

VEGETATION ASSESSMENT TO UNDERSTAND THE
EFFECT OF FERAL GOAT POPULATIONS ON NATIVE
FLORA COMPOSITION

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Abstract

A vegetation assessment was conducted to understand the effect of feral goats (*Capra hircus*) on the vegetation of Isolated Hill Scenic Reserve located in Southern Marlborough.

New Zealand forests evolved without the pressure of mammalian herbivores but following human settlement they became subject to intensive browsing following the introduction of exotic mammals.

This study focuses on the presence of feral goats. Interest arises from the settlement of other countries and the subsequent liberations of feral goats which are now considered to be responsible for the significant removal of native vegetation as well as playing a dominant role in erosion. Changes in plant communities have occurred with the pressure of goat browsing as well as secondary effects such as habitat degradation

The purpose of this research was to investigate the changes in plant species composition since the initial and subsequent research conducted in 1985 and 1994. An analysis of previous work on the diet of multiple introduced ungulate species was also conducted. Previous studies were not limited to only feral goat studies and included other introduced herbivores to provide a broad overview of diets.

The New Zealand Forest Service implemented a programme for monitoring the seral forest in Isolated Hill Scenic Reserve using standard Forest Service vegetation quadrants. 32 quadrants were established, including three exclosures, in various locations around the Reserve to allow assessment of feral goat impacts on seral forests (forest whose constituents are of varied age classes). Nine forest service plots, including three exclosures were re-measured and an additional nine plots were measured.

Given the progression of vegetation change that has been observed during the course of this study, both analytically and observationally, Isolated Hill Scenic Reserve in its current state, involving the notable presence of feral goats and the vegetation types will continue to diminish in diversity.

Introduction

1.1 Browsing of Indigenous Vegetation

Similar to many other island archipelagos the biota of New Zealand has experienced dramatic changes through human colonisation (Saunders and Norton 2001). Changes to the flora of New Zealand began with the arrival of Polynesian settlers who introduced burn offs to clear forested land as well bringing two mammal species the rat (*Kiore*) and dog (*Kuri*) (McGlone 1989) which combined with the intensive hunting of indigenous bird species started a change in forest composition that is still ongoing. A number of different mammalian herbivore species were then introduced following European contact with New Zealand. The first of these were released primarily as food sources for stranded sailors and whaling depots. However when the full scale of settlement began the new arrivals brought with them a number of farmed and hunted species to provide food and sport and in some instances to make their new home more like the “old country” (Thomson 1922). However the introduction of any new herbivore changes an ecosystem (Caughley 1989), when exotic herbivores were introduced they changed the composition of the New Zealand forests with these changes being potentially irreversible. In the montane or sub-alpine zones, introduced herbivores are a major new effect on the vegetation composition, much of which is now depleted from its pre-Polynesian state due to this pressure (Atkinson and Greenwood 1989). The impact from the colonisation of New Zealand by human settlement has been catastrophically devastating on the indigenous biota (Saunders and Norton 2001) with significant losses of both flora and fauna. Before human settlement New Zealand was forested below the climatic tree line (McGlone 1983), however in the space of just over 1000 years forest cover has been reduced from approximately 75% down to 25% (Saunders and Norton 2001).

The forest plants of New Zealand evolved without the pressure of mammalian herbivores but rather with the presence of avifauna, notably the now extinct moa (*Dinornithidae* spp.) (Clout and Hay 1989). Moa were a common and widespread flightless bird in pre-Polynesian New Zealand (Atkinson and Greenwood, 1989) although it is generally agreed that they became extinct by around 1400 AD through hunting. They were thought to prefer lowland areas though some evidence of colonisation has been found to indicate that higher altitude ranges

were also utilised (Atkinson and Greenwood 1989), their habitat is thought to have certainly included forest but there is some debate whether grasslands were utilised to the same extent (Caughley 1989). Despite their size there is no reason to assume that any of the moa species were restricted to tussock-grassland though their dependence on just forests still is still contested (Atkinson and Greenwood, 1989). Moa fossil deposits have been found in areas that were under forest cover well after the Polynesian discovery of New Zealand (Anderson 1983). Originally 13 species of Moa were suspected to have existed (Cracraft 1976) but that number has since been revised and it is accepted that there were in fact 12 separate species in existence (Millener 1982).

It is possible to assume that moa species had a profound effect upon forest composition as an individual of one of the smaller moa species would have been capable of destroying a juvenile woody plant should the plant have been palatable (Atkinson and Greenwood 1989). As there is also evidence to suggest that moa species cohabited areas it is a safe assumption that plant species less than a metre high would have been subject to intense browsing by multiple species, a further indication that mechanisms of survival would have been in place as suggested by Atkinson and Greenwood (1989). To some degree it would appear that native plants did evolve some structural deterrents to reduce the browsing impact of moa and other indigenous bird species that fed upon them (Greenwood and Atkinson 1977). However these deterrent structures have had a reduced effect as protection against introduced ungulates (Atkinson and Greenwood 1989; Atkinson 2001) such as goats and deer.

New Zealand's native plant species would have no doubt adapted to some degree to the presence of moa as it is widely accepted that flora species evolve with adaptations to reduce the effect of browsing arising with herbivores present (Atkinson and Greenwood, 1989). Some New Zealand plants show adaptations to moa browsing such as *Podocarpus hallii*, *Podocarpus totara* and *Podocarpus acutifolius* which all have spine tipped leaves making them potentially less palatable to browsing moa (Atkinson and Greenwood, 1989). Another adaptation that has been suggested though somewhat more contentiously is divaricated growth. It is thought that the dense tangled branches worked in a cage like function to prevent moa from browsing (Greenwood and Atkinson 1977; Bond, Lee et al. 2004). Often the species that display divaricated growth either have a juvenile stage or are small, and recent studies (Bond, Lee et al. 2004) indicate that it would be a successful defensive strategy against moa and other bird browsers. However despite these adaptations it is doubtful that moa

stripped bark from stems and snapped branches off the way goats (*Capra hircus*) will with plants such as the *Pseudopanax* species as well as with other podocarps (Atkinson and Greenwood, 1989). As the feeding ecology of moa does not mirror that of introduced mammalian herbivores (Wood, Rawlence et al. 2008) which would further suggest that deterrent strategies developed by New Zealand's flora would be less effective against the ungulates.

The rapid removal of moa from the ecosystem, along with regular fires that replaced the occasional lightning induced fires (Atkinson and Cameron 1993) would have been one of the first significant factors influencing the change in New Zealand forests. The general consensus between archaeologists is that moa became extinct primarily due to hunting (Anderson 1983; McGlone 1989). This is further supported by evidence that moa didn't become extinct during the Holocene period prior to human arrival and were unlikely to be affected by climatic changes (McGlone 1989). Further evidence can be provided by their behaviour in comparison to surviving bird species. Moa were flightless, typically large and mostly diurnal (active in the day) and built nests on the ground (McGlone 1989) making them relatively easy prey for early Maori hunters.

Of particular interest for this study is the presence of feral goats. This interest arises from the settlement of other countries and the subsequent liberations of feral goats which are now considered to be responsible for the significant removal of native vegetation as well as playing a dominant role in erosion (McGregor, Dupont et al. 2009). Wholesale changes in plant communities have occurred with pressure of goat browsing as well as secondary effects such as habitat degradation (Cruz, Carrion et al. 2009). It has been recorded that under seriously intense disturbances such as grazing by goats the vegetation becomes dominated by herbaceous plants (Koniak and Noy-Meir 2009) and as New Zealand's native forest is predominantly composed of woody species it is important to determine if such changes could or are occurring here. Feral goats can be found across New Zealand in a number of differing areas (Parkes 1990; Rudge 1990; Norton 1995) often on areas set aside for nature conservation.

New Zealand had no browsing species for several hundred years prior to the arrival of European settlers along with no known mammalian browsers with the result that many of the native flora species have proved extremely palatable to introduced species. Following contact

with Europeans the New Zealand vegetation again experienced browsing and grazing, this time by a wide variety of introduced northern hemisphere mammals with the addition of select marsupials from Australia (Caughley 1989). As a result of this there has been a large and in most instances negative impact upon ecosystems in New Zealand with each of the introduced herbivores filling a feeding niche that would have been substantially different from that of previous moa (Caughley 1989). Forest dwelling mammals, in particular goats and numerous deer species have been introduced to New Zealand over an extended period of time (Wardle, Barker et al. 2001) and following their successful colonisation of various regions of New Zealand they have had a profound effect on the composition of New Zealand's native forests. Atkinson (2001) noted that goats and pigs were the first examples of large mammalian herbivores to reach New Zealand and by the end of the 19th century were considered widespread. They are known to browse juvenile vegetation and have been noted to restrict regeneration on natural disturbance sites, such as landslips or blow downs.

Following their introduction, mammals have spread to many remote environments that at a glance appear pristine and untouched to the untrained eye (Atkinson 2001). The effect introduced ungulates have can be quite profound, specifically where plant composition and ecosystems is concerned. It has been documented that plant-herbivore relationships have a significant impact on ecosystem composition (Hobbs 1996). In the case of New Zealand this is serious as there were no major herbivores for some time (moa) and no large mammal ungulates at all. Typically seed was spread either by bird life or by wind or seasonal casting (such as *Nothofagus* species (Dawson and Lucas 2000)). Therefore the presence of introduced ungulates will have a notable negative effect on species composition in an ecosystem such as the one presented by New Zealand as both seed production and nesting space for seed dispersing birds can be reduced from excessive browsing. The effect of introduced mammal's ranges from seed predation and the depletion of palatable flora to the loss of forest canopies through defoliation and to some extent the forced ruin of forests (McKelvey 1995; Wardle, Barker et al. 2001; Campbell and Atkinson 2002; Bellingham and Lee 2006). The damage imposed by invasive animal species is not only limited to flora and fauna but it has been proposed that intensive grazing by both domestic and feral stock has been responsible for accelerated rates of natural erosion though it is considered the evidence was largely subjective (Bellingham and Lee 2006). This was also suggested by the reduction of plant biomass due to browsing, which in turn is thought to reduce rainfall interception which

increases surface water run-off and exacerbates soil and slope stability (Grant 1985; Bellingham and Lee 2006). However despite these suggestions it is still contentious whether human impact via introduced mammals, is directly or indirectly responsible for scree formation (rocky slopes, increased runoff and reduced soil) though the associated vegetation may have been reduced with some increase in marginal spread (Wardle 1991; Bellingham and Lee 2006).

It is widely accepted that grazing and browsing inhibits most regeneration (Smale, Dodd et al. 2008) so within reason it is safe to assume that Isolated Hill Scenic Reserve will have limited regeneration due to the presence of feral goats and to a lesser extent feral pigs and red deer. There is the possibility that, from continuous browsing, fragmentation may occur, this being the division of formerly continuous expanses of natural habitat into scattered fragments within modified environment (Denyer, Burns et al. 2006). In this case the modification is as a result of the browsing effects from the introduced herbivores. There is no doubt that New Zealand's forest understories have been severely impoverished by the browsing effects of introduced mammals (Wardle, Barker et al. 2001; Bellingham and Lee 2006). Habitat fragmentation alters areas of continuous habitats into small remnants (Boulton, Richard et al. 2008). Forest fragmentation is a significant threat to biodiversity and may have down reaching consequences (Laforteza, Coomes et al. 2010), such as increased erosion and loss of habitat. Fragmentation occurs when areas of unbroken forest are broken down in to smaller sized remnants (Laforteza, Coomes et al. 2010) and can be a result of heavy browsing by introduced herbivores. When fragmentation occurs new forest edges are created, and continuous habitat and patch sizes decrease (Collinge 1996; Laforteza, Coomes et al. 2010). This can disrupt the movement and spread of both for a and fauna species and in its most severe form result in reduced populations or extinction (Driscoll and Weir 2005). Fragmentation can also result in a loss of fecundity as species may become isolated and genetic drift decreases. Notable impacts of forest fragmentation are changes in environmental conditions, increased weed invasion, a change in species behaviour and genetic decline (Burns, Floyd et al. 2011) which can result in long term changes such as species composition change, forest structure alterations and a decrease in population size.

It is important to understand that there are three main ways in which ungulates can alter the flow of nutrients and energy in an ecosystem. They can; 1) alter species composition through browsing which effects the litter outputs of less eaten plants; 2) the alteration of the chemical

composition of plant tissue structure through digestion and; 3) altering soil and plant micro environments (Augustine and McNaughton 1998).

The change in litter inputs due to species browsing means the soil may not become as fertile due to the presence of less plant litter while the change in plant chemical composition means that seeds that are normally spread by birdlife may not be able to survive through the digestion process of an ungulate so seed is not spread. These two effects lead, in part to the third effect which is the alteration of the soil and plant microenvironment meaning growing conditions, such as specific bacteria that might be required for growth of specific plant species are not present so species composition may change. Soil microbial biomass is important part of the decomposition process and helps regulate the supply of plant available nutrients from the soil (Wardle, Walker et al. 2004).

