebrates otherwise hidden in the soil. Soil was searched thoroughly and then replaced into the hole once the observation period (~30 to 45 min) ended. This process was repeated four times over the two-day period. Locations were picked based on substrate and wind exposure. Each location was a minimum of 10 metres away from the road to avoid influence from vehicular disturbance. Additionally, each site consisted of soil soft enough for digging and some rocks or large grasses including Snow Tussock (*Chionochloa macra*) or Silver Tussock (*Poa cita*) surrounding the hole in order to dampen wind effects on the exposed soil being blown away during observation. After sorting through the soil samples, invertebrates spotted were documented then released back where they were found. Identification using photos taken of the specimens was completed after the field work ended.

In addition to soil inspections, most of the data was compiled from iNaturalist (iNaturalist Open-Source Software: https://www.inaturalist.org). Over 30 observers took photos of plants and animals and compiled them into one dataset available to the public. Each photo is fitted with a possible identification that is checked and verified by either observers, peers, or professionals in the field. Along with photos, GPS coordinates, date, and time are attached to each observation as well.

Creation of a map on Google Earth was used with latitudinal and longitudinal data from iNaturalist and DOC (Figure 16.1). Only the invertebrate orders listed in Figure 16.2 were compiled within Google Earth Pro. Layered with the observation locations of soil invertebrates, outlines of NZ DOC Public Conservation Land maps were downloaded from the Department of Conservation Te Papa Atawhai 2023 website. Google Earth 2023 provided base layer information with topography and general elevation visible.

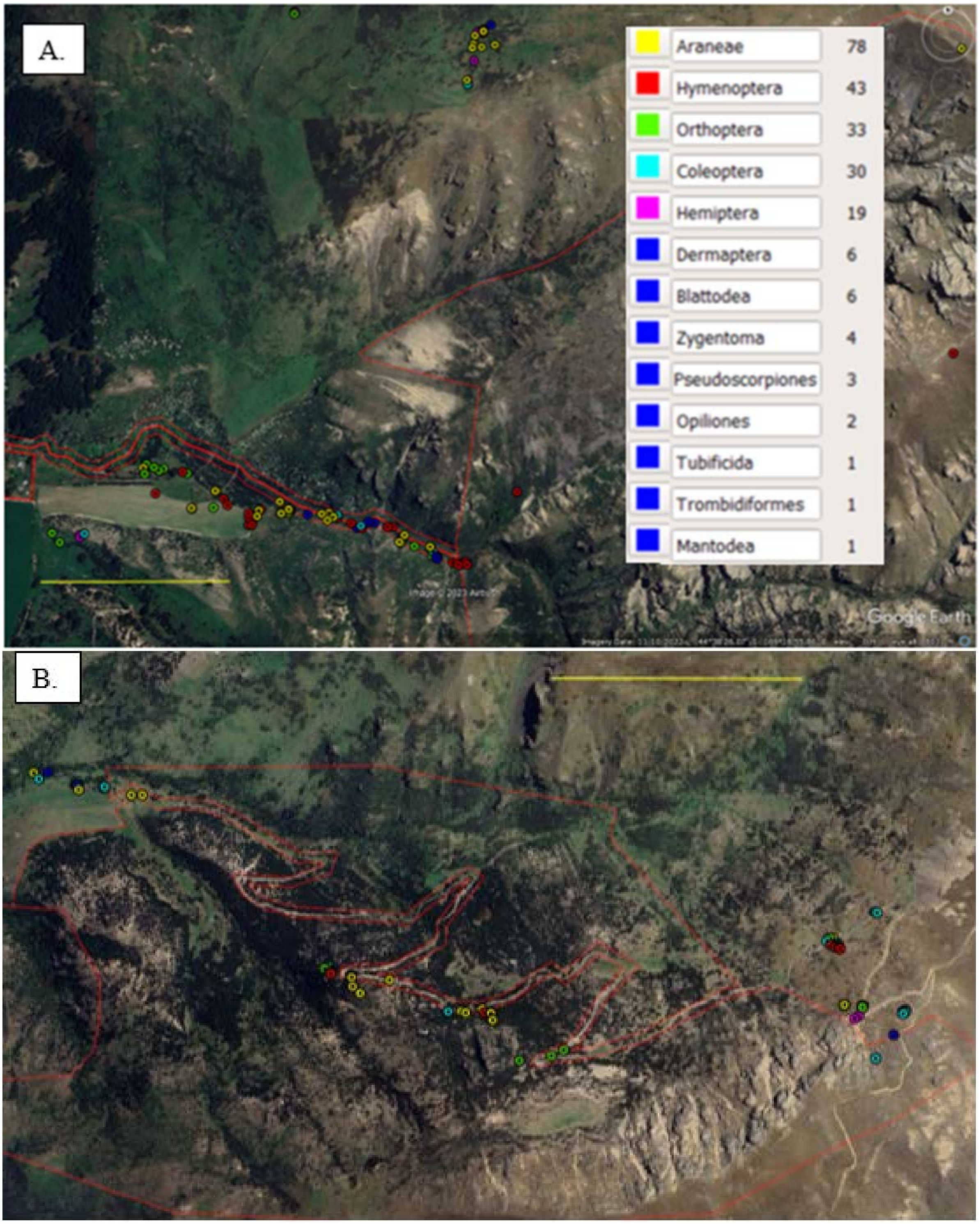

Figure 16.1: Maps (A and B) of Mt. Grand field observation sites showcasing 13 soil surface invertebrate orders. Google Earth Maps. A.) Zoomed in on Hospital Gulley collection sites. B.) Zoomed in on Lagoon Creek collection site. The yellow line in both photos indicates 500m for scale.

Finally, previous knowledge of the study station and the roles played by soil invertebrates within ecosystems comes from reputable journals, peer-reviewed articles, course material, and participation.

16.3: Results

There is no shortage of soil invertebrate biodiversity on Mt. Grand. According to iNaturalist, there are over 55 invertebrate species present within the study area. The major orders include: Araneae (spiders), Coleoptera (beetles), Hymenoptera (ants specifically), Orthoptera (grasshoppers), and Hemiptera (True bugs) (Fig. 3). This paper focuses on ants specifically within the context; however, wasps and bees are included in the analyses (Table. 16.2). Additionally, within iNaturalist, 0 observations were made of the family Lumbricidae (earthworms). Soil sample methods yield 2 different spider species both belonging to Araneae, ants, beetles, spittlebugs and one Enchtraeidae (potworm).

Table 16.1: Compiled data summary from iNaturalist showing the number of individual observations per order of soil invertebrate.

Order	Common Name	Number of Observations
Araneae	Spiders	78
Blattodea	Cockroaches, termites	6
Coleoptera	Beetles	30
Dermaptera	Earwigs	6
Hemiptera	True bugs	19
Hymenoptera	Ants, wasps, bees, etc.	43
Mantodea	Mantises	1
Opiliones	Harvestmen	2
Orthoptera	Grasshoppers, weta, etc.	33
Pseudoscorpiones	False scorpions	3
Tubificida	Potworms	1
Trombidiformes	Mites	1
Zygentoma	Silverfishes	4

https://www.inaturalist.org. (Project Mt-Grand-Biodiversity)

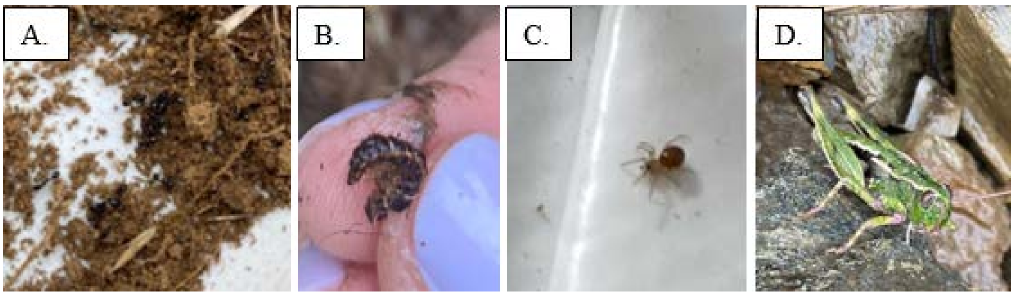

Table 16.2: Examples of photos used in iNaturalist highlighting some of the most common soil surface invertebrate orders found on Mt. Grand.

Photos taken by observer Colleen Ann Buchanan. A.) Hymenoptera: ants found in a soil sample, B.) Coleoptera: dermestid beetle found in a decaying brushtail possum carcass, C.) Araneae: spider found in soil sample, D.) Orthoptera: *Sigaus australis* grasshopper found among rocks.

16.4: Discussion

Soil invertebrates are highly diverse and contribute to the complex ecosystem at Mt. Grand. It is important to note that not all species present at Mt. Grand were detected, nor was the sampling effort conclusive enough to portray a proportional snapshot of the biodiversity (Sherley & Evans, 2016). Hence, with Lumbricidae receiving 0 observations, it does not mean there are no earthworms within the survey area. Furthermore, the cold and rainy conditions may have hindered collection efforts due to low visibility or altered behavior of invertebrates.

According to the New Zealand Department of Conservation, soil samples obtained by this spade method are objectively site-specific due to the fine-scale variability of invertebrate diversity and abundance (Sherley & Evans, 2016). Thus, it is nearly impossible to imply any generalizations with only four samples taken across the study area. Additionally, invertebrate sightings compiled from iNaturalist may be skewed due to certain species being more conspicuous than others. The most abundant orders include Aranea, Hymenoptera, Coleoptera, and Orthoptera which may be due to these orders including species that are easier to see and take pictures of compared to orders like Tubificida or Trombidiformes. This data set is inconclusive and therefore unable to highlight differences between managed vs. unmanaged land use. However, previous publications reveal the importance of invertebrates as bioindicators of ecosystem health. Invertebrates are abundant, small and have relatively quick generational turnover times making them ideal and universal bioindicators to study (Hodkinson & Jackson, 2005).

Specifically, studying and comparing heteropteran species and populations between the private and DOC owned land can provide insight into land health. For example, individuals belonging to Miridae are usually more common in low-growing, undisturbed habitats. They are also less tolerant to chemical sprays and habitat destruction than the families of Anthocoridae (Fauvel 1999). So, finding more individuals of Miridae in area 1 than area 2 could lead one to assume that area 1 is less disturbed and has less human impact. Another example comes from ants as viable bioindicators of agroecosystem condition. Ant populations vary significantly between agricultural fields and field margins while also being affected by soil variables and tillage practices (Peck, et al., 1998). This means that studying ants will showcase the reach of agricultural disturbance at the soil level depending on the level of disturbance evident on an area of land.

To continue, a more general approach comparing taxa may be more useful in this context. Isopods are useful when looking specifically at soil systems and are easier to identify than mites or earthworms (Gerlach, et al., 2013). Millipedes, ants, ground beetles, harvestmen and gnaphosid spiders are better groups to look at ground layer indicators. For more open habitats, butterflies, ants and orthopterans are better suited (Gerlach, et al., 2013). Of course, these groups should be studied in conjunction with other groups when available to get a better depiction of the system in its entirety.

Ultimately, important bioindicators depend on the specific location and function of the land, but focusing on the rarity or endangerment status, and functionality (food chain position and decomposer status) of invertebrates will highlight which species are ideal to study (Büchs, et al., 2003). These factors allow for specificity in design and greater accuracy in evaluation of ecosystem health at the scale on Mt. Grand.

16.5: Conclusion

In combining the iNaturalist data with the field observations and previous publications review; this report exhibits a surface level look into the range of biodiversity present at Mt. Grand. Even deeper, this highlights the importance of understanding invertebrates and their roles as qualitative indices of the environment within alpine ecosystems. Further studies comparing disturbed vs. undisturbed land gradients using invertebrates as bioindicators will allow for an accurate and well-rounded understanding of ecosystem health. The ecosystem health and land management on Mt. Grand can be improved when studying and conserving soil dwelling invertebrates due to their diversity and abundance within the system.

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Chapter 17: Climate Change and Spider Diversity at Mt Grand

Carla Osterburg

Abstract

With climate change impacting ecosystems globally it is important to understand how species react and adapt to this. Mt Grand is a place where multiple ecosystems exist in close vicinity of each other and can be studied easily to discern the effects of climate change on the species present there. Arachnids are a widely distributed group of animals and, therefore, a highly suitable study group to investigate how changing environmental conditions affect their diversity and distribution. The aim of this study was to investigate which and how many spider families occur at which elevations and to assess if they are suitable indicators for climate change at Mt Grand. Overall, twelve families of spiders were identified within the samples collected across Mt Grand, with all twelve at low elevations (below 900m) and ten of the twelve sampled at high elevations (above 900m). Due to a restricted sampling period, no statistical analysis with the data were possible and future recommendations would be to increase the duration of the sampling period, as well as using different methods. Ultimately, more studies should be conducted at Mt Grand to better understand the impact of climate change on spiders and the ecosystems present there.

Key words: Spiders, Distribution, Diversity, Otago, Mt Grand

17.1: Introduction

With climate change affecting species globally, they are required to adapt in order to avoid extinction (Chinn & Chinn 2020; Pacifi et al.2015). Certain characteristics can make a species more vulnerable to the effects of climate change, for example low mobility, or certain habitat requirements (Pacifi et al. 2015). Alpine or generally mountainous environments are some of the first to experience direct effects of climate change, for instance through melting of glaciers (Grabherr, 2010). These can ultimately lead to trickle-down effects affecting other species, for example in Glacier National Park, the melting of glaciers led to a change in species occurrence in streams (Grabherr, 2010; National Geographic, 2015). Mt Grand spans a range of different ecosystems, including mountainous ones and has experienced multiple land-uses over the years (Department of Conservation, 2005). Therefore, it is an ideal place to investigate how climate and land-use change affects different species. Spiders are an excellent study group, as both abiotic and biotic factors determine their diversity (Måsviken et al. 2023). New Zealand is home to more than 2000 spider species, exhibiting great taxonomic diversity (Paquin et al. 2010). Most of the pre-existing literature focuses on the taxonomy of spiders or interactions between invasive and native species in New Zealand (e.g., Malumberes-Olarte et al. 2014; Sirvid 2014). Fewer studies have focused on spider diversity or distribution and the impacts of climate change on these in New Zealand. However, one study by Chinn & Chinn (2020) investigated how climate change affects multiple invertebrates, including spiders along elevation gradients. Most recently, Måsviken et al. (2023) conducted a study in Sweden and showed that climate was important for phylogenetic and functional diversity, whereas vegetation was not only important for the two aforementioned aspects of diversity, but also for taxonomic diversity. This ties in with the knowledge that spider diversity is dependent on habitat availability, for which vegetation and its physical structure is often used as a proxy (Malumbres-Olarte et al. 2012).

The aim of this study is two-fold:

(i) firstly to showcase investigate which spider families are present at Mt Grand, with a specific focus on the elevations they occur at and to consider how climate change could affect the spider diversity.

(ii) Secondly, to see investigate which spiders are present on native versus non-native plants, as these may offer different habitats to spiders and thusly affect spider diversity.

17.2: Materials and Methods

17.2.1: Fieldwork

Spiders were sampled using multiple techniques in the field. To research which spiders were present on native vs. non-native plants I used tree beating to collect spiders (and other insects). Tree-beating was chosen as a technique, due to time constraints. This technique involves beating a bush or tree, thereby collecting invertebrates, in this case spiders, in a beating tray placed directly beneath the bush. To standardise the collection method, I beat each tree or bush 10 times. Afterwards the insects were collected in vials, labelled with the species of tree, or bush the insects were collected from, the date and which sample it was (a number) and placed in a freezer at -18°C (Figure 17.1). Furthermore, GPS locations of the trees and bushes were noted. The spiders were identified to a family level at a later date. In addition to tree beating, opportunistic ground searches were performed at different elevations.

Figure 17.1: A spider in the Lycosidae family captured and photographed in a vial (Photo credit: Shannon Marshall).

17.2.2: I-Naturalist

The data collected in the field was were pooled with observations of spiders recorded at Mt Grand by other students and uploaded to the platform I-Naturalist. I-Naturalist is a citizen science platform where photographs of species may be uploaded and identified by any users (I-Naturalist 2022). Afterwards all spider observations were extracted and saved in a CSV spreadsheet. Finally, all the data was prepared for analysis in Excel and the statistical analysis programme R.

17.2.3: Map Creation and Statistical Analysis

To create a distribution map of the spiders present at Mt Grand I used R version 4.2.1 (“Funny-Looking Kid”) (R Core Team 2022). The following packages were used to build the map(s) and analyse the data: “dplyr”, “mapview” (v.2.11.0) (Appelhans et al. 2022), “Rnaturalearth”, “Rmapshaper”, “sf” (v.1.0.9) (Pebesma 2019) and “tidyverse” (v. 1.3.2.) (Wickham et al. 2019).

After downloading the data from I-Naturalist, I cleaned the data and prepared it for use in R in Excel spreadsheets. The next step was to extract the elevation from the data, based on the coordinates. I did so by using the R package “elevatr” (v.0.4.1) (Hollister 2021), which allows you to extract the elevation of a GPS point based on the coordinates provided from an online geographic database. As vegetation changes are described to occur around 900m at Mt Grand, this was also the value chosen to split the observations into two categories (below 900 m and above 900m) to investigate which and how many families occur in these ranges (Department of Conservation 2005).

17.3: Results

As the data collected in the field was not enough to test any hypotheses related to species distribution and occurrence of spiders on native vs. non-native plant species, the focus of the study shifted to showing which spiders were present at which elevations. Table 17.1 shows the elevation ranges at which various spider taxa were found in Chinn & Chinn's (2020) study versus the elevations these taxa were found at in Mt Grand.

The observed ranges at Mt Grand for the different taxa were all within the given ranges identified by Chinn & Chinn (2020), except for Salticidae, which were found at lower elevations at Mt Grand.

Table 17.1:Spider taxa suggested for monitoring alpine ecosystem conditions, the best sampling methods and whether they were present at Mt Grand and if so, at which elevations.
*Adapted from Chinn & Chinn (2020). * and bold denotes which taxon was observed at Mt Grand and its corresponding elevation.*

Spider taxa	Elevation range (m a.s.l.)	Suggested sampling methods	Surveyed at Mt. Grand	Elevations observed at Mt. Grand (m a.s.l.)
Arachnida: Aranae Agelenidae Clubionidae* Huttonidae	600 – 1800	Night observation, pitfall traps, rock turning, quadrats, transects, timed counts	Y	701-1158 752*
Lycosidae (Wolf spiders)	0 – 2200	Day observations, stone turning, pitfall traps	Y	752-1016
Salticidae (Jumping spiders)	1400 – 3000	Pitfall traps, rock turning, quadrats, timed observations	Y	752-1016

The most commonly sampled family was the Pisauridae family (Figure 17.2) with 18 observations, folllowed by the Thomisidae family with 10 observations (Table 17.2). The least sampled families were Lycosidae, Araneidae and Clubionidae with two observations each. Figure 17.3 shows the distribution of the sampled spider families across Mt Grand.The code along with the dataset is openly accessible under: https://github.com/carlaosterburg/ECOL_609 and can be freely used to recreate the interactive map.

Table 17.2: Number of observations per elevation (meters) of each spider family.

Count of Family	Elevation						
Family	**701**	**752**	**890**	**973**	**1016**	**1158**	**No. Obs.**
Pisauridae	11	7					18
Thomisidae	1	1	7		1		10
Salticidae		1	2	3	1		7
Gnaphosidae		1		1	4	1	7
Corrinnidae		2		1	3		6
Theridiidae			4		1		5
Zoropsidae		1		1	1		3
Cycloctenidae		2		1			3
Hexathelidae		3					3
Lycosidae		1			1		2
Araneidae			1		1		2
Clubionidae		1			1		2
No. Obs.	**12**	**20**	**14**	**7**	**14**	**1**	**68**

Figure 17.2: A Nurseryweb Spider which is part of the Salticidae family
Captured by Mike Bowie and uploaded to I-Naturalist (Photo credit: Mike Bowie).S

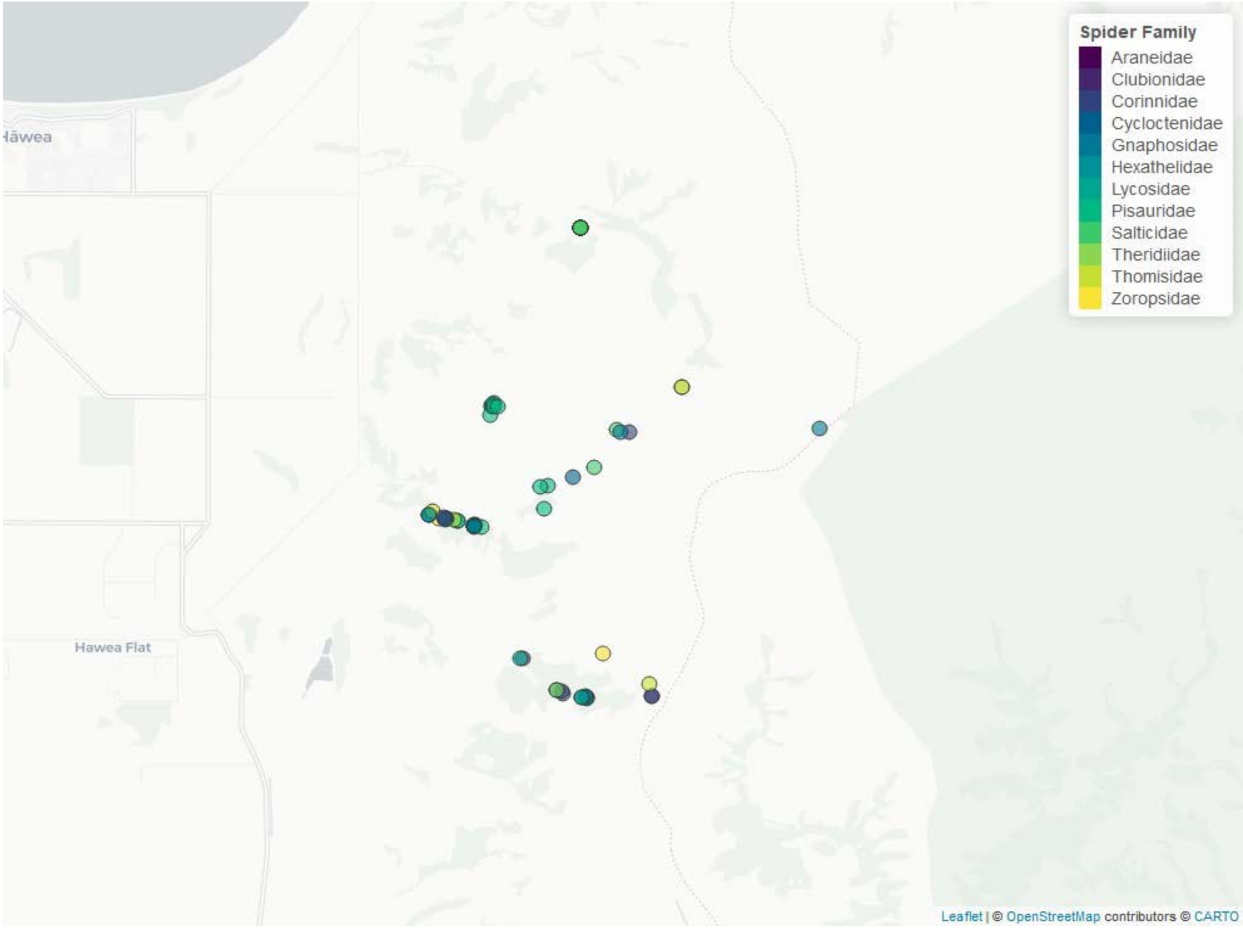

Figure 17.3: Map showing the sampling sites of the different spider families.
The different spider families are shown by the different coloured dots and the corresponding family names in the legend. The code to create and view the interactive map is via the GitHub repository.

17.4: Discussion

The results show that even within a limited timeframe twelve different spider families were observed and identified at Mt Grand. Of these, all twelve were observed at low elevations (below 900m), whilst ten were observed at high elevations (above 900m). Unfortunately, not all spider samples could be included in the analysis, as not all of them were identified down to the family level. This meant that the sample size for the elevational observations was smaller than it could have been.

In tussock grasslands, *Lycosidae* have been suggested as potential indicators to changes in grassland structure (Malumbres-Olarte et al. 2012), as well as a good indicator species for effects of climate change in Chinn & Chinn's (2020) study. However, they were only observed twice at Mt Grand. In the future, sampling efforts should focus on this family to research any changes in the tussock grasslands at Mt Grand.

Ultimately, time constraints and unsuitable weather conditions made data collection more difficult. For spiders multiple sampling techniques exist, which also vary depending on the ecosystem they are in. Curtis et al. 2022 showed that in pastures pitfall traps and hand collection are the most efficient methods to collect spiders. These sampling methods should be used in the pasture landscapes at Mt Grand in the future. Furthermore, Green (1999) recommends vacuum- and pit-sampling over all four seasons, both diurnally and nocturnally to obtain representative samples of spider species compositions in trees and bushes.

Finally, Chinn & Chinn (2020) created a framework for which sampling techniques to use to at which elevations and this should be used as guidance.

17.5: Conclusion

In conclusion, despite a short timeframe to sample spiders across Mt Grand, a diverse assemblage of spider families was observed both at low and high elevations. Considering *Lycosidae* are a family of spiders which have been identified by multiple studies as good indicators of structural changes in grasslands and of climate change effects, they should be further researched at Mt Grand. This would allow farmers to anticipate and respond to how climate change may affect their land in a timely manner.

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17.7: Appendix

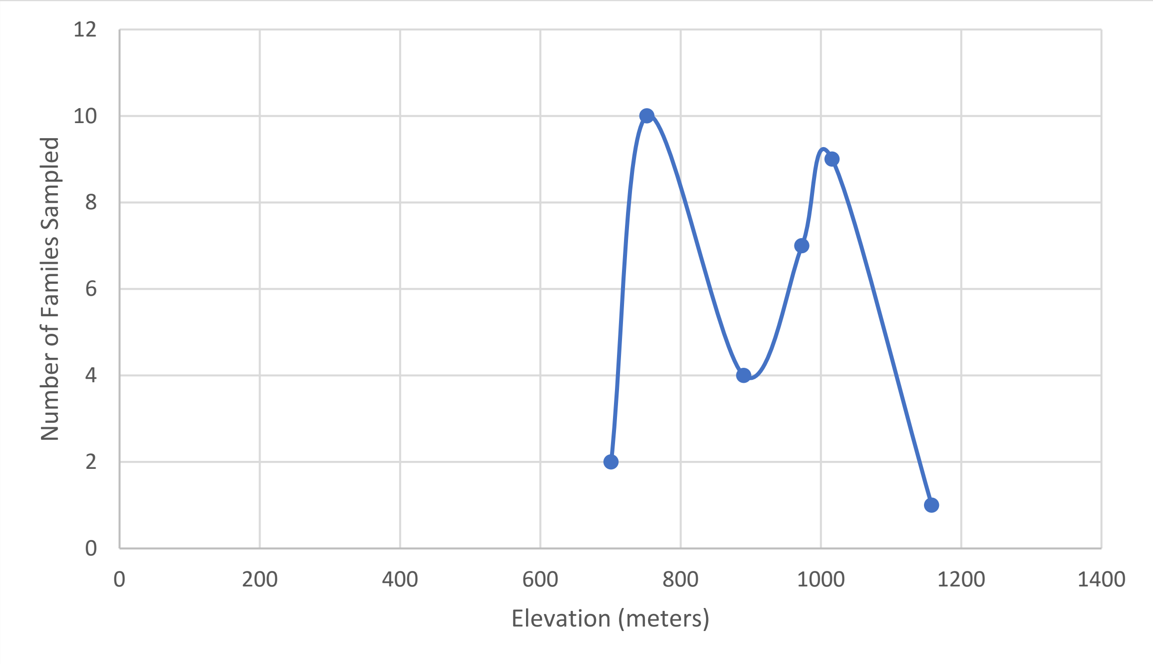

Table 17.3: Number of spider families sampled across 5 different elevation points.(Raw data)

Chapter 18: Crucial Bioindicators: Aquatic Invertebrates of Mount Grand Station

Bungum & Eckert

Abstract

Aquatic invertebrates are essential bioindicators of stream health due to the various sensitivities of freshwater invertebrate species and life stages. However, aquatic invertebrates are threatened by habitat degradation, pollution, and encroaching agricultural development. These current threats are exacerbated in the high country due to high levels of endemism and susceptibility to drastic changes over small distances. New Zealand offers a unique perspective on aquatic invertebrate biodiversity in the high country due to its own unique endemism. This study assessed the abundance of aquatic invertebrates and the Macroinvertebrate Community Index (MCI) of six sampling sites at Mt Grand Station, Otago, New Zealand, to understand differences in diversity and relative stream health between riffle and non-riffle (or pooling) sites. Riffle sites had a higher invertebrate abundance than non-riffle sites but relatively similar invertebrate diversity. MCI values were higher for riffle sites compared to non-riffle sites, but when the site was considered as a factor, Lagoon Creek had higher MCI scores overall. Future studies should consider how land use and agriculture impact these diverse aquatic communities and their respective MCI values.

Key words: Aquatic invertebrates, New Zealand, high country, Mount Grand Station, MCI

18.1: Introduction & Background

It is generally well-known that agricultural development of natural habitats worldwide has led to decreases in the overall health and biodiversity of those areas (Tscharntke et al., 2012). Losses in species assemblages have also been exacerbated by the effects of climate change, with particular environments, such as high alpine/montane areas, being at greater risk and less resilient than other environments (Giersch et al., 2016). Aquatic invertebrates are among the most sensitive taxa to environmental changes and are often important indicators of overall water and ecosystem health (Giersch et al., 2016; Provost, 2018). While environmental changes are occurring globally, the situation is especially critical in New Zealand.

Despite being a large landmass, New Zealand has exceptionally high levels of endemism, especially concerning insect biodiversity due to its long isolation (Buckley et al., 2022). Compared to most other places, the geology of New Zealand is relatively young, with the montane environments only existing for the last one million years or so (Buckley et al., 2022). The evolutionary history of species inhabiting these areas is thus similarly short, although as with similar taxa in other areas, alpine species are specifically adapted to very particular habitats (Giersch et al., 2016; Buckley et al., 2022).

An additional factor unique to New Zealand is the late arrival of humans and a delay in the associated anthropogenic ecological destruction (Provost, 2018) of humans. Most importantly, human presence triggered the intense degradation of previously forested landscapes, causing the upheaval and disturbance of riparian habitats and leading to decreases in water quality (Provost, 2018). While lower elevation areas typically receive the worst effects of such habitat and water quality losses (Collier & Clements, 2011), higher elevation catchments remain at risk, especially as they remain less studied than lower catchments. Agriculture-induced land use changes have featured heavily across New Zealand's landscape, and the alpine areas have not been spared (Provost, 2018).

Knowing this, it is crucial to understand the biotic and abiotic factors affecting stream health in vulnerable habitats. Aquatic invertebrates, usually abundant in stream ecosystems, are important bioindicators of habitat health (Stark, 1993). Due to their ecological niches, preferences and biological factors, macro-invertebrates in the benthos in riverine systems can be used to estimate local stream conditions (Begum et al., 2022). While some invertebrate species are tolerant of types of pollution, others are less resilient to anthropogenic and habitat disturbance and pollution (Kushwaha et al., 2016).

Macroinvertebrate Community Indexes (MCI), which are derived by giving a "sensitivity score" to various taxa expected to be present at a particular site (Stark & Maxted, 2007), are vital tools for assessing relative stream health. Highly sensitive taxa include mayflies, stoneflies, and caddisflies. While a standalone MCI framework for the study area does not yet formally exist, we can use existing protocols developed for other areas within New Zealand. We used a guide from the Taranaki Regional Council (TRC, 2009) to assess stream health at Mt Grand Station. While not perfectly fine-tuned for our study area, we believe it gives a sufficient approximation of what one might expect in such a high-country habitat.

Mt Grand Station, located near Lake Hawea on the South Island of New Zealand, represents one such habitat. It currently supports high-country wool and beef operations, although, at lower elevations, agricultural intensification such as irrigation has occurred in neighboring areas (Provost, 2018). Previous research by Provost (2018) has investigated the stream quality at three of Mt Grand's water catchments: Cameron, Grandview, and Lagoon Creeks. During that study, the fourth catchment, Hospital Creek, was dry and, thus, not studied.

Conditions during the fieldwork for this report permitted us to sample this area as well. Due to resource and time restrictions, we were limited to sampling at Hospital and Lagoon Creeks only. However, the spatial and land-use differences between the two catchments allowed us to create different expectations and conclusions regarding the overall health of the station's sampled waterways.

We assessed the relative stream health of Hospital and Lagoon Creek, monitoring a total of six sites. Sites were defined either as *riffle* (faster-moving water) or *non-riffle* (pool), as few studies have focused on pooling zones of streams and rivers (Mermillod-Blondin et al., 2000). As habitats, these riffles and non-riffle could noticeably differ within the same stream (Angradi, 1996; Buss et al., 2003). We expected riffle areas of streams to have higher MCI values and invertebrate abundance than non-riffle areas (as seen in Brown & Brussock, 1991) due to faster-moving waters likely having a more gravelly substrate and, thus, more suitable habitat for larger invertebrates.

18.2: Materials and Methods

18.2.1: Sample collection

Sampling for aquatic invertebrates occurred on March 20 - 21, 2023, at Mount Grand Station, Central Otago, New Zealand (-44.65, 169.32). Three sites were sampled, one at Lagoon Creek (-44.663, 169.333) and two at Hospital Creek (-44.652, 169.326), with riffle and non-riffle samples being taken at each site for a total of six sampling points. Riffle sites were defined as faster-flowing water, while non-riffles were defined as slower-flowing or pooling water. It is well-established in the literature that riffle areas tend to support greater biodiversity (Brown & Brussock, 1991); we sought to try and measure biodiversity differences in macroinvertebrate communities while investigating the role stream type may play.

A kick net was inserted at the sample point while a team member stirred up rocks and sediment approximately 50 cm upstream for 10 seconds. The net was then lifted out of the water and emptied onto a clean, white observation tray, and the net was rinsed onto the tray with non-stream water. Samples were then quickly sifted through to remove large clumps of detritus, leaves or sticks that did not contain aquatic invertebrates. Any remaining aquatic invertebrates or small detritus were funneled into an airtight container containing 70% ethanol via sieve (1 mm). Exact geographic coordinates were taken with each sample, written on Rite in the Rain paper (JL DARLING LLC, USA) and preserved in the sample. Containers were stored in a dark, dry location for nine days until analysis.

18.2.2: Sample analysis

Samples were analyzed on March 29 - 30, 2023, at Lincoln University, Canterbury, New Zealand, using (S6D-CL Compact Digital Stereo Zoom Microscope 7x – 45x). Samples were individually assessed under the microscope on plastic weigh boats, working in a "snake-like" pattern from the top right and ending in the bottom left portion of the weigh boat. Identified invertebrates were removed from the weigh boat using tweezers and set into a transparent petri dish. After assessing the whole weigh boat, aquatic invertebrates on the petri dish were placed underneath the microscope for pictures. Pictures were taken using an iPhone XR (Apple; California, USA) and a Google Pixel 4a (Google; Mountain Valley, California, USA).

Aquatic invertebrates were then identified to either family or order level and life stage using confirmed iNaturalist submissions, the Critter Identification Card from the Greater Wellington Regional Council (GWRC), the Landcare Research: Data & Database website and A Photographic Guide to Freshwater Invertebrates of Taranaki's Rivers and Streams by the Taranaki Regional Council (TRC, 2009). After identification, invertebrates were given a sensitivity score according to the Critter Identification Card from the GWRC. This sensitivity score was used to calculate the Macroinvertebrate Community Health Index to assess approximate stream health at each site using the equation below. Identified non-aquatic invertebrates were not included in MCI scoring or considered in aquatic-species diversity counts.