The degradation of species composition can be defined as the reduction or change to a lower quality state of characteristic or function (Smale et al., 2008) and therefore forests can be degraded in a number of ways. Smale et al. (2008) indicates that the regenerative ability of plant and tree populations can be reduced which in turn can potentially reduce the diversity of the plant community. Following changes such as these the forest structure can change significantly which can result in adverse environmental conditions such as erosion and the degradation of both flora and fauna species. As native forests contribute to soil stabilisation, water purification and to a lesser extent carbon sequestration these three factors can be compromised with a change in forest structure (Smale et al, 2008). The New Zealand forest floor biota evolved in the absence of ungulate trampling. Open and un-compacted soils were most likely present along with shallow feeding roots near the surface (Duncan and Holdaway 1989). Trampling damage among conditions such as these would have had serious effects with the arrival of European settlers and their livestock releases. This is because during movement over softer ground the ungulate hoof, works like a chisel with the toes splaying out while the hoof edge will cut into the substratum (Duncan and Holdaway 1989). This will cause additional damage and may in some instances be responsible for rapid decline of soil conditions particularly in steeper areas where run off occurs. Abiotic factors in New Zealand forests such as temperature, aeration, pH and soil chemistry as well as soil water availability can be directly or indirectly distorted (Stritar, Schweitzer et al. 2010) via trampling from introduced ungulates. While it is expected that non-favoured browse species will flourish with the decrease in palatable species the nonconsumptive influences of introduced

herbivores, such as trampling (a direct effect) or decreased soil fertility (an indirect effect) (Heckel, Bourg et al. 2010).

With the change in forest structure and composition it is then possible for further invasive organisms to then take hold (Cadenasso and Pickett 2001). These additional invasions can be by other exotic flora or fauna species.

Wardle (2001) noted that browsing mammals usually reduced the diversity of browse layer plants and also altered the habitat diversity of both the litter layer and in turn the soil fauna. In some instances the fecundity of a plant species may be affected by browsing of shoots and inflorescences necessary for continued species growth. An example of this occurred where browse damage from hares (*Lepus europaeus*) almost completely prevented seed production by *Carmichaelia juncea*, a native broom species of New Zealand (Grüner and Norton 2006). A reduction in indigenous plant species richness can be attributed to the direct effects of grazing and severely reducing or exterminating specific species populations (Smale et al, 2008). An example of this can be seen through the change in the presence levels of *Pittosporum patulum* in the South Island, New Zealand. *P. patulum* is an endemic low tree, found commonly in montane forest and sub-alpine scrub in the South Island, with a range from Nelson and Marlborough down to north Otago, predominately on the east coast (Rogers and Walker 2005). Introduced mammalian herbivores have been linked to the decline of *P. patulum* particularly in the Nelson and Marlborough region through defoliation and stem decapitation (Rogers and Walker, 2005) both of which inhibit growth and therefore the reproductive success of the species drastically. The lack of adults and sub-adults along with the high levels of the mentioned defoliation provide a reasonable indication that *Pittosporum patulum* is in fact threatened by herbivory from introduced mammalian pests and provides an example of what may be occurring at a larger species scale.

1.2 Purpose

The purpose of this research is to investigate the changes in plant species composition since the initial and subsequent research conducted in 1985 and 1994. This can then be broken down into a number of components that explore the potential behind any changes that may have occurred over the course of the last 26 years. Of particular interest is the change between the results of current research and 1994 which consisted of data collected and analysed by Cochrane (1994).

What are the changes in species composition due to the effects on browsing from feral goats? This broad question has several underlying questions that need to be investigated to gain a full understanding of changes that have occurred. Vegetation changes can show influence from inter-specific competition where goat browsing has occurred. For instance has the suppression of woody species encouraged the growth of vascular plant species?

Since the last study was done (Cochrane 1994), a period of 17 years, have there been notable growth rates and if so have these growth rates followed the expected behaviour? Are these changes consistent with what Cochrane (1994) found when compared to the original dataset collected by the New Zealand Forest Service in 1985. However if the growth rates are low what are the potential factors contributing to this behaviour? This is of interest because many existing large trees were established well before the introduction of grazing mammal species (ca 230 years ago) and the long-term consequences of herbivory on forest structure and success remains uncertain (Bellingham and Lee 2006).

Finally if goat numbers have decreased have the changes present stayed or is the environment slowly showing changes of returning to the original composition of species? In a 36 year study of forest recovery, following the removal of goats it was found that they had eradicated six plant species and significantly reduced at two thirds of the remaining tree and shrub species ultimately changing the direction of vegetation composition and succession (Atkinson 2001).

2.0 Diet Study

2.1 Introduction

As part of this study a broader overview was conducted to observe similarities between different research projects investigating the diet patterns of introduced mammalian species in New Zealand. The studies focused on a variety of different introduced mammals and were conducted in a number of differing locations around New Zealand within the last 30 to 40 years as research papers, reports or in some cases, as dissertations for Masters or Doctorate degrees.

Some studies concentrated specifically on one introduced animal species, while others made a comparative analysis of multiple species impact upon flora composition. Following the research approximately 250 flora species were included in this study (for a full list of flora species see appendices 6.1). The studies covered a number of specific mammal species introduced into New Zealand, including the marsupials, possums (*Trichosurus vulpecula* Kerr) and wallabies (*Macropus bicolor*, *M. eugenii* and *M. parma*), five deer species, red deer (*Cervus elaphus*), sambar (*C. unicolor*), rusa (*C. timorensis*), fallow (*Dama dama*) and white-tailed deer (*Odocoileus virginianus*), three members of the *Caprinae* goat-antelope subfamily, chamois (*Rupicapra rupicapra*), tahr (*Hemitragus jemlahicus*) and goats (*Capra hircus*). Also included were wild pigs (*Sus scrofa*), and two *Lagomorphs*, rabbits (*Oryctolagus cuniculus*) and the hare (*Lepus europaeus*). In one study wapiti (*Cervus canadensis*) were recorded in a study along with red deer but were not differentiated between and given the similarities between the two species they were counted as one for this report.

The data collected through the course of the research was collated in a number of Excel™ spreadsheets to be used in Canoco®, an ordination software tool.

2.2 Approach

This approach involved three steps; data sourcing, MS Excel analysis and ordination using Canoco for Windows. These three steps provided a clear and accurate representation of what similarities or dis-similarities different mammalian species have in regards to their diet.

Data was sourced by researching diet analysis studies previously conducted in New Zealand over the last 60 years. From this research 49 studies were found to be suitable for use in ordination in this project. To be deemed as suitable, the studies had to make a clear distinction as to what introduced fauna species ate which flora species (i.e. amalgamated findings could not be used). This ensured that no untenable data sets were created.

The data obtained from the research papers (Poole 1951; Mason 1958; Gilmore 1965; Harvie 1973; Purchas 1975; Rudge 1976; Mills, Lee et al. 1978; Fitzgerald and Wardle 1979; Vujcich 1979; Parkes 1984; Coleman, Green et al. 1985; Williamson 1986; Kelton and Skipworth 1987; Mitchell, Fordham et al. 1987; Nugent and Challies 1988; Thomson and Challies 1988; Nugent 1990; Fraser 1991; Allen 1992; Nugent 1993; Parkes 1993; Chimera, Coleman et al. 1995; Owen and Norton 1995; Parkes and Thomson 1995; Nugent, Fraser et al. 1997; Stafford 1997; Cochrane 1998; Reddiex 1998; Parkes 1999; Wong and Hickling 1999; Sweetapple 2000; Yockney and Hickling 2000; Fitzgerald and Gibb 2001; Nugent, Fraser et al. 2001; Cochrane, Norton et al. 2003; Sweetapple 2003; Sweetapple, Fraser et al. 2004; Forsyth, Richardson et al. 2005; Husheer and Frampton 2005; Rogers and Walker 2005; Parkes and Forsyth 2008; Sweetapple 2008) was collated into a spreadsheet in Microsoft Excel in columns by author, and plant species was noted as being present or absent. If a particular species was present it was assigned a “1”, if it was absent from that study it was assigned “2”. This allowed for a basic presence/absence sheet which could be used in ordination. The animal species focused on in the study were also noted and further spreadsheets according to animal species were created. The mean number of flora species detected in each diet analysis was also calculated along with the standard deviation. The list of flora species for this study is in Appendix 7.1.

For each animal species a formula was used, $=\text{Countif}(\text{range}, \text{criteria})$, to determine how many of the 250 recorded plant species were recorded as being consumed in the diet studies of those particular mammals from all the studies. It is important to note that there was not an

even number of studies collected for each mammal species; for instance there were 20 studies found on possums and only 1 for chamois. This meant that plant species recorded as being consumed are only representative of those studies used in this study and therefore do not necessarily represent the full diets of particular mammals.

Ordination was carried out using the computer program Canoco (Version 4.5), a package designed for Windows. This software allows the user to create an ordination diagram using Canodraw, the graph tool of Canoco. The diagram allows, in theory, the reconstruction with some error, of the primary data and the matrix similarities and differences among samples and species (Leps and Smilauer 2003). This is useful for interpreting the content of an ordination diagram and helps explain and present different theories. In this case a Detrended Correspondence Analysis (DCA) was performed. No weighting was applied to allow all the data to be able to be presented as we were interested in the total overall result, not a specific level of occurrence.

2.3 Results

2.3.1 Excel Analysis

Table 2-1 Mean and standard deviation of flora species recorded by mammal species.

Species	Number of Studies	Mean No. of flora species present per study	Standard Deviation
Wallaby	3	22.3	20.6
Possum	20	16.1	8.5
Red Deer	3	21.7	15.2
Sambar Deer	2	14.0	18.4
White-tail Deer	1	29.0	n/a
Fallow Deer	2	20.0	15.6
Rusa Deer	1	20.0	n/a
Pig	3	5.0	2.0
Goat	5	29.2	17.2
Tahr	2	12.5	12.0
Chamois	1	23.0	n/a
Rabbit	1	23.0	n/a
Hare	2	23.0	4.2

Table 2-1 shows the average number of flora species present per study along with the associated standard deviations. In the case of the species where there was only one study to obtain data from (white-tail deer, rusa deer, chamois and rabbits) the result presented is not an average but rather the total number of species present. The standard deviation displays how much variation or dispersion there is from the average with a smaller standard deviation showing minimal spread among the data source while a larger standard deviation would indicate a large range in data.

Table 2-2 Total number of flora species recorded for each mammal from collated studies.

Species	Total Flora Species Recorded	Number of Studies
Wallaby	59	3
Possum	125	20
Red Deer	46	3
Sambar Deer	28	2
White-tail Deer	29	1
Fallow Deer	35	2
Rusa Deer	20	1
Pig	15	3
Goat	103	5
Tahr	22	2
Chamois	23	1
Rabbit	23	1
Hare	27	2

Table 2-2 shows the overall number of flora species for each mammal species. The lowest recorded number is 15 (pig) while the highest is 125 (possum). Also displayed is the number of studies found for each species, to provide a simple indicator of what previous research has been conducted in the past.

2.3.2 Ordination Analysis

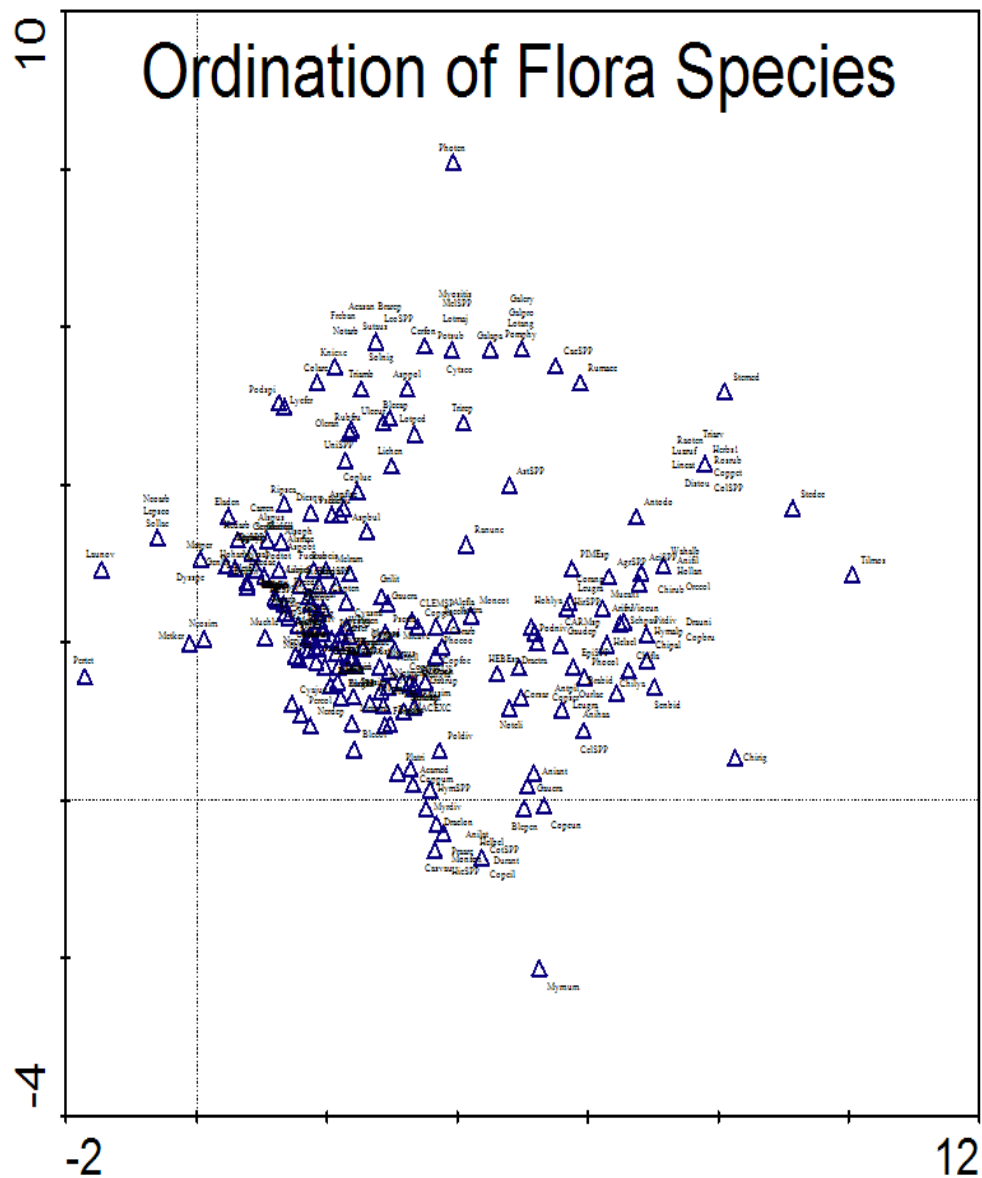


Figure 2-1 Ordination output for flora species showing similarities in species browsed.