Equation 1: Calculating MCI for stream health

$$\frac{(Add\ sensitivity\ score\ of\ types\ of\ aquatic\ invertebrates\ collected)}{(Number\ of\ different\ invertebrate\ types)} \times 20 = MCI$$

The MCI was used to assess relative stream health using the guidelines provided by the GWRC, as seen in Figure 18.1. A simple analysis using Microsoft Excel was done to visualize invertebrate distribution between sites and riffle versus non-riffle areas and understand the abundance of various aquatic invertebrates.

Stream health assessment using MCI

Excellent	>120
Good	>100 to 120
Average	80 to 100
Poor	<80

Figure 18.1: Macroinvertebrate Community Index assessment values from the Greater Wellington Regional Council

18.3: Results

Overall, 63% of the 257 invertebrates collected at the sites chosen from Mount Grand Station were found in the riffle areas. Conversely, only 37% of the total invertebrates were collected from non-riffle areas (Figure 18.2), meaning aquatic invertebrates were relatively more abundant in faster-moving waters. Thirteen different invertebrates were found in non-riffle sites and 12 at riffle sites. However, both riffle and non-riffle sites contained non-aquatic invertebrates (Figure 18.3). Eleven aquatic invertebrates were found in riffle areas and 10 in non-riffle areas.

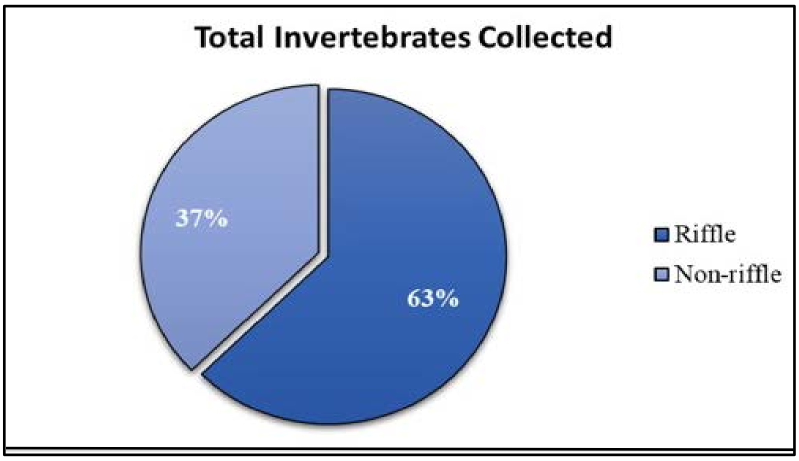

Figure 18.2: Percentage of total invertebrates collected from riffle and non-riffle sampling points in Hospital and Lagoon Creek, Mt Grand Station, Otago, NZ

Despite the relative similarity in the total number of types of invertebrates seen between the two types of sampling points, the types found in the riffle and non-riffle areas were not all the same (Figure 18.3). Riffle and non-riffle areas shared eight common aquatic invertebrates, such as Cased caddis flies, mayflies, stoneflies and beetles. However, they differed with some of the less-common invertebrates, seen only at select sites. Snails, along with snout mites and worms, were only seen at riffle sites. Dobson and crane flies were found in the non-riffle areas and non-aquatic species, such as spiders and insects of the order Lepidoptera.

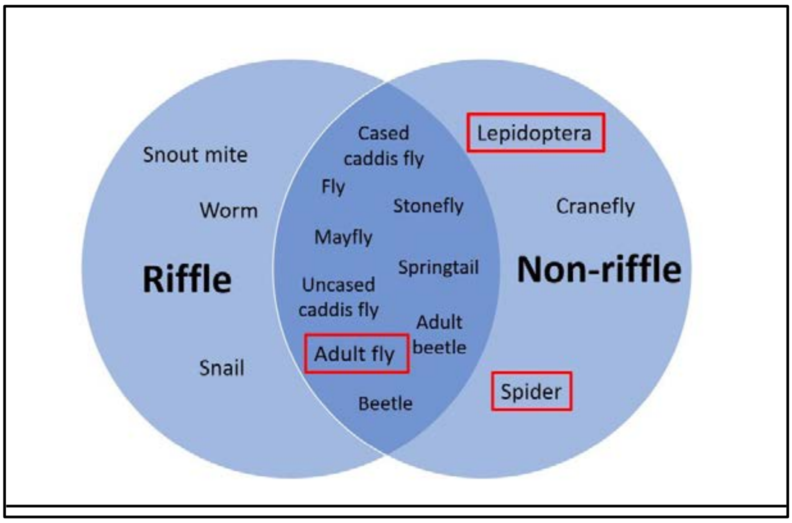

Figure 18.3: Diversity of orders/life stages found in riffle and non-riffle sampling points in Hospital and Lagoon Creek at Mt. Grand Station, Otago, NZ.
Invertebrates in red boxes indicate non-aquatic invertebrates

Overall, flies in larvae form were the most prolific aquatic invertebrate (69), with 70% (48) of flies being found in the non-riffle, slower-moving sites (Figure 18.4). Conversely, out of the 57 mayflies collected, 67% (38) were found in the faster-moving riffle sites. Snails were only seen at riffle sites, with 95% (38) coming from Sample Site #5. There was a mixture of cased and uncased caddis flies; however, the majority of both cased (82%) and uncased caddis flies (73%) were found in the riffle sites. The cranefly, dobson fly, adult beetle, snout mite, springtail and worm were seen less frequently, with < 4 observations during sampling.

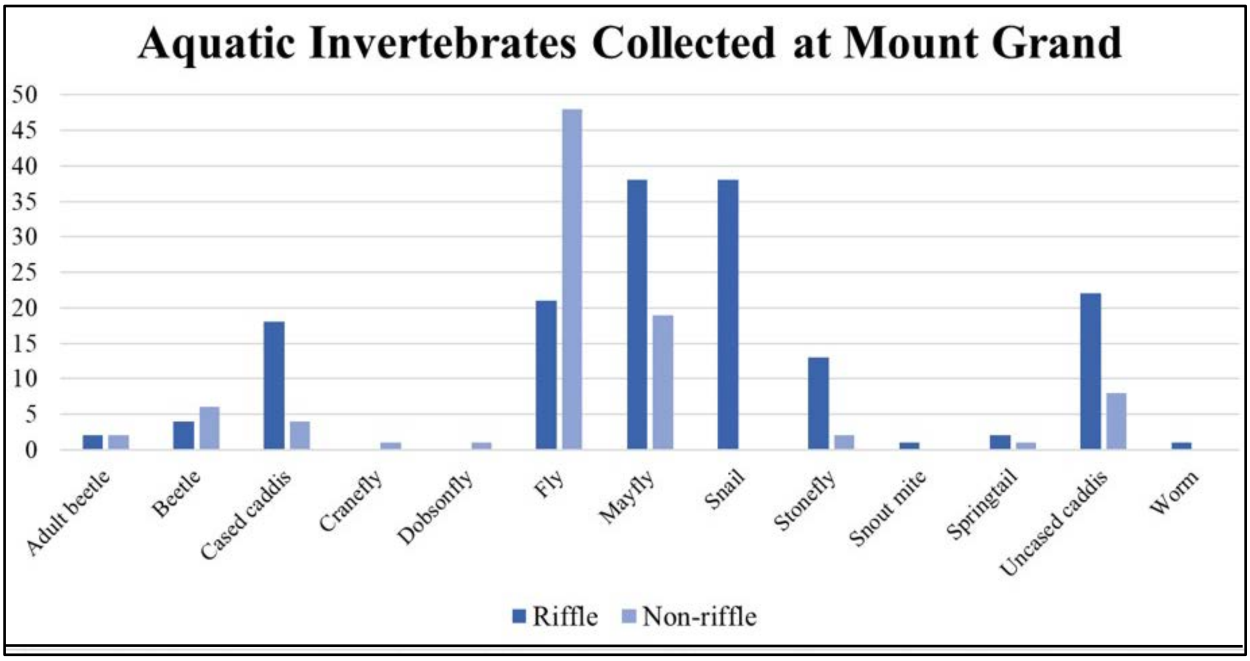

Figure 18.4: Abundance of species in riffle and non-riffle sampling points in Hospital and Lagoon Creek at Mt. Grand Station, Otago, NZ.
Flies were dominant in non-riffle sample areas whereas cased and uncased caddis flies, mayflies and snails dominated riffle sites.

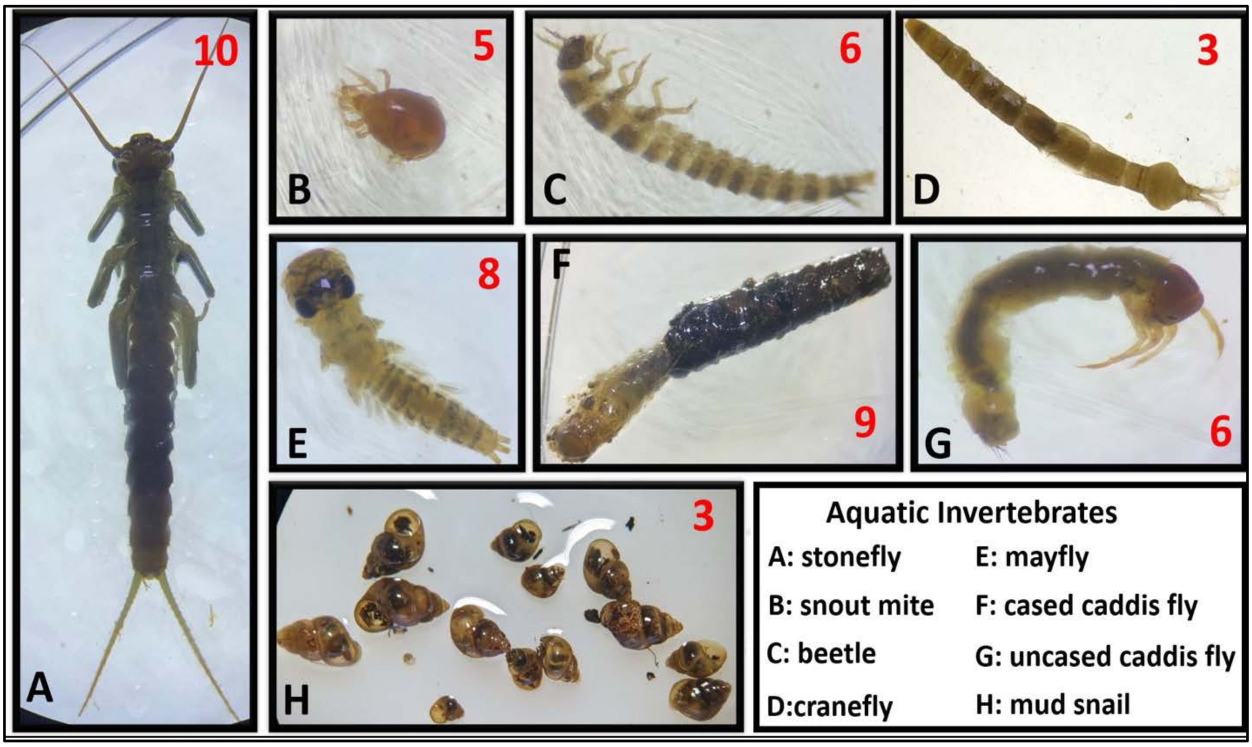

Figure 18.5: Samples of aquatic invertebrates collected from Hospital and Lagoon Creek at Mt. Grand Station, Otago, NZ.
Black letter indicates type of aquatic invertebrate and the number in red indicates the sensitivity value used to calculate the Macroinvertebrate Community Index (MCI) from the Greater Wellington Regional Council.

Out of the aquatic invertebrates collected, large stoneflies and cased caddisflies are the most sensitive to stream health based on their sensitivity scores (10 and 9, respectively) (Figure 18.5). Worms and flies were the least sensitive (1 and 2, respectively). Overall. The MCI of riffle sites averaged 109, indicating “good” stream health. Conversely, non-riffle sites averaged an MCI score of 99, falling into the “average” category. However, when the sites were categorized by both stream location and site condition (i.e., riffle versus non-riffle), Lagoon Creek had a larger disparity between the MCI of riffle (123) versus non-riffle (103) than the MCI of riffle (95) and non-riffle (95) sites in Hospital Creek (Table 18.1). Riffle sites in Lagoon Creek were considered “excellent,” and non-riffle sites were considered “good,” while both riffle and non-riffle sites were considered to be “average” for Hospital Creek.

Table 18.1: MCI calculated for riffle and non-riffle sites between Hospital and Lagoon Creek at Mt. Grand Station, Otago, NZ.

Average MCI		
Stream	**Riffle**	**Non-riffle**
Hospital Creek	94.65	94.55
Lagoon Creek	123	103
AVERAGE	108.83	98.78

Hospital Creek was sampled twice for riffle and non-riffle, while Lagoon Creek was sampled once for riffle and non-riffle.

18.4: Discussion

Overall stream biodiversity and health results came with both expected and unexpected outcomes. Regarding invertebrate diversity, riffle and non-riffle samplings generated a similar number of invertebrate types (Appendix I). However, the riffle sections contained more individual organisms and aquatic invertebrates than non-riffle sampling sites, also seen in Brown & Brussock, 1991. Notably, the overlap in species was high between the two water types, particularly when considering two indicator species: mayflies and caddisflies.
Snails and worms were only found in riffles, with 95% of snails being found in Lagoon Creek. At the same time, non-riffle sites contained more non-aquatic individuals, such as an adult fly (also seen in one riffle site), spider, and an unidentified member of the order Lepidoptera (e.g., moths and butterflies) (Appendix I). This finding is expected if we assume that the calmer waters more effectively “trap” anything that falls in than faster-moving riffles. Rather than being washed away, terrestrial invertebrates remain suspended in the slower-moving water. Snails often indicate lowered water quality (Stark & Maxted, 2007), and they – along with chironomid flies (midges) and worms – tend to dominate in soft-bottomed streams with higher sedimentation and enrichment levels. Lagoon Creek, to which cattle had unfettered access, was one such habitat.

While most of the snails and worms collected came from Lagoon Creek – an expected outcome – the somewhat puzzling finding was that the overall MCI of Lagoon Creek was higher than Hospital Creek, despite greater numbers of the low-scoring taxa. Water quality was visibly poorer in Lagoon Creek, with high levels of sedimentation from cattle fecal matter, especially when the bottom was stirred up for sampling. The sampled area was also extremely close to a crossing point for livestock; sheep and cattle were seen crossing < 5 meters from the sampling sites. Contrastingly, Hospital Creek was excluded from grazing and was surrounded by much rockier and brushier terrain, meaning the streams themselves were more secluded and protected. We, unfortunately, did not collect enough samples nor spend enough time in these areas to draw further conclusions. However, this finding presents interesting questions regarding the habitat preferences of indicator species, given their apparent success in a heavily trafficked area.

Among the indicator invertebrates specifically, we noted one key difference between riffle and non-riffle sites – the clear presence of a higher number of mayflies, stoneflies, and caddisflies in the faster water (Figure 18.4). This is what one would expect and thus indicates that the water flow and habitat play a vital role in supporting a variety of invertebrates even in the same stream (Buss et al., 2004). Any future agricultural developments that may impact streams – directly or indirectly – must be cognizant of this fact. Agricultural disturbance is known to produce numerous stressors on stream ecosystems, such as nutrient loading, sedimentation and changes to surrounding vegetation (Allan, 2004). However, most metrics consider concentrations of nutrients such as nitrogen and benthic sediment to affect the habitat conditions of aquatic invertebrates (Lange et al., 2014) and should be considered in future studies.

18.5: Conclusion

Moving forward, we recommend implementing a continuous monitoring program to track changes in stream health over a more extended period. Sporadic “spot-checks” of MCI and other health measuring methodologies are suitable for a snapshot of the current situation but do not permit a holistic and long-term understanding of the environment in relation to changing land usage and climatic factors (Lange et al., 2014). Unfortunately, these one-off inventories are all that has been done thus far.

As Hospital Creek has garnered very little research, more should be done to better understand the effects of grazing exclusion on aquatic invertebrate communities. Given the three major drainages available to study, a comparison can easily be made between the gullies and compared to the differing land-use strategies prevalent in each area. The upper reaches of each basin are critical to monitor, as these will always remain the less disturbed areas, ostensibly more suitable for macroinvertebrates to inhabit. Castro et al., 2018 also highlight that aquatic invertebrate diversity can change with altitude, offering another topic of investigation for the New Zealand high country.

Additionally, it would be extremely beneficial to monitor the chemical makeup of the stream. In addition to invertebrate community scores, one can also gain much insight by measuring nutrient loading levels, flow rates, substrate and several other measures of stream quality (Begum et al., 2022). Again, this should be done continuously, perhaps with automated systems, to allow researchers to track changes over time. This may even enable us to predict changes in the invertebrate community before they occur. For example, if a particular nutrient increases in concentration following weather events, we could infer community changes based on previous knowledge of the stream system and community assemblage. Overall, there were some encouraging signs in our limited-scope study. The health of each stream and water type was, at the very least, “average” on the MCI scale, with one stream exceeding that by a good margin. Many indicator species were present in all samples, revealing that overall stream health suffices to support these communities despite the impact of grazing and agriculture on the natural landscape. However, it is not a sign to rest on our laurels, and a proactive approach is needed to maintain and improve this status. Continuous review is the only real way to achieve this, and small studies like this only play a small role in the long-term management of fragile high-country ecosystems.

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18.7: Appendix

Sample	type	site	cased caddis	fly	large stonefly	mayfly	medium stonefly	small stonefly	snail	snout mite	springtail	uncased caddis	worm	adult beetle	beetle
1	riffle	HC	2	10	1	5	1	3	2	1	2	3	1	0	0
2	non-riffle	HC	0	22	1	4	1	0	0	0	1	5	0	1	5
3	non-riffle	HC	1	20	0	12	0	0	0	0	0	0	0	1	0
4	riffle	HC	3	11	3	24	0	0	0	0	0	11	0	2	2
5	riffle	LC	13	0	0	9	0	5	36	0	0	8	0	0	2
6	non-riffle	LC	3	6	0	3	0	0	0	0	0	3	0	0	1
	TOTAL		22	69	5	57	2	8	38	1	3	30	1	4	10
	riffle	18	21	4	38	1	8	38	1	2	22	1	2	4	0
	non-riffle	4	48	1	19	1	0	0	0	1	8	0	2	6	1

Figure 18.6: Raw data table of types of invertebrates: different orders and life-stage types determined by MCI values.
Type of water and site are defined in the top table, while invertebrate types are separated by water type in the bottom table

Sample 1 riffle, HC		
ID types	**Total score**	**MCI**
11	54	98.18181818
Sample 2 non-riffle, HC		
ID types	**Total score**	**MCI**
11	49	89.09090909
Sample 3 non-riffle, HC		
ID types	**Total score**	**MCI**
6	30	100
Sample 4 riffle, HC		
ID types	**Total score**	**MCI**
9	41	91.11111111
Sample 5 riffle, HC		
ID types	**Total score**	**MCI**
6	37	123.3333333
Sample 6 non-riffle, HC		
ID types	**Total score**	**MCI**
6	31	103.3333333

Figure 18.7:MCI values calculated for each site

Chapter 19: Lepidoptera species in Tussock Grassland Ecosystems: A Case Study at Mt. Grand

Ronja Haerdtner

Abstract

Lepidoptera, encompassing butterflies and moths, play critical ecological roles in various ecosystems worldwide, including pollination and bioindication. The conservation status of Lepidoptera in New Zealand highlights the need for protective measures due to the environmental challenges they face. Tussock grasslands, characterized by *Chionochloa* and *Festuca* species, provide important habitats for Lepidoptera, contributing to pollination and plant reproductive success. Understanding their habitat preferences and needs is essential for effective management and conservation. This report documents an inventory of Lepidoptera species on Mt. Grand, New Zealand. Monitoring of Lepidoptera populations can provide valuable insights into ecosystem dynamics and environmental shifts and therefore is recommended. The conservation of Lepidoptera in New Zealand's Tussock Grassland High Country ecosystems is crucial for maintaining ecological integrity and functioning.

Key words: Lepidoptera, Butterflies, Moths, Agriculture, Conservation, Tussock grassland

19.1: Introduction

Lepidoptera, comprising butterflies and moths, are a diverse group of insects with approximately 160,000 known species globally (Mitter et a. 2017). Lepidoptera provide essential ecosystem services such as pollination (Lebhuhn et al. 2013) and inhabit various terrestrial habitats worldwide. Their role as bioindicators makes them valuable for assessing environmental changes and the effectiveness of conservation measures (Gerlach et al. 2013). Threats such as habitat loss, invasive species, climate change, and pesticide use pose challenges to the long-term survival of Lepidoptera populations (Patrick, 2004). Conservation efforts should focus on addressing these threats and preserving the habitat quality required by Lepidoptera.

Tussock grasslands, characterized by extensive areas of tussock-forming grasses such as *Chionochloa* and *Festuca* species, are important ecosystems that uphold diverse native flora and fauna, including Lepidoptera (Mark et al., 2013). They serve as habitats for Lepidoptera species, which contribute to the pollination success and reproductive fitness of native plant communities (Buxton et al., 2018). While bees are commonly acknowledged as primary pollinators, moths have been identified as additional or alternative pollinators in New Zealand (Buxton et al., 2018).

The presence and abundance of Lepidoptera in tussock grasslands are influenced by various factors, including grazing intensity, the structure of vegetation cover, and habitat heterogeneity (Jerrentrup et al., 2014). Grazing regimes and land management practices should consider the habitat requirements of Lepidoptera to ensure the maintenance of healthy and diverse populations within these grassland ecosystems. Monitoring Lepidoptera populations and trends provides valuable insights into ecosystem dynamics and health. Changes in the abundance and diversity of moth species in tussock grasslands have been observed over several decades, indicating potential environmental shifts (White, 1991). Long-term monitoring can contribute to our understanding of the impacts of environmental changes on Lepidoptera populations and guide the implementation of effective conservation strategies.

19.2: Materials and Methods

To gain insights into the Lepidoptera fauna at Mt. Grand, two types of light traps were used: a 160W mercury vapor lamp with a trap box, deployed at the woolshed, and a blue light UV lamp placed at the bottom of the valley.

Additionally, 5-6 yellow pan traps, filled halfway with water and a 5drops of dishwashing detergent (to break the surface tension, were utilized to attract Lepidoptera specimens. The collected specimens were recorded using iNaturalist, and species identification was conducted if possible.

19.3: Results

A total of 156 Lepidoptera observations were recorded using iNaturalist, with 25 species identified to the species level. Among the identified species*, Ichneutica mutans* was the most frequently observed, with 16 recorded sightings. *Achyra affinitalis* and *Orocrambus vitellus* followed closely, each with 12 observations. The genus *Ichneutica* dominated the observations, with a total of 45 recorded sightings. Of those, 16 observations were *I. mutans* and 23 observations only identified on genus level.

Table 19.1: Identified species on iNaturalist found during the field course on Mt. Grand

Species name	Count
Achyra affinitalis	12
Asaphodes aegrota	1
Capua semiferana	1
Clepsis divulsana	2
Crocidosema plebejana	3
Epiphyas postvittana	2
Epyaxa rosearia	1
Eudonia leptalaea	1
Eudonia philerga	1
Eudonia sabulosella	1
Eudonia submarginalis	2
Helicoverpa armigera	4
Hygraula nitens	5
Ichneutica atristriga	2
Ichneutica lignana	1
Ichneutica mutans	16
Ichneutica propria	6
Orocrambus flexuosellus	1
Orocrambus ramosellus	7
Orocrambus vittellus	12
Phaeosaces apocrypta	1
Physetica phricias	2
Plutella xylostella	1
Pseudocoremia	1
Scopula rubraria	5

Table 19.2: Specimen which could only be identified on genus level on iNaturalist found during the field course on Mt. Grand

Genus name	Count
Agrotis sp.	1
Capua sp.	1
Crambidae sp.	1
Eudonia sp.	4
Gymnobathra sp.	1
Hepialidae sp.	1
Ichneutica sp.	23
Lepidoptera sp.	12
Metacrias sp.	1
Noctuidae sp.	2
Noctuinae sp.	1
Orocrambus sp.	9
Psychidae sp.	3
Pyraloidea sp.	1

Pyraustini sp.	1
Scoparia sp.	1
Zizina sp.	1

19.4: Conclusion

The results show presence and diversity of Lepidoptera species at Mt. Grand providing valuable insights into the local butterfly and moth fauna. Further, more standardized research is needed to assess population trends, densities and threats faced by these species.

In conclusion, Lepidoptera species play significant ecological roles in Tussock Grassland High Country ecosystems in New Zealand. Their contributions as pollinators, bioindicators, and biodiversity components underscore the importance of their conservation. Managing and conserving Lepidoptera populations in these unique grassland ecosystems is crucial for maintaining the ecological integrity and functioning of the high country environment.

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Chapter 20: Malaise Trap Surveying at Hāwea's Mt Grand

William Frost

Abstract

New Zealand is home to a diverse and abundant alpine fauna of insects. These insects have evolved numerous adaptations allowing them to thrive in harsh conditions. Despite the large diversity of this alpine insect fauna, they remain understudied. Due to the threat of climate change, mammalian predation, weeds, and human activities to their populations, more studies are required. This study provides the results of a malaise trap survey conducted at Mount Grand near Hāwea, New Zealand. The study aims to determine what effect habitat has on the diversity of insect orders, whether the most diverse insect orders were found in more pristine habitat types and which orders of winged invertebrates were most commonly collected. Malaise traps were used over three or two days to survey insect fauna across varying habitats and altitudes at Mount Grand. The survey results showed that habitat and the quality of the site vegetation did not significantly affect insect abundance. It also found that Diptera were collected in significantly higher abundance than other winged insect orders. While this survey had many constraints, it provides the steps for establishing a more robust and in-depth study in future.
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20.1: Introduction

New Zealand’s Southern Alps are one of the fastest-growing mountain zones in the world (Dennis., 2007). Little tectonic activity occurred for 85 million years following New Zealand’s separation from Gondwana (Dennis., 2007). The convergence and subduction of the Australian plate by the Pacific plate resulted in a substantial uplift beginning around 5 million years ago (Upton & Craw., 2009). Mesozoic metamorphic rock like greywacke quickly formed the series of mountains known as the Southern Alps (Upton & Craw., 2009). This mountain range now sits well over 3000 metres with an annual uplift of 8mm (Upton & Craw., 2009). Such a drastic change in geology has created a vast diversification of endemic plant fauna throughout these alpine zones.

The Southern Alps are home to 600 species of alpine plants that took advantage of a newly emergent mountain range (Heenan et al., 2013). Many of these species are evolutionarily young lineages formed at high altitudes over the past 5 million years (Heenan et al., 2013). The alpine zone of New Zealand, or areas above the treeline at 1500m, makes up 9% of New Zealand’s total land mass (Mark et al., 2021). Despite this, massive radiation of endemic flora has occurred with incredibly high levels of endemism (93%) (Mark et al., 2021). Among these species are various endemic genera, seemingly evolving within New Zealand over the past 5 million years (Mark et al., 2021). Such a large diversity of alpine plant fauna has provided a wide variety of available niches for many species of invertebrates.

New Zealand has an abundance of alpine insects due to the geographic isolation of the mountains and the hugely diverse fauna of alpine plants (Mark et al., 2021). Like alpine plants, there is high endemism in New Zealand’s alpine insect fauna (Buckley et al., 2022). Despite the alpine zone representing only 9% of New Zealand’s landmass, it contains around 40% of New Zealand’s insect species (Mark et al., 2021). These species have evolved various survival mechanisms to persist in harsh alpine conditions. Alpine insects are primarily diurnal species due to the extreme weather conditions they face at night (Mark et al., 2021). Many alpine insect species undergo only one generation annually as summer periods are short in the alpine zone (Mark et al., 2021). These insects have evolved to undergo a specialist diapause, allowing their eggs and larva to hibernate within the soil over winter (Mark et al., 2021). In the case of several species of Orthoptera and other groups, generation times may be up to 6 years. These individuals can freeze themselves over winter and survive up to 82% of their body water freezing (Mark et al., 2021).

Despite its diversity, unique traits, and features, New Zealand’s alpine fauna is substantially understudied (Buckley et al., 2022). There is a particular lack of knowledge of the taxonomy of alpine insects, with more new species discovered frequently (Buckley et al., 2022). Due to geographic isolation, many previously winged insect lineages have lost their flight dispersal mechanisms (Mark et al., 2021). Examples include the Acrididae grasshopper family and the Zelandoperla genus of stoneflies (Mark et al., 2021). For this reason, most existing studies use standard methods like pitfall trapping and hand collection to gather specimens for analysis. Little focus has been given to alternative methods like Malaise traps which are a reliable indicator for populations of Hymenoptera and Diptera (Sweeney., 1980). Despite their reliability, studies of alpine insects using malaise traps in New Zealand’s alpine environments are rare. Historically studies have focused on traditional terrestrial methods and light trapping for moths. However, many of New Zealand’s alpine fauna are diurnal (Mark et al., 2021), and light trapping may not be an effective means of capture. An alternative method for winged insect sampling, like malaise traps, may be better for winged insect orders. More studies are needed to determine the effectiveness of malaise traps for studying winged alpine invertebrates.

More studies are required to help bridge the knowledge gap for New Zealand alpine fauna (Buckley et al., 2022). With few published studies and a lack of taxonomic understanding (Buckley et al., 2022), more focus must be placed on New Zealand's alpine insects. A significant threat is placed upon New Zealand's alpine insects by land loss due to climate change and development (Chinn & Chinn., 2019). Global warming is expected to reduce many New Zealand Acridid grasshoppers' possible distributions and fundamental niches (Koot et al., 2022). A rising snowline caused by climate change is expected to cause similar population shifts for numerous critical families of alpine insects (Chinn & Chinn., 2019). This places populations of alpine insects at a substantial risk due to a lack of resources (Koot et al., 2022) and possible land use changes for high-country farming and tourism. With rising temperatures, the range of introduced mammalian predators is also expected to increase (Walker et al., 2019). This will result in reduced ranges of available habitat for alpine insects at high altitudes, with a lack of quality habitat at lower altitudes due to mammalian predation, high temperatures and land use changes.

Here we describe the findings of a Lincoln University study for the ECOL 609 field course at Hāwea's Mount Grand—a high-country farm in New Zealand's South Island, which contains intact alpine habitat. Specifically, the following questions were investigated.

1. What effect did habitat type have on the diversity of insect orders?
2. Is the greatest diversity of insect orders found in more pristine alpine habitats?
3. Will winged invertebrates like Hymenoptera, Lepidoptera, and Diptera be the most abundant?

20.2: Methods

20.2.1: Study area:

Figure 20.1: Google Maps showing the Mount Grand area within the South Island of New Zealand

This study was conducted at Mount Grand, New Zealand, a High-Ccountry sheep station owned by Lincoln University. The station is located within 5km of the adjacent town Hāwea, within New Zealand's Otago Lake district (44°30'S 169°17'E) (Land Information New Zealand [LINZ]., 2006). At its lowest altitudinal point, Mt Grand is located 420m above sea level with a maximum altitude of 1445m above sea level (LINZ., 2006). Mt Grand comprises 1971 hectares (ha) of a pastoral lease with an adjacent 162-ha freehold (LINZ., 2006). Historically much of this site has been used for high-country merino sheep farming. Grazing occurred across most of the site until the Department of Conservation claimed two sites under the 1997 Conservation Act. These sites comprise a 20.3-ha Lagoon Creek Scientific Reserve and a 0.15-ha Hospital Creek Reserve (LINZ., 2006).

Mt Grand station is located within the Southern Alps, where orographic rainfall is prominent (Henderson & Thompson, 1999). This results in high average rainfall levels, which fall between 690mm per year at lower altitudes and up to 1500mm a year within the alpine zone (LINZ., 2006). On average, the summer temperature of the area is relatively high at lower altitudes of the station. Winters are freezing, with harsh frosts and snowfall at the higher altitudes of the property (LINZ., 2006). The surrounding area has a high tectonic activity level creating a parent rock comprised mainly of metamorphic greywacke (LINZ., 2006). The soil types across the site have been previously mapped as Gladbrook along 75 ha of the flats, combined with Arrow soils (800 ha) and Dunstan on the mountains (1100 ha) (LINZ., 2006).

These valleys and mountains are comprised of many plant species. In the lowland areas, grazed pasture is surrounded by regenerative Kanuka patches (*Kunzea ericoides*) (LINZ., 2006). Kanuka continues up the Hospital Creek hillside into a mixed regenerative area comprised of exotic species like *Buddleja davidii* and many native species like Cabbage tree (*Cordyline australis*), Lowland tutu (*Coriaria sarmentosa*) and, in small patches, *Olearia fimbriata* (LINZ., 2006). Further up the hillside is an abundance of *Chionochloa spp,* interjected by smaller alpine species like *Carmichaelia vexillata* and *Dracophyllum spp* (LINZ., 2006). Throughout all these habitat types, there is an abundance of Hawkweed (*Pilosella sp*) (LINZ., 2006), a noxious weed that outcompetes and displaces many native plant species.

Native plant interactions are vital for alpine insects, which are often highly specific to one host species (Mark et al., 2021). Areas with diverse alpine flora will also commonly have an abundance of diverse insect fauna (Mark et al., 2021). However, the highest abundances of alpine insects are expected to be found at higher altitudes in more pristine habitat types. A greater diversity of alpine plants will likely encourage a higher diversity of alpine insects specific to that flora.

20.2.2: Experimental design:

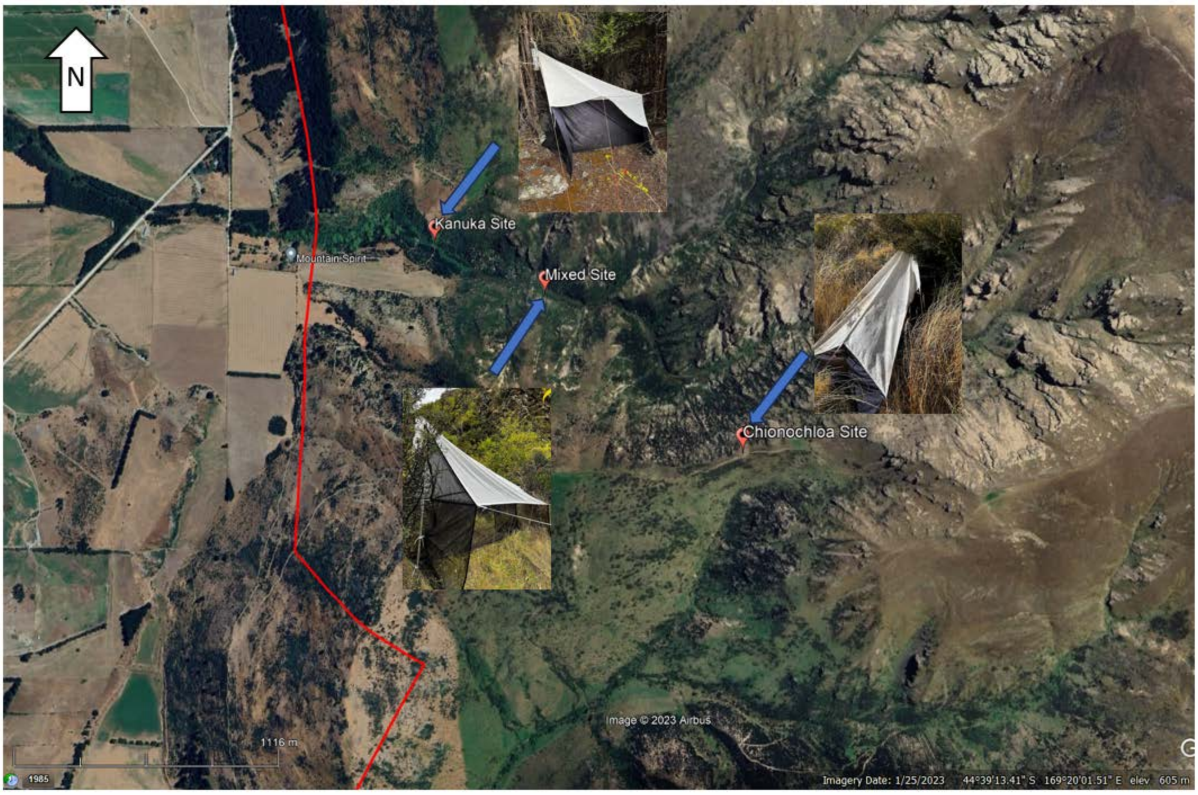

Figure 20.2: Google Maps showing the three site locations within Mount Grand

Data collection was conducted from the 19th to the 21st of March 2023 while on a Lincoln University field trip for ECOL 609 Conservation Biology. Due to equipment and time constraints, only three malaise traps were established. One in a pristine *Chionochloa* tussock land (44°64'S 169°34'E), a second in regenerative Kanuka (44°65'S 169°32'E) and a third in mixed regenerative (44°65'S 169°32'E).

On the first day of March 19, only one trap was established within the regenerative Kanuka site due to time constraints caused by a late arrival. On the second day of March 21, both *Chionochloa* and mixed regenerative sites were established in the early morning. This meant the Kanuka site was set for three days, and the other two were only for two days. All traps were set with 50ml of mono propylene-glycol, a preservative solution to trap and kill insects. On the 21st of March, all three traps were collected, and glycol specimens were poured into small plastic pottles for storage.

Upon return to Lincoln University, specimens were strained and placed into a solution of 90% ethanol for better preservation. Each insect was identified to order level via a stereo microscope and returned to the ethanol solution.

20.2.3: Data analysis:

Insect data were collated onto a Microsoft Excel version 2302. This data was converted into bar graphs to represent the dataset visually. Data from Excel was also analysed using the data analysis extension package. An ANOVA function was then run to display the graphed results, measuring the effects to provide a significant value between sites.

20.3: Results

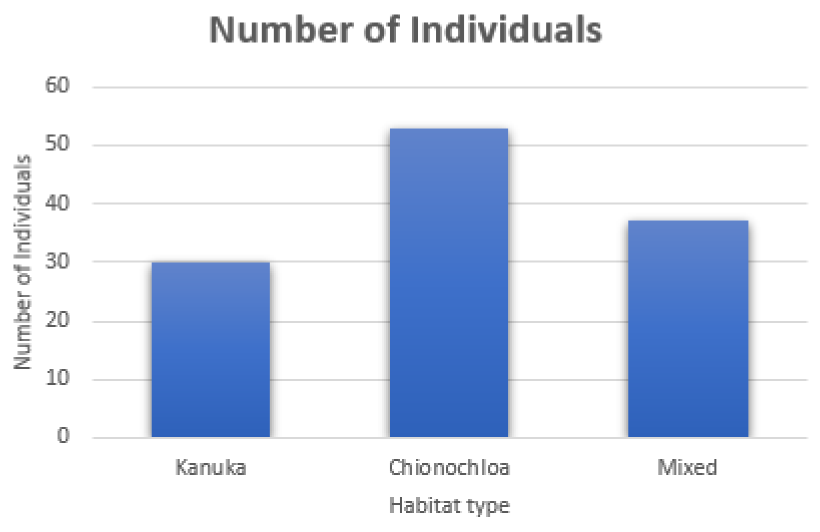

Figure 20.3:Difference in total individuals across the three vegetation types.

Results found that across the three vegetation types, *Chionochloa* had the most considerable diversity of orders (6 Insect orders). *Chionochloa* also had the highest abundance of insects, with 65 individuals total across the sampling period (Figure 20.3). The mixed regenerative site had the second most diverse range of orders with five orders. However, the insects' abundance was less than *Chionochloa*, with 37 individuals (Figure 20.3). Finally, the Kanuka site had the lowest diversity of orders, with four different orders and the lowest abundance of individuals at 29 (Figure 20.3). These results suggest that *Chionochloa* had the highest order diversity and abundance; however, a single factor ANOVA found that the variation between habitat abundance was insignificant (P=0.613). Suggesting that there was less of a marked difference between habitat types than first expected.

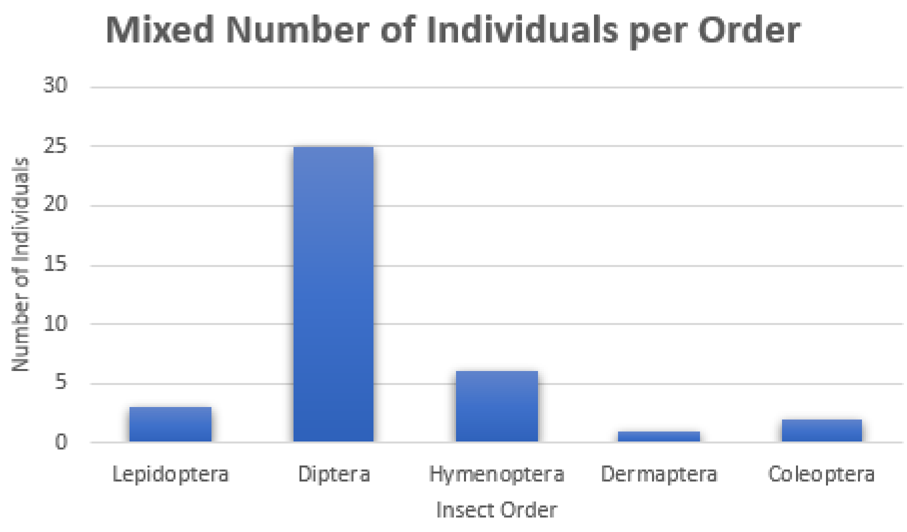

Figure 20.4:Abundance of insects in different orders within the mixed vegetation habitat type.

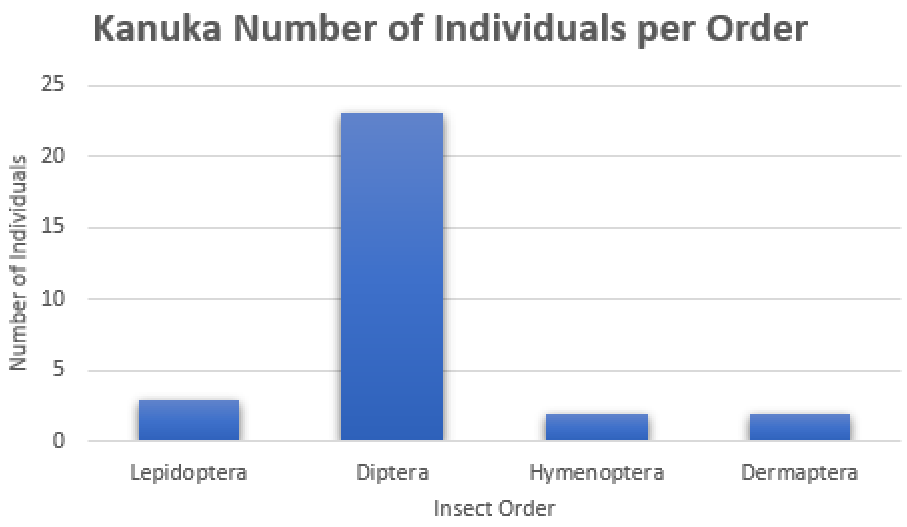

Figure 20.5: Abundance of insects in different orders within the Kanuka habitat type.

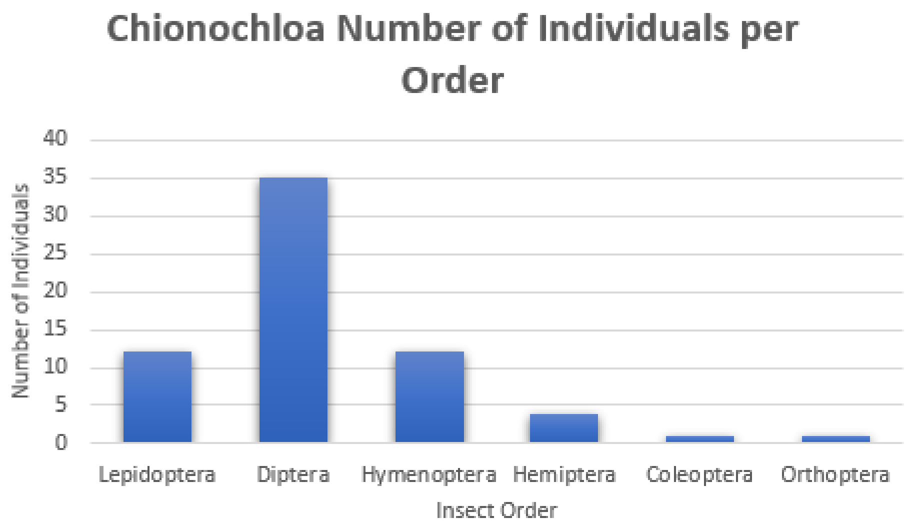

Figure 20.6: Abundance of insects in different orders within the Chionochloa tussock grassland habitat type.

There was, however, a significant difference between different orders within sites. The analysis found that across all sites, there was a significantly greater abundance of insects within the order Diptera compared to other orders (P<0.000) (Figure 20.4), (Figure 20.5), (Figure 20.6). *Chionochloa* had more Lepidoptera and Hymenoptera than the Kanuka and Mixed vegetation types. It also had one order (Hemiptera) not seen in malaise samples from mixed or Kanuka vegetation. However, it lacked an order found in the two other habitat types (Dermaptera). Mixed vegetation and Kanuka malaise samples both had significantly more dipterans than other orders (P<0.000) (Figure 20.4) (Figure 20.5); however, both sites had low levels of other insect orders.

20.4: Discussion:

So, did habitat type have a notable effect on the diversity of insect orders and was this effect linked to the habitat quality? Results showed that the *Chionochloa* habitat type had the most extensive diversity of orders compared to the other two habitat types. However, this was not a significant finding. Of the three habitat types, the *Chionochloa* habitat is arguably the most pristine/ intact native environment as it is a plant group known to have higher levels of endemism in New Zealand (Pirie et al., 2010). However, this habitat type did not contain significantly more insect orders than regenerative Kanuka and mixed vegetation types. Previous studies using pitfall methods have found that lower-quality exotic and regenerating habitats can still provide an available niche for numerous species of carabid beetles (Berndt & Brockerhoff., 2019). Due to a lack of disturbance adaptations and high habitat specificity, several carabid species still require pristine natural habitats (Berndt & Brockerhoff., 2019). However, a species-rich carabid assemblage can still be found in modified habitat types (Berndt & Brockerhoff., 2019). This may suggest that the abundance of winged insects may not vary as substantially between habitats as initially expected. Winged insects can disperse much easier and faster than terrestrials (Koot et al., 2022). This suggests that if a high-quality source population of winged insects exists in the higher altitudes of Mount Grand, they may be able to redisperse to lower altitudes as the habitat regenerates. Many New Zealand alpine pollinators have been shown to generalise across many alpine flowering plants without discrimination (McGimpsey & Lord, 2015). This implies that if patches of flowering alpine species or even other flowering plants existed in other habitat types, then winged pollinators could easily redisperse. Therefore, some winged insect orders may be common across habitat types due to their ability to generalise and disperse.

Among the three habitat types, the most common insect order was Diptera by a significant margin. Malaise traps are an excellent unbiased indicator for many groups of Dipterans, Hymenopterans and Lepidopterans (Sweeney., 1980). A study in Baihua mountain reserve near Beijing, China, found that malaise traps were an excellent comprehensive insect community monitoring method for surveying Tachinid fly groups (Wenya et al., 2021). Finding a high richness and diversity of flies sorted into 144 species in 85 genera suggested further malaise studies should be implemented to assess the diversity of China's tachinid flies (Wenya et al., 2021). A second malaise trap study on Asilid flies found an 85% species richness in an Illinois prairie habitat (McCravy., 2017). Further proving the effectiveness of this method for surveying fly richness. While reliable for many other insect orders, the large black shape formed by a malaise trap is believed to provide an excellent visual lure for many dipterans (Krčmar., 2021). Alpine environments present different challenges, however, due to the hostility of the weather conditions. Despite this, malaise traps can reliably perform in high wind conditions at New Zealand's Mount Cook National Park (Sweeney., 1980). This study in Mount Cook collected a vast diversity and abundance of dipterans and other orders. This suggests that while this method favours Diptera, it is also helpful for unbiasedly surveying other winged insect groups like Lepidoptera and Hymenoptera (Sweeney., 1980). These findings suggest that the significantly higher abundance of Diptera within all three habitats samples may be accredited to the effectiveness of malaise traps as an unbiased monitoring method. Diptera also has large populations due to shorter generation times and high fecundity, which may also explain the high presence of this order among malaise samples.

Due to the lack of malaise sampling in New Zealand, there are few studies to compare these results. Malaise trapping within an alpine zone is even rarer due to the challenges of setting up a trap that will not be blown away or affected by the weather. The only other published work is a master's thesis from 1980 that found high levels of Diptera and other insect orders (Sweeney., 1980). Comparatively, this study only found a high abundance of Diptera and a relatively poor abundance of other orders (Sweeney., 1980). Another unpublished study for the Department of Conservation's Tu te Raniwhanoa dryland invertebrate study based in the Mackenzie district of New Zealand used malaise traps. The results of this survey have not yet been published. However, this study also found abundant Diptera in malaise samples.

Due to several issues with this study, the reliability of the findings of the results is likely very low. The quality of the malaise traps used was very variable. The trap used in the mixed vegetation habitat type was much newer and attached to a pole. The other two malaise traps were much older and needed to be tied to kanuka trees. This may have affected the quality of the results as they could only be placed in secluded places next to trees. It is also possible that the fauna of those trees may have crept into the malaise affecting the quality of the results. Another substantial issue was the lack of time which the traps were set for. Ideally, a malaise survey should be conducted from seven days to upwards of several weeks. The malaise traps used for this survey were only set for three days and a minimum of two days, limiting the number of insects caught. Further issues with the study included the weather, as it rained for the second and third days. It was also freezing, which likely affected the number of insects flying throughout the habitat types. The survey was also conducted in late March, which is slightly later in the insect season for New Zealand. Many insects may have already been dormant or in smaller abundance compared to the peak of summer. Finally, the number of malaise traps used and the number of habitat types accessed was far lower than ideal due to a lack of traps, time constraints and weather conditions. A more comprehensive study implementing more traps across more habitat types may find a greater diversity of alpine insects. Providing a more robust study with more significant results.

There is a significant opportunity for future studies using malaise traps in alpine zones. Such a small amount is known about New Zealand's insect fauna, especially the fauna found within our often-inaccessible alpine zones. More malaise studies should be done to analyse the alpine fauna of Diptera, Hymenoptera and Lepidoptera. Without these studies, many parts of our alpine fauna may remain understudied. It is also essential to begin sampling the abundance of these species to determine what effect climate change and increased predation may have on our alpine insect species in future.

20.5: Acknowledgements

Many thanks to Dr Nicholas Dickinson as the course examiner to ECOL 609, for providing the opportunity to run a field study at Mt Grand. Thanks also to Mike Bowie and Samantha Fitzgerald for their help and assistance in setting up two malaise traps for this study. Thanks also go to Dr James Ross and Dr Tom Maxwell for their assistance in providing transportation to collect malaise traps.

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Chapter 21: Finding of an Undescribed Onychophora (Peripatus/Velvet worm) Species on Mt. Grand

Ronja Haerdtner

Abstract

Onychophora, commonly known as velvet worms, are a distinct phylum often considered the sister taxon to Arthropoda. This report documents the discovery of a rare Onychophora specimen on Mount Grand in New Zealand, a location outside the known range of the described onychophora species in New Zealand. The specimen exhibits pale coloration with characteristic blue lines and possesses 15 pairs of legs, suggesting its affiliation with the genus Peripatoides. Genetic analysis is necessary for precise identification and to determine if it represents a new species. New Zealand's Onychophora fauna is poorly studied, with only nine described species out of an estimated 30. Insufficient knowledge poses a major threat to their conservation. The specimen's discovery highlights the need for increased research and understanding of New Zealand's velvet worms, similar to studies conducted on related taxa. Further investigation, including genetic and phylogenetic analyses, is crucial for clarifying the taxonomy and conservation status of New Zealand's Onychophora.

Key words: Onychophora, Velvet worm, Peripatus, Conservation, New species, New Zealand

21.1: Introduction

Onychophora, commonly known as velvet worms, are not insects. The phylum is currently most often placed as the sister taxon to Arthropoda (Figure 21.1, Telford et al. 2015). Their difference to Arthropoda is obvious with their soft body without an exoskeleton, unjointed limbs (“lobopods”), and not-segmented body (Budd 2001). It is widely agreed on that Onychophora are united with Tardigrada and Arthropoda in the clade Panarthropoda (Nielsen 2012), but the exact relationship of these three panarthropod groups is discussed controversially (Mayer & Whitington 2009).

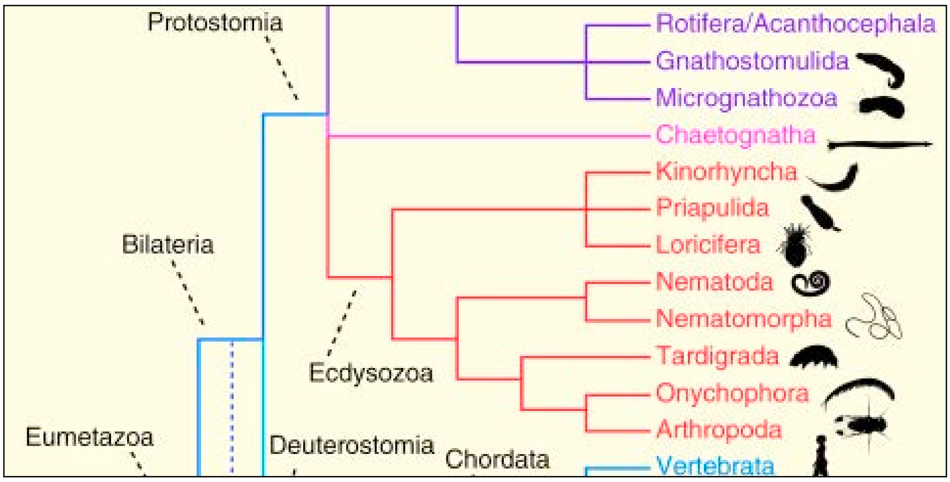

Figure 21.1: Phylogenetic position of Modified after Telford et al. 2015

Globally, 210 valid species of the phylum Onychophora, have been described (Oliveira et al. 2012). They can be divided into two main groups known as Peripatidae and Peripatopsidae (Allwood et al 2010, Oliveira et al. 2012). These two groups probably diverged prior to the separation of Gondwana more than 175 million years ago (Allwood et al. 2010). While Peripatidae show an equatorial distribution (Figure 21.2, Oliveira et al. 2012), the Peripatopsidae live in the southern hemisphere and is the family which can be found in New Zealand (Figure 21.2, Allwood et al. 2010). Although there might be around 30 present (DOC 2023), there are currently only nine Onychophora species described in New Zealand, divided into two genera (Trewick et al. 2018). Seven of those are assigned to the ovoviviparous genus *Peripatoides, and two to the* oviparous *Ooperipatellas* (Trewick et al. 2018).

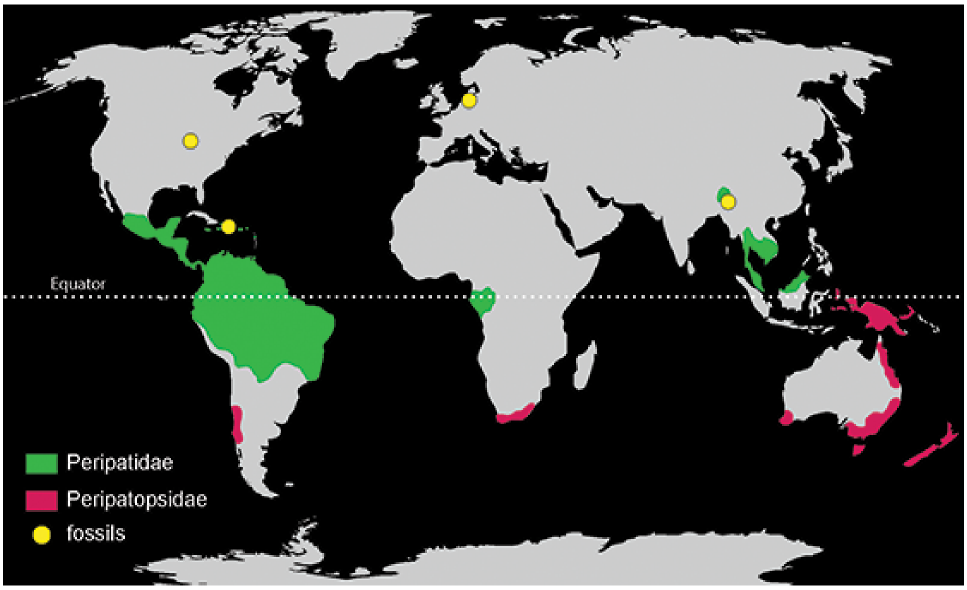

Figure 21.2: Global distribution of Onychophora (Oliveira et. al 2023).

All known species of Onychophora in New Zealand are endemic. On the South Island, Ooperipatellus occur west of the main divide, the Southern Alps, but at least two undescribed species of Peripatoides are present in the east near Dunedin (Trewick 1998, 1999). Onychophora are found mostly in forested parts of New Zealand, but also in remnant patches, scrubs and sometimes gardens. Occasionally they have been found in pasture, alpine and city park sites (Massey University 2021).

New Zealand's species have either 13 or 14, (Genus Ooperipatellus) 15 or 16 (Genus Peripatoides) leg pairs. The number of legs can be used for identification (Massey University 2021).

In New Zealand, velvet worms are often referred to as "peripatus" which is problematic as a common name, because it is also a genus name of species that occur only in the neotropics, but not in Australasia (Massey University 2021).

21.2: Materials and Methods

During the fieldtrip I constantly have been turning around stones next to the path, wherever we went. This meticulous examination yielded a noteworthy discovery: Besides many skinks, geckos and interesting spiders, I excitingly found an Onychophora specimen. This is especially interesting because Mount Grand, the location of the discovery, lies beyond the documented distribution range of Onychophora in New Zealand. Moreover, the presence of an Onychophora specimen in sheep-grazed farmland adds further intrigue, as this habitat type is not commonly associated with Onychophora occurrences. The specimen was specifically encountered beneath a middle-sized stone, situated within alpine sheep-grazed farmland at an elevation of approximately 1022 meters. The precise geographical coordinates of the discovery site are recorded as 44°40'01.6"S 169°21'13.9"E.

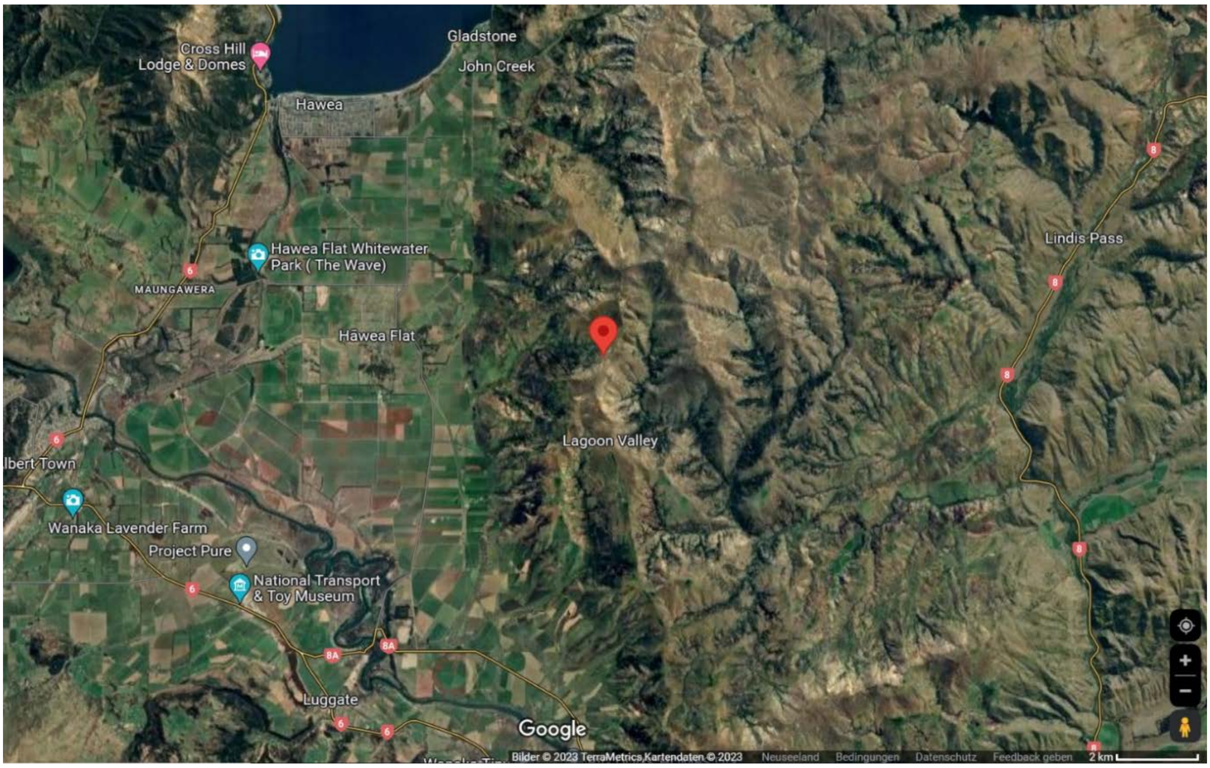

Figure 21.3: Location of Onychophora specimen found during the field course for ECOL609 in the wider landscape.

Figure 21.4: Location of Onychophora specimen found during the field course for ECOL609 on Mt. Grand.

Upon collection, the specimen was placed in a glass vial to ensure its preservation. Prior to the vial being filled with ethanol, photographs of the live specimen were taken using a smartphone, allowing for initial documentation of its morphological characteristics (Figure 21.8). Subsequently, the specimen was stored in a refrigerator to maintain its structural integrity until higher-resolution images could be obtained under a microscope. In line with advancing the investigation, the specimen was then sent to Prof. S. Trewick for genetic analysis and sequencing. This crucial step aims to unravel the specimen's genetic makeup and will provide insights into its taxonomic classification, shedding light on its evolutionary relationships and potential identification as a new species.

21.3: Results

Specimen discription

The found specimen is a pale Onychophroa with light dots, three blue dorsal lines down the length of the body and one blue ventral line on the base of each leg. The head was smashed in the collection process and can therefore not be described anymore, but one can clearly count 15 pairs of legs. The individuum is approximately 6,5mm long, including the head.

Figure 21.5: Ventral view of the found Onychophora with 1mm scale. One can clearly count the 15 pairs of legs and see the blue ventral lines on the base of the legs.

Figure 21.6:Dorsal view of the found Onychophora. Clearly visible are the 3 dorsal blue lines.


Figure 21.7: Dorsal close up of the found Onychophora.


Figure 21.8: Onychophora specimen as it was found, before it was put in ethanol. The picture shows the original pale colour with white dots.

21.4: Discussion

The blueish colour, the lines down the length of the body, the “dotty” pattern and especially the 15 pairs of legs strongly indicate that the found Onychophora belongs to the genus Peripatoides. It is very unusual for an adult Peripatoides to be this pale. Related genera in Australia are known to be much paler as juveniles than as adults and show similar colours to the greyish-blue of the found individual, so I am suspecting it probably is a subadult. The specimen has been sent to Prof. Steve Trewick at Massey University in hope to confirm which genus it is. Due to the high morphological similarities between species, it will be hard to tell what species it belongs to until it is placed in a densely sampled phylogeny. Based on the locality, outside of the known range of Peripatoides (Figure 21.9), it is highly likely that the found Onychophora belongs to an undescribed, or even not yet documented new species.

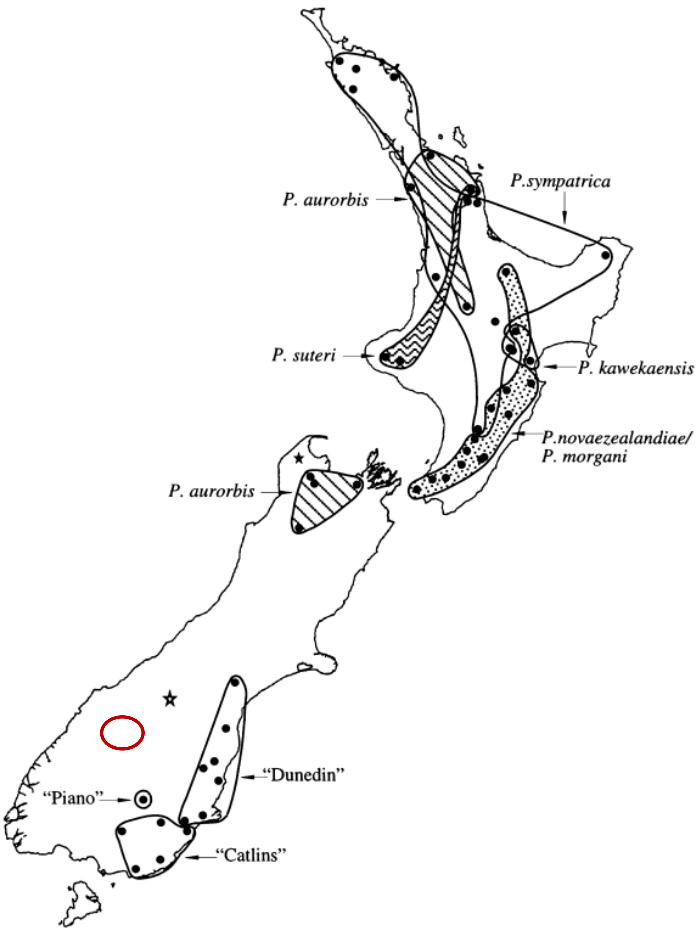

Figure 21.9: Approximate geographical ranges of Peripatoides taxa, based on phylogenetic analysis of mtDNA COI sequence data by Trewick (2000) with the approximate location of Mt. Grand, where the specimen was found during the field course, indicated in red. Modified by Trewick (2000).

New Zealand’s Onychophora are highly understudied. According to the Department of Conservation, New Zealand is likely to have around 30 species of velvet worms (DOC 2023), but only 9 of them are described scientifically so far, of which three have already been classified as “At Risk” because they are naturally uncommon (Trewick et al. 2018). The Department of Conservation lists “Insufficient knowledge” as one of the three major threats to Onychophora in New Zealand. The few existing New Zealand specific scientific publications about Onychophora are from the late 1990s/early 2000s. Oliveira, Read and Mayer’s world checklist of Onychophora from 2012 concludes that both genera present in New Zealand require more research (Oliveira et al. 2012). More studies like, for example, done for the closest relatives to the New Zealand, the Tasmanian viviparous velvet worms are needed for New Zealands velvet worms.

21.5: Conclusion

In conclusion, New Zealand is one of the few temperate areas in the world where velvet worms occur. Unfortunately, New Zealand's Onychophora are highly understudied, which is referred to as a major threat by the Department of Conservation. We were very lucky to find such a rare and cryptic animal during our field course at Mt. Grand. Based on its morphology and range I suspect the individuum is a juvenile of a new species of the genus Peripatoides, but we hope to achieve more clarity through the genetical analysis by Prof. Trewick at Massey University.
The fortuitous discovery of such a rare taxon during our field course on Mount Grand underscores the importance of continued research efforts in this area. To address the significant knowledge gaps surrounding New Zealand's velvet worms, enhanced and comprehensive research efforts are crucial. Such endeavours are vital not only for accurate taxonomic classification but also for effective conservation strategies and the preservation of this unique and ecologically important group of organisms.

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Chapter 22: Inventory of Small Invasive Mammals at Mt Grand Station

Antonia Ulle

Abstract

Introduced invasive mammals have had disastrous impacts on New Zealand's indigenous fauna and flora. They alter native ecosystems and have been implicated in the extinction of several native species. Managing and controlling these pests requires a good understanding of their distribution and behaviour and intensive monitoring of their populations is needed to guarantee effective pest control. This study aims to produce an inventory of small invasive mammals at Mt Grand Station, a high country sheep run on New Zealand's South Island in a landscape shaped and influenced by pastoral farming. Small mammal presence was recorded at Mt Grand over of two days using monitoring devices (tracking tunnels, wax tags, trail cameras) and field observations. Six species of small invasive mammals were detected: Brushtail possums (*Trichosurus vulpecula*), European hedgehogs (*Erinaceus europaeus*), House mice (*Mus musculus*), European rabbits (*Oryctolagus cuniculus*), cats and rats. The results from this study enhance our understanding of the distribution of small invasive mammals in New Zealand's pastoral high country habitats. This knowledge forms the base for further research on the ecology and habitat use of small invasive mammals in high country pastoral landscapes. Additionally, it may inform conservation efforts that aim to enhance the native biodiversity of these agroecosystems.

Key words: Small invasive mammals, Monitoring, Pest management, High country, Pastoral landscapes, Biodiversity conservation

22.1: Introduction

Invasive species are one of the greatest threats to biodiversity worldwide (Clavero & García-Berthou, 2005; Pimentel et al., 2005). In New Zealand, where native biodiversity has evolved in the absence of terrestrial mammals, introduced mammals pose a significant threat to fauna and flora and have pushed many native species to the brink of extinction (Department of Conservation, 2020a). Over 50 species of mammals have been introduced to New Zealand since the arrival of humans (Veblen & Stewart, 1982), and several invasive mammalian predators and herbivores now persist in various habitats throughout New Zealand. These species prey on native animals, compete with them for food and habitat, carry diseases, and alter ecosystems and species dynamics (Clout, 2006; Craig et al., 2000; Empson & Miskelly, 1999; Macinnis-Ng et al., 2021) and are therefore considered major conservation pests.

In New Zealand's high country, a landscape that has undergone significant changes following the intensive development of pastoral farming, rabbits have traditionally been considered a major pest because they significantly modify the open country and thereby cause economic damage to pastoral farming systems (Norbury & Duckworth, 2021; Peden, 2007). However, rabbits are not the only invasive species in New Zealand's high country. In fact, the entire suite of small invasive mammals present in New Zealand can be found throughout various high country habitats. Ferrets (*Mustela furo*), weasels (*M. nivalis*) and stoats (*M. erminea*) that were released for rabbit control (McIntyre, 2007) are still present in lowland pastures, scrubland and tussock grasslands (Foster, Maloney, Seddon, et al., 2021). Stoats even occur at high altitudes in the alpine zone. Hedgehogs (*Erinaceus europaeus*) and feral cats (*Felis catus*) are abundant in lowland habitats and braided river systems where they prey on the nests of endangered birds (Jones & Norbury, 2006; Norbury & Heyward, 2008; Sanders & Maloney, 2002). Ship rats (*Rattus rattus*) and house mice (*Mus musculus*) are considered significant predators of native wildlife like birds, reptiles and invertebrates in pastures, cropland, shrubland and forests (Innes & Russell, 2021; King et al., 2011; Murphy & Nathan, 2021). Possums (*Trichosurus vulpecula*) live in indigenous forests, tussock grasslands, and indigenous and introduced grasslands, where they alter vegetation structure through selective browsing and prey on native animals (Clout, 2006; Cowan & Glen, 2021).