Figure 2-1 shows the graph generated by Canodraw (Canoco graphing tool) to show the results of the ordination. In this case it is possible to see a tight grouping of flora species at the co-ordinates (using the x and y axis) at (2,2). This clumping of data is indicative of plant species that occurred in most studies.

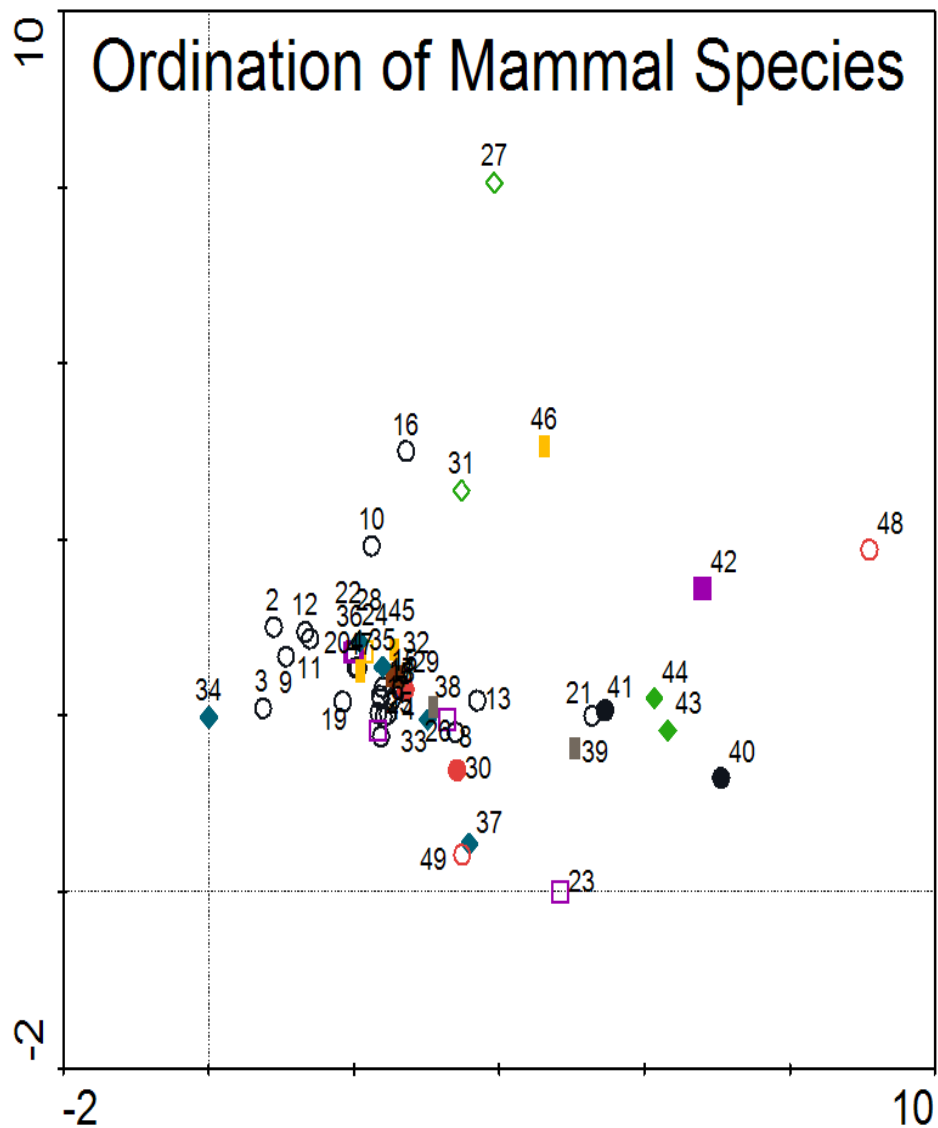


Figure 2-2 Ordination output for diet studies of mammal species. ■ Wallaby, ● Tahr, ■ Rabbit, ◆ Hare, ○ Pig, ○ Possum, ● Fallow, ◆ Goat, ■ Red Deer, ◆ Sambar, ■ Chamois, ■ White Tail, ● Rusa.

The ordination (Figure 2-2) shows a notable clumping of data, indicating that there is a relative similarity in diet type between the bulk of the species. It is interesting that in some instances there may be a distinct difference between the same species e.g. pig, (48 and 49).

2.4 Discussion

2.4.1 Excel Analysis

The statistical output from MS Excel (Table 2-1) provides an interesting though potentially biased view of the diet results by mammal species. In some cases where there is a large standard deviation this is most likely due to the number of studies available for that mammal species. Some studies concentrated on a wide variety of plant species, thereby conducting a detailed diet analysis, while others concentrated on the effect an introduced herbivore may have on a particular plant species, therefore limiting the data available and creating a larger standard deviation.

Table 2-2 indicates that each of the introduced mammals show a wide variety of diets indicating that they are not selective feeders. These large diet compositions also indicate that there may be some overlap (similarity) between diet compositions in different mammals.

2.4.2 Ordination Analysis

Both ordination diagrams (Figure 2-1 & 2-2) show the same end result from two different perspectives. Figure 2-1 demonstrates that the majority of flora species show similar levels of occurrence in mammal diet across the studies, indicated by the clumping of data which does show some spread further from the main body of data points. The majority of the outliers are typically species that only occur one to four times, which can be due to some studies concentrating on one plant species or on one genus. It is important to note that as there was no weighting applied to the ordination this means that the data presented does not necessarily show the ideal representation as the outliers will pull and skew the diagram out of accurate shape. However it is clear that while a large proportion of the flora is consumed by the majority of the mammals it also explains the spreading out of data from around the main clumping. This spread can be explained by the fact that while there is some similarity in diet there is some difference between each mammal species diet. This similarity may be described by interspecific competition for example, rabbits and red deer may share some flora species but ultimately there will be some difference given their differing body types and preferred environment.

These results are mirrored in Figure 2-2, where it is possible to see a similar trend in the distribution of data albeit on a smaller scale. It is interesting to see that for the most part those mammals of the same species display a similar trend, i.e. are grouped close together.

However there are some exemptions from this observation, the first being pigs, (numbers 48 & 49). In this case the difference here can be explained by study number 48, which was conducted on the Auckland Islands and its vegetation is classed as sub-alpine to alpine, whereas 49 was from a more temperate locale. Another outlier of note is study 27 (Sambar Deer) and its variation in the trend is explained the fact that only one plant species was recorded in its diet study.

Both ordination diagrams support the theory that there is minimal selectivity in the diets of introduced mammals given the wide range of plant species encountered and therefore the majority of differences may be explained by other factors such as limitations as studies concentrating on one plant species or genus, or the body size and home range of the mammals of interest. Despite the minimal selectivity, there is also the indication that most of the introduced species are ranked generalists. This indicates that while most flora species may form a part of the diet their likelihood of browse is influenced by the presence or absence of other palatable species. For instance if a highly preferred species is available, then the less preferred species will not be browsed, however if the highly preferred species should be unavailable then the less preferred species will be more likely to be browsed.

2.5 Limitations

During the course of the research for this project, a number of different limitations and difficulties were encountered, though in some instances these limitations were not the fault of the authors of the research and therefore their work should still be considered accurate.

The first limitation encountered when researching data for this project was where research projects looking at multiple mammal pests did not differentiate the results found between species. This meant that it was not possible to correctly identify what animal species ate what plant species as the data was collated into one table. This made these particular studies unsuitable for this study especially as it could result in inaccurate results if used during the data analysis. However some studies with multiple animal species were encountered where the results had been separated and these were able to be used in this analysis.

A second limitation encountered was the method of recording plant species. In some cases only a few plant species were recorded as being browsed upon as the study was only focused on those particular species. This meant that some differences in the results between different studies concerning the same animal may be due to this approach in a particular study rather than an actual difference in diet.

Another difficulty encountered was the reclassification of flora species. Some studies were conducted where a particular classification was accepted at the time but has since been reclassified with another name. If any doubt arose regarding the name of a particular species then an up to date text book, the Nature Guide to the New Zealand Forest (Dawson and Lucas 2005) was consulted to ensure that the same species was not listed twice under two different names.

3.0 Isolated Hill Scenic Reserve

3.1 Location

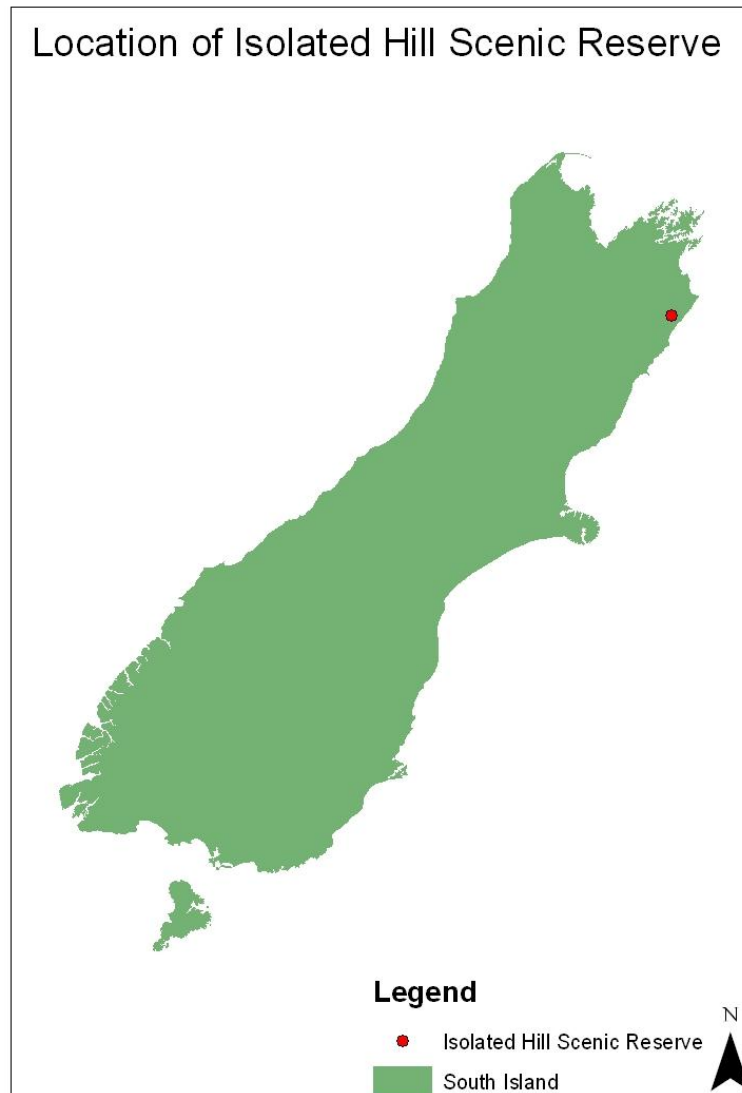


Figure 3-1 Location of Isolation Hill Scenic Reserve.

Isolated Hill Scenic Reserve is located approximately 42 kilometres south of Blenheim (Figure 3-1). Access is gained via the Ure Valley Road which runs along the Waima River. The Blue Mountain Station is located at the end of the Ure Valley Road and is the entry point to the track that leads into the Reserve. The reserve (Figure 3-2) is 2835 hectares in area and is located in the catchments of Brian Boru Stream, Isolation Creek, Ben More Stream and

Woodside Creek. Within the reserve the terrain is extremely varied and ranges from steep cliffs, heavily forested areas and inaccessible gorges (Cochrane 1994).