Managing these invasive mammals to reduce the pressures they exert on native species and ecosystems is a cornerstone of New Zealand's Biodiversity Strategy (Department of Conservation, 2020b). Because the effective management of invasive mammals requires a sound understanding of their distribution and behaviour, intensive monitoring of pest mammal populations is an essential precursor to any control operation.
The aim of this project is to monitor small invasive mammals at Mt Grand Station, a high country sheep run in the Queenstown Lakes district of New Zealand's South Island, and produce an inventory of the species found there. Its results will contribute to our understanding of the distribution of small invasive mammals in New Zealand's pastoral high country habitats and inform conservation efforts aiming to enhance the native biodiversity of these agroecosystems.

22.2: Materials and Methods

Monitoring devices for the detection of small mammal presence were set up on the first day at Mt Grand Station (20.03.2023). Five lines of four to five tracking tunnels each were set up in different locations on the Grandview Mountain Track and Grandview Ridge Track between Hospital Gully and Lagoon Gully. One line of ten tracking tunnels and wax tags was set up along a fence line in Hospital Gully. One Bushnell trail camera was set up at the entrance of Lagoon Gully with cut up carrots used as bait. Locations of monitoring devices are shown in Figure 22.1. For detailed information on each tracking device refer to Table 22.1 in the Appendix.

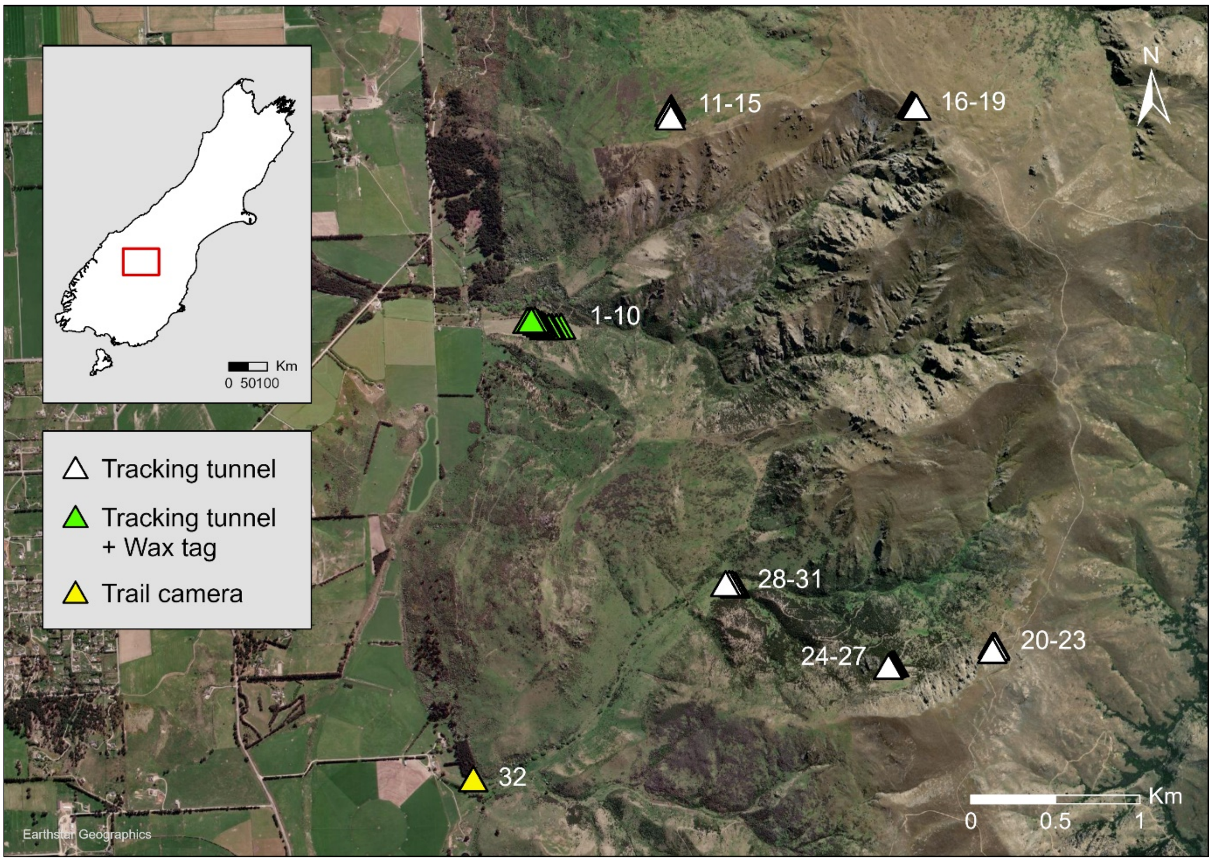

Figure 22.1. Placement of tracking devices for mammal monitoring at Mt Grand.
Coloured triangles indicate the type of monitoring device used. Numbers indicate the device number. The study area is shown in red on the insert map.

Plastic tracking tunnels were assembled on site, lined with a tracking card with ink and a small amount of peanut butter in the centre, and mounted on the ground using tent pegs. Wax tags were attached to wooden fence posts or trees with a staple gun roughly 30 cm above the ground. They were placed as close to tracking tunnels as possible wherever suitable locations to attach them were available. A blaze consisting of flour, icing sugar and cinnamon was applied underneath each wax tag as a lure (Ogilvie et al., 2006). Monitoring devices of one line were placed roughly 20 m apart. Locations of each monitoring device were marked using a Garmin GPS device. All monitoring devices were left over night and collected on 21.03.2023.

Upon completion of the fieldwork, the coordinates for each mammal detection (by monitoring devices or through field observation) were retrieved from the GPS devices and the Mt Grand Biodiversity project on iNaturalist and analysed and visualised in ArcGIS Pro.

22.3: Results

Six species of small invasive mammals were detected at Mt Grand Station, either by the monitoring devices or through observations in the field: Brushtail possums, European hedgehogs, House mice, rats, European rabbits, and cats (see Figure 22.2, Table 22.2 in the Appendix).

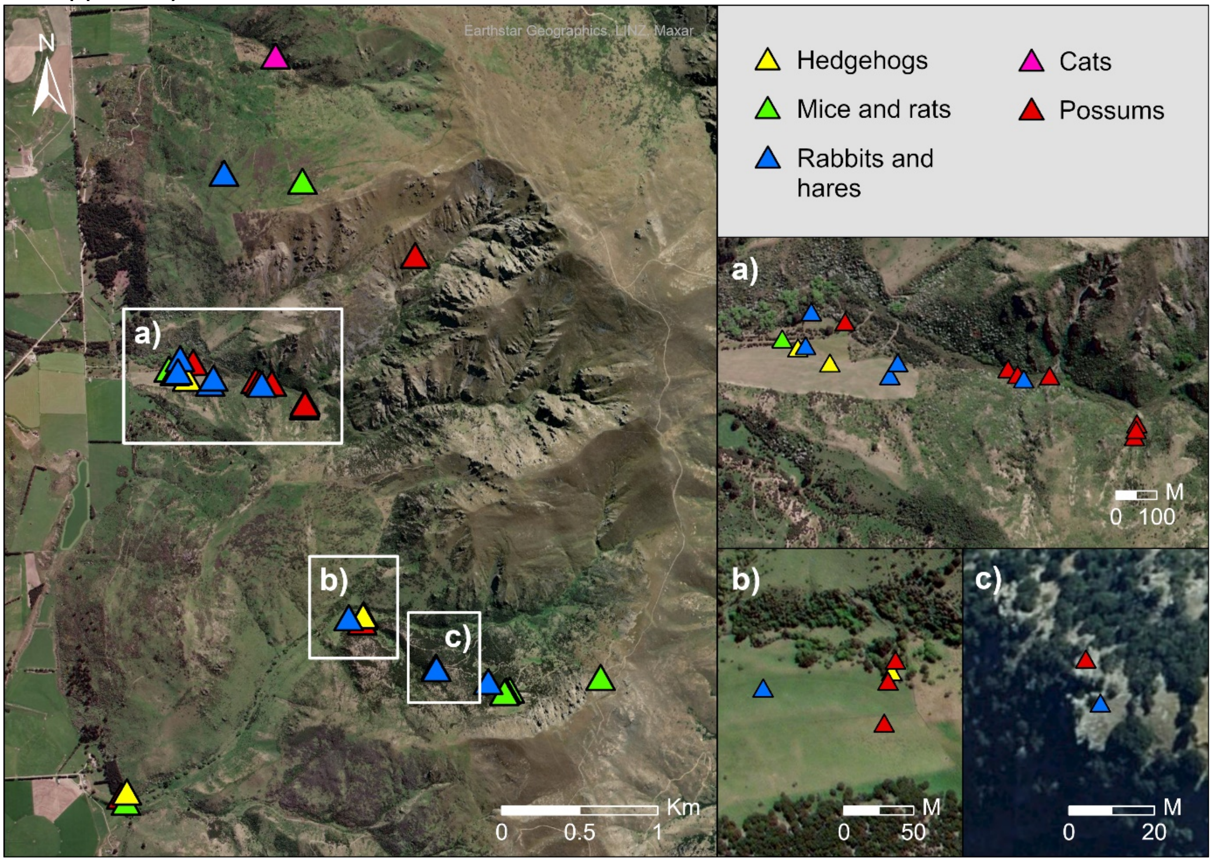

Figure 22.2: Mammal observations at Mt Grand Station.
The observations shown here are either detections by monitoring devices (Tracking tunnels, wax tags, or trail cameras) or observations entered on iNaturalist (carcasses, faeces, burrows, or direct observations of living individuals). Species of the same family are grouped: Mice and rats (Muridae), and rabbits and hares (Leporidae)

Possums, hedgehogs, mice, cats, and rabbits could be identified at the species level. However, the species of rat detected by the trail camera could not be identified. Moreover, evidence of lagomorph presence (faeces, carcasses) could not always definitively be attributed to either European rabbits or European hares (Lepus europaeus). In these instances, the observation is listed as “Rabbits and hares”.

The most detected species was the brushtail possum. Possums were detected 13 times over two days, with most detections being observations of faeces or carcasses in the field. Only one live possum was detected by the monitoring devices, namely by the trail camera at the entrance of Lagoon Gully (see Figure 22.3). Possums were detected up to an elevation of 907 m.

Figure 22.3: Possum (left) and hedgehog (right) detected by the trail camera in Lagoon Gully.

Hedgehogs were detected four times: once by the trail camera (see Figure 22.3), twice by tracking tunnels (see Figure 22.4), and once in the field where a live individual was observed. The highest elevation a hedgehog was detected at was 560 m.


Figure 22.4:Hedgehog tracks (left) and mice tracks (right) on a tracking card.

House mice were detected by tracking tunnels (see Figure 22.4) at 6 different locations up to an elevation of 1111 m. One rat was detected by the trail camera at an elevation of 409 m. Rabbit or hare presence was detected in nine instances. These were either observations of burrows, faeces (often found at latrine sites), carcasses or, on one occasion, a live individual. Rabbits were detected up to an elevation of 892 m.
Evidence of cat presence (faeces) was found on one occasion at an elevation of 624 m.

22.4: Discussion

Monitoring devices and field observations confirmed the presence of six species of small invasive mammals at Mt Grand. Observations from iNaturalist effectively added to the species detections by monitoring devices, and both methods in tandem helped paint a picture of which mammals are present at Mt Grand.

The presence of rabbits at Mt Grand was not a surprise, considering that rabbits are a known and widespread pest of pastoral landscapes where they have become well-established since their introduction in the 19th century (Hunt et al., 2011). What was surprising was the lack of detections of mustelid species (ferrets, weasels, stoats) which were introduced to New Zealand to control rabbits and now persist in pastoral habitats (Cross et al., 1998; King, 2017; Ragg & Moller, 2000). Rabbits make up large parts of stoat and ferret diet in areas similar to Mt Grand (Dowding et al., 2015; Murphy et al., 2004), so the absence of these species at Mt Grand was unexpected. Weasels have been hypothesised to decrease activity in rainy conditions to avoid hypothermia (Brandt & Lambin, 2005), and the same might be true for stoats and ferrets, so their non-detection could be related to the heavy rainfalls at the time of the fieldwork. It is also likely that only ferrets, the largest of the three mustelid species, are present in the study area and suppress weasels and stoats. Ferrets, along with feral cats, prey on stoats, and stoats are therefore less likely to occur in areas where these species are abundant (Foster, Maloney, Seddon, et al., 2021; Moller & Alterio, 1999). While it is unclear whether ferrets just went undetected during this project or are actually absent in the area, cats were detected at Mt Grand on one occasion and are likely numerous throughout the area due to the proximity of human settlements. Cat presence could therefore limit the occurrence of stoats at Mt Grand.

Hedgehogs were detected at a mean altitude of 475 m. Several studies suggest that hedgehogs may infrequently be detected at altitudes up to 2000 m above sea level, however, hedgehog density and activity are said to be decreasing with increasing elevation (Foster, Maloney, Recio, et al., 2021; Foster, Maloney, Seddon, et al., 2021), which could explain their non-detection at higher altitudes during this study.

Mice were most often detected in shrubby habitats at higher altitudes, with the highest observation at over 1100 m above sea level. While some studies predict that mouse abundance should be highest in lower altitudes (Foster, Maloney, Seddon, et al., 2021), others report higher abundance in alpine areas than in adjacent habitats at lower altitudes (Wilson & Lee, 2010). In the case of Mt Grand, mice are either truly more abundant at higher altitudes due to high predator or competitor abundance at lower altitudes (cats, stoats, ferrets, rats) or were simply not detected as frequently at lower altitudes.
One rat was detected by the trail camera. Although it could not be identified at the species level, it can be assumed that it was either a Norway rat (*Rattus norvegicus*) or ship rat (*R. rattus*) due to the limited range of Pacific rats/kiore (*R. exulans*) (Wilmshurst & Ruscoe, 2021).

Most evidence of possum presence was found in the vegetated areas at lower altitudes, with the mean elevation of possum detections being 585.45 m. This finding corresponds with other studies reporting that possums prefer habitats with vegetation cover for foraging and shelter (Foster, Maloney, Seddon, et al., 2021), which were primarily located at lower elevations at Mt Grand. The highest elevation at which possums were detected was just over 900 m above sea level, and this was also the only evidence of possum presence outside of vegetated areas (northernmost observation in Figure 22.3). None of the monitoring devices detected possums except for the trail camera. This was likely due to the limited use of monitoring devices specifically targeting possums (only one line of wax tags was set up in

Hospital Gully) and the weather conditions during the fieldwork with heavy rains washing away the flour blaze.

The results of this study confirmed the presence of several small invasive mammals at Mt Grand Station and detected four species that were not listed in the most recent Conservation Resources Report on the tenure review of the property (Department of Conservation, 2005). Based on the findings of other studies on the ecology of small invasive mammals in New Zealand, it is likely that more species than the ones detected are present at Mt Grand. For example, mustelid presence seems highly likely in the Mt Grand area due to the abundance of rabbits, a preferred food source of both ferrets and stoats. The non-detection of certain pest mammals during this study should therefore not be understood as complete absence from the area until confirmed by more in-depth research. Additionally, the results of this study highlight that rabbits are not the only species of conservation concern present at Mt Grand and that native species in the area would benefit from a pest control approach targeting multiple pest species.

22.5: Conclusion

By producing an inventory of small invasive mammals at Mt Grand, this study has laid the groundwork for future studies on invasive mammals in the area. In the future, quantifying the abundance of each species of invasive mammal and conducting an in-depth analysis of their distribution and habitat use could deepen our understanding of their ecology in a landscape shaped and influenced by pastoral farming. The knowledge generated by this and future studies may inform conservation efforts aiming to control invasive pest mammals in pastoral landscapes, thereby aiding the conservation of New Zealand’s native biodiversity.

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22.7: Appendix

Table 22.1:Monitoring devices used for mammal monitoring at Mt Grand Station with their respective coordinates, elevation, and species detections

Device number	Device type	Latitude	Longitude	Elevation (m)	Species detected
1	Tracking tunnel, Wax tag	-44.6509184595 19744	169.32203337550163	129.90	-
2	Tracking tunnel, Wax tag	-44.650934971868992	169.32168720290065	125.58	-
3	Tracking tunnel, Wax tag	-44.65094025246799	169.32135494425893	116.93	-
4	Tracking tunnel, Wax tag	-44.650902114808559	169.32111714966595	114.76	-
5	Tracking tunnel, Wax tag	-44.65090362355113	169.32081732898951	113.80	European hedgehog
6	Tracking tunnel, Wax tag	-44.650760209187865	169.32056620717049	112.60	-
7	Tracking tunnel, Wax tag	-44.650660213083029	169.32031734846532	110.68	-
8	Tracking tunnel, Wax tag	-44.650522246956825	169.32011090219021	105.87	House mouse
9	Tracking tunnel, Wax tag	-44.650537502020597	169.31984544731677	105.39	European hedgehog
10	Tracking tunnel, Wax tag	-44.650539262220263	169.31956700049341	103.47	-
11	Tracking tunnel	-44.639562992379069	169.33097200468183	986.41	-
12	Tracking tunnel	-44.639656031504273	169.33093403466046	991.94	-
13	Tracking tunnel	-44.639734989032149	169.33093302883208	991.75	-
14	Tracking tunnel	-44.639858035370708	169.33082297444344	992.55	House mouse
15	Tracking tunnel	-44.640057021752	169.3309129960835	993.42	Card Missing
16	Tracking tunnel	-44.639959959313273	169.34889502823353	1250.94	-
17	Tracking tunnel	-44.640001030638814	169.34896904043853	1251.01	-
18	Tracking tunnel	-44.640056015923619	169.34909895993769	1250.65	-
19	Tracking tunnel	-44.640120975673199	169.34922301210463	1253.47	-
20	Tracking tunnel	-44.668942987918854	169.35313995927572	1078.85	-

21	Tracking tunnel	-44.668953968212008	169.35330399312079	1082.17	-
22	Tracking tunnel	-44.669047007337213	169.35326803475618	1083.61	-
23	Tracking tunnel	-44.669196959584951	169.35309302061796	1088.53	House mouse
24	Tracking tunnel	-44.66968503780663	169.34572096914053	947.29	House mouse
25	Tracking tunnel	-44.669697023928165	169.34555903077126	947.55	-
26	Tracking tunnel	-44.66973097063601	169.34543003328145	946.87	House mouse
27	Tracking tunnel	-44.669809006154537	169.34528301469982	948.30	House mouse
28	Tracking tunnel	-44.665108015760779	169.33415402658284	548.21	-
29	Tracking tunnel	-44.665036015212536	169.33393500745296	545.35	-
30	Tracking tunnel	-44.665007013827562	169.33369796723127	543.19	-
31	Tracking tunnel	-44.665011037141085	169.33342496864498	540.98	Card Missing
32	Trail camera	-44.674784000962973	169.31397702544928	409.12	Brushtail possum, European hedgehog, Rat

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Table 22.2: Mammal detections at Mt Grand Station with coordinates.
Mammal presence was either detected by monitoring devices or through observations in the field. These observations were taken from iNaturalist, in which case the user who uploaded the observation is stated.

Species	Type	Observer: Monitoring device (MD) or iNaturalist user	Latitude	Longitude	Elevation (m)
Brushtail possum	Carcass	ktschmid	-44.650005	169.32135	468.47
Brushtail possum	Faeces	ecoman	-44.66817	169.339834	780.97
Brushtail possum	Faeces	katdoug	-44.652839	169.330169	608.45
Brushtail possum	Carcass	laurs39	-44.6651	169.334106	561.05
Brushtail possum	Faeces	francescobini99	-44.652558	169.330262	585.14
Brushtail possum	Faeces	francescobini99	-44.651408	169.327622	535.35
Brushtail possum	Faeces	albert_salemgareyev	-44.652687	169.33023	596.54
Brushtail possum	Faeces	francescobini99	-44.651212	169.326338	517.01
Brushtail possum	Faeces	catherinepriemer	-44.651347	169.32663	514.83
Brushtail possum	Carcass	cabuchanan	-44.664967	169.334183	559.55
Brushtail possum	Faeces	ecoman	-44.644426	169.339657	906.91
Brushtail possum	Carcass	marcus_bjoers	-44.66537	169.334054	567.54
Brushtail possum	Live individual	MD 32	-44.674784000962900	169.31397702544900	409.12
European hedgehog	Live individual	laurs39	-44.665039	169.334144	560.63
European hedgehog	Tracks	MD 5	-44.65090362355110	169.32081732898900	470.59
European hedgehog	Tracks	MD 9	-44.650537502020500	169.31984544731600	462.65
European hedgehog	Live individual	MD 32	-44.674784000962900	169.31397702544900	409.12
House mouse	Tracks	MD 8	-44.650522246956800	169.32011090219000	458.60

House mouse	Tracks	MD 14	-44.639858035370700	169.33082297444300	981.18
House mouse	Tracks	MD 23	-44.669196959584900	169.35309302061700	1111.32
House mouse	Tracks	MD 24	-44.66968503780660	169.34572096914000	965.18
House mouse	Tracks	MD 26	-44.66973097063600	169.34543003328100	963.68
House mouse	Tracks	MD 27	-44.669809006154500	169.34528301469900	966.95
Rat	Live individual	MD 32	-44.674784000962900	169.31397702544900	409.12
European rabbit	Live individual	colinjensen	-44.665108	169.332974	548.28
European rabbit	Burrow	colinjensen	-44.649753	169.320313	459.57
European rabbit	Burrow	francescobini99	-44.651245	169.322662	491.78
European rabbit	Carcass	albert_salemgareyev	-44.65145	169.326813	519.81
Rabbits & Hares	Carcass	antoniau	-44.650495	169.320089	464.38
Rabbits & Hares	Faeces	antoniau	-44.650964	169.322924	487.69
Rabbits & Hares	Faeces	ronjahaerdtner	-44.668264	169.339871	779.01
Rabbits & Hares	Faeces	nicolawegmayr	-44.669142	169.344005	892.37
Rabbits & Hares	Faeces	marcus_bjoers	-44.639195	169.324536	807.51
Cats	Faeces	nicolawegmayr	-44.632572	169.329116	623.62

Chapter 23: Mt Grand Lizard Inventory

Samantha Fitzgerald

Abstract

Lizards hold significant cultural and ecological value to New Zealand and need to be conserved for future generations. We are still discovering new species to this day and learning more vital information about their ecology. With this, we can ensure that the right conservation plans are implemented with the resources we have. Currently, there is little known about what lizard species there are on Mt Grand and their abundances. The aim of this study is to examine what species are present on the station and gain a better understanding of their distribution. This study adds to the baseline knowledge. It opens doors for future herpetology study in high country farming systems and enables a greater understanding of the species' ecology. During the field trip over two hand searching days, three lizard species were observed: Southern Alps gecko (*Woodworthia "Southern Alps*"), McCann's skink (*Oligosoma maccanni*), and New Zealand grass skink (*Oligosoma polychrome*). They were observed across both sampling sites, Lagoon valley and Hospital gully on Mt Grand in rocky and grassy habitats.

Key words: Mt Grand, Southern Alps gecko, New Zealand grass skink, McCann's skink, high country, alpine zone, lizard.

23.1: Introduction

There are currently 124 known lizard species in New Zealand, 76 native skink species and 48 endemic gecko species (Hitchmough, et al., 2021). Currently 86% of our lizard species are at risk or threatened according to the New Zealand Threat Classification System (NZTCS) (Hitchmough, et al., 2021). New species of skinks and geckos are still being described and discovered. Genetic analysis has exposed some cryptic species and there are still small populations in extreme remote areas that are waiting to be discovered (Knox , n.d.). Herpetology in New Zealand is still being developed to this day.

Geckos have evolved with the splitting of Gondwana land 80 million years ago and have adapted throughout various habitats, from the ground to the canopy in forests and scrubland, and to rocky scree areas (Knox , n.d.). However, there is uncertainty with how our native skinks came to be on Aotearoa. It is possible they crossed land bridges, catching debris across the ocean, or they split with Gondwana (Knox, n.d). Since their divergence, they have adapted traits that are different to most lizard species around the world. They give birth to around 2-3 young annually, which is believed to of evolved due to the cooler climate of New Zealand (Knox , n.d.). Additionally, some species live in alpine zones with harsh conditions. Due to these factors, they are hard to monitor and are vulnerable to environmental and anthropogenic changes.

Habitat modification, urbanisation, mammalian predators, and agricultural intensification threaten our endemic lizard species (Hitchmough et al., 2016). We are only just starting to understand how these factors are impacting populations. With a deeper understanding of their ecology, we can form an effective conservation management plan for these species. However, there are still many gaps in our knowledge that will be beneficial to aid conservation efforts.

There has been little literature in New Zealand surrounding the relationship between farming, the alpine zone, and lizard populations. Some farming practises may threaten species, some may be beneficial. This has not been quantified yet. Lizard studies at Mt Grand will expose how farming can be beneficial or detrimental for our native lizard species, opening new channels for research and conservation.

The aim of this study was to undertake an inventory of lizard species present on Mt Grand to gain a better understanding of their distribution.

23.2: Methods

The inventory occurred through observer hand searches across two different sites on Mt Grand from the 20th to 21st March 2023.

23.2.1: Study site

Mt Grand is a 2,127-hectare high country station located near Lake Hawea, Central Otago (44°37'52.8"S 169°19'02.8"E) (Lincoln University, n.d.) (Figure 23.1 and 23.2). Currently 1,975 hectare is pastoral lease with 162 in freehold (Hill Country Futures, n.d.). The station is primarily a merino sheep high country station with some cattle ranging from 400m-1445m altitude.

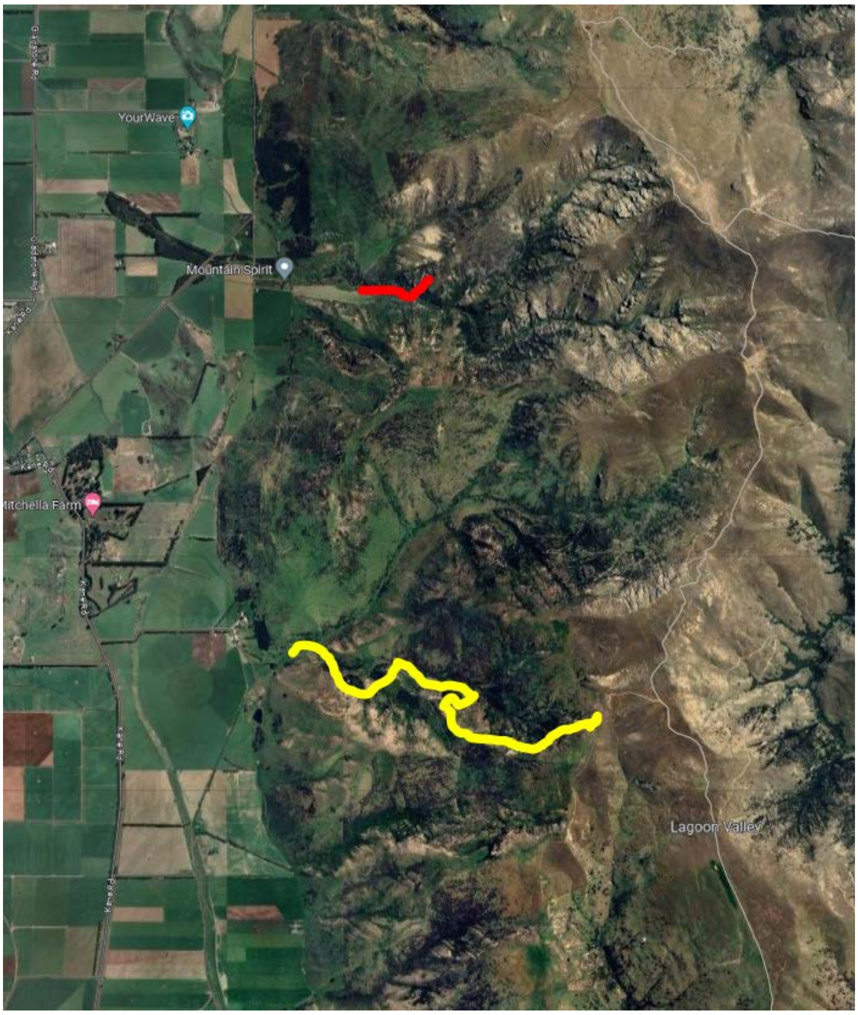
Figure 23.1: Location of Mt Grand station (red point) in the South Island, New Zealand

Figure 23.2: Closer view of Mt Grand station around the Lake Hawea area

Low lying areas are primarily intensive farming system with high producing exotic grasses. Valleys and medium altitudes (below 900 m) are a mixed scrub of Matagouri (Discaria toumatou), sweet briar (Rosa rubiginosa), Coprosma's (Coprosma sp.), and Kanuka (Leptospermum ericoides) as dominate species with a mixture of other native and exotic species throughout. Higher altitudinal areas are primarily tussock grassland (Poa Colensoi, Chionochloa rigida, and Festuca novae-zelandia) with some exotic weeds (e.g. Hieracium spp. [Pilosella syn.]).

Hospital gully and Lagoon valley area were used as two study sites within Mt Grand (Figure 23.3). Hospital gully had two hours of handsearching while Lagoon valley had 4-5 hours. The hand searching routes are shown in Figure 23.3.

Figure 23.3: Routes taken at Hospital Gully (red) and Lagoon Valley (yellow) (photo derived from google maps)



23.2.2: Hand searching

General hand searching was used to find lizards at the two sites (Figure 23.3). There was a set of habitat characteristics that was used to determine whether to conduct a search or not. Hand searching consisted of carefully lifting wood and stones from their placement. Geckos were searched for in rocky areas such as screes, bluffs, and piles including decaying wood. Skinks were searched when moving across grassy areas by looking out for movement when disturbed by walkers. Additionally, under rocks and wood laying on the ground were lifted to observe any individuals. When individuals were caught by hand, photographs were taken and released back into the reconstructed natural refugia.

23.3: Results

23.3.1: INaturalist Observations

There has have been observations of three different skink and gecko species since 2016, with 21 in total (Table 23.1, Figure 23.4) in a defined area including Mt Grand station (Figure 23.4). There was no information about habitat type and or where they were specifically found (e.g., under stones), recorded with any observations.

Table 23.1 - Lizard species and count recorded on INaturalist.

Species	Count
McCann's skink	14
New Zealand Grass skink	1
Southern Alps gecko	6

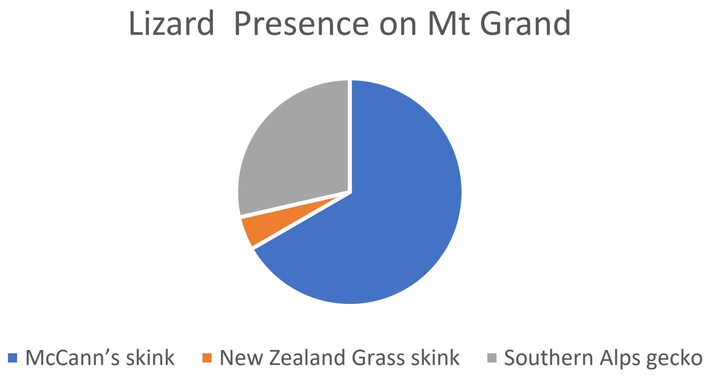


Figure 23.4: Proportion of lizard species that were found on Mt Grand

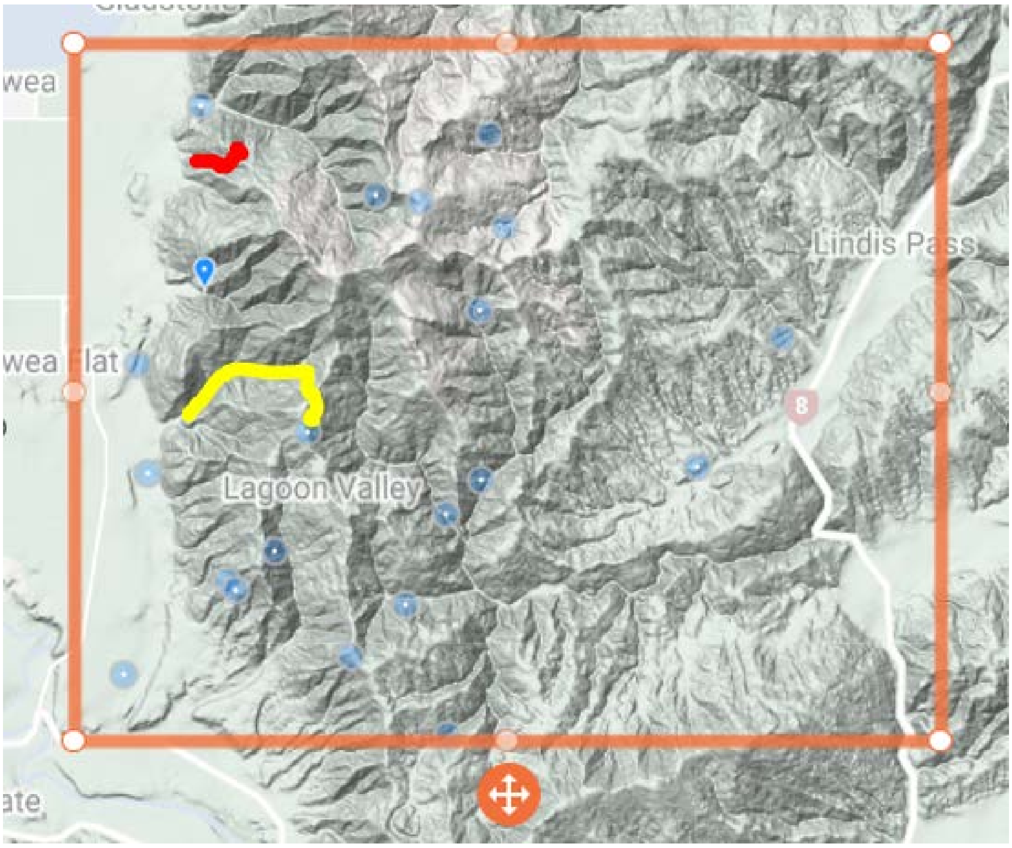


Figure 23.5: INaturalist area for search results of lizards. Blue dots are gecko or skink observations.

23.3.2: Personal Observations

Gecko and skink species were found at both sites, lagoon valley and hospital gully. All three of the same species were found to that of what was observed on INaturalist and approximately 30 ±10 lizards were found over the two hand searching sampling days. They were found in a variety of different habitats. Skinks were primarily found at the base of hospital gully where farming was more intensive. The highest portion of geckos observed was at the peak of Lagoon valley where the Department of Conservation reserve is. They were found underneath sheets of rocks that were piled together with small gaps. Other individuals were found under or between rocks at various habitat types throughout the altitudinal change.

There were two juveniles found in a rotting log at the base of hospital gully on the day we arrived (not a formal monitoring day).

23.4: Discussion

Lizards are of great ecological value to Mt Grand and their presence shows many positive attributes about biodiversity on farms. Going into the study, we were unsure about the presence of lizard species on the station, but the results showed promise for significant populations. Currently there are three known species - Southern Alps gecko, New Zealand grass skink, and McCann's skink, on Mt Grand station. The geckos observed on Mt Grand were primarily in rocky habitats with skinks in grassy areas, which aligns with the saxicolous behaviour and preferences of the species.

However, there is possibility for other species. When conducting a wider search on INaturalist with a ~20km radius surrounding the station (Figure 23.6), another six species have been observed - Kawarau gecko (Woodworthia Cromwell), Otago skink (Oligosoma otagensa), Grand skink (Oligosoma grande), Nevis skink (Oligosoma toka), Jewelled gecko (Naultinus gemmeus), and New Zealand Forest geckos (genus Mokopirirakau). There is possibility that these species were once or still are present on Mt Grand. More extensive field work would need to be conducted to get a full species inventory. According to NZTCS, six of these species at either threatened – nationally declining (Otago and Grand skink) or at risk – declining (Kawarau gecko, Jewelled gecko, Southern Alps gecko, and Nevis skink) with only three species not threatened (NZ Forest gecko, NZ Grass skink and McCann's skink).

It is crucial that we conserve these precious taonga. They are considered sacred creatures in Māori culture. They can be seen as bad omens and are sometimes feared as they linked it with Whiro, the god of darkness (Haami, 2023). Although they were feared, lizards were also viewed as guardians. They were placed near burials caves to watch over the deceases and released near mauri (Haami, 2023).

Along with their cultural value, they also hold ecological significance. It has been proven that they are excellent seed dispersers of at least 23 known native plants including five divaricating shrubs (Wotton et al., 2016). Seeds are dispersed in an approximate radius of 20 meters from the parent plant, reducing intraspecific competition. Lizards are especially playing a crucial role in areas where there are no remaining frugivorous birds to disperse seeds (Wotton et al., 2016). Lizards defecate in rocky crevices, which could provide ideal conditions for establishment of seedlings (Wotton et al., 2016). With the reduction of seed dispersal by lizards and birds, there is knock on effect in reduction of natural plant regeneration in areas such as Mt Grand. In the alpine zones there are 117 fleshy-fruited alpine plant species that rely on seed dispersal from fauna. Kea is primarily the main disperser in these zones (Wotton et al., 2016). However, with the drastic decrease in Kea populations over the past few decades, lizards have become important dispersers of these vulnerable plant species. However, lizards only disperse over a small local scale compared to Kea who disperse over a larger landscape. This reduces colonisation by plants of new sites, long distance seed dispersal, and genetic variation. Overseas in Spain, there has been evidence of plants becoming rare due to the local extinction of lizards as their dispersal channels have disappeared (Wotton et al., 2016). We need to continue to push and advocate for lizard conservation in New Zealand to ensure that aspects such as seed dispersal, cultural and ecological values are retained. There are many different methods that could be used to conserve the species. Predator management through trapping and exclusion fences as well as translocations, plantings, artificial refugia can be used for conservation.

The diet of lizards is primarily insectivorous, which can benefit farming systems through control of pest invertebrate species such as slugs (Biaggini & Corti, 2021). Lizards also play a crucial role in the trophic levels, they have prey and get preyed on (Biaggini & Corti, 2021). In Biaggini and Corti's (2021) study found that the Italian wall lizard (Podarcis siculus), preferred different areas depending on the crop. in the vineyard they occupied it throughout, whereas in the cereal crops, they preferred the margins. This may be due to the more complex structure of margins that provide protection and resources for the population. However, there is very little literature that examines the benefits of lizards in agricultural systems and their interactions.

Despite the developments with lizard studies in New Zealand, problems are still occurring which make lizard conservation efforts difficult. However, this is not only found for New Zealand species, but also globally. Problems include not understanding the full taxonomy, distributions, and population trends across all species (Hitchmough et al., 2016). There are gaps in consistency of detecting low density populations, detection, and management of species in tough habitats (e.g., scree areas in alpine zones and arboreal species) and tools for large scale pest management (Hitchmough et al., 2016).

Introduced mammalian predators threaten our endemic lizard species. Predators include rodents (rats, Rattus spp. and mice, Mus musculus), hedgehogs (Erinaceus europaeus), mustelids (Mustela spp.) and feral cats (Felis catus). Each plays a significant role in the decline in the species populations.

Mice are difficult to eradicate and have detrimental impacts on lizard populations. There is limited natural lizard refugia that are small enough to exclude mice (Norbury, et al., 2022). Because of this, with lizards present, mice need to be at low densities. Suppressing mouse populations is expensive and problematic from mainland areas that aren't surrounded by predator proof fences or large bodies of water (Norbury et al.,2022; Norbury et al., 2014). There are constant reinvasions from the surroundings. Multiple studies have proven that mice are limiting factors for lizard populations ranging from translocation efforts to already established populations (Norbury et al., 2014; Newman, 1994). Newman (1994) found that the gecko (Hoplodactylus maculatus) and McGregor's skink (Cyclodina macgregori) populations had significantly increased on Mana Island with the eradication of mice. Newman also found an increase in the Cook Strait giant weta (Deinacrida rugosa). The removal of mice would not only benefit lizards but also invertebrates.

In addition to mice, hedgehogs cause a significant negative impact on lizard species. Studies have shown that they consume both skinks and lizards. Spitzen et al., (2009), found that 21% of the 158 hedgehogs in their study over two seasons on Macrae's flat, Otago, had fed on lizards. The remains of 43 skinks and one common gecko were identified in 25 female and 8 male hedgehogs. Both Jones et al. (2005) and Spitzen et al. (2009), found that there were discrepancies between sexes, with females consuming more lizards compared to males, it is not known why this occurs (Spitzen et al., 2009). Hedgehogs not only target lizards but also invertebrates, birds, eggs, and vegetation/seeds (Jones et al., 2005; Nottingham et al., 2019). They are mainly considered insectivorous omnivores, but their impacts on lizard populations is starting to be recognised as they could cause catastrophic impacts (Reardon, et al., 2012).

To sustain lizard populations on Mt Grand, predator control will need to be implemented. This will not only benefit lizard populations, but also endemic invertebrates, birds, and plant species that reside on the station. Initially, further monitoring would need to be undertaken of endemic and pest species to gain a baseline. This data can then be used to aid in the development of a pest management plan. The main pest species targeted would be mustelids, rodents, hedgehogs, pigs, rabbits, goats, and deer. A study conducted by Reardon et al. (2012) found that control of predators either by near eradication or predator proof fencing enabled Grand and Otago skink populations to rebound. This may be applicable to other species throughout New Zealand. Suppression of pest species will not only enable a localised recovery of lizard abundances but also invertebrates. Additionally, native plants will be able to regenerate. Eradicating pigs, deer, and goats are also of benefit to the farming system on Mt Grand. They increase erosion and soil instability, eat crops, and spreads diseases (e.g., possums spreading bovine TB to cattle) (Predator Free NZ, 2023).

Predator Free NZ recommends three different pest control methods for on farms: toxins, trapping, and shooting. Each method comes with pros and cons and should be used accordingly to the context and target species. Toxins are effective with high mustelid, rodent and possum densities. However, there is handler and environmental health concerns as well as risk of consumption by livestock or pets causing primary and secondary poisoning. Bait stations can be used around yards where there are high pest densities. Trapping on a farming system is useful for continuous control of suppressing a species once an initial knock down has occurred. However, these are labour intensive, have expensive set up costs and only target mustelids, rodents, possums, and hedgehogs. Shooting is useful for targeting possums, rabbits, and feral cats. Hunters can also come and shoot feral goats and deer in the mid to high altitudes of the station. A combination of these techniques will best suit pest control on Mt Grand as each one targets different species and across the different terrains and habitats.

In addition, habitat destruction through agriculture intensification threatens our endemic species. There is a lack of information worldwide on the ecology of lizards in agricultural landscapes (Biaggini & Corti, 2021). However, this study shows us that lizards can still reside in agricultural landscapes. Individuals were found in lower altitudes along the lagoon path (Figure 23.3) where agriculture is more intensive. One observation that could explain this is the presence of favourable natural refugia, such as dead wooden logs and thin scrub scattered throughout. This habitat supports both gecko and skink species. This isn't typical of an intensive farming system, typically no shrubs or wooden logs are present. If the natural refugia is present and there is a nearby established population, then it will support the population further, even if there is agricultural practices occuring in proximity. Lizards were also found at higher altitudes up the Lagoon valley. The area was less intensively grazed compared to the lower altitudes. Overall, more geckos and skinks were found in this area. This may be in part to lowering producing farmland but also an increase in favour natural refugia of rocky outcrops and food sources (e.g., Coprosma spp.). Further studies would need to be undertaken to examine this question in full.

23.4.1: Future study scope on Mt Grand

There is very little knowledge about lizards on Mt Grand, because of this there is plenty of scope for future studies that could be conducted especially with more time, money, and resources. Artificial cover objects (ACOs) could be integrated into a monitoring plan to fully understand the relative abundance, distribution, and population trends (Batson et al., 2015).

Along with monitoring, they can be used for inventory, restoration, translocation, and mitigation (Lettink, 2012). ACOs encourage lizards to occupy the retreat to benefit them from the thermal properties of the structure (Batson et al., 2015). ACOs can increase the detectability of rare and cryptic species, is cost-effective, and increases the restoration potential in degraded habitats (Lettink & Cree, 2007).

There is a possibility of another six lizard species on Mt Grand. They have been found within a 2km radius around the station and if their favourable habitat is present, then there is possibility that there is an established population. Further monitoring would need to be undertaken to investigate this. There may also be the possibility of translocating species onto the station if there is appropriate habitat and an intensive predator management plan implemented.

Once there is a better understanding on the species richness and abundances, further studies about their ecology such as habitat preferences, distribution patterns and behavioural components can be examined within a farming system. Additionally, the impacted of cultivated areas, which crops affect dispersal, how do they behave in margins could be examined further (Biaggini & Corti, 2021). It is crucial that conservation not only occurs in protected areas, but also in private landownerships

23.5: Conclusion

This short study will be able to set up opportunities for future studies that will fill gaps in the literature. It shows great promise that lizards can survive in a farming environment. Conservation of lizard species is critical as they provide many ecosystem services and hold cultural and ecological values. Future generations need to experience and observe native species. Conservation of species can be done through extensive predator control and restoring natural habitats, changing the landscape into a heterogenous environment.

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23.7: Appendix

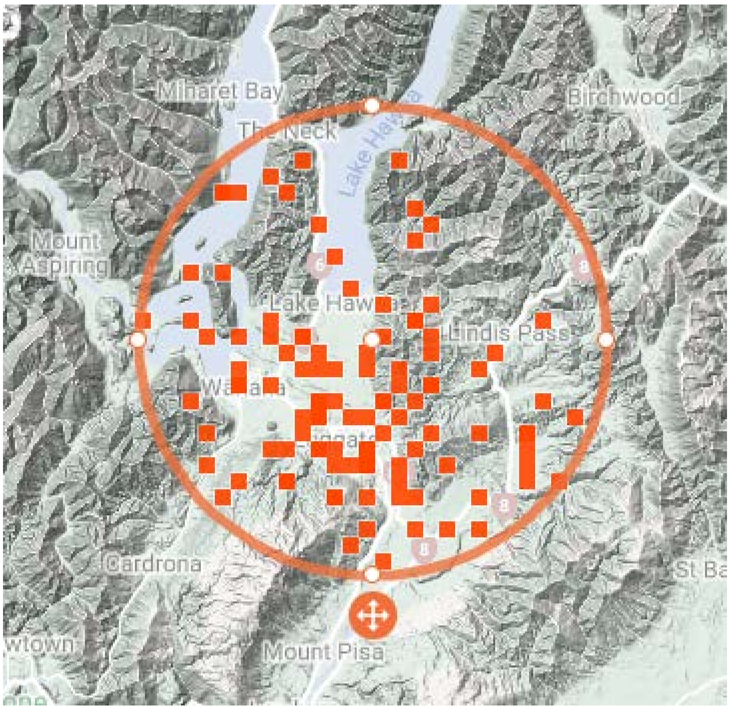

Figure 23.6: 20km radius surrounding Mt Grand for all lizard species found within

Chapter 24: Assessing Hedgehog Presence to Inform Conservation Measures and Future Monitoring

Francesco Bini

Abstract

Among the various invasive mammalian species which have been introduced in New Zealand, European hedgehogs are nowadays widespread throughout the North and South Islands and prey upon numerous native and endemic species. We conducted a monitoring project via use of tracking tunnels and camera traps at Mt Grand Station (Hawea, Central Otago) to assess their presence. Only 2 out of 31 tunnels and 1 of the 2 cameras detected hedgehogs' passage, and they were all at low altitudes: such results might reflect the influence of factors like the short time span that could be dedicated to field work, the season and the weather. In the area of detection at the two tunnels, several species which can represent potential hedgehogs' prey were observed, most of which were endemic. Thus, it can be asserted that hedgehog's presence can indeed represent a threat for those taxa and should be controlled.

Key words: Hedgehogs, tracking tunnels, camera traps, altitude, season, weather, prey

24.1: Introduction

New Zealand's native biodiversity is threatened by pressure exerted from invasive mammals, which have been involved in the decline or the extinction of many endemic species (King, 2005; McLennan et al., 1996; Murphy et al., 2004; Russell & Stanley, 2018). Among these, European hedgehogs (*Erinaceus europaeus*) were first introduced to New Zealand in the late 1800s and since then have dispersed throughout the temperate areas of the mainland and numerous offshore islands, in various natural and human-modified environments (Jones & Sanders, 2005; Jones & Norbury, 2006). Hedgehogs are mainly insectivorous but are known to feed on mice (*Mus musculus*), lizards, frogs and ground-dwelling birds (Jones & Sanders, 2005; Jones et al., 2005; Lettink & Monks, 2019). Variable availability of food as well as of refugia is the main factor which dictates variation in hedgehogs' local abundance (Jones & Sanders, 2005; Micol et al., 1994).

In the dryland environments found in the central areas of New Zealand's South Island the variability in available resources results in patches of both suitable and unsuitable habitat for hedgehogs, with the first ones providing mainly invertebrates, dry shelter refuge and dispersal opportunities (Doncaster et al., 2001; Rodriguez Recio et al., 2013). In particular, in those areas such optimal characteristics can be found in the pastoral landscapes modified for grazing: there is evidence, in fact, that these landscapes have been positively selected by hedgehogs in New Zealand (Reeve, 1994; Rodriguez Recio et al., 2013).

Mt Grand Station is a Lincoln University owned hill country pastoral farm located in Hawea (Central Otago) (Wei et al., 2023), and there is evidence that this area is inhabited by hedgehogs (Department of Conservation, 2006; Wiedenmann, 2016).

In this report we present the results of a project carried out at Mt Grand Station. The aim was to assess the presence of hedgehogs, investigating any spatial patterns in their distribution and reasons for these, evaluating overlaps with prey species' distribution and providing recommendations for the implementation of conservation measures and for future monitoring.

24.2: Materials and Methods

Mt Grand Station is situated south-east of Hawea (Central Otago), on the eastern side of the Hawea Flat. It has an extension of 1,607 ha and the area where it is located is characterised by a continental type of climate, with hot and dry summers and cold winters (Lambers et al., 2013). Annual rainfall is 703 mm, but the annual and seasonal variability is relevant (Maxwell et al., 2010).

The field work for this project was carried out in two sections of Mt Grand which were visited in two consecutive days, the 20th and the 21st of March 2023. On the first day we travelled along the ridgeline surrounding Hospital Creek and Lagoon Creek, partially staying on the Grandview Mountain Track and going from elevations of about 100 m a.s.l. to a maximum of around 1200 m a.s.l. On the second day we visited Hospital Creek. During both days we deployed tracking tunnels, a motion triggered camera trap and a time lapse camera trap to detect the presence of hedgehogs (Gillies & Williams, 2013; Gillies & Brady, 2018). The tunnels which were used were made of plastic and were secured to the ground with metal pegs. Each of them contained a plastic card, on the central part of which we applied tracking ink, so that the hedgehogs' tracks would be stamped on the card in case of passage of the animal, and we placed peanut butter as a bait (Gillies & Williams, 2013; Wiedenmann, 2016) (Figure 24.1). We set up a total of 31 tracking tunnels grouped in 6 lines deployed at different altitudes and in areas with different vegetational characteristics (Figure 24.2).

The first line of tunnels was deployed in a paddock of lucerne (alfalfa) dating back to the previous growth season, at the bottom of Hospital Creek. The tunnels were placed in a range of elevations going from 103 m a.s.l. to 130 m a.s.l.; above each one of them wax tags (WaxTags®, Pest Control Research, Christchurch, NZ) were placed too, to detect any signs of presence of possums as well (Pickerell et al., 2014). Lines 2, 3 and 4 were placed at locations in the higher section of the study area, where there is dominance of species such as snow tussock (*Chionochloa spp.*), blue tussock (*Poa colensoi*) speargrass (*Acihpylla aurea*), and presence of rocky outcrops too; these lines were set up at ranges of altitude of 986-993, 1251-1253 and 1079-1089 m a.s.l., respectively. The fifth line of tunnels was deployed at 947-948 m a.s.l., where the tussock grassland progressively approaches the kanuka shrubland. Line 6, finally, was placed in a low pasture area, between 541 and 548 m a.s.l. (Department of Conservation, 2006; Wiedenmann, 2016).

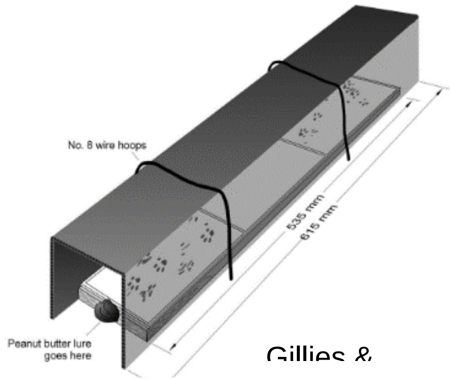

Figure 24.1: Tracking tunnel for detection of small mammals.

The motion triggered camera trap (a Bushnell Aggressor Trophy Cam®) and the time lapse camera trap (a Kinopta BlackEye®) were placed in a site where no tracking tunnels where deployed: the first was attached to a tree and the second was set up on a tripod. The site was a fenced off section of pine trees in a paddock.

Furthermore, to assess potential overlaps with prey species' distribution, I relied on observations made by other course participants which were uploaded to the iNaturalist website, as well as on any other ones from observers in the past.

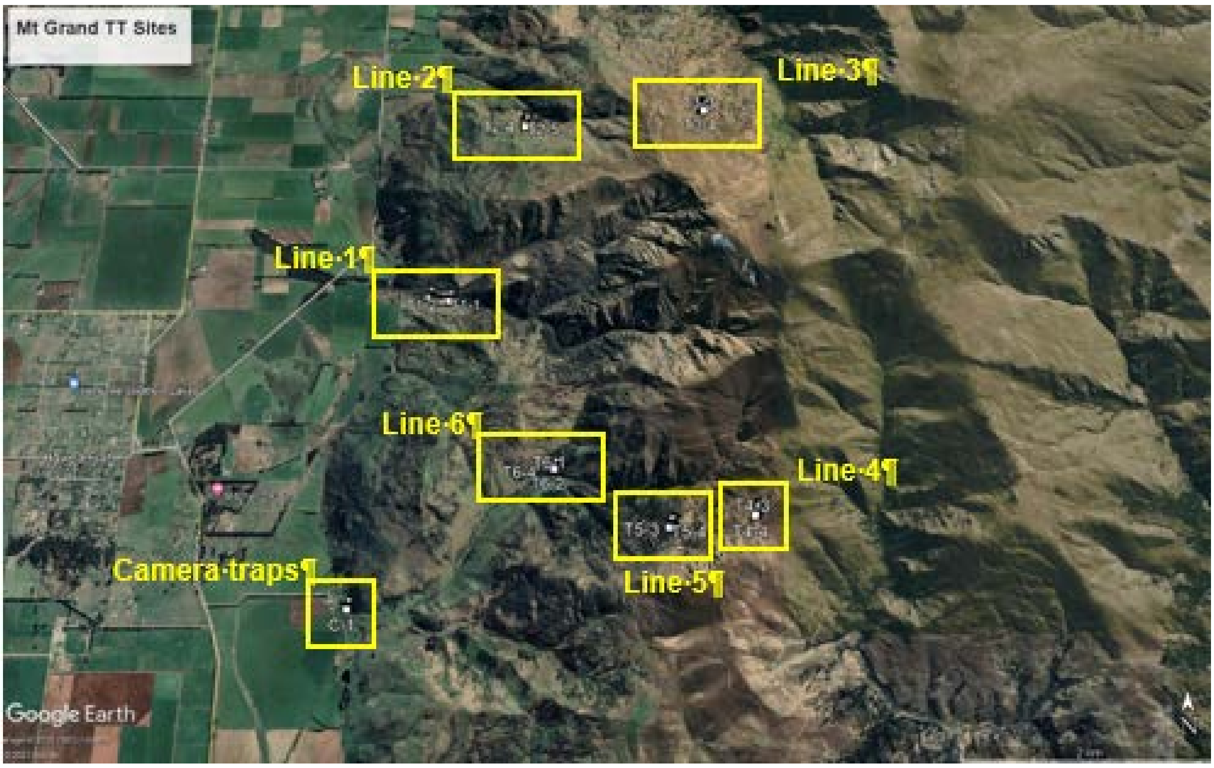

Figure 24.2: Mt Grand Station area.
Sites of tracking tunnels and camera traps deployment are shown

24.3: Results

Appendix 1 shows the results of mammals monitoring with the tracking tunnels and the camera traps

Of all the tunnels, only TT1-5 and TT1-9 detected the presence of hedgehogs; they both belonged to the first line. Those two in particular were set up at elevations of 114 and 105 m a.s.l., respectively. One of the camera traps, which was placed at 409 m a.s.l., took a picture of an individual at night (Figure 24.3).

In Appendix 2 it is possible to see the species observed in proximity to the tunnels where the passage of hedgehogs was detected, and which can potentially fall prey to them; the decision of which taxa to consider and show in the table was based on Jones et al. (2005) and Jones & Norbury (2011), who studied hedgehogs' diet in New Zealand.

Figure 24.3: Picture of a hedgehog taken by one camera trap.

Most of the listed taxa consist of insects (Class Insecta) or spiders (Class Arachnida). Among the first ones, there were 12 taxa belonging to the Order Lepidoptera (butterflies and moths), which were all captured with a blue UV light trap two days prior to the beginning of the study: 10 of these are endemic to New Zealand. The Order Hymenoptera resulted second in terms of quantity of observations and, notably, 9 of them were Buff-tailed bumble bees (*Bombus terrestris*) 3 taxa belonging to the Order Orthoptera were reported, and all of them are endemic.

Regarding the observations of taxa of the Class Arachnida, all of them belong to the Order Araneae; one species, the nursery web spider (*Dolomedes minor*), and the *Hexathele* genus, which comprehends the banded tunnelweb spiders, are endemic to New Zealand. One endemic skink species was observed, the common skink (*Oligosoma polychroma*), also known as northern grass skink, and a Southern Alps gecko (*Woodworthia southern alps*), which is endemic too, was found (the position of the *W. southern alps* observation is not reported because it is obscured on iNaturalist, being that taxa rare and/or threatened). Finally, two observation of California quails (*C. californica*) were made.

24.4: Discussion

The results of the monitoring show a very low number of hedgehogs detections, only at 2 out of 31 tracking tunnels. These two detections occurred only at the first line and specifically at 114 and 105 m a.s.l., even if we had placed multiple other devices at higher altitudes.

These results, together with the detection at the camera trap at 409 m a.s.l., are partly consistent with the literature regarding the altitudinal range where hedgehogs are most likely to be found in New Zealand. In fact, this species is usually abundant in lowlands and its occupancy probability decreases with increasing altitude (Foster et al., 2021a; Mitchell-Jones et al., 1999; Hunter, 2018). Hedgehogs prefer low altitude habitats such as pastures and grasslands, where greater invertebrate abundances and opportunities for shelter and dispersal can be found, especially in dense and long, herbaceous vegetation. Their presence can also be associated with shrub habitats too, where species like matagouri

(*Discaria toumatou*), sweet briar (*Rosa rubiginosa*) and porcupine shrub (*Melicytus alpinus*) can be found, under and close to which hedgehogs can nest (Foster et al., 2021a; Shanahan et al., 2007; Tajik et al., 2019). The area around the paddock where we were able to detect hedgehogs was indeed grassy and with low, herbaceous vegetation and, towards the beginning of the creek, shrubs were occurring with higher density; observations of *D. toumatou*, *R. rubiginosa*, kanuka shrubs (*Kunzea* spp.), butterfly bush (*Buddleja davidii*) and tutu (*Coriaria* spp.), among others, were made during field work (Figure 24.4).

Figure 24.4: Area of deployment of the first line of tracking tunnels

However, the results we obtained were unexpected too. Wiedenmann (2016), in fact, who conducted lizards monitoring with tracking tunnels at Mt Grand, detected hedgehogs' presence between 900 and 1300 m a.s.l. in areas of rocky outcrops, tussock grassland, scree slopes and kanuka shrubland. Such areas are in close proximity to where we placed the other lines of tunnels and have thus very similar characteristics in terms of vegetation. In addition, it is known that hedgehogs are present, even if less frequently, above 1800 m a.s.l. (Foster et al., 2021a, 2021b; Mitchell-Jones et al., 1999); moreover, their presence is associated with tussock habitats too (Foster et al., 2021a; Moss, 1999; Rodriguez Recio et al., 2013).

Tracking tunnels are widely used to monitor invasive mammalian species in New Zealand, including hedgehogs (Anton et al., 2018; Blackwell et al., 2002; Carter et al., 2016; Elliott et al., 2018; Pickerell et al., 2014). Various factors could have potentially played a role in determining the poor detection success we obtained.

Among them, the possibility that hedgehogs in the area had already entered hibernation or intermittent hibernation when field work was being carried out should be considered. In New Zealand, the period when hibernation takes place varies a lot depending on the latitude, and in low areas of the South Island it can occur over several months (Foster et al., 2021b). Furthermore, Foster et al. (2021b) found evidence that intermittent hibernation may begin around mid-March and Moss (1999) estimated that hedgehogs may have entered hibernation in mid-April in two areas of the South Island between 400 and 600 m a.s.l.. It is known that the size of hedgehogs' home range decreases as the cold season approaches and to a relevant extent especially just before hibernation (Moss, 1999; Parkes, 1975): thus, we hypothesize that during our study there could have been a low probability to detect them.

The very wet weather that was encountered during field work could have influenced our results too, since it can affect the detection efficacy of tracking tunnels (Carter et al., 2016; Gillies & Williams, 2013; Pickerell et al., 2014). In addition, hedgehogs spend more time in their nests when the weather is harsh, seeking protection and because the conditions won't allow them to forage (Moss, 1999; Parkes, 1975; Reeve, 1994; Rodriguez Recio et al., 2013).

Another possible factor could be represented by the short timeframe dedicated to field work. In other studies where tracking tunnels were used, in fact, these were left in place for longer periods: for instance, Pickerell et al. (2014) left them operating for 21 nights in an area of South Canterbury and it is also recommended setting the tunnels up at least 3 weeks prior to the first survey session, to allow time for the animals to condition to the devices' presence (Gillies & Williams, 2013). However, it must be noted that Wiedenmann (2016) was able to detect hedgehogs in 5 out of 50 tunnels left operating for 24 hours in the same study area as ours and that Anton et al. (2018) deployed the tunnels for just 4 non-consecutive nights in residential and forested areas of Wellington.

Finally, natural food sources' availability could have influenced our detection success too, with fewer individuals being attracted to the baits (Short et al., 2002; Pickerell et al., 2014). On the other hand, of the two camera traps that were set up, the motion triggered one captured the passage of an individual, even if left operating only for one night.
Camera traps have proven to be successful at monitoring mammalian species in New Zealand, including hedgehogs (Sam, 2011; Latham et al., 2012; Glen et al., 2013; Nichols, 2018). Interestingly, Anton et al. (2018) found that camera traps detected significantly more hedgehogs than tracking tunnels. Our results are thus consistent with the literature and demonstrate that camera traps can be used successfully for future hedgehogs monitoring at Mt Grand. Camera traps are advantageous because they can be left active over longer periods compared to tunnels without any additional effort, and this enables them to detect animals which might occur at low densities too (Nichols et al., 2017; Rowcliffe et al., 2008). However, the probability of detection of cameras, like tracking tunnels, can be influenced by factors such as weather or behaviour of the targeted species.

One final aspect with important implications for biodiversity conservation is the presence of potential prey species in the area where hedgehogs' passage was detected.

Around the lucerne paddock and at the beginning of Hospital Creek, there were numerous observations of individuals of taxa belonging to the Order Lepidoptera (butterflies and moths) and Hymenoptera (bees, wasps and ants). These are known to be typical hedgehogs' prey (Jones et al., 2005, 2013; Jones & Norbury, 2011). Jones et al. (2005) and Jones & Norbury (2011) found that the most frequently observed food item of captured hedgehogs were beetles (Coleoptera) and that earwigs (Dermaptera) occurred with a relevant frequency too; individuals of these two orders were observed much less in the area. It is possible to hypothesize that, besides Lepidopterans and Hymenopterans, the most frequently detected and thus possibly contributing importantly to prey abundance, Coleopterans can still be heavily targeted by hedgehogs in the area, since they provide the majority of energy intake (Reeve, 1994). Moreover, the high number of bumblebees observed at the paddock could suggest that such rich aggregations could be targeted and exploited by hedgehogs (Jones et al., 2005).

The observations of a common skink, a Southern Alps gecko and California quails suggest that lizard and avian fauna (regarding the latter especially eggs and chicks) could represent potential prey too (Jones et al., 2005, 2013; Jones & Norbury, 2011; Lettink & Monks, 2019; Norbury et al., 2013).

The fact that 20 out of the 33 observed taxa are endemic is certainly of conservation concern. Notably, the Order Lepidoptera comprehends the higher number of endemic taxa and each of the three taxa of the Order Orthoptera is endemic too. Furthermore, the New Zealand grasshopper (*P. marginale*) and the common skink (*O. polychroma*) were already reported to be preyed upon by hedgehogs (Jones et al., 2005).

24.5: Conclusion

The results obtained from this study allow us to confirm the presence of hedgehogs at Mt Grand Station. However, because of the poor detection success we reported for the tracking tunnels and given that the species is known to be more broadly present in the area, we recommend that future monitoring effort should be carried out with different methods. Specifically, it would be preferrable to conduct it over a longer time span, in the austral summer and spring seasons and with better weather conditions. Additional surveys could be carried out with alternative monitoring tools too, which have been found to be more effective than the standard-sized tunnels, such as cat tracking tunnels (Pickerell et al., 2014), to test if different outcomes can be obtained. Furthermore, we are able to hypothesise that hedgehogs inhabiting the area can prey upon several endemic species.

Therefore, we highlight that future assessments of hedgehogs' presence at Mt Grand are strongly recommended and that it can be a powerful tool to inform how to best implement conservation measures in the area.

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24.7: Appendices

24.7.1: Appendix 1

Table 24.1: Results of mammal monitoring.

Tunnel ID	Device	Species	Position	Altitude
TT1-1	TT WT	-	44°39'3.30"S 169°19'19.32''E	130 m
TT1-2	TT WT	-	44°39'3.37"S 169°19'18.07''E	126 m
TT1-3	TT WT	-	44°39'3.38"S 169°19'16.88''E	117 m
TT1-4	TT WT	-	44°39'3.25"S 169°19'16.02''E	115 m
TT1-5	TT WT	E. europaeus	44°39'3.25"S 169°19'14.94''E	114 m
TT1-6	TT WT	-	44°39'2.74"S 169°19'14.04''E	113 m
TT1-7	TT WT	-	44°39'2.38"S 169°19'13.14''E	111 m
TT1-8	TT WT	M. musculus	44°39'1.88"S 169°19'12.40''E	106 m
TT1-9	TT WT	E. europaeus	44°39'1.94"S 169°19'11.44''E	105 m
TT1-10	TT WT	-	44°39'1.94"S 169°19'10.44''E	103 m
TT2-1	TT	-	44°38'22.43"S 169°19'51.50''E	986 m
TT2-2	TT	-	44°38'22.76"S 169°19'51.36''E	992 m
TT2-3	TT	-	44°38'23.05"S 169°19'51.36''E	992 m
TT2-4	TT	M. musculus	44°38'23.49"S 169°19'50.96''E	993 m
TT2-5	TT	Card Missing	44°38'24.21"S 169°19'51.29''E	993 m
TT3-1	TT	-	44°38'23.86"S 169°20'56.02''E	1251 m
TT3-2	TT	-	44°38'24.00"S 169°20'56.29''E	1251 m
TT3-3	TT	-	44°38'24.20"S 169°20'56.76''E	1251 m
TT3-4	TT	-	44°38'24.44"S 169°20'57.20''E	1253 m
TT4-1	TT	-	44°40'8.19"S 169°21'11.30''E	1079 m
TT4-2	TT	-	44°40'8.23"S 169°21'11.89''E	1082 m
TT4-3	TT	-	44°40'8.57"S 169°21'11.76''E	1084 m
TT4-4	TT	M. musculus	44°40'9.11"S 169°21'11.13''E	1089 m
TT5-1	TT	M. musculus	44°40'10.87"S 169°20'44.60''E	947 m

TT5-2	TT	-	44°40'10.91"S 169°20'44.01''E	948 m
TT5-3	TT	M. musculus	44°40'11.03"S 169°20'43.55''E	947 m
TT5-4	TT	M. musculus	44°40'11.31"S 169°20'43.02''E	948 m
TT6-1	TT		44°39'54.39"S 169°20'2.95''E	548 m
TT6-2	TT		44°39'54.13"S 169°20'2.17''E	545 m
TT6-3	TT		44°39'54.03"S 169°20'1.31''E	543 m
TT6-4	TT	Card Missing	44°39'54.04"S 169°20'0.33''E	541 m
C1	Cameras	T. vulpecula, E. europaeus, Rattus spp.	44°40'29.22"S 169°18'50.32''E	409 m

24.7.2: Appendix 2

Table 24.2: Potential hedgehogs' prey species observed in proximity to the tunnels which detected hedgehogs' passage

Class	Order	Observed taxon	Status*	Position	Time
Insecta	Lepidoptera	I. mutans		44°39'1.18"S 169°19'22.28''E	18/03/23
		I. propria		44°39'1.18"S 169°19'22.28''E	18/03/23
		I. lignana		44°39'1.18"S 169°19'22.28''E	18/03/23
		O. vitellus		44°39'1.18"S 169°19'22.28''E	18/03/23
		O. ramosellus	N	44°39'1.18"S 169°19'22.28''E	18/03/23
		Scoparia spp.	N	44°39'1.18"S 169°19'22.28''E	18/03/23
		E. submarginalis		44°39'1.18"S 169°19'22.28''E	18/03/23
		E. rosearia		44°39'1.18"S 169°19'22.28''E	18/03/23
		C. semiferana		44°39'1.18"S 169°19'22.28''E	18/03/23
		Pseudocoremia spp.		44°39'1.18"S 169°19'22.28''E	18/03/23
		Gymnobathra spp.		44°39'1.18"S 169°19'22.28''E	18/03/23
		A. aegrota		44°39'1.18"S 169°19'22.28''E	18/03/23
	Hymenoptera	B. terrestris	IN	44°39'3.55"S 169°19'21.64''E	21/03/23
				44°39'2.56"S 169°19'12.91''E	21/03/23
				44°39'3.91"S 169°19'25.70''E	20/03/23
				44°39'4.25"S 169°19'24.18''E	20/03/23
				44°39'4.53"S 169°19'24.18''E	20/03/23
				44°39'4.61"S 169°19'24.22''E	20/03/23
				44°39'4.96"S 169°19'24.66''E	20/03/23
				44°39'5.17"S 169°19'24.33''E	20/03/23
				44°39'5.24"S 169°19'24.61''E	20/03/23
		P. advena		44°39'1.18"S 169°19'22.28''E	18/03/23
		Austroponera spp.	N	44°39'4.66"S 169°19'34.93''E	20/03/23
		N. ephippiata		44°39'1.18"S 169°19'22.28''E	18/03/23

	Orthoptera	S. australis		44°39'0.84"S 169°19'16.68''E	21/03/23
		P. marginale	N	44°39'6.72"S 169°19'1.50''E	19/03/23
				44°39'0.45"S 169°19'13.86''E	21/03/23
		B. nigrovus		44°39'4.45"S 169°19'24.61''E	20/03/23
				44°39'0.88"S 169°19'11.56''E	21/03/23
	Coleoptera	Byrrhidae	N	44°39'4.39"S 169°19'34.90''E	20/03/23
		P. reticularis		44°39'5.98"S 169°19'4.45''E	19/03/23
	Dermaptera	F. auricularia	IN	44°39'4.34"S 169°19'31.30''E	20/03/23
Arachnida	Araneae	Gnaphosidae		44°39'4.25"S 169°19'28.12''E	20/03/23
		D. minor		44°39'4.56"S 169°19'34.42''E	20/03/23
		Uliodon spp.		44°39'3.98"S 169°19'25.42''E	21/03/23
		P. opilio	IN	44°39'3.85"S 169°19'17.35''E	20/03/23
		Hexathele spp.		44°39'2.32"S 169°19'20.39''E	19/03/23
				44°39'2.34"S 169°19'20.13''E	20/03/23
		Clubiona spp.		44°39'2.34"S 169°19'20.13''E	20/03/23
		Sidymella spp.		44°39'4.03"S 169°19'29.11''E	18/03/23
		N. coloripes	IN	44°39'3.26"S 169°19'27.94''E	21/03/23
Reptilia	Squamata	O. polychroma	NT	44°39'4.34"S 169°19'31.69''E	21/03/23
		W. southern alps	At risk - declining		
Aves	Galliformes	C. californica	IN	44°39'6.29"S 169°19'19.00''E	20/03/23
				44°40'33.05"S 169°18'56.59''E	21/03/23

Words in bold: endemic taxon; N: Native taxon; IN: Introduced taxon; NT: Not Threatened taxon.
* According to the New Zealand Threat Classification System and the New Zealand Checklist.