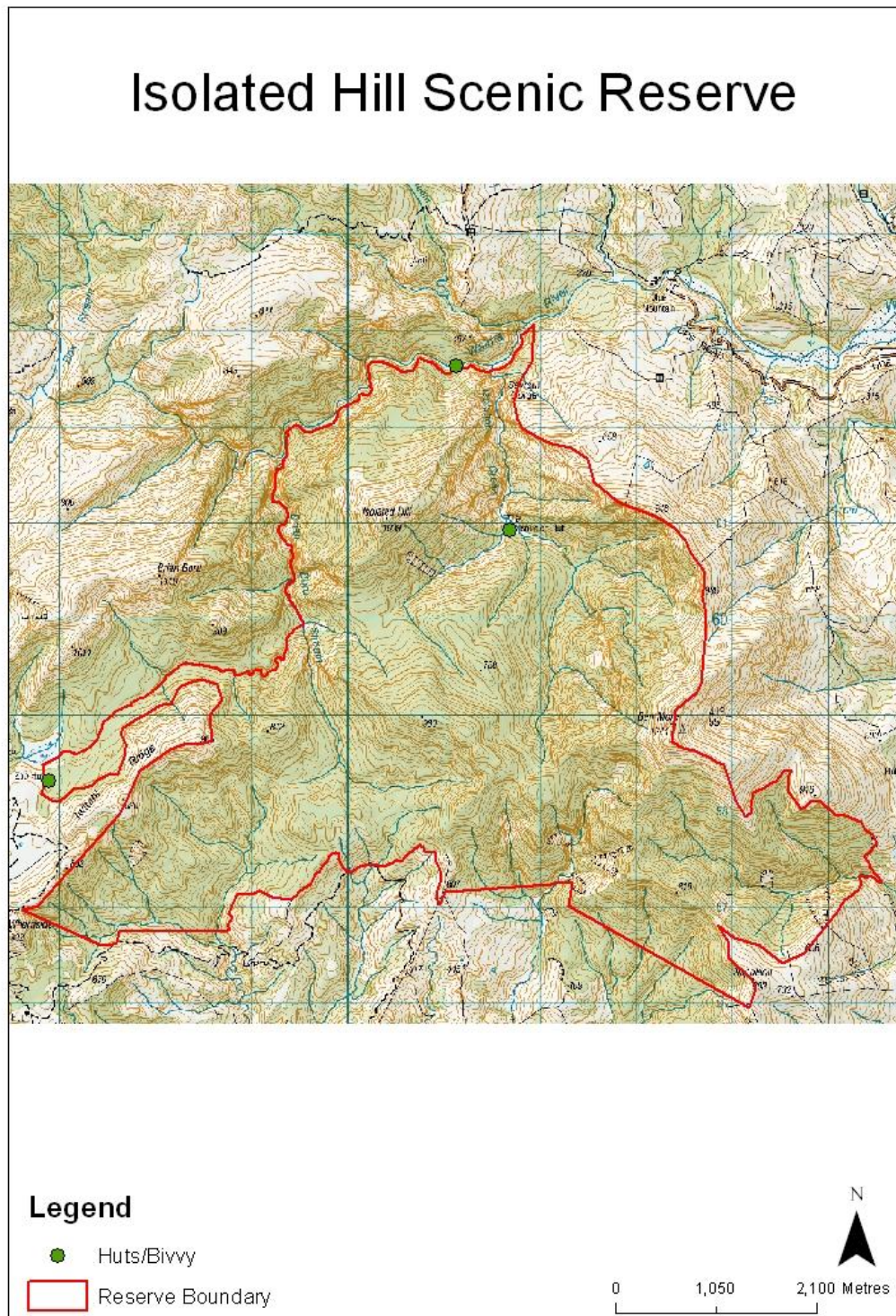


Figure 3-2 Isolated Hill Scenic Reserve boundary.

3.2 Topography

The Seaward Kaikouras are one of the youngest mountain ranges in the world and one of the most highly active, both tectonically and geomorphically (Pettinga and Wandres 2005). As such they have experienced significant upheaval (estimated uplift rates of about 4 to 6 metres per thousand years (Pettinga and Wandres 2005) in recent times (relative to the Earth's history), which has resulted in terrain that is steep, with scarps that are steep and broken. The Reserve contains a number of gorges many of which are impassable. The altitude of Isolated Hill Scenic Reserve ranges in from 150 metres (located two kilometres upstream from Blue Mountain Station, at the northern point of the Waima River) up to 1244 metres at the summit of Mount Ben More (McKinlay 2000). Isolated Hill itself has steep cliffs and peaks at 1039 metres. Another notable mountain in the area is Brian Boru which peaks outside the reserve at 1110 metres (Hayward 1985) although its eastern slopes fall within the reserve. Rainfall is spread evenly across a 12 month period with 80 to 100 one millimetre rainfall days per year.

3.3 Geology

The geology of Isolated Hill Scenic Reserve is representative of the surrounding area of the Seaward Kaikoura Ranges. This consists of Cretaceous mudstones with overlaying deposits from the Paleocene consisting of Amuri Limestone which forms the major geological features of the Reserve (Druce and Williams 1989). The limestone is recorded as being up to 750metres in depth, and extends in a broad swath west-east through the reserve (Cochrane 1999). Hayward (1985) describes the rocks in the area as being comprised of sandstone/siltstone greywacke, which are covered by a sequence of rock types including sulphurous sandstone, siltstone and limestone. In other studies the mudstone has been noted of particular interest due to their proneness to mass movement and slumping (Cochrane 1999).

Found in the limestone of the area are bands of silica rich chert which reduces the erosion of the limestone and as such results in the stable surfaces of the steep walled gorges and escarpments (Hayward 1985). Found between the areas of limestone are thin wedges of sulphur argillite, mudstone and sandstone (McKinlay 2000), the presence of the sulphur

argillite is the probable cause of the sulphur smelling pools that are encountered along Isolation creek (McKinlay 2000) and Pers. Obs.). The soils of the Reserve and its surrounding area are Amuri and Kaitoa steep land soils and Kekerengu hill soils (Breese, Timmins et al. 1986). Greywacke to the north and south surround the limestone/sandstone complex with these large greywacke areas being considered to form the backbone of the South Island geological make up (Druce and Williams 1989).

Along the lower reaches of the Waima river Torlesse greywacke of the lower Cretaceous are found (Breese, Timmins et al. 1986).

3.4 Vegetation of Isolation Hill Scenic Reserve

The vegetation of Isolation Hill Scenic Reserve is quite diverse due to the soil conditions, the geology of the region and the significantly varying altitude. This diversity in species type ranges from lowland forests through to tall tussock grassland (McKinlay 2000). Following significant land disturbance in its history, involving burning and land clearance the resulting secondary forests produced are examples of several stages of post-fire succession (McKinlay 2000) (Hayward 1985). These present vegetation patterns are considered highly fragmented due to the long history of fire and geological disturbances, a common trend in the Seaward Kaikoura Range (Wardle 1971; Druce and Williams 1989). This fragmentation would suggest that the vegetation of the hill slopes would have been broad lowland podocarp-hardwood forest (*Nothofagus* spp. forest along with *Podocarpus hallii* forest leading to subalpine scrub) in pre-Polynesian times (Druce and Williams 1989). The various forests and shrublands of the Reserve are recognised as twelve differing classes (Williams 1982) (Hayward 1985; Cochrane 1994) and (McKinlay 2000).

These classes are:

- (1) *Prumnopitys taxifolia* – *Griselinia littoralis* – *Melicactus ramiflorus* forest on gentle to moderate hill slopes;
- (2) *Nothofagus fusca* forest on moderate hill slopes;
- (3) *Nothofagus solandri* on moderate and steep hill slopes;
- (4) *Podocarpus hallii* forest on steep hillslopes and ridges;

- (5) *P. hallii* – *G. littoralis* – *Phyllocladus alpinus* forest on upper hill slopes and crests;
- (6) *G. littoralis* – *Dodonaea viscosa* – *Kunzea ericoides* forest on moderate to steep slopes;
- (7) *K. Ericoides* forest on steep hill slopes.
- (8) *D. viscosa* – *Hebe strictissima* – *Leptospermum scoparium* scrub and woodland on steep hill slopes and fans;
- (9) Sparse vegetation occurring on scarps including *Pachystegia insignis* – *Hebe hulkeana* – *Senecio monroi* – *Wahlbergia mathewsii* – *Gentiana astonii* – *Myosotis arnoldii*.
- (10) *Cassinia leptophylla* – *Coprosma* spp. – *Polystichum* spp. scrub on steep hill sides;
- (11) *Chionolchloa pallens* – *Coprosma* spp. shrubland on steep hill slopes and crests;
- (12) *Poa cita* grassland on hillslopes.

Further more in his research Cochrane (1994) indicated the possibility of a 13th vegetation class following field observations. This vegetation class is dominated by *Buddleja davidii* with *L. scoparium*, *C. leptophylla*, *Coriarea arborea*, *Hebe salicifolia*, *Echium vulgare* and *Holcus lanatus*. This vegetation type occurs mostly on fine alluvium in the stream and river beds, in particular in the areas of, Isolation Hut, Brian Boru Bivvy and the convergence of Isolation Creek and the Waima River (Cochrane 1994). It was also noticed that weeds are only a minor problem due to the limestone country but *B.davidii* thickets were noticed to form notable thickets in the upper Isolation Creek area (O'Brien 1993).

4.0 Herbivores

4.1 Goats (*Capra hircus*)

Goats were first introduced into New Zealand originally by Captain Cook on the 2nd of June 1773 when he released three goats on the eastern reaches of Good Charlotte Sound to provide an emergency food source for ships and the castaways of wrecks (Wodzicki 1950). Further liberations of goats occurred during the course of the European settlement of New Zealand, with three main reasons behind continued releases. Firstly, to be used as a food source, secondly to help develop a mohair and skin industry and thirdly (somewhat ironically given its pest status now) weed control of improved and developing pasture land (Clark 1974). The habitats that goats were introduced to had not been previously been subjected to browsing by mammals and the feral goat population steadily became established in the areas of their liberation due to the abundance of palatable plants species (Rudge and Campbell 1977). Today's feral goats are the descendants of animals that were either escaped from, or were liberated by their owners and due to their tenacious behaviour and adaptability were able to survive in the bush and hills of New Zealand. The largest populations of feral goats occurring within New Zealand are located in the King Country, the Hawes Bay and Gisborne area of the Northern East Coast and lastly Marlborough (Clark 1974) and to some degree parts of Otago. Marlborough is of particular interest as the Isolated Hill Scenic Reserve is located in this district.

Rainfall and climate have had some influence on the spread of feral goats in New Zealand however this is not a decisive or limiting factor in their movements (Wodzicki 1950) though it has been observed that cold and wet weather will dissuade goats from utilizing open areas (Clark 1974; Cochrane 1994). They prefer a dry climate, similar to which is found in Marlborough for instance as well as the landscapes their ancestors would have experienced in the Middle East (Wodzicki 1950). As previously mentioned, with some exceptions most feral goats are confined to localised areas, however they have a combined range from the North Island down to Otago ((Wodzicki 1950)). The localised populations can be accredited to two significant factors, current herds are still in the immediate vicinity of the original liberations and secondly, rivers form effective boundaries limiting spread though smaller streams may be crossed ((Wodzicki 1950)). However despite rivers being considered suitable migration

blocks goats have been observed on both sides of the Waima River though this may be due to multiple releases as well as suitable crossing points at low or particularly rocky points in the rivers course. Cochrane (1994) noted that the Waima River may in fact be a corridor for goat access to the reserve with sign noted on walking tracks.

Feral goats have a notable presence in Isolated Hill Scenic Reserve, and in particular have been noted in abundance by Cochrane (1994) on the north facing slopes of Isolated Hill as well as being readily found on the tops. This is in fitting with most goat locations in New Zealand where preference appears to be given to areas that are north-east or north-west facing, particularly rocky, or scrub covered outcrops, resulting in a warm dry environment. Observations (actual sightings, fresh sign and browse damage) by myself and Cochrane (1994) indicate that feral goats in the Reserve appear to prefer Mahoe/Broadleaf forests, in particular stands adjacent to or nearby bluffs or slips.

The feral goat is an even toed, horned ruminant that belongs to the tribe *Caprini* (Clark 1974) that incorporates both sheep (*Ovis*) and goats (*Capra*). The genus *Capra* to which the feral goat belongs incorporates both goats and ibexes and as such nine distinct species and one sub species are recognised today, *Capra pyrenacia*, *C. ibex*, *C. nubiana*, *C. sibirica*, *C. walie*, *C. caucasica*, *C. cylindricornis*, *C. aegagrus*, *C. hircus*, and *C. falconeri*. It is worth noting the distinction between the wild goat (*C. aegagrus*) and the feral goat (*C. hircus*).

Wild goats are as the name suggests wild, their breeding, genetics and movements have not been controlled or influenced by man for agriculture or as a food source. Feral goats (a sub species of the wild goat) can trace its lineage back to where goats were first domesticated and with feral goats in New Zealand referring to populations that occurred from the liberation of domesticated stock.

Feral goats consume the foliage of most plants and trees (McKinlay 2000) though they can be considered preferential generalists they will consume any vegetation within their reach at an alarming rate. They are capable of navigating exceedingly steep and difficult terrain, often in areas that would be considered difficult for humans, and due to this natural agility are capable of accessing, and browsing even the most difficult to reach vegetation (Cochrane 1994) (McKinlay 2000). As is the case in Isolated Hill Scenic Reserve feral goats will often inhabit areas with other mammalian pests, such as deer and pigs, and the combination of browsing

damage inflicted by multiple pest species such as these can be extremely devastating for the vegetation (McKinlay 2000).

4.2 Other notable herbivores

4.2.1 Red Deer (*Cervus elaphus*)

New Zealand has a number of deer species that were first introduced during the 1850's and liberation continued through until around 1923. The species of deer that were introduced include wapiti (*Cervus canadensis*), fallow (*C. dama*), white-tailed (*Odocoileus virginianus*), sika (*C. Nippon*), sambar (*C. unicolour*), rusa (*C. timoriensis*), and most notably red deer being the most abundant and wide-ranging through New Zealand.

Of all the deer species introduced red deer have become the most widespread and therefore in my view the most destructive of the seven introduced species. While all these species are established through the country to some extent none spread at the tenacious rate of Red deer (Grzelewski 2007).

Red deer were first released around Nelson in 1851 from stock imported from prestigious game-parks in England and Scotland. Red deer were also released in the North Island in particular around Wairongomai Valley and some stock from Austria were released on a station in the Waiararapa (Brockie 1992). Around one hundred liberations continued through until early 1924 though this is in some debate with some sources indicating that they were released up until the 1940's (Brown 2004). Two significant herds were also released into the South Island, one in the Rakaia River Valley around 1897 and an earlier herd was released in Otago near Palmerston in 1871. Small numbers of Deer were also released on Stewart Island at around the same time as the earlier liberations.

Since their various liberations starting in the 1850's Red deer have spread quickly and in a manner that could only be described as out of control and by 1925 the deer occupied a considerable part of the South Island and it is safe to assume that as time went on the three main herds released in the Nelson, Rakaia, and Otago soon spread out and overlapped other areas leading to a larger genetic base and the breeding obviously became more prolific.