Chapter 25: Do European Rabbits have the Ability to Cause Large Scale Soil Erosion on Mt Grand Station?

Rebecca Anderson

Abstract

The European rabbit (*Oryctolagus cuniculus*) is a species of rabbit from the Iberian Peninsula. They were introduced into New Zealand as a food source and for game hunting in the 1830's and it was not long before the population reached unprecedented levels throughout most of New Zealand, but particularly in Central Otago. Mt Grand Station, overlooking Lake Hawea in Central Otago, is a Lincoln university run high country farm. Mt Grand has a large flock of merino sheep and a smaller herd of breeding cattle. Due to the location of Mt Grand Station in Central Otago, there is a large population of rabbits which cause widespread destruction predominately in the lower altitude paddocks of the station. The rabbits have; in multiple cases, used the hillside for burrows as it is easier to dig. Due to their burrowing habits, there is potential for soil erosion on the lower levels of the farm due to the large caverns created by the large number of rabbits on the farm. This project aimed (i) to evaluate the effects of rabbits are grazing herbivores at Mt Grand Station, and (ii) to determine whether or not the rabbits burrowing nature on Mt Grand Station could affect the rate soil erosion, which is arguably a large factor to consider on any high-country station.

Key words: Agriculture, conservation, pest management, *Oryctolagus cuniculus*, Mt Grand station, control, erosion

25.1: Introduction

Mt Grand Station is a high country station located in Hawea, Central Otago (Maxwell et al., 2016). The Station, which is operated by Lincoln University is a 2,131 ha commercial sheep and beef farm. After tenure review, Mt Grand boasts 1,607 ha of predominately steep hill country with the maximum altitude at 1445 m above sea level (Wei et al., 2022). The nature of high-country soils is much the same to those found at Mt Grand. The soils have been created over millennia from the breakdown of loess, schist and alluvial gravels; they are prone to erosion by wind and water as they are light soils (Wei et al., 2022). The effect of grazing animals on this landscape can be a causation of the erosion on high country farms.

The European rabbit was introduced to New Zealand in the early to mid 1800's, and certainly prior to 1838 (Fox, 2008). The European rabbit was suited to the drier climates in South Canterbury and Central Otago, where the grass was shorter and the weather was similar to the Mediterranean climate of which they originate (Fox, 2008). Prior to the 1880's rabbit had become destructive in their population size, and had begun to threaten New Zealand's fragile agriculture industry (Conservation, 2023). In New Zealand, rabbits are described as an agricultural pest species as 7-10 rabbits are able to eat as much as one ewe (Conservation, 2023), they provide a food source for vectors of bovine tuberculosis and they have the ability to render farms useless due to burrowing and scraping increasing soil erosion (Conservation, 2023). On Mt Grand Station, rabbits are found in the lower altitude paddocks where they are able to find shelter from the changeable weather under the pine trees and in the shrub land. The rabbits at Mt Grand Station burrowing into the hillsides as the soil is easier to dig into.

25.2: Materials and Methods

This study was carried out at Mt Grand Station, Central Otago. For the purpose of this study, I set out two types of trail cameras on day 1, both in the Fern Spur block in a group of fenced

Figure 25.2: Trail cameras and carrot bait placement

Figure 25.1: Large rabbit hole in foreground and location of trail cameras

off pine trees. One camera that I used was a motion trigger camera (Bushell Aggressor) and the second was a timelapse camera (Kinopta Blackeye) that had the ability to run over several days. These cameras were set up and left overnight to potentially catch any rabbit interaction with the carrot lure. For the rabbit lure, I cut up 1 kg of carrots prior to leaving for Hawea. James, Anna and I then set up the trail cameras on a tree and on a tripod, then aimed them towards the rabbit bait which we put on the ground in front of a series of large rabbit holes. On day 2, I searched for signs of rabbits but walking around the perimeter of the lower paddock in the Hospital Gulley block. As I walked around the perimeter, I searched for signs of rabbits by looking out for rabbit droppings and rabbit holes.

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25.3: Results

Following the setting out of trail cameras and doing a perimeter walk of the lower-level Hospital Gulley paddock, there was sufficient evidence to conclude there are a significant number of rabbits at Mt Grand Station. Where the trail cameras were placed in the Fern Spur block, there were large rabbit holes scattered throughout the shaded hillside as shown in the Figures 25.2 and 25.3. Evidence of rabbits at Mt Grand Station could clearly be seen in the Hospital Gulley block as large rabbit hole networks and burrows could be seen on the hillside located on the right side of the lower paddock (Figure 25.4).

Figure 25.3: Image showing a rabbit hole in Fern Spur

Figure 25.4 Image showing Hospital Gulley rabbit holes beneath Kānuka (Kunzea ericoides)

Along with the rabbit holes strewed throughout the hillsides, evidence of rabbits on Mt Grand Station were fresh rabbit droppings and a dead rabbit along the fence line in Hospital Gulley.

25.4: Discussion

Mt Grand Station had extensive evidence of the presence of rabbits. In the lower paddock of Fern Spur block and Hospital Gulley block, rabbits were clearly present as large burrows and warren systems were scattered through the hillside of both blocks. The hillside paddock in Hospital Gulley was littered with rabbit holes amongst the tree roots. Fresh rabbit droppings were also found in hospital gulley, suggesting that rabbits were around prior to the field tour group arriving in the paddock.

During the field tour to Mt Grand Station, the weather was extremely wet and changeable, not suitable for rabbits.limiting the opportunity for field observation In a study by Palomares (2003) concluded that the density of rabbits dramatically decreased in years when there is significant rain in comparison to drought years. This study also concluded that rabbit warrens decreased along with the number of entrances during heavy rainfall. However, another study found that after heavy rainfall, rabbits had an increased breeding probability, which was likely due to the increase of food availability after a period of rainfall (Wells et al., 2016). High country farms within the South Island have tendency to have lower rainfall at the higher altitudes and therefore can provide rabbits the right conditions to grow to extremely high densities, where the natural pest control mammals (cats and mustelids) are unable to keep the numbers low (Norbury & McGlinchy, 1996). It is a well-known fact that rabbits are prolific herbivores who can devour significant levels of food. Their eating habits are a serious problem not only in the high country of New Zealand, but also in many secluded islands around the planet. In the north Atlantic ocean, a chain of islands called the Azores archipelago became an island where the European rabbit was introduced in the 15th century (Bried et al., 2009). The rabbits caused much of the vegetation cover to reduce significantly over the island, thus dramatically increasing the rate of soil erosion on the windswept island (Bried et al., 2009). The area of Otago where Mt Grand is located is susceptible to predominately wind erosion due to the lack of grassland vegetation cover, which is further depleted by overgrazing by sheep, cattle, deer and rabbits (Raab et al., 2022).

To decrease the rate of erosion in the soil caused by rabbits, undertaking control measures may be necessary. On the Azores archipelago, the rabbits were poisoned using cereal baits containing 20 ppm of brodifacoum (Bried et al., 2009). The poisoning was carried out three times and rabbits were successfully eradicated off the island. Although the Azores archipelago is a much smaller area, widespread poisoning of rabbits on Mt Grand would have the potential to reduce the problem. Another control option would be to allow hunting groups to come onto the property and shoot the rabbits as game. With the station having good four-wheel drive tracks across the farm, a great deal of game shooting could take place onto the farm, reducing the rabbit numbers significantly. With sheep grazing periodically, and much of the overgrazing being caused by deer and rabbits, there is the potential to greatly improve the soil erosion rate on the station by reducing the number of mammalian herbivory in the form of pest species, therefore decreasing the rate of soil erosion.

25.5: Conclusion

To conclude, soil erosion occurs on high country farms due to wind, rain and importantly overgrazing. Overgrazing reduces the amount of vegetation cover which allows greater levels of soil erosion from wind and rain. Burrowing and herbivory behaviour by rabbits on Mt Grand Station can increase the amount of soil erosion through the reduction of the vegetation cover and burrowing out soil that is being held in by the tree roots. Reduction of soil erosion can take place by reducing the number of rabbits and other grazing pest mammal species by poison and game hunting practises.

25.6: References

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Chapter 26: Inventory of Birds at Mt. Grand Station

Colin Jensen

Abstract

The transformation of native landscapes for pastoral farming has had significant economic benefits for New Zealand, but these changes present challenges for native biodiversity. While some research on these challenges has been conducted, many gaps in knowledge exist, and the exact dynamic between native biodiversity and agroecosystems is unclear. This study focuses on the avian biodiversity of Mt. Grand Station, a high country agroecosystem in Otago, New Zealand, with the aim of establishing a base inventory of bird diversity present at the station. Standard five-minute bird counts, acoustic recordings, and incidental observations were recorded over several days in March 2023. A total of 25 bird species, including 10 native and 15 introduced species, were observed. Two species considered to be at risk by the Department of Conservation, the New Zealand falcon and pipit, were recorded. Results from this study showed that native bird diversity was not skewed towards higher elevations and away from anthropogenic pressures. These outcomes suggest that even in areas heavily influenced by agriculture, native bird species can persist. This highlights the potential for a combination of land sparing and sharing approaches to conserve avian biodiversity in agroecosystems. Conservation focuses and research could be directed towards species of concern, such as the New Zealand falcon and pipit. However further research into all native species is needed to confirm species presence, estimate abundances, and understand the ecological requirements of native birds in high country agroecosystems. This study provides a valuable baseline for future investigations and contributes to the understanding of the relationship between birds and pastoral farming in New Zealand.

Key words: Birds, Conservation, Five-minute bird counts, Agroecosystem, Pastoral farming, Native avifauna

Brown creeper (*Mohoua novaeseelandiae)* photographed at Mt. Grand

26.1: Introduction

Pastoral farming in the form of sheep, beef, and dairy production is a major industry throughout New Zealand. It is a primary driver of the nation's economy, being responsible for more than 35% of all export earnings (Norton et al., 2020), and a major user of land, with almost half of all land countrywide currently being used for production in these three industries (Pannell et al., 2021). In order for agriculture to be possible at this scale, significant changes have been made to New Zealand's landscape over the last several hundred years (MacLeod et al., 2006). Prior to the arrival of humans, more than 85% of New Zealand was covered in forests; today, that number sits at 25% (Perry et al., 2014).

While these changes in land use and composition have resulted in successes for the economy of a country dependent on its agricultural outputs, the same cannot be said for indigenous avifauna. Since the arrival of humans in New Zealand, 40-50% of indigenous bird species have gone extinct (Doherty et al., 2016). Today, New Zealand is still home to more than 200 native bird species, however, 178 of those are considered by the Department of Conservation (DOC) to be threatened or at-risk (Robertson et al., 2021). Although introduced predators are often flagged as the primary threat, there is growing concern that agriculture and its intensification could further exacerbate the problems native birds are facing (MacLeod et al., 2012). While some research has be done on the relationship between avian diversity and agroecosystems in New Zealand (e.g. MacLeod et al., 2012, MacLeod et al., 2009), there remain many gaps in knowledge, and it is unclear exactly how native birds respond to landscape alterations driven by pastoral farming practices (MacLeod et al., 2012).

Although the composition of native biodiversity in pastoral farm landscapes across New Zealand has been altered significantly (Norton et al., 2020), there is a relatively large amount of native vegetation on pastoral farmland. Nearly 25% of the remaining indigenous vegetation across New Zealand is located on land used for sheep, beef and dairy production. This means that more than 10% of all land in New Zealand is pastoral farmland covered with native vegetation (Pannell et al., 2021). Because the survival of native avifauna is intrinsically connected with native flora (Kelly et al., 2003), this land, if managed correctly, has the potential to be a significant source of habitat for native birds. While recent changes in tenure review policies have left the future management of pastoral leases and farmland uncertain (Brower et al., 2020), what remains clear is that management decisions need to be directed and focused. Regardless of the bureaucratic channels through which conservation efforts are organized, the base of these decisions needs to lie within scientific research and data (Downey et al., 2021). To understand how to best manage pastoral farmland and strike a balance between agriculture and conservation, it is imperative to understand the biodiversity present in a given agroecosystem.

The purpose of this research is to establish a base inventory of avian biodiversity for one such high country agroecosystem. The study area for this project is the Mt. Grand Station, located near Hawea in Otago, New Zealand. The Mt. Grand Station is owned and operated by Lincoln University, and is composed of 2,136 ha spread between 400 and 1447 meters (Provost 2018). Work investigating clovers (Wei et al. 2022), soils (Maxwell et al. 2016), and tussock grasses (Duncan et al., 2001) has been done at Mt. Grand, however hardly any published data exists on its avian biodiversity. The most recent tenure review presents a relatively brief overview of the birds that were seen during surveys of the area, totalling to 12 species, 5 of which are native (Department of Conservation, 2005). No indication of survey effort was given, nor were the specific localities of each observation. In order to gather a more comprehensive overview of bird diversity at Mt. Grand, this study employed a series of sampling strategies across several days in March 2023.

26.2: Materials and Methods

Standard five-minute bird counts (5MBC) were conducted at 10 different sites throughout the Mt. Grand area (see Figure 26.1), covering a range of habitats and land use types. All species identified via sight or sound in the five-minute period were recorded. Most counts were conducted between 09:00 and 13:00. Because some species are more active outside of these hours, AR4 V1.4 acoustic recorders were placed near three of the 5MBC sites to increase the likelihood that all species in an area would be accounted for. These recordings were analysed using audio spectrograms in Kaleidoscope version 5.5.2, with a primary focus placed on recordings made during the hours around dawn (6:45-8:45) and dusk (18:55-20:55), as this is when many species are most active, and times when 5MBC were not conducted. Incidental observations (see Figure 26.1) made outside of 5MBC's were included in the species totals.

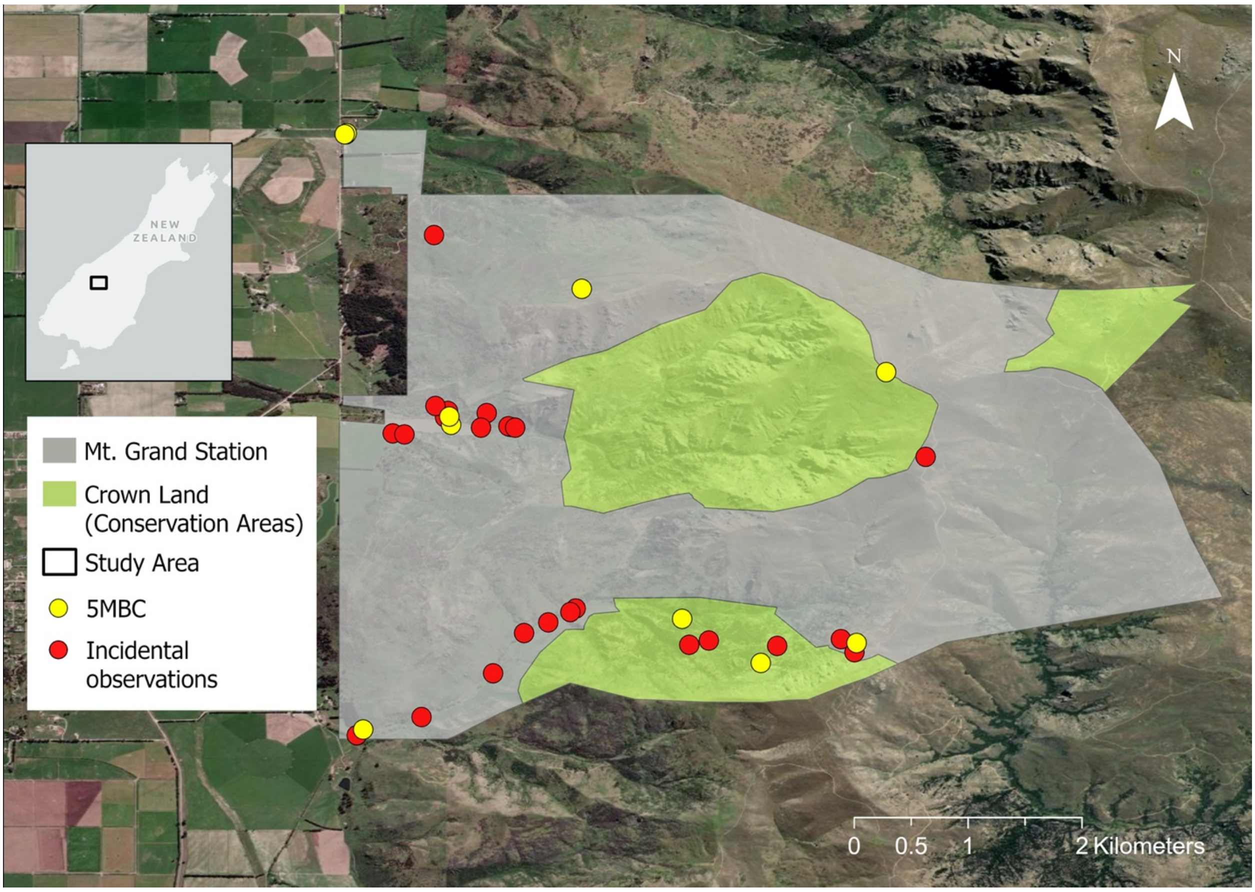

Figure 26.1: Map of Mt. Grand station showing the location of each 5MBC (yellow) and all incidental observations of native species (red). Areas operated by the Mt. Grand Station are shown in grey, while Crown land is shown in green

Observations uploaded to iNaturalist in the Mt. Grand Biodiversity Project were also included in the incidental observation data. Specific GPS coordinates were recorded for every observation, although some incidental observations made at the same time and within a close proximity (<100 meters) of each other were given the same coordinates. Elevation data for each point was determined after the study (see Tables 26.3 and 26.4 in Appendix). Observations from iNaturalist were checked individually for location accuracy, and any data points located outside of the Mt. Grand study area were not included in the results. Most of the observations in this study were made on station land, however some were made in DOC managed conservation areas. Observation efforts took place between the 19th and 21st of March 2023, and were spread out across the station, with sampling efforts primarily made along Lagoon Creek, Hospital Gulley, and the 4x4 track leading through the alpine areas of the station.

26.3: Results

In total, 25 species, including 10 native and 15 introduced species were seen during survey efforts at Mt. Grand (see Tables 26.1 and 26.2). 19 species (seven native, 12 introduced) were observed during five-minute bird counts. No species were seen exclusively in the bird counts, while three species (one native, two introduced) were only observed incidentally. One additional species (rock pigeon (*Columba livia)*) was only detected during the audio recordings. All species except for three (pipit (*Anthus novaeseelandiae)*, chukar (*Alectoris chukar)*, skylark (*Alauda arvensis)*) were recorded via two separate methods, and a majority of species (15) were observed during all three sampling techniques. Of the ten native species, all but one (brown creeper (*Mohoua novaeseelandiae)*) were observed on land managed by the Mt. Grand Station. Two species considered by the Department of Conservation to be at-risk, the New Zealand falcon (*Falco novaeseelandiae)* and the New Zealand pipit, were seen during the survey efforts

Table 26.1: List of all native bird species seen at Mt. Grand, including the sampling method(s) through which each was detected.

Common name	Scientific name	Method of detection
Bellbird	Anthornis melanura	5MBC, incidental, audio recording
Brown Creeper	Mohoua novaeseelandiae	incidental, audio recording
Grey warbler	Gerygone igata	5MBC, incidental, audio recording
New Zealand falcon	Falco novaeseelandiae	5MBC, incidental
New Zealand fantail	Rhipidura fuliginosa	5MBC, incidental, audio recording
New Zealand pipit	Anthus novaeseelandiae	incidental
Silvereye	Zosterops lateralis	5MBC, incidental, audio recording
Spur-winged plover	Vanellus miles	5MBC, incidental, audio recording
Swamp harrier	Circus approximans	5MBC, incidental
Tomtit	Petroica macrocephala	incidental, audio recording

Table 26.2: List of all introduced bird species seen at Mt. Grand, including the sampling method(s) through which each was detected.

Common name	Scientific name	Method of detection
Australian magpie	Gymnorhina tibicen	5MBC, incidental, audio recording
California quail	Callipepla californica	5MBC, incidental, audio recording
Chaffinch	Fringilla coelebs	5MBC, incidental, audio recording
Chukar	Alectoris chukar	incidental
Common starling	Sturnus vulgaris	5MBC, incidental, audio recording
Dunnock	Prunella modularis	5MBC, incidental, audio recording
Eurasian blackbird	Turdus merula	5MBC, incidental, audio recording
Eurasian skylark	Alauda arvensis	incidental
European goldfinch	Carduelis carduelis	5MBC, incidental, audio recording
European greenfinch	Chloris chloris	5MBC, incidental, audio recording
House sparrow	Passer domesticus	5MBC, incidental
Lesser redpoll	Acanthis flammea	5MBC, incidental, audio recording
Rock pigeon	Columba livia	audio recording
Song thrush	Turdus philomelos	5MBC, incidental, audio recording
Yellowhammer	Emberiza citrinella	5MBC, incidental

26.4: Discussion

26.4.1: General Takeaways

Results from this study show a broad diversity of both native and introduced species across Mt. Grand. Twice as many native and introduced species were observed in this study than were mentioned in the most recent tenure review (Department of Conservation, 2005). Among the species observed, there were a few notable observations and omissions. Using the New Zealand median expected occupancy data from the DOC as a reference (Walker & Monks 2017), several species with relatively low expected occupancy values were seen. The New Zealand falcon, tomtit, brown creeper, and New Zealand pipit were the four native species with relatively low occupancy probabilities seen during this study. While New Zealand falcons are known to frequent high country environments, they are generally rare (Seaton and Hyde, 2013), and the relatively high number of observations (5) made during this study was encouraging. There were also several species with relatively high expected occupancy values that were not seen during the course of this study. These included the welcome swallow, paradise shelduck, and the black-backed gull. The paradise shelduck was mentioned in the most recent tenure review report, so it is likely that this species is present at Mt. Grand, but was just not detected during this study. Moreover, absences from the results of this study could be due to a species truly not being present at Mt. Grand, or they could be due to limitations of the survey (duration and inclement weather). The ultimate absence of a species at Mt. Grand should not be assumed until more comprehensive surveys have been conducted.

In addition to a few unexpected species being observed, the results of this study also showed some unexpected trends in distributions. Literature review and recently described observations resulted in a pre-survey expectation that native bird distribution at Mt. Grand would likely be skewed towards higher elevations (e.g. Walker et al., 2019). It was expected that lower elevation areas, where predator abundance and human influence is highest, would have relatively low levels of bird diversity. However, results from this study suggest that this is not necessarily the case at Mt. Grand. While definitive statements about bird abundance cannot be made, these results show that many native species are present, even in the more influenced areas. Eight of the ten native species seen during the study were seen at elevations below 500 meters and in environments that are at a close proximity to areas of more intense agriculture. One species, the brown creeper, was only seen in a section of DOC managed conservation land that is adjacent to the Mt. Grand Station. Overall, these results suggest that even in landscapes heavily influenced by pastoral farming, native bird species can persist, and they help paint a compelling picture about the future of conservation work in these areas.

An ongoing topic in conservation and agriculture is the debate between land sharing and land sparing (Paul and Knoke 2015). Some argue for the land sparing approach, emphasizing the creation of conservation areas free from the influence of agriculture. Others argue for the sharing approach, where farms adopt more environmentally friendly practices that allow land to be used for both conservation and agriculture. Results from this study loosely suggest that an either/or approach to the sparing versus sharing question may not be the best solution. While some species (i.e. brown creeper) may possibly be more abundant in conservation areas, this study shows that many species are still found in active farmland. Additionally, research shows that more mobile species like birds require habitat connectivity in agroecosystems, and not just a patchwork of fragmented conservation areas (Zhang et al., 2021). This supports a growing consensus that a combination of sparing and sharing is likely the best way forward (Norton et al., 2020). Unfortunately, agriculture practices that are the most conservation-conscious are often not the most economically viable for farmers. Understanding and implementing agricultural practices that can enable pastoral land to be beneficial to both the farmer and to native biodiversity could be the key to a stable future for New Zealand's agroecosystems, and further research into practices that would make this possible is needed.

26.4.2: Conservation Focuses

Two species seen during this study, the New Zealand falcon and the New Zealand pipit, are considered by the Department of Conservation to be at-risk. Both species are experiencing declines in population, with the southern population of the falcon (*F. n.* "southern") classified as endangered (Robertson et al., 2021). The falcon was observed at several locations across the station, including lower elevation and alpine environments. The pipit was observed exclusively in the alpine zone, above 1300m. Considering that both species were observed on multiple occasions (5 – falcon, 2 – pipit), it appears that the habitat at Mt. Grand could be quite suitable for them. Future research into their abundance and ecological requirements at Mt. Grand could be beneficial to guiding conservation decisions and determining if further action to protect these species in this area is necessary.

26.4.3: Future Studies

While this study has greatly increased the knowledge of species present at Mt. Grand, many unknowns still exist. Although best attempts were made to gather enough observations to give a comprehensive overview of bird diversity, limitations in survey duration and weather conditions mean that some species may have been missed. Future studies encompassing broader temporal (more time, in different seasons/weather) and spatial (all areas of the station) ranges could help solidify our understanding of the native birds present at Mt. Grand. In addition to confirming species presence/absence, it is equally important to understand if a species has an adequate population size to remain stable and viable. As such, studies aiming to estimate abundances and densities of native bird species at Mt. Grand could be very beneficial. Furthermore, results from these studies could be compared with results from other areas that have not been as affected by pastoral farming, and any differences in diversity and abundance could be analysed. Generally speaking, because relatively few studies have been done on birds in high country agroecosystems, any studies that could further our understanding of the relationship between birds and high country farms would be useful. While the results from this project are merely a first step towards understanding birds in high country agroecosystems, continuing research and conservation efforts at Mt. Grand have potential to be a model for other high country stations. As there are currently 171 Crown pastoral leases covering 1.2 million ha of South Island high country (Parliamentary Service 2020), research efforts in these areas could make a significant impact on our ability to maintain an appropriate balance between agriculture and biodiversity conservation.

26.5: Conclusion

Efforts from this study suggest that there is a broad diversity of both native and introduced bird species present at Mt. Grand. Ten native species, including two that are at-risk were observed at various locations across the station. Results from this study suggest that future work should be done to understand how conservation efforts at Mt. Grand could be implemented to protect these species. Because many native bird species were observed in heavily farmed areas, this research also suggests that promoting a combination of land sharing and land sparing techniques could be the most beneficial for conserving avian biodiversity. While this study has provided an important first step towards understanding birds in a high country agroecosystem, future studies investigating the true abundance and densities of native bird species at Mt. Grand would be beneficial.

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26.7: Appendix

Table 26.3: Observation data from all ten five-minute bird counts, including elevation at each site. Count data is the number of individuals seen per each species

5MBC number	Latitude	Longitude	Elevation (meters)	Species	Count
1	-44.62797	169.31317	397	Swamp harrier	1
				Australian magpie	1
				New Zealand fantail	1
				Silvereye	1
				European starling	16
				Song thrush	1
				Eurasian blackbird	2
				House sparrow	5
				Common chaffinch	1
				European goldfinch	4
2	-44.62806	169.31301	395	Australian Magpie	1
				Silvereye	3
				European Starling	11
				House Sparrow	11
				Common Chaffinch	6
				European Greenfinch	1
				European Goldfinch	4
3	-44.675	169.31448	423	California Quail	7
				Swamp Harrier	1
				New Zealand Falcon	1
				New Zealand Bellbird	2
				Gray Gerygone	1
				New Zealand Fantail	2
				Silvereye	3
				Eurasian Blackbird	2
				Dunnock	2
				Common Chaffinch	3
4	-44.65095	169.3214	480	New Zealand Bellbird	1
				New Zealand Fantail	2
				European Starling	1
				Eurasian Blackbird	1
				Common Chaffinch	3
				Lesser Redpoll	1
				European Goldfinch	3
				Yellowhammer	2
5	-44.65032	169.32126	476	New Zealand Bellbird	2
				Gray Gerygone	2
				New Zealand Fantail	2
				Silvereye	7
				Common Chaffinch	2
				European Goldfinch	3
				Yellowhammer	1
6	-44.640226	169.331711	999	Yellowhammer	4
				European Goldfinch	5
7	-44.64682	169.355704	1120	Swamp Harrier	1
8	-44.668937	169.353301	1103	No birds detected	N/A
9	-44.669739	169.345847	958	Grey Warbler	3
				Silvereye	2
				Song Thrush	1

10	-44.666262	169.339642	638	Common Chaffinch	17
				Silvereye	6
				European Goldfinch	2
				Eurasian Blackbird	4
				New Zealand Bellbird	2
				Grey Warbler	2
				Dunnock	5
				Yellowhammer	3
				Lesser Redpoll	2
				New Zealand Fantail	2

Table 26.4: All observations of native bird species recorded via incidental observation, audio recorder, or through iNaturalist. Only native bird species are included

Species	Latitude	Longitude	Method	Elevation (meters)
Bellbird	-44.65173	169.31774	Incidental	474
	-44.650377	169.320925	Incidental	469
	-44.666551	169.329060	Incidental	518
	-44.65032	169.32126	Auditory recorder	472
	-44.669739	169.345847	Auditory recorder	975
	-44.650025	169.324209	iNaturalist	520
	-44.651181	169.323769	iNaturalist	497
Brown creeper	-44.669739	169.345847	Incidental	975
	-44.669739	169.345847	Auditory recorder	975
	-44.668406	169.347139	Incidental	933
Grey warbler	-44.666551	169.329060	Incidental	518
	-44.650377	169.320925	Incidental	469
	-44.65032	169.32126	Auditory recorder	472
	-44.669739	169.345847	Auditory recorder	975
	-44.665459	169.331230	Incidental	528
	-44.65173	169.31774	Incidental	474
New Zealand falcon	-44.651647	169.316816	iNaturalist	460
	-44.668909	169.353213	Incidental	1099
	-44.667868	169.352158	iNaturalist	1027
	-44.65173	169.31774	Incidental	474
New Zealand fantail	-44.65173	169.31774	Incidental	474
	-44.666551	169.329060	Incidental	518
	-44.670550	169.324725	Incidental	483
	-44.650377	169.320925	Incidental	469
	-44.65032	169.32126	Auditory recorder	472
	-44.667973	169.341735	iNaturalist	778
	-44.651117	169.326094	iNaturalist	515
	-44.651064	169.325925	iNaturalist	514
	-44.64988	169.32116	iNaturalist	466
	-44.628053	169.313136	iNaturalist	392
New Zealand pipit	-44.653501	169.358828	Incidental	1314
	-44.64682	169.355704	Incidental	1345
Silvereye	-44.666551	169.329060	Incidental	518
	-44.665727	169.330819	Incidental	526

	-44.674016	169.319080	Incidental	440
	-44.65032	169.32126	Auditory recorder	472
	-44.669739	169.345847	Auditory recorder	975
	-44.650377	169.320925	Incidental	469
	-44.651175	169.326467	iNaturalist	518
	-44.65173	169.31774	Incidental	474
Spur-winged Plover	-44.65032	169.32126	Auditory recorder	472
Swamp harrier	-44.667375	169.327172	Incidental	499
	-44.635992	169.320059	Incidental	615
	-44.675455	169.313971	iNaturalist	414
	-44.668308	169.340205	iNaturalist	790
	-44.65173	169.31774	Incidental	474
Tomtit	-44.649467	169.32016	Incidental	458
	-44.65032	169.32126	Auditory recorder	472

Chapter 27: Complexity of Plant-Animal Interactions at Mt Grand Station

Lauren Stump

Abstract

Mount Grand Station in New Zealand's high country is shaped by a combined land-sparing and land-sharing philosophy that allows for coexistence of introduced pasture species for grazing at lower elevations and native tussock grassland habitat at higher elevations. The plant–animal interactions that connect these seemingly separate ecosystems form a complex web of connections that range from mutualistic to antagonistic in nature and support crucial ecosystem services like pollination and seed dispersal. To identify and describe these interactions, a two-day assessment of Mount Grand was conducted in March 2023 and included observational surveys along transects both in the high-elevation tussock habitats and low-elevation shrubland and riparian habitat of Hospital Gully. All observed plant–animal interactions were recorded (e.g., active pollination), along with evidence of past interactions (e.g., sooty black mold on kānuka branches) and signs of future interactions (e.g., fruit growing on shrubs). What emerges is a glimpse into the breadth of diversity and complexity of interactions within these communities. These connections have significant conservation implications, and understanding Mount Grand's interaction webs will aid managers in implementing control efforts that address problematic introduced species while protecting non-target species and ensuring ecosystem services are not compromised. Future studies should expand upon these preliminary interaction webs to be more comprehensive, incorporate the magnitude of each interaction, and include tertiary interactions. Well-informed management actions based on thorough understanding of Mount Grand's complex plant–animal interactions will increase the likelihood of positive conservation outcomes and improve our ability to be good stewards of this high-country habitat.

Key words: Interaction web, mutualism, land sparing, ecosystem services, introduced species

27.1: Introduction

As a location where livestock pasturelands meet wild high-country habitat, Mount Grand Station is a microcosm of New Zealand's unique combination of introduced and native ecosystems. According to the station's land-sparing management philosophy following Tenure Review, intensification of grazing and forage production takes place on the lower altitude grasslands comprised of introduced controlled pasture species, allowing the higher-altitude native tussock grasslands to be spared from grazing pressure (*Mount Grand Conservation Resources Report*, 2005). This delineation between grazed and non-grazed areas allows for the development of two distinct habitats that, despite the appearance of separation, are interconnected by the species that inhabit them. This interconnection comes in the form of plant–animal interactions, which may be mutualistic, commensal, or antagonistic. Interactions such as predation and herbivory drive species adaptation while others like pollination and seed dispersal provide essential ecosystem services that shape community structure (Hooper et al., 2005).

As in habitats across New Zealand, introduced pest and predator species disrupt these complex webs of species interactions. Control efforts seek to remove introduced species not only because they directly harm native species, but also because they decrease ecosystem stability by removing the key ecosystem services provided by native species (Hooper et al., 2005; Kay, 2009). Our ability to select appropriate management actions to address these problem species will depend on the depth of our understanding of the ecosystem's interaction webs. By studying plant–animal interactions at Mount Grand, we will gain insight into the complexity within these communities and be able to better predict how the ecosystem will respond to both management actions and natural environmental perturbations (Hooper et al., 2005).

27.2: Materials and Methods

In March 2023, a two-day assessment of Mount Grand Station's biodiversity, agricultural usage, and conservation value was conducted by myself and a team of observers from Lincoln University. On Day 1 (March 20th), we conducted our surveys in three locations along an established driving route through steep, high elevation tussock grassland habitats and rocky outcrops, as well as mid-elevation modified short tussock grasslands. Site 1 was located 680 m above sea level at 44°41'00.9"S, 169°19'29.2"E. Site 2 was located 655 m above sea level at 44°39'01.1"S, 169°20'03.9"E. Site 3 was located 980 m above sea level at 44°40'11.3"S, 169°20'43.0"E. On Day 2 (March 21st), we conducted our surveys along a walking trail through the shrubland and creek habitat of Hospital Gully. We entered the gully through the station's enclosed pasturelands at an elevation of approximately 500 m above sea level and traversed eastward through the narrow gorge, characterized by mixed shrubland and a few riparian species, to a final elevation of approximately 600 m above sea level. Observations were carried out along the entire four-hour return transect walk, rather than at discrete points.

To catalogue plant–animal interactions, I conducted a simple observational survey at each location. At each location on Day 1, I walked transects of approximately 35 m x 35 m, while on Day 2 I walked a line transect of approximately 2.25 m in each direction, 4.5 m in total. While walking each transect, I recorded and photographed every interaction I could either see occurring or could see evidence of having occurred (or would occur in the future). This included observations such as damage by herbivores, pollinators visiting flowering plants, fruits grown by various shrub species, sooty black mold growing on kānuka branches, and changes in vegetation color where livestock are grazed. I recorded species identification, details of the interaction, and initial impressions of the interaction's effect on the landscape.

By the end of Day 2, I had compiled a list of approximately two dozen plant–animal interactions.

Because of the short duration of the assessment, my personal observations were too limited to thoroughly catalogue the station's wide variety of plant–animal interactions. To overcome this deficit, I used observations posted on iNaturalist by my own teammates and prior assessments of Mount Grand's biodiversity. I supplemented this further with an extensive literature review of species found in New Zealand's high country. This work culminated in lists of plant and animal species that I used to identify and describe the networks of interactions between them. Although these lists are not exhaustive, a truly exhaustive review of every species and its interactions across the station is beyond the scope of this project. Instead, what follows is a thorough overview of the primary categories of species interactions and the crucial ecosystem services they provide, providing a hint at the incredible breadth of diversity and complexity within these communities. These results are divided into the following categories: habitat, predation, herbivory, omnivory, pollination, and seed dispersal.

27.3: Results

The results of the 2023 biodiversity assessment at Mount Grand Station are presented in the following tables of plant and animal species (Tables 27.1 and 27.2), which were then used to identify and describe the networks of interactions between them.

Table 27.1: Subset of plant species found at Mount Grand Station, Otago, New Zealand, used to identify plant–animal interactions within both native tussock grassland and exotic pasture communities. Species come from the author's personal observations during the March 2023 biodiversity assessment, observations by other scientists recorded on iNaturalist.org, and literature review of New Zealand high-country.

Plants of Mount Grand Station, New Zealand

Common Name	Māori name	Scientific Name	Native / Introduced	Endemic / Indigenous / Naturalized
Speargrass / Spaniard†	Taramea	Aciphylla colensoi	Native	Endemic
Colenso's mingimingi†		Acrothamnus colensoi	Native	Endemic
Brown top grass		Agrostis capillaris	Introduced	Naturalized
Sweet vernal grass		Anthoxanthum odoratum	Introduced	Naturalized
Butterfly bush / buddleia†		Buddleja davidii	Introduced	Naturalized
Common broom†	Mākaka	Carmichaelia australis	Native	Endemic
Desert broom		Carmichaelia petriei	Native	Endemic
Slim snow tussock		Chionochloa macra	Native	Endemic
Narrow-leaf snow tussock†	Wī kura	Chionochloa rigida	Native	Endemic
Tutu†		Coriaria sarmentosa	Native	Indigenous
Wild broom†		Cytisus scoparius	Introduced	Naturalized
Cocksfoot		Dactylis glomerata	Introduced	Naturalized
Matagouri†	Tūmatakuru	Discaria toumatou	Native	Endemic
Tussock hawkweed†		Hieracium lepidulum	Introduced	Naturalized
Mouse-eared hawkweed		Hieracium officinarum	Introduced	Naturalized
Kānuka†	Kānuka	Kunzea ericoides	Native	Endemic
Porcupine shrub†		Melicytus alpinus	Native	Endemic
Silver tussock†	Wī	Poa cita	Native	Endemic
Blue tussock		Poa colensoi	Native	Endemic
Bracken†	Rarauhe	Pteridium esculentum	Native	Indigenous
Sweet briar†		Rosa rubiginosa	Introduced	Naturalized
Sheep's sorrel		Rumex acetosella	Introduced	Naturalized
Dwarf mingimingi	Pātōtara	Styphelia nesophila	Native	Indigenous
Red clover		Trifolium pratense	Introduced	Naturalized
White clover†		Trifolium repens	Introduced	Naturalized
Subterranean clover		Trifolium subterraneum	Introduced	Naturalized
Woolly mullein†		Verbascum thapsus	Introduced	Naturalized

† Observed by the author during Mount Grand biodiversity assessment in March 2023.

Table 27.2: Subset of animal species found at Mount Grand Station, Otago, New Zealand, used to identify plant–animal interactions within both native tussock grassland and exotic pasture communities.
Species come from the author's personal observations during the March 2023 biodiversity assessment, observations by other scientists recorded on iNaturalist.org, and literature review of New Zealand high-country.

Animals of Mount Grand Station, New Zealand

Common Name	Māori name	Scientific Name	Native / Introduced	Endemic / Indigenous / Naturalized
Cotton web spinner		Achyra affinitalis	Introduced	Naturalized
European woolcarder bee		Anthidium manicatum	Introduced	Naturalized
Bellbird	Korimako	Anthornis melanura	Native	Endemic
Common tussock butterfly		Argyrophenga antipodum	Native	Endemic
Buff-tailed bumble bee†	Pī	Bombus terrestris	Introduced	Naturalized
Cattle (Hereford)†	Kau	Bos taurus taurus	Introduced	—
California quail	Tikaokao	Callipepla californica	Introduced	Naturalized
Harrier hawk †	Kāhu	Circus approximans	Native††	Indigenous
Giant scale insect†		Coelostomidia wairoensis	Native	Endemic
Fallow deer		Dama dama	Introduced	Naturalized
Nurseryweb spider†		Dolomedes minor	Native	Endemic
European hedgehog†	Hetiheti	Erinaceus europaeus	Introduced	Naturalized
New Zealand falcon	Kārearea	Falco novaeseelandiae	Native	Endemic
New Zealand cutworm		Ichneutica mutans	Native	Endemic
Tiger moth		Metracrias huttoni	Native	Endemic
Stoat		Mustela erminea	Introduced	Naturalized
McCann's skink	Mokomoko	Oligosoma maccanni	Native	Endemic
Common grass moth		Orocrambus vittellus	Native	Endemic
Rabbit†	Rāpeti	Oryctolagus cuniculus	Introduced	Naturalized
Sheep (Merino)†	Hipi	Ovis aries	Introduced	—
New Zealand grasshopper	Māwhitiwhiti	Phaulacridium marginale	Native	Endemic
Norwegian rat		Rattus norvegicus	Introduced	Naturalized
Fantail†	Pīwakawaka	Rhipidura fuliginosa	Native	Endemic
Alpine grasshopper†	Māwhitiwhiti	Sigaus australis	Native	Endemic
Boar†	Poaka	Sus scrofa	Introduced	Naturalized
Possum†	Paihamu	Trichosurus vulpecula	Introduced	Naturalized
Red admiral butterfly	Kahukura	Vanessa gonerilla	Native	Endemic
Southern Alps gecko†	Pāpā	*Woodworthia* sp. 'Southern Alps'	Native	Endemic
Silvereye†	Tauhou	Zosterops lateralis	Native†††	Indigenous

† Observed by the author during Mount Grand biodiversity assessment in March 2023.
†† Self-introduced from elsewhere in Australasia in the past 800 years; now considered native.
††† Self-introduced from Australia in the 1850s; now considered native.

27.3.1: Habitat

Figure 27.2: Scree slope habitat for lizards such as Oligosoma maccanni and Woodworthia sp. 'Southern Alps.'

One of the most fundamental interactions between plants and animals is how plant communities provide habitat for animals and their prey species. This relationship is often mutualistic, as the plant receives some form of benefit from the animal it shelters (such as pollination or seed dispersal, discussed in detail below) (Bronstein, 2015). The native tussock grasslands of Mount Grand provide habitat for species in a somewhat challenging location; traits such as slow growth, long lifespans, and mast year seed production indicate these grasses have adapted to the relatively nutrient-poor soil and heat-deficient climate (Scott et al., 1996). As such, they are able to provide habitat for native insects such as the common tussock butterfly that lays its eggs on tussocks, particularly silver tussocks, so the larvae can feed as soon as they emerge (Stupples, 2003). Other grassland moths include the New Zealand cutworm, common grass moth, and tiger moth (White, 1991). Native grasshoppers like the New Zealand and alpine grasshoppers utilize these grasslands both as habitat and a food source; prime habitat contains a combination of tall tussock plants that they both consume and use for shelter and open, sunny areas for basking, as well as a variety of smaller, more palatable forbs (Watson, 1970). These herbivorous insects compete with introduced fallow deer who also graze snow tussocks (O'Donnell et al., 2017). Rocky areas within both grasslands and shrublands (Figure 27.1) provide habitat for native lizards such as the McCann's skink and Southern Alps gecko who utilize scree and boulders for shelter and basking (*Attracting Lizards to Your Garden*, 2005; Frank & Wilson, 2011; Hardy, 1977). They also depend on tussock grasses for insect prey and divaricating shrubs like matagouri, mingimingi, and porcupine shrub for fruit (Wotton et al., 2016). Web-building spiders like the nurseryweb spider utilize these plants, most often porcupine shrub, for structural support of their webs (Figure 27.2). This transition area between shrubland and grassland, incorporating species like tutu and bracken, is also quality habitat for a variety of bird species, such as the fantail, bellbirds, and California quail (Leary, 2013; Powlesland, 2013; Robertson et al., 2007).

Figure 27.1: Nurseryweb spider (Dolomedes minor) nest on a porcupine shrub (Melicytus alpinus).

Native tussock grasslands are not the only plant community to provide habitat for native species. Following the arrival of early Polynesian settlers who cleared forests and later European settlers who further increased the amount of open land for agriculture, the harrier hawk was able to self-introduce from Australia and establish within the open farmland and high country grasslands like those found at Mount Grand (Robertson et al., 2007; Seaton et al., 2013). These ground-nesting birds thrive in open environments that provide long grasses for shelter for their bulky nests and habitat for prey species (small and fledgling birds, lizards, and introduced mammals) that supplement the carrion in their diets (Robertson et al., 2007; Seaton et al., 2013). Similarly, the New Zealand falcon utilizes a combination of tussock and grazed grasslands to hunt small birds and rabbits and nests on the ground where scrub provides cover and protection (Seaton & Hyde, 2013). Farmlands also support generalist birds like the silvereye and fantail, meaning their populations have not suffered the way other species have following widespread conversion of grasslands to farmland across the high country (Armitage, 2013; Powlesland, 2013; Robertson et al., 2007).

Unfortunately, this conversion has increased the amount of prime habitat for introduced mammals like rabbits, who are found less commonly in intact, healthy tussock grasslands (D. Norbury, 1996). These herbivores prefer plant communities that have been modified by grazing and burning to produce a shorter, more open sward, and their herbivory causes further deterioration of the grassland communities in which they inhabit (D. Norbury, 1996). Feral pigs can also be found where farmland and grasslands meet, utilizing scrubland patches for shelter, and lowland bush and scrub along waterways (like that found at the base of Hospital Gulley) provide habitat for the Norway rat and possums (Brockie, 2015; McIlroy, 2005). Clearly, it is these introduced species that have the greatest negative impact on plant communities, not the native species that have coevolved alongside the plants. While grazing by introduced livestock can be beneficial for introduced plant communities found in pastures, herbivory by livestock and rabbits and rooting by pigs can increase the prevalence of problematic “weed” species. Livestock stock tracks and grazing cause disturbance, and rabbits graze to the point of leaving bare ground, all of which benefits plants that like disturbance such as woolly mullein (Gross, 1984). Rabbit grazing and pig soil disruption generally decrease health of pastures and grasslands and create a negative feedback loop in which increasing establishment of weed species further excludes native plants and depletes soil nutrients, restricts regeneration of native species, and weakens the plant communities’ resilience and ability to support the animal species that depend on it (Howell, 2008; O’Donnell, 2017; D. Norbury, 1996).

27.3.2: Predation

Both predation and herbivory are antagonistic interactions that encourage coevolution of prey acquisition and defensive capabilities. Although predation is an animal–animal interaction, it is relevant to our discussion of plant–animal interactions because of the strong tertiary influence predators can have on plant communities through their consumption of prey species. At Mount Grand, for example, insectivorous birds and omnivorous lizards reduce the impact of insect herbivory on nearly all plant species. Insectivorous fantails and silvereyes consume spiders, beetles, flies, larvae, aphids, and moths (Heather & Robertson, 2015). Bellbird nestlings are almost entirely insectivorous, and adults increase insect consumption during winter and over the breeding season (Craig et al., 1981). This dietary flexibility allows them to live in low-nectar and low-fruit habitats where other honeyeaters cannot (Spurr et al., 2011). Lizards such as the Southern Alps gecko and McCann’s skink are omnivorous and consume spiders, millipedes, small beetles, and larvae (Frank & Wilson, 2011; Hardy, 1977).

However, many of these native bird and lizard species are themselves prey for introduced mammalian predators. Stoats predate almost entirely on birds, particularly nestlings and eggs, which are also prey for possums and hedgehogs, although possums are generally more herbivorous (Brockie, 2015). Hedgehogs and possums will also supplement their diets with insects and snails, while stoats will also consume rats, mice, and rabbits (Brockie, 2015). Hedgehogs, rats, and stoats will all consume lizards and have begun putting significant pressure on the populations of native species like the Southern Alps gecko and McCann’s skink (Brockie, 2015; Jones et al., 2013; Spitzen–van der Sluijs et al., 2009). The McCann’s skink is currently listed as “Not Threatened” under the New Zealand Threat Classification System, buffered from the impacts of predation by their high abundances, at least for now; the Southern Alps gecko’s population is not as large and resilient, and the species is now considered “At Risk – Declining” (Hitchmough et al., 2021). All of these introduced predatory mammals are prey species for the native harrier hawk, whose presence within the habitat can therefore help relieve predation pressure on native lizard and bird species (Heather & Robertson, 2015).

27.3.3: Herbivory

While insects may be the primary prey for numerous insectivorous bird and lizard species, insects are themselves important herbivores of nearly all plant species found in both pastures and native habitats at Mount Grand. Larvae of a variety of butterfly and moth species grow, feed, and pupate on grass species. The native New Zealand cutworm and common grass moth are sometimes considered agricultural pests when their larvae feed on introduced pasture species; they do prefer the native grass species they evolved alongside, however, and their populations have begun to decline due to the dominance of introduced grasses (White, 1991). The native New Zealand and alpine grasshoppers will sometimes consume the snow tussocks they inhabit, although they prefer "succulent grasses" like the silver tussock; their generalist feeding habits mean they avoid overexploiting any single species, an advantageous trait that evolved from long coevolution with native tussocks (Watson, 1970). Another close relationship between two native species is the interaction between the giant scale insect and kānuka trees. The scale insect pierces the tree's outer bark to access the phloem food source within, excreting the excess water and sugar as "honeydew," a sticky substance that causes black sooty mold to grow on the kānuka's branches (Figure 27.3; Gardner-Gee & Beggs, 2009; Martin, 2018). Because these two species have coevolved, the harm caused by the insect and mold do not significantly harm the tree; the honeydew is also an important food source for bellbirds, and their consumption of honeydew helps limit mold growth (Spurr et al., 2011). Unfortunately, introduced *Vespula* spp. wasps also feed on honeydew, and its availability across New Zealand has facilitated these wasps' spread (Martin, 2018).

Figure 27.3: Black sooty mold on a kānuka (Kunzea ericoides) branch due to scale insect (Coelostomidia wairoensis) herbivory.

Another problematic introduced species is the rabbit, whose herbivory has drastic consequences for both native and introduced plant communities. Rabbits graze native tussocks down to the stump, killing them and reducing their coverage across the landscape, and limit regeneration of many native shrubs by browsing seedlings (D. Norbury, 1996). Their herbivory also decreases pasture productivity and increases the competitiveness and establishment of weed species like sweet briar, woolly mullein, and hawkweed (Howell, 2008; *Rosa rubiginosa*, 1998). While it is also a prey species for the native harrier hawk, this predation is nowhere near sufficient to keep rabbit populations in check, making rabbit control a priority for farm managers and conservationists alike (Heather & Robertson, 2015).

The impact of herbivory by introduced livestock herbivores, primarily sheep and cattle, cannot be overstated. However, in the context of Mount Grand, their impact is primarily restricted to the pastures in which they are rotationally grazed. Although herbivory is typically considered antagonistic, the relationship between livestock and pasture plants could almost be considered mutualistic. Pasture species include a large number of grasses and clovers introduced from pastures in Europe where the livestock themselves came from, indicating a long period of coevolution; this includes brown top grass, sweet vernal grass, sheep's sorrel, cocksfoot, and white, red, and subterranean clover (Dickinson, 2023). These species flourish when adequately grazed, and clovers in particular benefit from grazing by cattle who remove tall, shading grasses and increase sunlight availability at ground level (Charlton, 2008). They also benefit from regular nutrient deposition by livestock, particularly in stock camps where the animals sleep (Charlton & Stewart, 1999). This effect can be strong enough to be visually apparent in color variation across pastures. Another visual impact of livestock on the landscape can be seen when sheep lick and eat soil where coarse salt has been spread to encourage grazing to occur in places the sheep otherwise rarely graze (steep slopes with less palatable species). Because of the station's inland location, soils at Mount Grand are relatively sodium deficient due to a lack of natural sodium input from sea spray; this means sheep do not ingest the necessary levels of sodium from grazing grasses grown here (Aspinall et al., 2004). Spreading salt allows farm managers to both increase the sheep's salt intake and manipulate grazing behavior—it can even be used to introduce trampling in areas recently sown with seeds to improve establishment (Aspinall et al., 2004).

27.3.4: Omnivory

Some species engage in both predation and herbivory. The two omnivorous species with the greatest impact on both plant and animal communities at Mount Grand are both introduced: possums and feral pigs. Although they supplement their diets with bird nestlings and eggs, insects, and snails, possums are primarily herbivorous and cause extensive damage to plants such as matagouri when consuming flowers and leaves (Brockie, 2015). In alpine regions, pigs seek out speargrass roots and snow tussock tillers, uprooting and killing the plants (O'Donnell et al., 2017). During breeding season, they increase their intake of animal material, such as insects, lizards, ground-nesting birds and their eggs, and even young rats and rabbits (McIlroy, 2005). Their highly varied diet and extensive damage to the landscape make them a particularly detrimental species that negatively impacts most (if not all) plant and animal species at Mount Grand.

27.3.5: Pollination

Pollination is an example of a mutualistic plant–animal interaction in which both species receive benefits, either in the form of food (nectar) or cross-pollination. Mount Grand's pollinators include a wide variety of species from classes Aves, Insecta, and Reptilia. Bellbirds are honeyeaters, meaning nectar comprises the bulk of their diets, so they spend considerable time pollinating flowers in search of food (Heather & Robertson, 2015). Silvereyes may be primarily insectivorous, but they will also readily incorporate nectar into their diet (Heather & Robertson, 2015). Moths such as the New Zealand cutworm, cotton web spinner, common grass moth, and tiger moth are responsible for pollinating a range of grass species (White, 1991), while bees and butterflies such as the buff-tailed bumblebee, European woolcarder bee, red admiral butterfly, and common tussock butterfly pollinate many flowering shrubs and trees (Figure 27.4; Barron, 2004). The Southern Alps gecko and McCann's skink also provide limited amounts of pollination when they supplement their insectivorous diets with nectar (Frank & Wilson, 2011; Hardy, 1977). Possums directly compete with these species for access to flowers and nectar, and while they may provide limited pollination, this benefit is heavily outweighed by the damage they do to the plants, consuming both flowers and leaves and effectively removing this crucial food source for pollinators (Brockie, 2015). The numerous plant species that depend on animal and insect pollinators include matagouri, porcupine shrub, speargrass, kānuka, mingimingi, buddleia, and multiple species of brooms, hawkweeds, and clovers (Charlton & Stewart, 1999; *Mount Grand Conservation Resources Report*, 2005; Timmins & Mackenzie, 1995).

Figure 27.4: Buff-tailed bumblebees (Bombus terrestris) on buddleia flowers (Buddleja davidii)

27.3.6: Seed dispersal

Seed dispersal is also an example of a mutualistic plant–animal interaction in which both species receive benefits, either in the form of food (seeds) or increased dispersal distance. While some animal species act as seed predators, many consume fruits and seeds that pass safely through their digestive systems to be deposited far from the parent plant. A large proportion of animal seed dispersers are birds, such as fantails, bellbirds, silvereyes, and California quail. Fantails are mainly insectivorous but also consume small fruits, and although quail are often seed predators, they do contribute to seed dispersal to a limited extent (Heather & Robertson, 2015). As honeyeaters, bellbirds consume primarily nectar, supplemented by insects and fruit, but these ratios vary seasonally; fruit may constitute over 75% of their diets during autumn (Craig et al., 1981). Lizards may also be key seed dispersers for high country grassland shrubs. A recent study by Wotton et al., (2016) found that New Zealand lizards, such as the Southern Alps gecko and McCann's skink, show a preference for white-blue fruits (a trait unique to these endemic lizards), which are typically associated with the divaricating shrubs and open habitat found at Mount Grand. Evidence suggests that these lizards may have influenced multiple plant species to evolve fruits of these colors (Wotton et al., 2016). Plant species that benefit from these avian and reptilian seed dispersers include matagouri, mingimingi, and porcupine shrub (Thorsen et al., 2009).

As with pollinators, possums also compete directly with some of these seed dispersers for fruit resources, although the magnitude of this negative effect is not as severe for seed dispersers as for pollinators (Brockie, 2015). Other introduced species, such as grazers like sheep and cattle, contribute to the spread of many species not just through seed dispersal (transporting seeds in their wool and hair), but also by grazing and disturbing landscapes, exposing them to invasion by "weed" species. For example, woolly mullein thrives in well-lit, disturbed soils and grows four to seven times faster when it germinates on bare soil; it is also a prolific seed-producer, spreading rapidly along stock tracks thanks to both disturbance and seed dispersal by grazers (Gross, 1984). Other introduced plant species that benefit from seed dispersers include sweet briar and hawkweeds (Thorsen et al., 2009).

27.4: Discussion

Plant–animal interactions within Mount Grand Station's native tussock and shrubland communities are primarily between native species, while interactions within the grazed pastures are primarily between introduced species that would have been native in their home ranges (with a few exceptions in both habitats). Both sets of interactions have developed over a long period of coevolution and are generally either mutualisms or commensalisms. The greatest threats to these relationships come from introduced species who either interrupt or take advantage of the benefits they provide. Previously mentioned examples include pigs and rabbits that damage both grazed and non-grazed plant communities, reducing their ability to regenerate and provide quality habitat (D. Norbury, 1996; O'Donnell et al., 2017). Introduced *Vespula* spp. wasps take advantage of the commensalism between kānuka and giant scale insects to further its expansion across the country (Martin, 2018). Possums directly compete with native insect and avian pollinators, reducing these species' ability to provide this essential ecosystem service (Brockie, 2015). Stoats, hedgehogs, and pigs prey on lizards and bird eggs and nestlings, reducing these species' ability to fulfill their ecological role as seed dispersers (Brockie, 2015; Jones et al., 2013; McIlroy, 2005). Understanding these "new" interactions between native and introduced species is crucial to identifying how these grassland habitats are being weakened and how management actions might interrupt or take advantage of these interactions to achieve conservation goals.

It would be an oversimplification, however, to say that all introduced species are problematic and all native species are entirely beneficial. The interactions these species have with others indicate otherwise. For example, butterfly bush is an introduced species that spreads rapidly and excludes native plants, but it is also an important seasonal food resource for native and introduced pollinators like the red admiral butterfly, buff-tailed bumblebee, and European woolcarder bee (Smale, 1990). Determining whether its detrimental effect on other plants outweighs its benefits to pollinators, and ultimately whether the plant should be allowed to spread or be intensively controlled, will come from an understanding of this plants' interactions with other species and linkages within the pollinator community in general. For instance, if we remove butterfly bush from Mount Grand, will other plant species be able to provide the necessary amounts of nectar and pollen for hungry pollinators in early spring? Management decisions should be informed by thorough understanding of plant–animal interactions to avoid unintentional limitation of ecosystem services.

Just as some introduced species may provide important ecosystem services, some native species may contribute relatively low conservation value. Native bracken can be found near waterways in lower elevation areas of Hospital Gully, where it provides soil stabilization and suppresses exotic grasses and shrubby weeds like sweet briar (McGlone et al., 2005). However, land managers often consider it a "persistent and aggressive weed" that dominates areas where it grows, excluding native as well as exotic species, while supporting very little diversity (McGlone et al., 2005). The high levels of phenols and tannins in the fronds make it unpalatable to herbivores, and because it reproduces via wind-dispersed spores, it produces neither flowers nor fruits (McGlone et al., 2005). As a result, despite being a native species with a long evolutionary history in this ecosystem, bracken take part in extremely few plant–animal interactions and provide limited conservation value for herbivores, pollinators, or seed dispersers. Understanding the number and magnitude of native species' interactions can inform management decisions about which native species to prioritize for protection based on their contributions to overall ecosystem health and resilience.

The majority of species, however, engage in numerous interactions with a variety of species, creating complex webs of interactions that are essential for Mount Grand's ecosystems to function. Mapping these webs as thoroughly as possible can improve conservation outcomes by allowing us to predict potential unexpected impacts of management actions on species other than the target. For example, if we eradicate rabbits from the landscape, we have now removed a prey resource for harrier hawks and the New Zealand falcon (Seaton et al., 2013; Seaton & Hyde, 2013). While both birds may continue to thrive thanks to a range of alternative prey sources, they may increase their predation pressure on those alternative species. We might find this acceptable from a conservation standpoint if those alternatives are other introduced mammals like possums, stoats, hedgehogs, or rats. However, if the harrier hawk compensates by increasing predation on native lizards and the falcon increases predation on other native birds, these native species may suffer, potentially limiting their presence in the landscape and interrupting the pollination and seed dispersal ecosystem services they provide. Norbury (2001) observed precisely this phenomenon; rabbit control and the resulting swings in rabbit abundance led to prey-switching by ferrets and cats, which increased predation pressure on the native skinks. If skink populations fall below critical densities, this predation could lead to local extinctions (G. Norbury, 2001). Despite the benefits gained by removing rabbits, losing these species and the ecosystem services they provide would be an unacceptable conservation outcome. Using comprehensive interactions maps to predict trickle-down impacts of management actions will allow us to preemptively support impacted species and buffer them from potential negative effects.

Understanding a species' full range of interactions can also help us avoid making costly (and potentially harmful) conservation decisions. For example, let us examine the case of introduced wild broom and the broom seed beetle, a seed predator introduced as a biocontrol agent. Wild broom is considered a “problem plant” due to its ability to spread rapidly, form dense uniform stands that exclude native species, and even increase invasion by other weed species by increasing available nitrogen in the soil (Dickinson, 2023; Timmins & Mackenzie, 1995). To control this weed, a specialist bruchid seed predator (*Bruchidius villosus*) was introduced in 1986. Unfortunately, the beetle was not as host-specific as initially expected and has since been observed utilizing other native species, a consequence that could have been avoided if the beetle’s full spectrum of species interactions in its home range had been investigated (Sheppard et al., 2006). This cautionary tale highlights the need for comprehensive interaction webs for any species considered for intentional introduction as a biocontrol agent. Thorough understanding of interaction webs within the target ecosystem can even preclude the need for external biocontrol agents by identifying alternative control methods that utilize preexisting interactions.

27.5: Conclusions

At Mount Grand Station, both native tussock and introduced pasture communities provide a diversity of habitats. These communities are shaped by a multitude of plant–animal interactions, which range from mutualistic to antagonistic and include predation, pollination, and seed dispersal. Introduced pest and predator species disrupt these complex interaction webs, and our ability to select appropriate management actions to address these problem species will depend on the depth of our understanding of these webs. Firstly, understanding species interactions allows us to identify which species are worth controlling or removing, based on the magnitude of their negative impacts on other species, and ensure that we are not eliminating essential ecosystem services that are not provided by alternative species. Secondly, it enables us to identify priority species for protection and enhancement based on their contributions to conservation outcomes. Thirdly, it can give us foresight into potential unexpected impacts of management actions on species other than the target so we might take preemptively action to support and buffer them from negative effects.

This report provides insight into the complex and dynamic interaction webs at Mount Grand using a subset of species present that should be expanded upon in future studies. We should seek to build comprehensive maps of these webs, starting with identification of as many species and interactions as possible. Next, we can investigate the magnitude of each interaction—how strongly species influence each other—and identify at-risk interactions between species who have no alternative partners. From there, we can extend our understanding to tertiary interactions to visualize the ripple effects of community-level changes throughout the web.

The land-sparing philosophy at Mount Grand, and the distinct grazed and non-grazed habitats it produces, also provide a valuable opportunity to study the effects of management actions on the plant–animal interactions that connect these seemingly separate ecosystems. Future studies could examine what effect a management action in one habitat type has on the other. For example, what effect will possum control in Hospital Gully have on the pasturelands? What effect will rabbit control across the pasturelands have on tussock grasslands? The spillover effects between these adjacent habitats may facilitate development of management techniques that benefit multiple habitat types simultaneously. In conclusion, the actions we take based on a solid foundation of species interaction knowledge will be well-informed and lead to positive conservation outcomes, enabling us to be better stewards of this unique high-country landscape.

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Chapter 28: Altitude and Macro-Invertebrate Diversity at Mt. Grand: Family Richness and Composition

Shannon Marshall

Abstract

Understanding the relationship between altitude and macro-invertebrate diversity is crucial for effective conservation and land management strategies. This study investigates the altitudinal patterns of macro-invertebrates at Mt. Grand, through the analysis of family richness using Shannon's Diversity Index. The results show that different macro-invertebrate orders exhibit distinct altitudinal preferences, with some orders more abundant at higher altitudes and others more common at lower altitudes. Altitude was found to significantly influence family richness, with a decrease in richness as altitude increased. However, the relationship between Shannon's Diversity Index and altitude was weak and not statistically significant. These findings provide baseline data on current altitudinal patterns of macro-invertebrates and can contribute to predicting their future movements in response to climate change. The results also have implications for conservation and land management strategies, suggesting the need for targeted efforts and altitude-based management practices.

Key words: Shannon's Diversity Index, Altitude, Macro-invertebrates, Conservation

28.1: Introduction

Macro-invertebrate species play a crucial role in agricultural systems, exerting significant influence over plant health, productivity, and overall food security (Cock et al., 2012). These organisms perform diverse ecological functions, serving as primary consumers, higher-order consumers, mutualists, parasites, and saprophytes, thereby contributing to complex and interconnected interactions within agricultural ecosystems (Cock et al., 2013). For instance, soil invertebrates, acting as ecosystem engineers, drive essential soil processes like water dynamics, aeration, and erosion protection by altering soil structure. Additionally, they impact carbon cycling and greenhouse gas emissions (Jones et al. 1994, Cock et al. 2013).

Despite the importance of macro-invertebrates, the relationship between their diversity and altitude still needs to be explored in New Zealand's high country, an agricultural hub. Altitude directly influences environmental factors such as temperature, precipitation, and vegetation, shaping species distribution patterns and community composition (Moeed and Meads, 1986). Previous generalizations based on studies of vascular plants and birds suggested a decline in diversity with increasing altitude (Andrew et al. 2003, Rahbek 1997, Shepherd 1998). However, such patterns may not hold true for other taxonomic groups, as different organisms exhibit varying diversity patterns along altitudinal gradients (Castro et al. 2019, McCain 2010).

Studies examining the relationship between altitude and macro-invertebrate diversity have yielded inconsistent results (Chinn and Chinn 2020, Hortal et al. 2013, Jacobsen et al. 1997, Moeed and Meads 1986). Some studies reported a positive correlation, indicating increased species richness and diversity with higher altitudes, often attributed to specialized and adapted species in montane ecosystems and reduced human disturbance (Castro et al. 2019, Lang and Reymond 1993). Conversely, other studies found negative or hump-shaped relationships, suggesting diversity peaks at intermediate altitudes due to factors such as ecological stability, habitat heterogeneity, and niche partitioning (Chinn and Chinn 2020, Jacobsen et al. 1997, Ward 1986). These discrepancies emphasize the necessity of site-specific investigations to uncover the nuances and generalizability of altitude-diversity relationships.

A study site's specific characteristics and geographical context greatly influence the relationship between altitude and macro-invertebrate diversity (Moeed and Meads 1986). Each ecosystem harbours unique species assemblages, ecological interactions, and environmental conditions, contributing to the observed diversity patterns (Moeed and Meads 1986). Moreover, the knowledge regarding macro-invertebrate community composition and ecology in New Zealand's tussock grasslands still needs to be improved. Therefore, it is crucial to comprehend the dynamics of macro-invertebrate communities along altitude gradients at Mt. Grand to better understand the area's conservation value, particularly in light of climate change. The process known as upslope colonization states that as temperatures rise, the alpine ecosystem will gradually move to higher altitudes (Dumbleton 1969). Thus, as the climate continues to warm, baseline data regarding current altitudinal patterns of macro-invertebrates will help predict their future movements.

Here, I attempt to contribute to this these baseline data by analyzing the relationship between altitude and macro-invertebrate species richness and using Shannon’s Diversity Index. By doing so, I aim to expand the current understanding of the altitude-diversity relationship and provide insights into the specific dynamics of macro-invertebrate communities at Mt. Grand.

28.2: Materials and Methods

At Mt. Grand, the macro-invertebrate community was sampled using a range of collection methods to obtain a comprehensive understanding of the species present. For terrestrial invertebrates, these methods included sweep netting, hand searching, rock turning, beating of woody vegetation, direct observation, malaise traps, and light traps. For aquatic invertebrates, kick sampling was conducted.