Red deer have thrived due to New Zealand's temperate climate with its mild winters, a lack of predators and competition from native species and a lack of disease which came about due to quarantine on board the ships on the way out to New Zealand (King 1990). The reason that Red deer have had such an impact on New Zealand's native flora is because of their large size and their complex digestive system means that they are able to consume all of the foliage of the species of plants that they find palatable (Nugent, Fraser et al. 2001).

4.2.2 Feral Pig (*Sus scrofa*)

The Feral Pig is widespread throughout New Zealand, due to the fact that like the Feral Goat it is adaptable to numerous conditions. They were introduced by Europeans during the late 18th century and the 19th century (Hayward 1985) and quickly established themselves in the wild and by as early as the 1850's were common in most districts (McKinlay 2000).

Pigs are omnivorous feeders that will root up the ground as they search for rhizomes, roots and invertebrates such as worms (Atkinson 2001). Most native forests in hill country will sustain few pigs year round while in other cases areas are used seasonally (Hayward 1985). Unlike Red Deer and Feral Goats they are typically considered to be a somewhat minor forest pest, whose numbers are traditionally kept down locally by hunters (Pettinga and Wandres 2005). In appearance most feral pigs seen in the wild in New Zealand range in colour either being black or shades of brown with black patches (Pettinga and Wandres 2005). Studies have indicated that Feral Pigs in the northern areas of the South Island will breed throughout the year, with farrowing (giving birth to a litter of pigs) occurring in larger numbers from June to November, with reductions through to April to June during the main mating stage (Druce and Williams 1989; McIlroy 2001)

While still considered a relatively minor pest there is a concern that their disturbance of ground while rooting for soil and litter invertebrates could have a far reaching effects on long term ecosystem processes such as nutrient cycles, as plant detritus will no longer be adequately broken down (Druce and Williams 1989). Other studies have found large numbers of earthworms in their diet further indicating that nutrient cycling may be adversely effected by the presence of Feral Pigs (Hayward 1985). The damage that occurs to the forest floor is also thought to indirectly affect Kiwi feeding habits as it removes, both the food source and also damages the area to an extent that may make further colonisation by invertebrates difficult

(McIlroy 2001). While many seedlings and smaller plant growth can be destroyed by the rooting the disturbed ground has the potential to become a seed bed for new seedling establishment though the dispersion of weeds or native plants by pigs is not understood in New Zealand (Atkinson 2001). It was found by Meads et al. (1984) that feral pigs have a greater effect in destroying litter layers when compared to other introduced ungulates. The destructive activities of pigs have not been limited to New Zealand's flora as they have also been found to eat the eggs, young and adult birds that nest on the surface or burrow (Rudge 1976)

4.2.3 Brushtail Possum (*Trichosurus vulpecula*)

The Brushtail Possum (*Trichosurus vulpecula* Kerr) was first successfully liberated in New Zealand in 1858 into the bush behind South Riverton (Wodzicki 1950). Further successful liberations occurred right through until the late 1920's in most areas of New Zealand. They were eventually introduced throughout the country to provide a fur industry during the 19th century it was noted as early as the 1920s that they were having a detrimental effect on the New Zealand vegetation (Atkinson 2001). Possums in particular covered a broad forest niche that would have almost definitely not had an equal counterpart among the moa species in terms of browsing (Caughley 1989). However it is important to note that canopy feeding birds, not only moa, played a significant role in browsing pressure on plants in prehistoric New Zealand (Clout and Hay 1989), these being kereru (*Hemiphaga novaeseelandiae*) and kokako (*Callaeas cinereus*). It was originally thought the possums release would enhance the New Zealand bush (Wodzicki 1950) as well as provide the beginnings of a successful fur and pelt industry. Within Isolated Hill Scenic Reserve possums have been observed and trapped or poisoned in the forest around Isolation Hut, in areas around Brian Boru Bivvy, and around the Zoo Hut (Cochrane 1994) though their actual distribution is unknown across the reserve. Of particular interest is that possums are the only pest of the four pests found in the reserve not able to be excluded from the exclusions due to their ability to climb, even though goats have been able to climb the fences in some cases they are less able than possums. Possums are considered a significant pest as they are selective feeders and consume the foliage and fruit of flora species that normally make up the diet of native birds (Poole and Johns 1970). While known to browse on a variety of native trees and plants their preferred diet is often the foliage of smaller tree species (McKinlay 2000). In 1967 possums were also found to be

carriers of bovine tuberculosis (TB) (Atkinson 2001). Like pigs, possums have been shown to be a notable predator of New Zealand's fauna as well, preying on eggs and birds alike (Brown, Innes et al. 1993).

On one occasion a pair of rats (*Rattus exulans*) was spotted in Isolation Hut. This would give possible cause to there being a rat population being present but on other trips no sign whatsoever was seen indicating that they may have been a one off pair. Since its introduction by Polynesian settlers the rat has no doubt played a significant role in the change of forest composition due to the predation of smaller bird species responsible for seed dispersal of plants and trees (McGlone 1989).

5.0 Isolation Hill Scenic Reserve study

5.1 Introduction

The New Zealand Forest Service implemented a programme for monitoring (Hayward 1985) the secondary seral forest in Isolated Hill Scenic Reserve using standard New Zealand Forest Service vegetation quadrants. 32 quadrants were established, including three exclosures, in various locations around the Reserve to allow assessment of feral goat impacts on secondary seral forests. This was to provide a basis for research into whether hunting programmes may provide a reduction in feral goat numbers to allow the redevelopment of a successful understory (Cochrane 1999). The three exclosures are heavily fenced and prevent browsing to provide a comparison of the forests natural state. The construction of an exclosure causes marked and usually rapid changes in species composition (Caughley 1989) thus providing an idea of original species composition.

The impact of feral goats has been considered in a number of vegetation studies ((Moore and Cranwell 1934; Turbott 1948; Atkinson 1964; Hayward 1985; Cochrane 1994; Cochrane 1999)). There are two models describing the effect of feral goats, a three stage model (Table 5-1) put forth by Moore and Cranwell (1934) following a study on the Coromandel Peninsula while Atkinson (Atkinson 1964) indicated a four stage (Table 5-2) model to be suitable in the description of goat patterns.

Table 5-1 Feral goat vegetation change model as proposed by Moore & Cranwell (1934). From Cochrane (1994).

Stage	Vegetation changes induced by feral goats
1	Feral goats remove seedlings and saplings of palatable species from the forest floor.
2	Ferns grow apace, although are unable to act as a nursery for palatable species due to continued browsing pressure from feral goats. Less preferred species abound.
3	Ferns succumb, grass species become the dominant ground cover and canopy loss occurs. Exotic plant species may invade.

Table 5-2 Feral goat vegetation change model as proposed by Atkinson (1964). From Cochrane (1994).

Stage	Vegetation changes induced by feral goats
1	Differentially browsing of only a few species in the understory tier. Regeneration of palatable canopy trees stopped.
2	Understory becomes dominated by low-preference or unpalatable species. Understory relatively open due to the effects of browsing and trampling.
3	Canopy now a mix of original palatable species and unpalatable/low-preference species. Annual seed crop reduced due to reduction of seed source.
4	Death of canopy trees, accompanied with an increase in the cover of grass and sedge species. Browse resistant shrubland/forest replaces original species.

Both of the vegetation change models show similar characteristics in the identification of browsing upon palatable species being an early indication of negative effects followed by an observation of an increase in numbers by low palatable species. However the later model (Atkinson 1964) shows effects attributed less directly to browsing, such as trample damage and directs this as a form of vegetation change as well. The final stage of Moore and Cranwell (1934) indicates that species loss is not total(native grasses) but that there is also a likely hood of invasive species taking hold. It could be assumed that this model is based upon early interpretations of European farming in New Zealand where it was more accessible for the spread of exotic plant species. The third stage of Atkinson (1964) suggests a mixed canopy of palatable and non-palatable species while stage four indicates the final change with canopy trees dying off (natural mortality process assumed) and browse resistant shrubland enters.

5.2 Approach

Data collection involved the use of the pre-existing plots already established by the New Zealand Forest Service (now Department of Conservation) located in and adjacent to Isolated Hill Scenic Reserve. Plots measure 20metres by 20metres. Trees in the existing plots have been tagged with a four digit number though there is no consistent number of tagged trees between plots. Of the existing plots only nine were located due to a lack of co-ordinates, encroaching weather and injuries. Of the nine plots found, three were exclosure plots; in addition nine new plots were measured to increase data availability (Figure 5). The plot size was kept the same (20m X 20m) and the trees were not tagged but were identified by species.

Tree diameter at breast height (DBH) was measured in all plots. This allows for the comparison of basal area (BA) as an indication of forest growth. Plot co-ordinates (New Zealand Map Grid) were determined by Global Positioning System (GPS). A visual analysis was conducted observing the presence of animal sign (tracks, stool, browse evidence and physical sightings).

The cover abundance of all species at a height equal to or less than one metre was assessed as a percentage of plot size (0% - 100%). The assessments were made by the author to ensure consistent judgment of cover and to reduce the likelihood of bias. Field assessments were made throughout the year and not confined to a specific season. It was chosen to only identify percentage cover at one metre height or less as an indication of browse and young growth between open and exclosure plots. It was decided that adult trees would be too large to show the immediate effects of browsing. Species cover, basal area and density are useful forest indicators for determining the levels of degradation in forest remnants (Smale Dodd 2008).

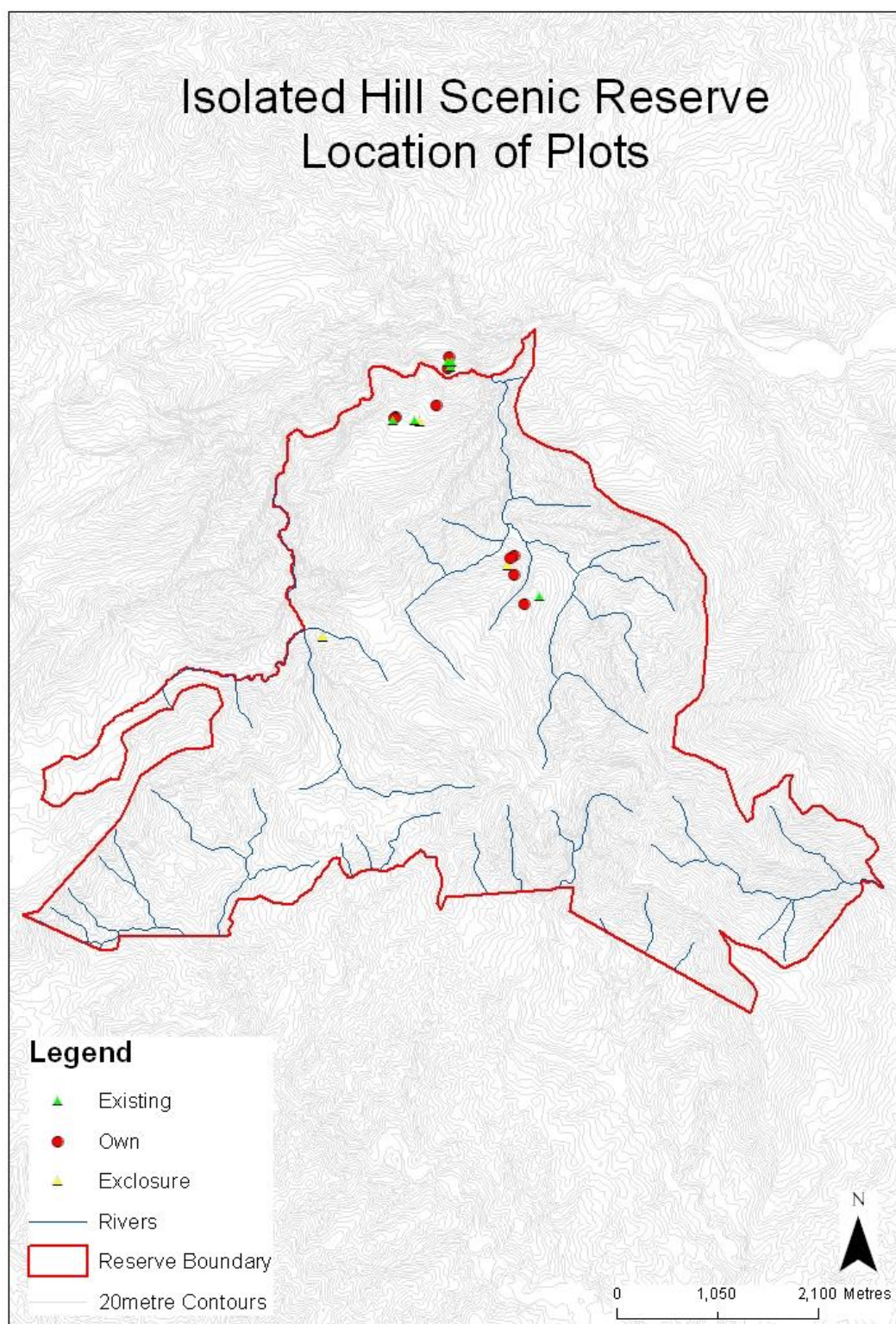


Figure 5-1 Location of plots in Isolated Hill Scenic Reserve

Field data were entered onto a spreadsheet with previous DBH data being supplied from existing records. The earlier data consisted of measurements of DBH from 1985 and 1994. Compiled with the present day data it is then possible to investigate vegetation composition.

The first stage of the analysis was to determine the basal area (BA) for each recorded tree from its associated DBH. From there the total BA per plot was calculated as was each plots mean BA and the standard error.

Palatable and non-palatable species were then identified with the total BA of each being calculated per plot as well as the standard error. Ratios of palatable and non-palatable species were also calculated (p/np) for each plot. Palatable and no palatable species were then split into three size classes, DBH less than or equal to ten, DBH of 10.1 to 29.9 and DBH of 30 or greater. Palatable and non-palatable species were defined based on the findings of Cochrane (Atkinson 1964; 1994) following research based on rumen analysis of goat stomachs. The preference of the species was measured by the volume of the species found within the stomach of sampled goats. Further personal observations also influenced the determination of palatable versus non-palatable species.

Percentage cover of species equal to or less than a metre in height were recorded as percentages and converted to a proportion of one. For example 45% became 0.45 of which the Arcsine of the square root was then found. This allowed for a more streamlined application in R®.

The above information was then collated and assigned a one, two or three to indicate what year the data represented with one being 1985, two being 1994 and three being 2011. Also assigned was either a zero or a one to define treatment being either exclosure (zero) or open (one). The compiled information was then able to be used in R® software package (Version 2.11.1).

In R® ANOVA (Analysis of Variance) tests were run to identify any significant relationships through the data sets across the years. ANOVA being a test in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. Factors are adjusted so that responses may be measured in an attempt to determine if an effect is present.

The equation used was the same for each variable with only the variable changing; Total BA, mean BA, standard error of the BA, palatable and non-palatable BA, ratio of palatable and non-palatable and the DBH classes of palatable and non-palatable.

$$aov(\text{VARIABLE} \sim \text{Treat} * \text{Year} + \text{Error}(\text{Year}))$$

In the case of the equation *aov* refers to ANOVA the command being preformed, *Treat* indicates whether it was an enclosure or open, *Year* factors in the three years (1985, 1994 and 2011) while *Error(Year)* indicates in the calculation that each year represents the same plot across three years in this case.

Another ANOVA test was run in R, this time investigating if there was a significant relationship between the treatment (open or enclosure) and the percentage cover of species one metre or less in height. The equation used was;

$$aov(\text{Treat} \sim \text{Percentage_Cover})$$

Again *aov* represents the ANOVA command. *Treat* as before refers to enclosure plots or open plots while *Percentage_Cover* is the recorded species cover per plot.

Further analysis were conducted using Canoco (for Windows Vers. 4.5) an ordination tool. Ordination arranges objects that are characterised by values on multiple variables so that similar objects are closer to each other while dissimilar objects are further apart. Ordination was undertaken using Detrended Correspondence Analysis (DCA) to determine the underlying structure of the data and to gauge relationships with specific variables (Norton, Espie et al. 2006) DCA was chosen over other ordination methods as it is technique widely used in ecological sciences to find the main factors or gradients in large, species rich but usually sparse data matrices that typify ecological community data. The ordinations were performed using the default options in CANOCO. The solution files for the tests were then exported to a spreadsheet and the second order averages were used in the analysis of data.

A further analysis was conducted testing the similarity of the species recorded during the assessment of vegetation one metre or less in height. Using Canoco® the percentage scores were run as a DCA, with a down weight on rare species to minimize their effect as outliers so the results will be less skewed. Other than this all the standard settings were used. From the results of the DCA it was possible to obtain the 1st, 2nd and 3rd order averages which were

then used in RTM. A three dimensional scatter plot was created to demonstrate the similarities in species.

5.3 Results

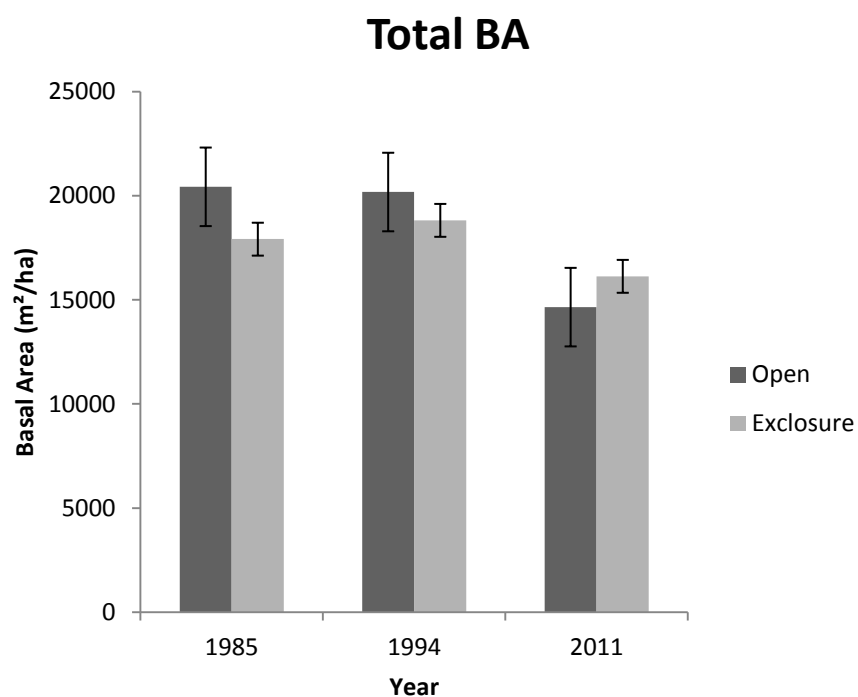


Figure 5-2 Mean total BA in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

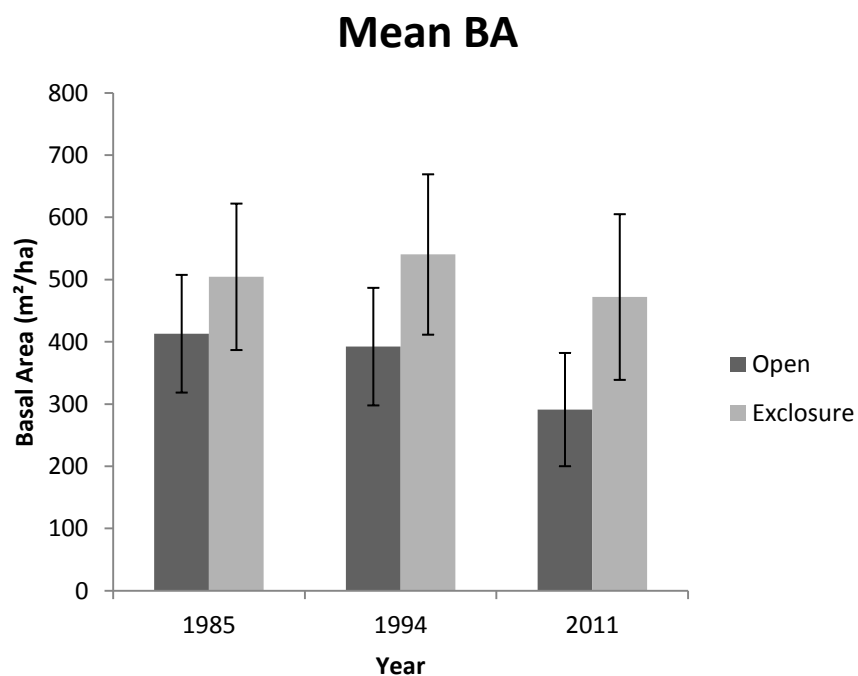


Figure 5-3 Mean tree BA in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

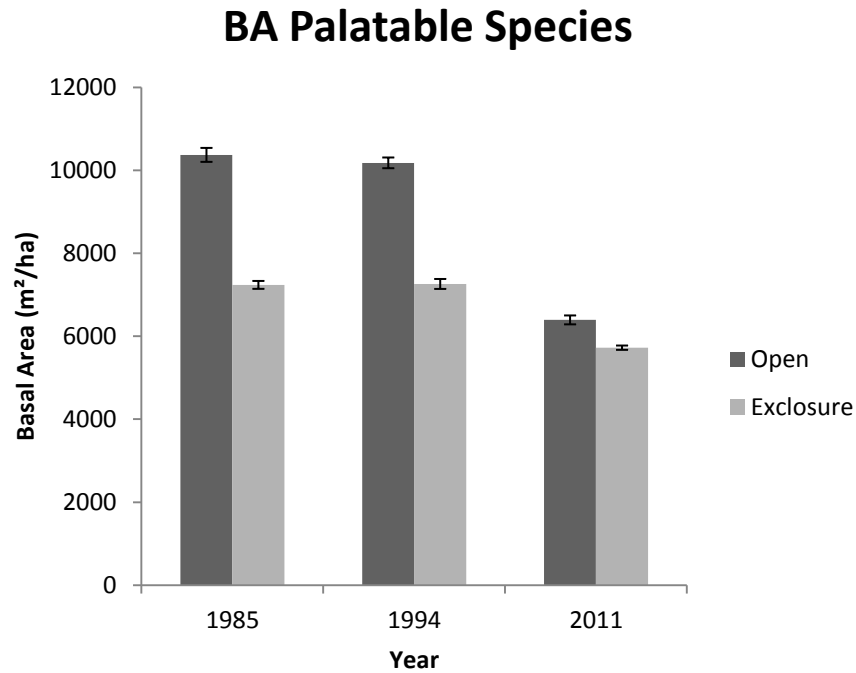


Figure 5-4 Mean BA of palatable tree species in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

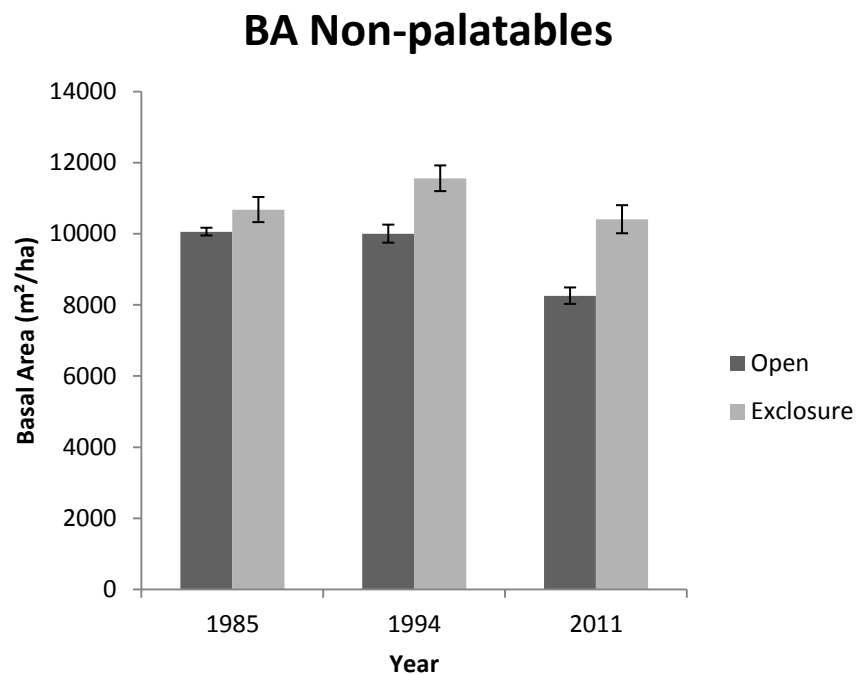


Figure 5-5 Mean BA of non-palatable tree species in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

BA of Palatables (<10DBH)

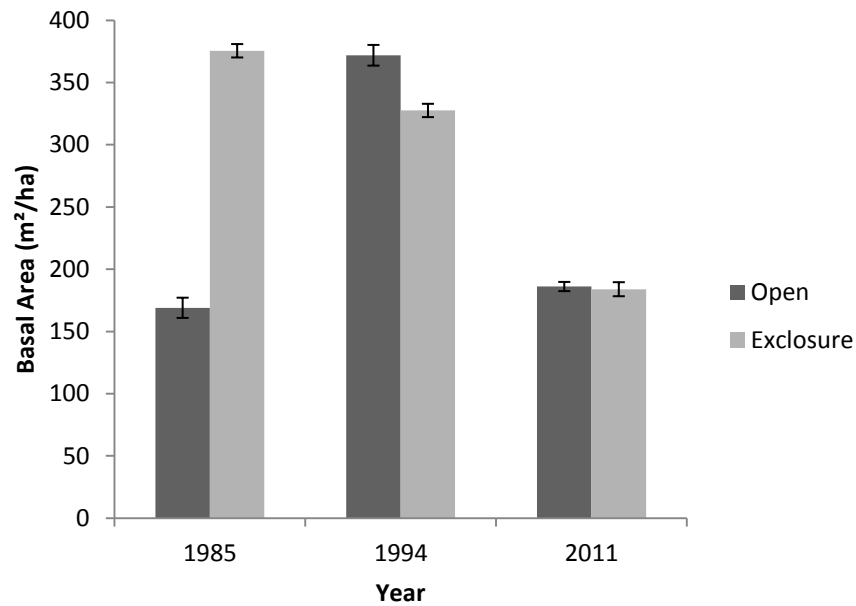


Figure 5-6 Mean BA of palatable tree species with a DBH equal to or less than 10 in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

BA of Palatables (10.1 - 29.9DBH)