All macro-invertebrates encountered were photographed and identified to species or lowest recognizable taxonomic unit, and their location was recorded on the iNaturalist group "Mt Grand Biodiversity." Observation data was then compiled and downloaded. The collected data was were imported into RStudio for further analysis.

Although identifying individual species would have been ideal, many observations were only identifiable at the ordinal order or familial family level. Consequently, family richness and diversity were analyzed, as this level provided the most observations and diversity. However, the ordinal level was used for the boxplot, as 20 orders were more manageable to visualize than 73 families.

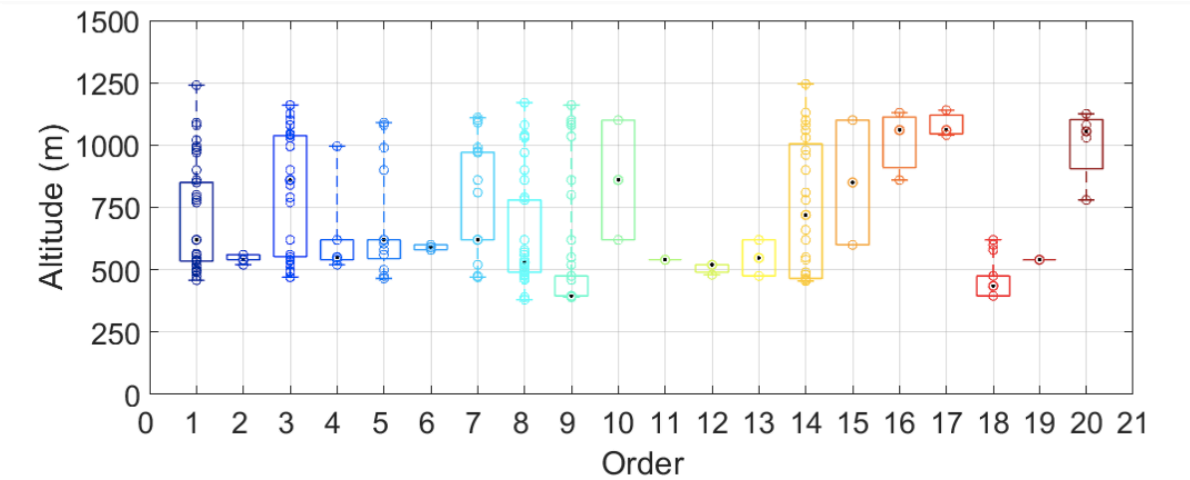
To first understand the distribution of the invertebrate community across the elevational gradient, a box plot was created. The number of observations and altitude of each observation were represented in the graph corresponding to each order observed.

The relationship between family richness and altitude was also examined. Datasets consisting of the number of unique families and the number of observations per altitude were created and merged. A linear regression analysis was performed to investigate the relationship between altitude and family richness, accounting for the number of observations at each altitude. A scatterplot with a regression line was generated to visualize this relationship, with point colours indicating the number of observations at each altitude.

Subsequently, the relationship between Shannon's Diversity Index and altitude was analyzed. The data was grouped by altitude, and the number of unique families at each altitude was counted. Shannon's Diversity Index was then calculated. A scatter plot with a regression line was created to visualize the relationship between Shannon's Diversity Index and altitude. The linear regression output provided insights into the strength and direction of this relationship. A Shapiro-Wilk test was also conducted to ensure this data was normally distributed.

28.3: Results

A total of 456 observations of macro-invertebrates from 73 families from 20 orders were found. The box plot (Figure 28.1) reveals several patterns between altitude and orders. Certain orders, such as #16 (Pseudoscorpiones), #17 (Stylommatophora), and #20 (Zygentoma), were primarily found at higher altitudes of 750 metres or above. Many other orders, however, were found more predominantly at lower altitudes, such as #1 (Araneae), #4 (Dermaptera), #5 (Diptera), #6 (Ephemeroptera), #8 (Hymenoptera), #9 (Lepidoptera), #11 (Mantodea), #12 (Megaloptera), #13 (Opiliones), #18 (Trichoptera), and #19 (Trombidiformes). However, it is important to note that light traps were only used at lower altitudes. Therefore the distribution of Lepidoptera is likely skewed in this case. Other orders were more evenly distributed throughout the altitudinal gradient. These include #1 (Araneae), #3 (Coleoptera), #7 (Hemiptera), #10 (Littorinimorpha), #14 (Orthoptera), and #15 (Plecoptera).



1. **Araneae:** Spiders
2. **Blattodea:** Cockroaches
3. **Coleoptera:** Beetles
4. **Dermaptera:** Earwigs
5. **Diptera:** True Flies
6. **Ephemeroptera**: Mayflies
7. **Hemiptera:** True Bugs
8. **Hymenoptera:** Sawflies, wasps, bees, ants
9. **Lepidoptera:** Moths
10. **Littorinimorpha:** Snails
11. **Mantodea:** Mantids
12. **Megaloptera:** Alderflies
13. **Opiliones:** Harvestmen
14. **Orthoptera:** Grasshoppers, Locusts, Crickets, Katydids
15. **Plecoptera:** Stoneflies
16. **Pseudoscorpiones:** False Scorpions
17. **Stylommatophora:** Land Snails and Slugs
18. **Trichoptera:** Caddisflies
19. **Trombidiformes:** Mites
20. **Zygentoma:** Silverfish

Figure 28.1: Observations of orders 1-20 vs. altitude (m).

Figure 28.2 demonstrates the linear regression model depicting the relationship between altitude and species richness, considering the number of observations at each altitude. The scatterplot shows the distribution of species richness along the elevational gradient, with point colour representing the number of observations at each altitude. The linear regression line indicates the general trend in species richness with increasing altitude. The relationship between altitude and species richness is statistically significant (*p*<*.001*), suggesting a general decrease in family richness with increasing altitude.

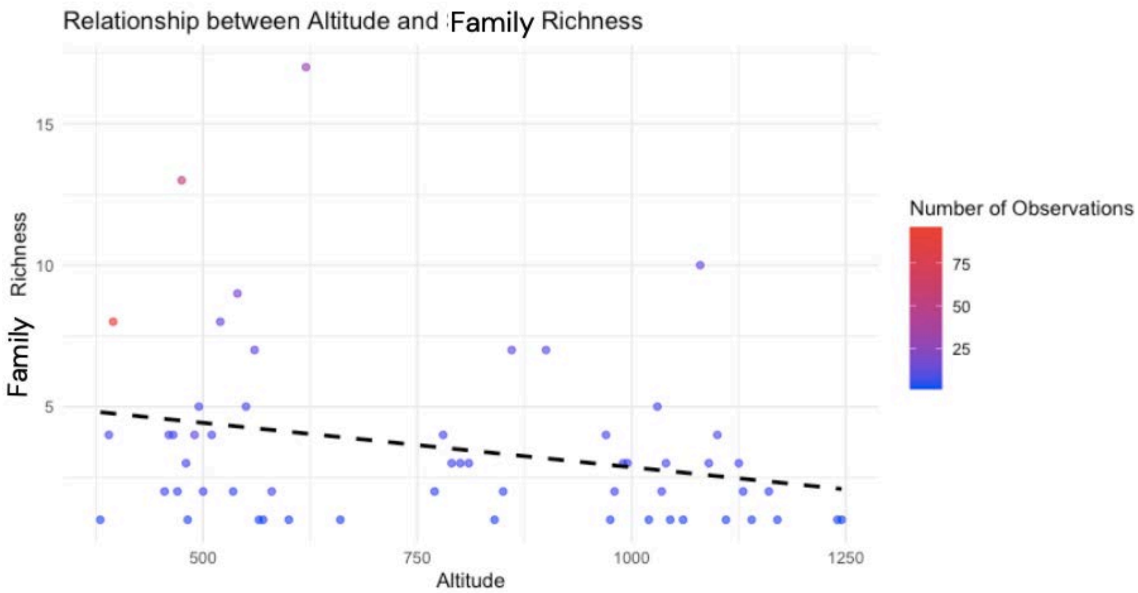


Figure 28.2: Distribution of species richness across the elevational gradient.
A linear regression model depicts the relationship between altitude and species richness, with the colour of each data point representing the number of observations recorded at that altitude.

The linear regression model for the relationship between altitude and Shannon's Diversity Index provided a p-value of 0.063, suggesting a weak relationship between Shannon diversity and the altitude of macro-invertebrates observed at Mt. Grand, as seen in Figure 28.3. This means that the relationship between diversity and altitude is not statistically significant, and it cannot be confidently concluded that altitude significantly impacts insect diversity. The Shapiro-Wilk test resulted in a p-value of 0.16, indicating that the residuals of the linear regression model were likely normally distributed.

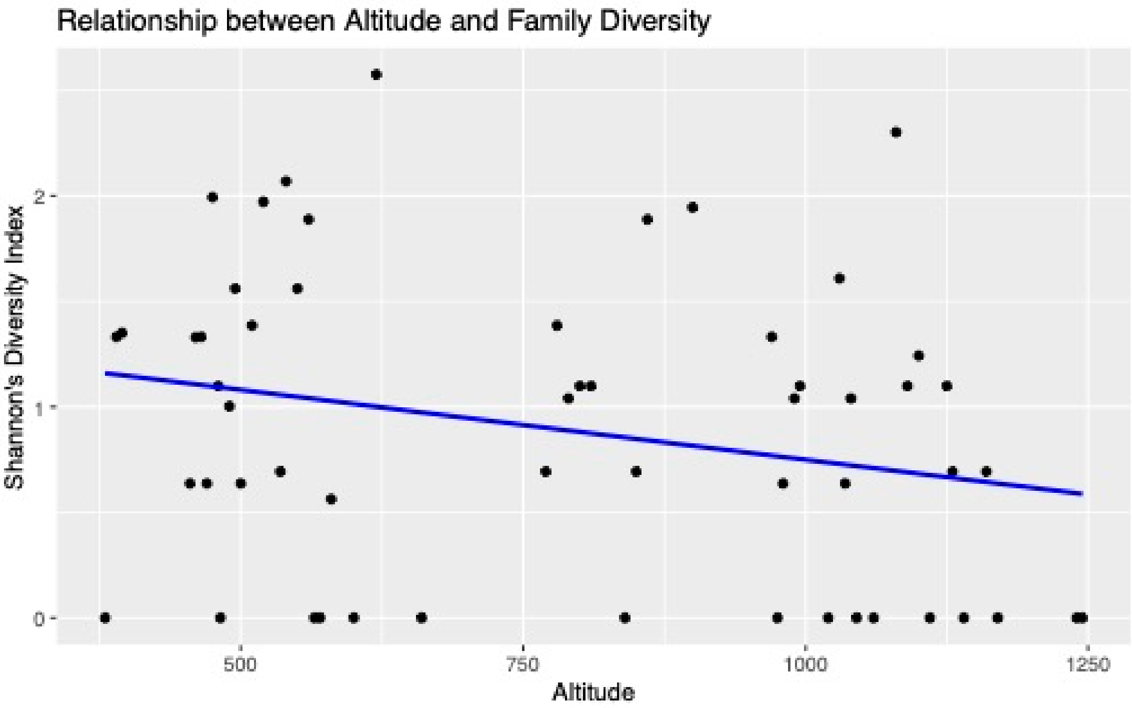


Figure 28.3: Comparison of family diversity and composition at different sites.
Each point represents a specific observation site and is determined by measures of abundance (family density or biomass) and family composition.

28.4: Discussion

The findings of this study provide valuable insights into the relationship between altitude and macro-invertebrate diversity at Mt. Grand. The distribution patterns of different macro-invertebrate orders along the altitudinal gradient were examined through a box plot (Figure 28.1). Certain orders showed a preference for higher altitudes, while others were more abundant at lower altitudes. These patterns shed light on the altitudinal preferences and habitat requirements of different macro-invertebrate taxa at Mt. Grand, contributing to our understanding of their ecological niches.

Acknowledging the limitations of examining invertebrate trends solely at the family and order levels is essential. Such an approach may mask significant patterns at the species level, as different members within each family or order may exhibit different distribution and abundance patterns that can vary with scale. Despite these limitations, the analysis conducted at the familial and ordinal levels provides preliminary insights into distributional patterns.

The analysis also revealed that altitude significantly influences the macro-invertebrate community, with family richness decreasing as altitude increases. This suggests that different altitudes support distinct macro-invertebrate assemblages, emphasizing the role of altitude as a key driver of community composition in this ecosystem. These findings align with previous studies reporting a decline in invertebrate diversity with increasing altitude (Chinn and Chinn 2020, Jacobsen et al. 1997). However, there was a sampling bias in lower altitudes, as shown in Figure 28.2. The data collection involved multiple observers using various methods, with more observations made at lower altitudes due to factors like rainfall, time constraints, and accessibility challenges in higher altitudes. This skewed sampling likely reinforces the observed higher species richness at lower altitudes.

In contrast, Shannon's Diversity Index analysis did not yield a statistically significant relationship with altitude. This indicates that while altitude may influence the total number of families present (family richness), it may have a weaker effect on the evenness of species distribution within the macro-invertebrate community. This weak relationship indicates that further investigation with larger sample sizes or additional variables may be necessary to determine the true nature of this relationship. This finding implies that other factors or mechanisms may influence species distribution's evenness within the macro-invertebrate community at the studied mountain. These factors could include microhabitat variations, resource availability, species interactions, or ecological processes that are not strongly correlated with altitude.

Although family richness was lower at high altitudes, this will likely change in the coming years. This baseline data on current altitudinal patterns of macro-invertebrates can aid in predicting their future movements in response to climate change. New Zealand’s average air temperature increased by 1.02 degrees Celsius between 1909 and 2017, a rate of 1 degree Celsius per century and roughly one order of magnitude faster than the preceding 2000 years of global average (Brailsford et al. 2012). Invertebrates, being cold-blooded organisms, are likely to undergo significant changes in response to climate change. When faced with warming, alpine communities can adopt different strategies, such as moving to higher elevations, adjusting their characteristics through genetic or environmental changes, migrating horizontally, or facing the risk of local extinction (Chinn and Chinn 2020). Upslope habitat tracking suggests that populations will occupy higher altitudes as the optimal conditions for their survival move upwards (Chinn and Chinn 2020). Therefore, conserving higher altitudes is becoming increasingly important.

Furthermore, these findings also have implications for the In agricultural systems of Mt. Grand. Macro-invertebrates play vital ecological roles, influencing plant health, productivity, and food security (Cock et al. 2012). Understanding the dynamics of macro-invertebrate communities along altitudinal gradients can inform land management strategies in agricultural landscapes. The findings of this study suggest that different macro-invertebrate taxa exhibit varying preferences for altitudinal zones, highlighting the need for targeted conservation efforts and habitat management practices tailored to specific altitudinal ranges. Additionally, this study adds to the broader comprehension of invertebrates in New Zealand. Stringer and Hitchmough (2012) emphasize the urgent requirement for extensive surveys of invertebrate populations nationwide due to the existing research gap. Currently, only a limited amount of information is available on the distribution of native invertebrate species. Access to comprehensive biological spatial data is crucial for developing geospatial tools that prioritize and plan conservation efforts. Surveys focusing on invertebrates, such as the one conducted in this research, play a vital role in identifying conservation needs and potential opportunities (Lester et al. 2014).

28.5: Conclusion

Understanding the altitudinal preferences of macro-invertebrates can guide the identification of priority areas for protection and the implementation of altitude-based management practices. We can support diverse macro-invertebrate populations and promote sustainable agricultural systems by tailoring conservation efforts and habitat management to specific altitudinal ranges. Furthermore, these findings contribute to the broader understanding of invertebrates in New Zealand, addressing the existing research gap and highlighting the need for comprehensive surveys of invertebrate populations nationwide. Further research focusing on specific taxa and utilizing larger sample sizes is recommended to deepen our knowledge of invertebrate abundance and environmental preferences.

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Chapter 29: Ecological Restoration: Opportunities for Enhanced Biodiversity and Ecosystem services at Mt Grand

Vivien Michel

Abstract

Ecological restoration is an important conservation practice and becomes a requirement for sustainable land use on Mt Grand. The aim of this study is to provide possible restoration opportunities on Mt Grand that will have positive outcomes for biodiversity and ecosystem services, as well as the farming system. Combining literature research and field observations, present ecosystems on Mt Grand are analysed in their historical and land use context and the state of degradation and natural resilience of these systems assessed. Novel ecosystems of undegraded tussock grassland, as well as native shrubland and mountain beech forest are identified as possible reference ecosystems for ecological restoration. Proposed restoration opportunities include regrowth of tussock grasses at eroded sites and weed management, as well as support of long-term natural succession to native forest, using kānuka as a restoration species.

Key words: Agriculture, Conservation, Ecological restoration, Natural succession, Ecosystem services, Biodiversity.

29.1: Introduction

In the 21st century, increased human pressure on the environment is causing widespread degradation of ecosystems and loss of biodiversity worldwide, thereby threatening the provisioning of ecosystem services upon which we all rely. If ecosystems are degraded as a consequence of our land use, ecological restoration is needed to preserve their functioning and provision of ecosystem services. Hence, ecological restoration becomes a requirement for sustainable land use on our planet (Halle, 2007).

Ecological restoration is defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Society for ecological restoration (SER), 2019), while the term *restoration ecology* refers to the science underlying ecological restoration. It is an important conservation practice that complements other conservation practices (SER, 2019; Young, 2000). Similarly, ecological restoration is also an integral part of sustainable production systems, as production systems inevitably degrade natural resources (Hobbs and Harris, 2001). It can be argued that ecological restoration needs to be an integral component of land management in today's world (Hobbs and Harris, 2001). Comparing the present ecosystem with an ideal undegraded reference ecosystem enables the setting of appropriate restoration goals. The state of an ecosystem before its degradation can serve as a potential reference, or another currently undegraded system. However, in some cases, alternative goals need to be considered if for example key species have been lost or climatic conditions changed so that the reference ecosystem cannot be supported anymore. Then, the creation of a novel ecosystem can be considered, comprising also non-native species that would naturally not be part of the system but can take over specific ecological functions in it (Hobbs and Harris, 2001).

Before restoration measures can be proposed, the current state of the ecosystem or landscape needs to be assessed and the underlying drivers that lead to this state identified (Hobbs and Harris, 2001). Literature research and field observations on Mt Grand are combined to achieve the objectives leading to the overall aim of the study:

Study Aim: To provide possible restoration opportunities with positive outcomes for biodiversity and ecosystem services, as well as the farming system on Mt Grand
Objectives:

1) To better understand present ecosystems on Mt Grand in their historical and land use context
2) To assess the state of degradation and natural resilience of these systems

29.2: Materials and Methods

To understand present ecosystems on Mt Grand in their historical context, literature research was conducted about the potential natural vegetation types on Mt Grand, as well as the land use history impacting vegetation in the South Island High country beginning with the arrival of Polynesian settlers around 800 years ago. Moreover, based on previous studies conducted on Mt Grand in recent years, vegetation and soil characteristics were investigated.

To assess the present state of the ecosystems, observations during a farm tour around Mt Grand were made on 20th March 2023. At several stops, signs of vegetation degradation including erosion and species invasions were documented, having implications for ecological restoration. Furthermore, signs of natural self-regeneration of forest, succession and landscape connectivity were documented by taking pictures of the landscape.

Further literature research provided information about ecological restoration opportunities and principles, ecosystem services and the potentials of natural succession in tussock grasslands and kānuka shrublands, that could be applied to present ecosystems on Mt Grand.

29.3: Results and Discussion

Potential natural vegetation and historical vegetation development
Naturally, mountain beech forest would widely cover the Mt Grand area up to the treeline (Duncan et al., 1997), with shrubland covering drier areas (Smith, 2003), representing the potential natural vegetation types below the treeline. Above the treeline, snow tussocks and alpine vegetation would be the dominant vegetation types, while in driest areas short tussocks and other grasses in association with mMatagouri would be seen (Duncan et al., 1997).

Since human arrival in New Zealand, significant changes in the vegetation cover occurred. The setting of fires by Polynesian settlers starting around 800 years ago destroyed most of the original forest cover (Duncan et al., 1997). Formerly forested areas were replaced by extensive snow tussock grasslands migrating down from higher altitudes, while drier areas that used to be dominated by scrubs such as kānuka and mānuka were taken over by short tussocks after the fire regime (Duncan et al., 1997). Remnant patches of mountain beech still remain in sheltered valleys where they escaped burning (Duncan et al., 1997).

The shaping of extensive grasslands was further intensified by Europeans from the mid-1800s on, with a further increase in fire frequency (Duncan et al., 1997; Lee, 2018). While only native birds and invertebrates used to graze New Zealand’s tussock grasslands before European settlement, with the conversion to farmland, exotic plants and animals were introduced. Livestock mammals such as sheep and cattle, as well as game species such as rabbits and deer, are now widespread in grasslands throughout the region (Smith, 2003).

As a result, high stocking rates of sheep, grazing by feral rabbits, and the extensive use of fire to promote nutritious regrowth of tussocks, caused extensive desertification, reduction in soil fertility and vegetation cover, as well as weed invasions (Duncan et al., 1997; Lee, 2018). Ongoing grazing pressure led to dominance of grazing-tolerant or low growing plant species in grasslands, being unpalatable to grazing mammals, such as the invasive *Hieracium pilosella* (Smith, 2003).

29.3.1: Main vegetation types today and their state of degradation

Based on field observations on Mt Grand, short tussock and snow tussock communities were dominating the landscape, mostly grazed by sheep. At several sites, shrubs were present in the tussock grasslands, including mMatagouri, sSweet brier and kKānuka (Figure 29.1).

Figure 29.1: Tussock grassland and shrubland was the dominant vegetation cover on Mt Grand, with sheep grazing.

This observation was in line with the vegetative cover map of New Zealand provided by Landcare Rresearch (2020), where short tussock and snow tussock grassland, and grassland with shrubs (including mMatagouri, sSweet brier, *Leptospermum*) were identified being the main vegetation types present in the wider Mt Grand area, with beech forest and pasture occurring only in the surroundings of Mt Grand. In comparison, according to the potential vegetation map of New Zealand (Landcare Rresearch, 2020), scrub, shrubland and tussock grassland would occur naturally only in the higher altitudes of the Mt Grand area, while mountain beech forest would dominate the lower altitudes with Hall's totara/ broadleaf forest to the South.

The different types of tussock grasslands dominating the Mt Grand area were further differentiated by Duncan et al. (1997) into four different types: 1) developed snow tussock communities characterized by a high biomass of tussocks, with exotic grasses and legumes growing in between the tussocks, 2) undeveloped snow tussock communities characterized by a moderate biomass, with low-growing native shrubs and herbs growing in between the tussocks, 3) degraded snow tussock communities characterized by a low biomass and high cover of exposed rock, often with weedy plants growing in between the tussocks, and 4) Hi*eracium pilosella* – community characterized by a low biomass of tussocks, with a high abundance of *Hieracium pilosella* along with other exotic weeds (Duncan et al., 1997). The invasion of *Hieracium pilosella* was identified as a major threat to pastoral productivity and nature conservation in the tussock grasslands on Mt Grand (Duncan et al., 1997; Smith, 2003).

Yellow Brown Earths were identified to dominate the high-altitude soils at Mt Grand that are shallow and stony and exhibit a low water holding capacity, making them prone to erosion, especially on steeper terrain and after loss of vegetation (Duncan et al., 1997; Smith, 2003). During the farm tour, several sites with extensive soil erosion were documented (Figure 29.4).

Figure 29.2: Examples for sites with soil erosion on Mt Grand.

29.3.2: Principles for ecological restoration on Mt Grand

To our knowledge, no active restoration projects have been carried out on Mt Grand so far, or any long-term restoration goals set. The aim of this study is to provide a discussion about possible restoration opportunities and their outcomes for biodiversity and ecosystem services. Many different restoration opportunities might be considered at Mt Grand for different taxa of plants and animals. This report focuses only on the vegetation of tussock grasslands, native shrublands and forests. Proposed restoration opportunities are based on the principles defined by the Society for ecological restoration (SER). Being proposed from an ecological point of view, restoration opportunities on Mt Grand moreover need to focus on the maintenance of a sustainable production system. Furthermore, restoration objectives also need to be discussed more broadly within society (Hobbs and Harris, 2001) and among stakeholders (Principle 1, SER, 2019) referring to questions such as: What do we want Mt Grand to look like? What is its amenity value? What ecosystem services do we want to get from the land in the long-term? How shall pastoral production be combined with biodiversity conversation? And how much money, restoration time, and effort are we willing to invest now to achieve desired restoration outcomes in the future?

The formulation of specific restoration goals is informed by the properties of a defined suitable native reference ecosystem that considers environmental change (Principle 3, SER, 2019). For the case of Mt Grand, possible reference ecosystems may include undegraded tussock grasslands, native shrublands, and native mountain beech forest. However, recognizing that ecosystems are dynamic and adaptable to changes, restoration should not aim for the recovery of a static ecosystem state of some defined point in the past but should rather focus on attributes and ecosystem services desired for the future (Hobbs and Harris, 2001; Pfadenhauer, 2001). The recovery of dominance of indigenous species in appropriate habitats can be formulated as a possible objective for restoration (Lee, 2018). Most appropriate would to create novel ecosystems on Mt Grand that consist of both native and introduced species which take over ecological functions (Hobbs and Harris, 2001). In particular, grazing livestock and nutrient-rich grasses growing in between the native tussocks are important introduced species that build the basis for the pastoral farming system on Mt Grand.

Based on the chosen reference system, realistic restoration goals that are economically possible and practically achievable (Hobbs and Harris, 2001) need to be formulated, and measurable success criteria included (Principle 5, SER, 2019). Attributes that can be considered in the setting of goals include habitat heterogeneity (Hobbs and Norton, 1996), implying a diversification of the landscape with different types of ecosystems and stages of natural succession, and habitat connectivity, which seems especially relevant for the connectivity of native forest patches that are pushed back to isolated sheltered valleys. Moreover, ecosystem resilience (Hobbs and Norton, 1996) to future disturbances, such as climatic changes or invasion by exotic species, can be considered in setting restoration goals, as well as the provision of ecosystem services, on Mt Grand particularly carbon storage, water retention, products of pastoral farming, and recreation in terms of tramping.

After the setting of goals, restoration measures for implementing these goals can be developed, before these are incorporated into land management and planning strategies (Hobbs and Norton, 1996). The overall outcomes of ecological restoration can comprise a more "natural" state of the restored ecosystems, increased native biodiversity, enhanced water retention capacity, and prevention of soil erosion (Pfadenhauer, 2001) on Mt Grand, which would also pay off positively in terms of the farming system.

In the following, possible restoration opportunities and outcomes are further discussed for tussock grasslands on Mt Grand, as well as successional kānuka shrubland and native forest, representing possible reference ecosystems. Table 29.1 provides an overview of possible restoration opportunities, outcomes and their practical achievement.

Table 29.1: Overview of restoration opportunities to enhance biodiversity and ecosystem services.

Reference ecosystem	Restoration opportunity	Main outcomes for biodiversity and ecosystem services	Practical achievement
Undegraded tussock grassland	- invasive plants management - promotion of tussock grasses	- prevention of soil erosion - enhanced water retention capacity of tussock grassland	- replanting of tussock grasses at eroded sites - control of rabbits and invasive plants at degraded sites - overall moderate livestock grazing intensity
Native kānuka shrubland	- support of natural establishment of kānuka in tussock grasslands	- habitat for many native species including lizards, moths, beetles and lichens - increased landscape heterogeneity	- grazing livestock exclusion by fencing off areas that consist of a higher kānuka density
Native mountain beech forest	- support of natural succession from native kānuka shrubland or grassland to native forest	- reestablishment of the potential natural vegetation - increased carbon storage - better connectivity of remnant native forest patches - increased landscape heterogeneity	- establishment of forest patches at suitable sites. criteria may include: climate and terrain; presence of native shrubs and proximity to forest patches and seed sources; land productivity and compatibility with the farming system - fencing and control of fires and weeds at these selected sites to exclude disturbances such as grazing, fires, or exotic woody species

Tussock grassland restoration

Exotic plants nowadays account for a significant component of the vegetation in the High Country (Young et al., 2016). It can be expected that accumulated episodes of intense livestock grazing result in degraded snow tussock communities, which are characterized by a high cover of exotic weeds including the invasive *Hieracium pilosella,* and a high cover of bare ground (Duncan, 1996).

Therefore, one could think that a cessation of livestock grazing might enable the recovery of degraded tussock grasslands. However, altered conditions through invasion of weeds or altered soil conditions can prevent the natural recovery of the grassland to its original state, even if the initial degrading factor has been removed (Smith, 2003). In fact, in degraded tussock grasslands, removing grazing pressure can lead to dominance of introduced palatable grasses at the expense of native tussock grasses (Smith, 2003). To restore degraded tussock grasslands, thus, requires active management of introduced and invasive plants and promotion of tussock grasses.

Further, tussock grasses provide essential ecosystem services in effectively storing water, building up new soil and sequestering carbon, thereby preventing soil erosion (Mark and Dickinson, 2008), which are all attributes important for the restoration of degraded tussock grasslands showing a high cover of bare soil. In sum, moderate livestock grazing intensity and prevention of overgrazing by rabbits, together with management of invasive weeds can promote the regrowth of tussock grasses and shrubs. This represents an important measure for the restoration of degraded soils that were observed at several sites on Mt Grand and prevent further soil erosion.

In contrast to degraded tussock grasslands, in unmodified snow tussock grasslands where introduced species are less abundant, removing grazing pressure can favour the growth of tussock grasses and native shrubs (Smith, 2003). In those areas of undegraded tussock grasslands and presence of native shrubs that formerly supported mountain beech forest, it can even be asked whether a recovery of native mountain beech forest, that could serve as another reference ecosystem on Mt Grand, will be achievable in the absence of grazing pressure.

Native shrubland and forest restoration through natural succession

In the absence of disturbance such as intense grazing, fires, or exotic woody species, it is in fact likely that native shrublands progress naturally towards native forest (Sullivan et al., 2007, Young et al., 2016). The reestablishment of native forest through natural succession can be of high interest in the High Country, not only because it resembles the potential natural vegetation at most sites below the treeline. Increased ecosystem services, especially carbon sequestration, can also be expected. Regrowth of forest would allow for better connectivity of remnant forest patches that survived burning in sheltered valleys and increase the overall landscape heterogeneity in the grassland dominated High Country. Moreover, establishment of forest patches in low productive areas would promote the coexistence of agriculture and native biodiversity in the High Country.

Natural succession was defined by Connel and Slatyer (1977) as the “changes observed in an ecological community following a perturbation that opens up a relatively large space.” In the historical context of the High Country, the burning of forest opening a large space that was then used for pastoral production can be understood as such a perturbation, which will likely be followed by natural succession after the disturbance regime. At Cass, a comparable study site to Mt Grand in the Eastern South Island High country, Young et al. (2016) conducted a long-term study of vegetation change over 100 years in response to past disturbances. At sites previously dominated by short tussock grasses, they observed an emergence and expansion of shrubland, including mānuka and other native shrubs, as a result of the relaxed fire regime and lower stocking rate (Young et al., 2016). It is argued that these shrublands, as elsewhere in the South Island High country, will probably develop into native mountain beech forest in the long-term over the next centuries. However, currently this is constrained by seed availability from mountain beech forest that has been pushed back to refuges in isolated sheltered gulleys (Young et al., 2016). Nevertheless, rare events of long-distance seed dispersal may contribute to the re-establishment of mountain beech (Young et al., 2016).

At Blue Nose on Mt Grand, a succession of kānuka into the tussock grassland was observed during the farm tour, with dense establishment in the valley and decreasing density uphill at an altitude of around 900 m (Figure 29.2).

Figure 29.3: Upphill succession of kānuka at Blue Nose site, Lagoon Valley, Mt Grand.

Kānuka, an indigenous shrub or small tree species, was found to be well adapted to dry soils where it naturally forms steady-state communities (Smale et al., 1995; Lee, 2018). It is also found to be a successional species, inhabiting grassland naturally from present seed sources (Davis et al., 2013). It has been observed to establish on bare ground and in lightly grazed, short-statured pasture at sites that were formerly occupied by forest (Allen et al., 1992). Once established, it is thought to enable tree growth and forest succession by building up mycorrhiza and improving microsite conditions (Davis et al.,2013).

To restore native forest on Mt Grand, active restoration planting or seeding of native shrub or tree species might not seem feasible involving high costs of planting and maintenance effort, as well as uncertain outcomes regarding resilience and overall biodiversity value of the restoration planting. A more achievable approach can be the use of kānuka as a restoration species, possibly enabling the natural self-regeneration of forest ecosystems.

However, in a study conducted in East Otago, New Zealand, that analysed succession from grassland to kānuka stands of different ages up to the start of turning into a broadleaved forest, Allen et al. (1992) also found kānuka to prevent establishment of later successional tree species under its dense canopy for a considerable amount of time. In the study, after around 50 years after kānuka establishment, kānuka stem density decreased so that other tree species were able to grow above a sapling stage. Kānuka was still clearly dominating the succession up to at least 70 years after its establishment (Allen et al., 1992), which implies that the establishment of forest through kānuka succession will only be achievable on large time scales.

Nevertheless, even if natural re-generation of forest might take a very long time, native kānuka shrubland can also be seen as a suitable reference ecosystem on Mt Grand, moreover representing an important habitat for much of New Zealand's endemic biodiversity, including lizards, moths, beetles and lichens, many of them dependent on shrub species (Lee, 2018).

The natural self-regeneration of shrublands and forest can be promoted as a restoration measure at suitable sites on Mt Grand, especially where natural succession was already observed starting with kānuka encroachment in the tussock grassland. Therefore, to prevent the suppression of later successional species by grazing, exclusion of grazing can be proposed. In addition to mammalian grazing, the management of mammalian predators would also be important to restore indigenous biodiversity including birds, lizards and invertebrates (Lee, 2018).

Succession is, however, dependent on many factors such as altitude, slope, aspect, grazing, seed availability and dispersal, or soil states (Young et a., 2016). Thus, criteria to select suitable sites for shrubland and forest restoration on Mt Grand, should include climatic and terrain aspects, presence of native shrubs and proximity to forest patches and seed sources, as well as land productivity and compatibility with the farming system. The progress of natural succession would need to be closely monitored in the long term following success criteria that need to be clearly defined for different taxa, and management interventions might be necessary if disturbances such as invasion by exotic weeds hinder the thriving of successional target species.

29.4: Conclusion

It has been pointed out that ecological restoration is important to consider within the interplay of biodiversity conservation and the farming system in the High Country on Mt Grand, having the potential to significantly improve the outcomes for both. The aim of the study was to propose possible restoration opportunities from an ecological point of view, providing the basis for a further discussion among stakeholders. Novel ecosystems of undegraded tussock grasslands, as well as native shrublands and mountain beech forest were identified as possible reference ecosystems. For the restoration of degraded tussock grassland and soils, supporting the regrowth of tussock grasses and shrubs is proposed facilitated by moderate livestock grazing intensity and prevention of overgrazing by rabbits, as well as management of invasive weeds. Further, for the restoration of native shrubland and forest the use of kānuka as a restoration species is suggested enabling natural self-regeneration of native forest ecosystems on large time scales. Outcomes of ecological restoration on Mt Grand may comprise increased ecosystem services including enhanced water retention capacity and carbon storage, as well as less soil erosion, supporting not only native biodiversity but also a sustainable land use on Mt Grand, thereby providing the basis for future economic gains of pastoral production. Further research supporting restoration efforts is needed to select suitable sites for the natural self-regeneration of shrublands and forest on Mt Grand, while also assessing the connectivity between native forest patches in the wider Mt Grand area. Moreover, long-term vegetation change across Mt Grand needs to be monitored.

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