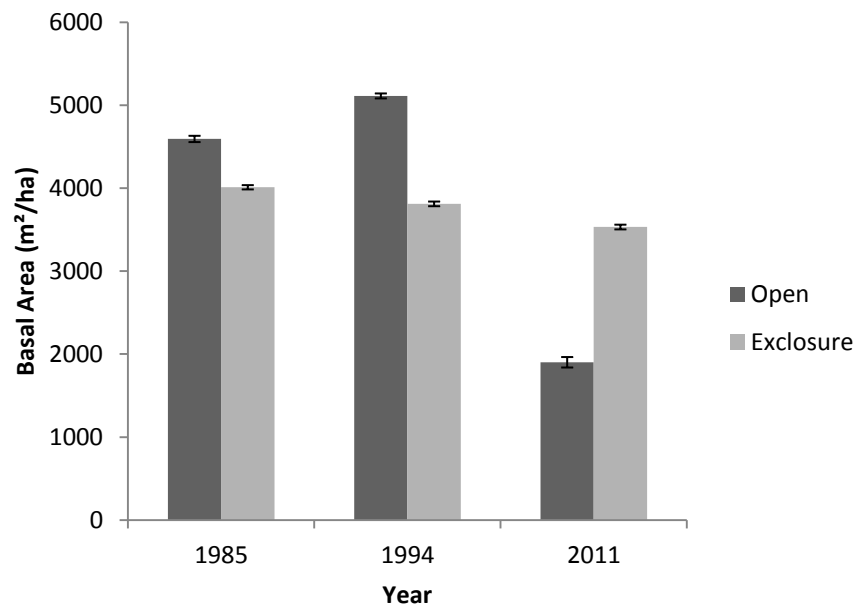


Figure 5-7 Mean BA of palatable tree species with a DBH in the range 10.1 to 29.9 in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

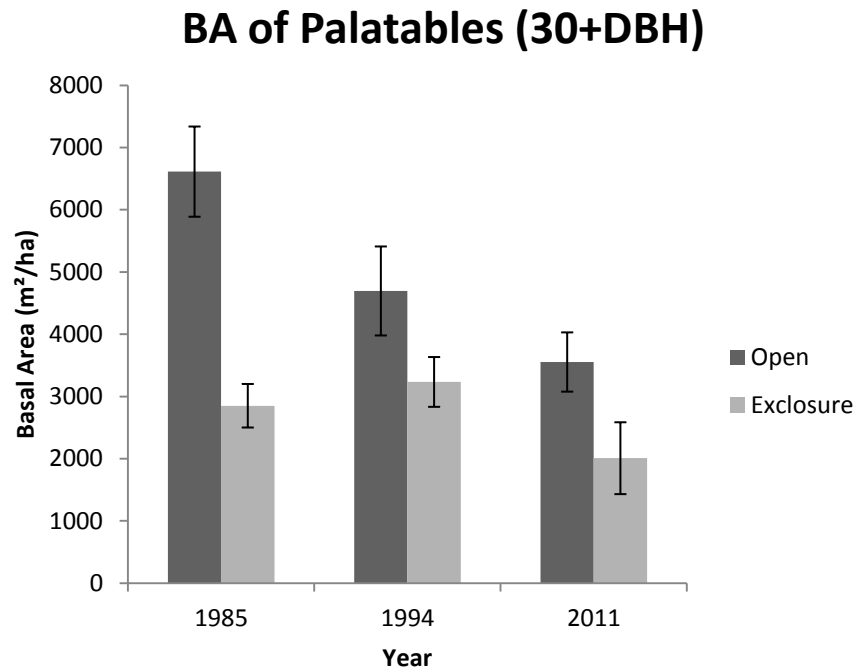


Figure 5-8 Mean BA of palatable tree species with a DBH equal to or greater than 30 in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

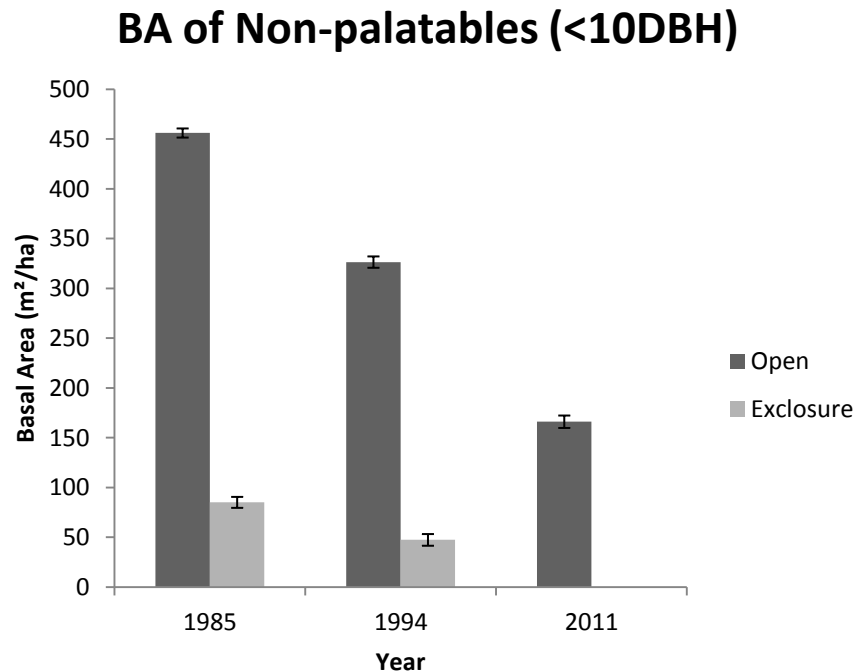


Figure 5-9 Mean BA of non-palatable tree species with a DBH equal to or less than 10 in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

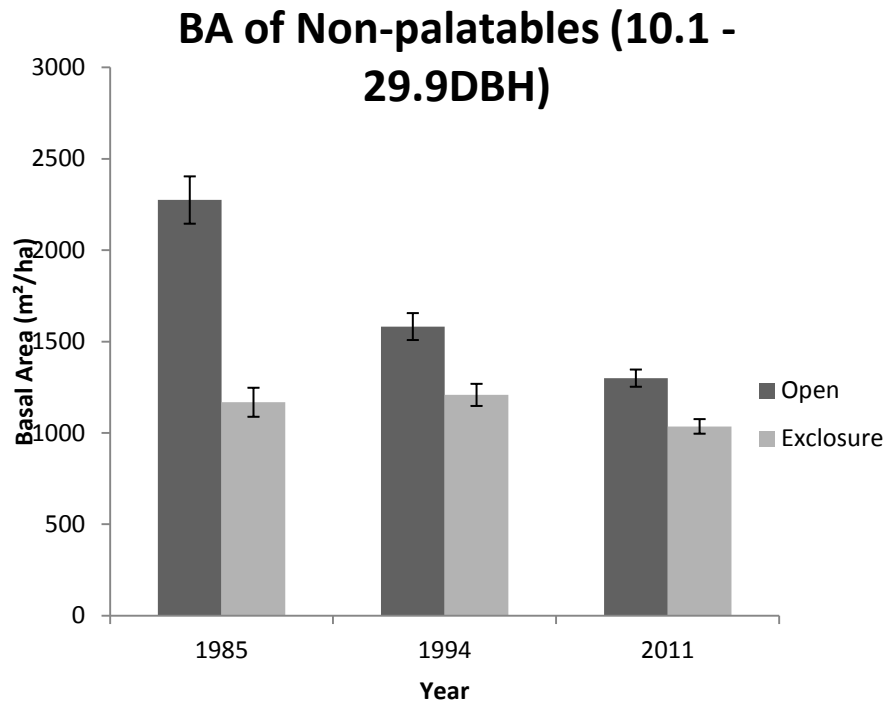


Figure 5-10 Mean BA of non-palatable tree species with a DBH in the range 10.1 to 29.9 in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

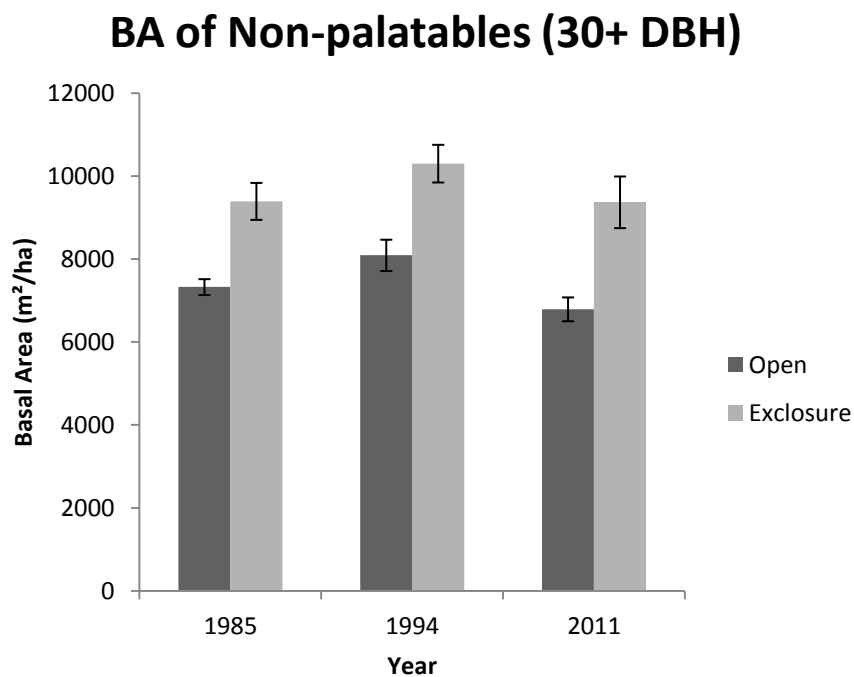


Figure 5-11 Mean BA of non-palatable tree species with a DBH equal to or greater than 30 in metres squared per hectare for exclosure and open plots for 1985, 1994 and 2011 with error bars indicating standard error of the mean.

Total BA (Figure 5-2) showed no significant differences in either the open or exclosure plots for 1985 and 1994, with the open plots having a larger value than the exclosure plots. In 2011 the exclosure plots had a higher BA value than the open plots, with both measures being lower than in the previous 2 surveys.

No significant differences are apparent between open and exclosure plots over the three sampling periods (Figure 5-3) although the mean basal area decreases from 1985 (400+ m²/ha) to 2011 (300 m²/ha). The exclosure plots do not show the same degree/magnitude of reduction in mean basal area.

Although there is a marked difference between the mean basal area of palatable species in open and exclosure plots (Figure 5-4) at the sampling periods of 1985 and 1994, there is not a significant difference when the two categories are viewed separately over time. However there is a significant decrease in mean basal area in both plots by 2011.

The mean basal area of non-palatable species (Figure 5-5) showed a significant decrease between 1994 and 2011 in the open plots although there was very little difference in the exclosure plots over the three sampling times.

Mean basal area of palatable species with a DBH of equal to or less than 10 (Figure 5-6) showed significant differences in the exclosure plots over the three sampling periods. Trees in the open plots showed significant differences with the basal area being 370 m²/ha in 1994 and 170 m²/ha and 180 m²/ha in 1985 and 2011 respectively. Palatable tree species with DBH of 10.1 to 29.9 (Figure 5-7) showed significant differences over time for both open and exclosure plots, as did the open plots of palatable species with a DBH of 30 plus (Figure 5-8). At this size range there were no discernable differences in basal area in the exclosure plots.

Mean basal area of non-palatables at 10 or less DBH (Figure 5-9) showed significant spatial and temporal differences whereas the mean basal area of this group with a DBH 10.1 to 29.9 (Figure 5-10) showed less difference and almost twice the volume in the exclosure plots. In the open plots there were significant differences in basal area over time even though the volume of two to three times that of the 10 or less DBH trees.

The differences in mean basal area for non-palatable 30 plus DBH were not significant in the exclosure plots and not hugely so in the open plots (Figure 5-11).

Results from the ANOVA analysis for the different basal area categories, (Total BA($P=0.616$), Mean BA($P=0.876$), SE($P=0.886$), BA palatable($P=0.649$), BA non-palatable($P=0.933$), Ratio of p/np($P=0.796$), <10 BA palatable($P=0.887$), 10.1 to 29.9BA palatable($P=0.296$), 30+ BA palatable($P=0.982$), <10 BA non-palatable($P=0.701$), 10.1 to 29.9 BA non-palatable($P=0.930$) and 30+ BA non-palatable($P=0.953$). These results are all greater than 0.05 level, the level at which these ANOVA's were conducted; this indicates no correlation from any of the tests.

ANOVA of the percentage cover of species less than one metre in height ($P = 0.0029$) showed a significant correlation at the 0.05 testing level.

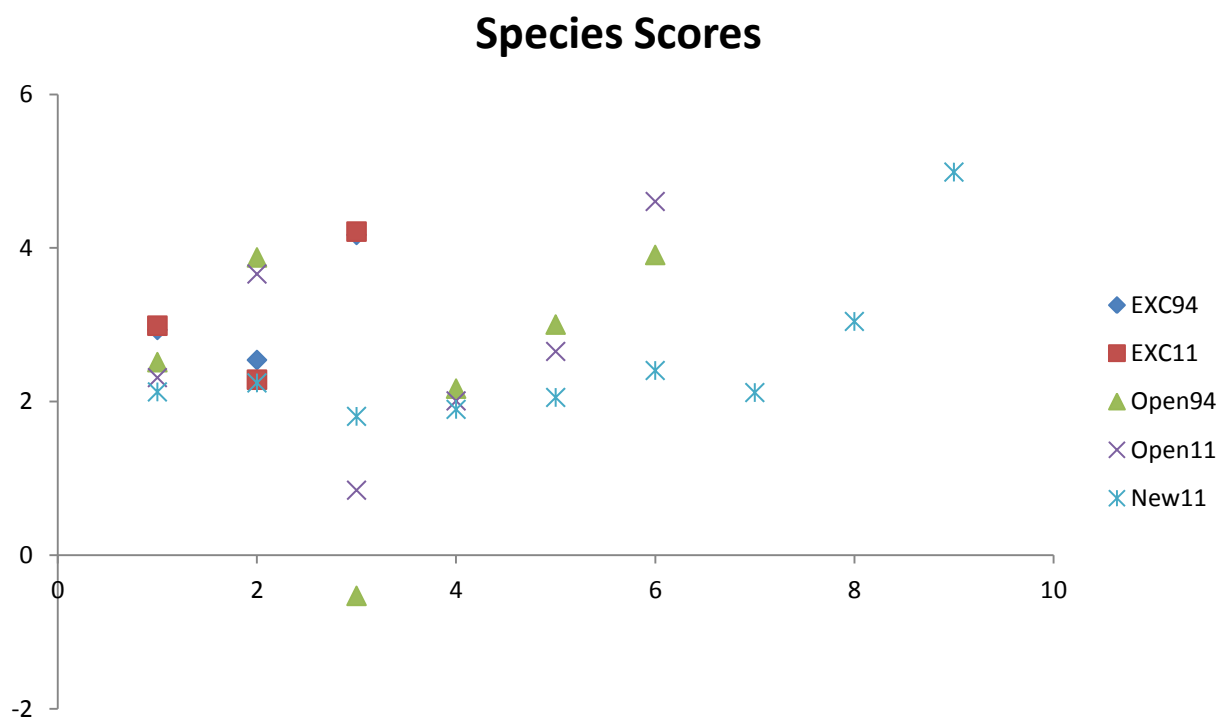


Figure 5-12 Detrended Correspondence Analysis of species range.

It can be seen (Figure 5-12) that the species present in the exclosures changed minimally between 1994 and 2011 as overlap is visible. The species present in the open plots is also relatively consistent though variation present is more noticeable than with the exclosures. The

new plots show some similarity with the exclosures and open plots though there is also a notable trend away from these species.

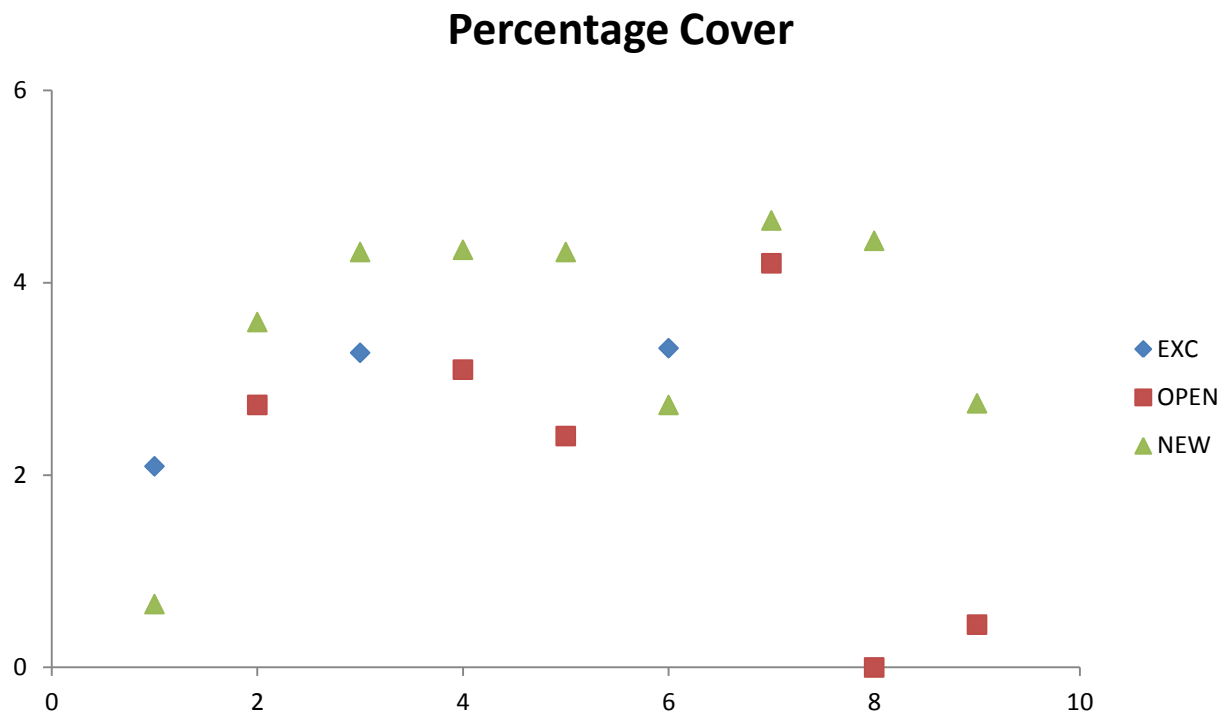


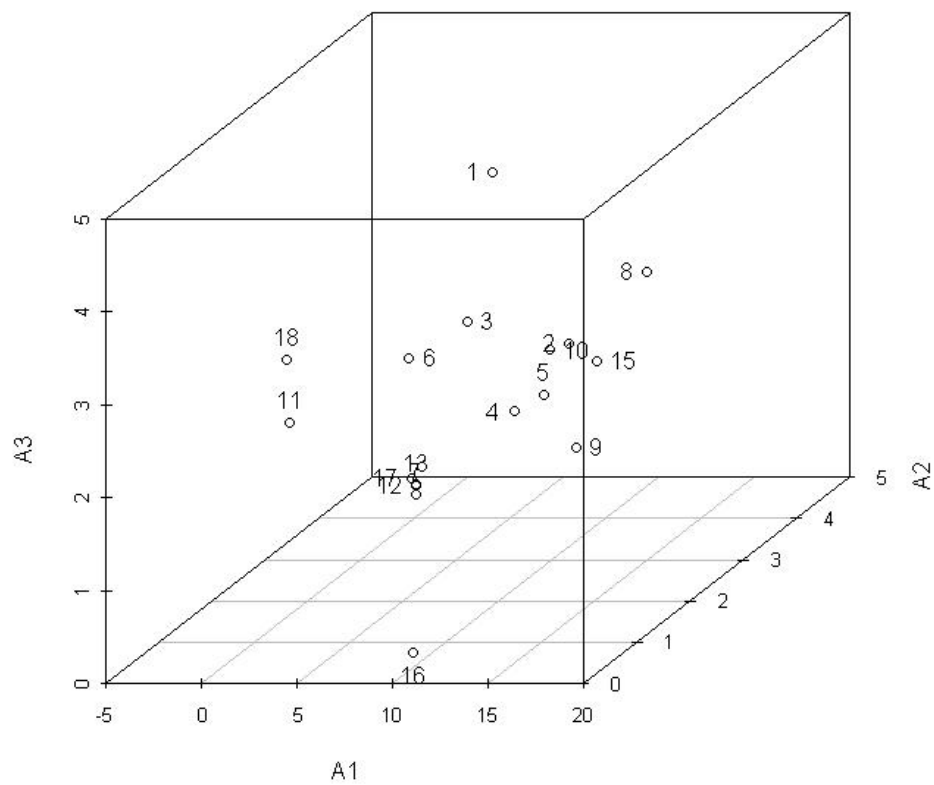
Figure 5-13 Detrended Correspondence Analysis of species present in percentage cover of species less than one metre.

There is no consistent correlation revealed by DCA of percentage cover of species less than one metre (Figure 5-13). The exclosures are somewhat varied though still on a similar scale while open plots in particular show no significant trend. As can be seen due to the wide spread along the axis's there is minimal similarity between the exclosures, the open plots and the new plots.

Table 5-3 Plots and vegetation species recorded in the one metre and below height assessment (Exclosure plots: 5, 17 and 20).

ID	Plot	Species
1	5	<i>Carpodetus serratus</i> , <i>Griselinia littoralis</i> , <i>Melicytus ramiflorus</i> , <i>Myrsine australis</i> , <i>Podocarpus</i> spp.
2	16	<i>Pittosporum tenuifolium</i> , Grass spp.
3	17	<i>Coprosma</i> spp., <i>Griselinia littoralis</i> , <i>Melicytus ramiflorus</i> , <i>Myrsine australis</i> , <i>Podocarpus</i> spp.
4	18	<i>Coprosma rotundifolia</i> , <i>Kunzea ericoides</i> , <i>Pittosporum tenuifolium</i> .
5	19	<i>Coprosma rotundifolia</i> , <i>Kunzea ericoides</i> , <i>Podocarpus</i> spp.
6	20	<i>Carpodetus serratus</i> , <i>Coprosma</i> spp., <i>Kunzea ericoides</i> , <i>Myoporum laetum</i> , <i>Pittosporum eugenoides</i> , <i>Pseudopanax crassifolius</i> .
7	22	<i>Coprosma</i> spp., <i>Kunzea ericoides</i> .
8	26	<i>Coprosma liniariifolia</i> , <i>Podocarpus</i> spp.
9	27	<i>Coprosma liniariifolia</i> , <i>Myoporum laetum</i> , <i>Podocarpus</i> spp.
10	OP1	<i>Podocarpus</i> spp.
11	OP2	<i>Coprosma</i> spp., Fern spp.
12	OP3	<i>Coprosma</i> spp., <i>Kunzea ericoides</i> .
13	OP4	<i>Coprosma</i> spp., <i>Kunzea ericoides</i> .
14	OP5	<i>Coprosma</i> spp., <i>Kunzea ericoides</i> .
15	OP6	<i>Coprosma microcarpa</i> , Grass spp.
16	OP7	<i>Coprosma</i> spp., <i>Melicytus ramiflorus</i> , <i>Olearia paniculata</i> .
17	OP8	<i>Coprosma</i> spp.
18	OP9	Grass spp.

The numbers grouped around 7,12,13,14(obsured) and 17 are all representative of undergrowth species of *Coprosma* spp. and *Kunzea ericoides* (with the exception of 17 which had *Coprosma* species only. Numbers 1,3 and 6 are representative of the three exclosure plots. Of the three plots where grass species were recorded (points 2, 15 an 18) there is some spread. Points 2 and 15 are relatively close given that grass species were not the only species present. Point 18 is isolated due to its singular grass species being recorded. Point 11 is also an outlier to some degree, this spread from other *Coprosma* spp. plots being due to the presence of fern species. Notably point 16 is also quite distant this being attributed to the presence of *Olearia paniculata*, a species that was only recorded in the understorey in this plot. Points 4 and 5 are close due the only difference in species recorded being *Pittosporum tenuifolium* and *Podocarpus* species respectively. Points 8, 9 and 10 are also close due to the presence of *Podocarpus* species.



5-14 Three Dimensional scatter plot of 1st, 2nd and 3rd order averages of canoco results on percentage cover of species one metre or less in height.

5.4 Discussion

With no significant differences observed for total basal area (Figure 5-2) between 1985 data and 1994 data it is safe to assume that the measurements taken in 1985 are not reflective of the exclosure plots effect given that it had just been implemented. For 2011 it is clear that while overall the BA is smaller for both open and exclosure plots than in the previous years, a factor that can be attributed to natural mortality along with a reduced seed source in the surrounding area, the exclosure plots show a higher total BA than open plots. Mortality can of adult trees of species such as *Griselinia littoralis* and *Melicytus ramiflorus* is a result of being heavily browsed until dieback and mortality occur in the open plots.



Figure 5-15 Plate A and Plate B showing evidence of browse by feral goats on the upper branches and shoots of adult *Griselinia littoralis* (Photos by H. Berkett).

Despite a decrease by 2011 (Figure 5-3) mean tree BA shows little or no significant change over time. This is most likely due to the mature tagged trees (with the exception of *G. Littoralis* and other species susceptible to browse as an adult (Figure 5-15)) being less

affected by goats. The decrease in BA from 1994 to 2011 is more than likely attributable to natural mortality.

When viewed over sampling periods 1985 and 1994 the difference in the BA of palatable species is consistent (Figure 5-4) however by 2011 these had decreased substantially. This is what would be expected as the palatable species numbers would have decreased due to browse. In 2011 the exclosures have a lower BA than the open plots which supports to some degree the evidence of goats gaining access to the exclosures as indicated by the evidence of sign (Pers Obs.) in one of the exclosures. However, as would be expected the opposite occurs in the BA of non-palatables (Figure 5-5) with the exclosures consistently having higher BA scores. The lack of notable change between 1985 and 1994 suggests that over the shorter time period (nine years) natural mortality is not as obvious when compared to the change between 1994 and 2011 (17 years) which show a realistic example of natural mortality.

Figures 5-6 and 5-7 indicate that in the particular size classes represented there are notable differences in both the open and exclosure plots. In both cases the BA of palatables in open plots increased somewhat between 1985 and 1994 before dropping significantly by 2011. This could be explained by an increase in herbivore numbers post 1994 as well an increase in stand mortality due to the effects erosion and loss of nutrients (Laforteza, Coomes et al. 2010). In both size classes exclosures all have decreasing BA from 1985 through to 2011 though the changes are less significant in Figure 5-7. The differences in this change could be accrued to more agile goats being able to gain access to the exclosures and only able to have a significant impact on the palatables with a DBH of ten centimetres or less. This theory is supported again by sighting sign in the exclosures and Cochrane (1994) shooting a juvenile goat in the Brian Boru exclosure, it having gained access from pushing under the netting.

A consistent decrease in BA for open plots of palatables (Figure 5-8) can be explained by browsing by goats (Scowcroft and Hobdy 1987; Dodd and Power 2007), and possibly with the larger trees the influence of possums (Cowan 1990) though this has not been investigated in this study. The minimal variance between the exclosures suggests that the quality of the soil in regards to nutrients and susceptibility to run-off may be lowered by the higher abundance of vegetation in comparison with open plots.

Figures 5-9, 5-10 and 5-11 show an increase in BA for non-palatable species in the enclosure plots as would be expected, given they are less likely to be browsed. The decrease in BA in the smallest size class (Figure 5-9) (decreasing over the sampling periods for both open and enclosure plots) can be attributed to effects of reduced vegetation cover and, in open plots possible trampling by herbivores. This could also be an influencing factor on the next size class as it also experiences a decrease in BA while in the largest size range (Figure 5-11) there is relatively little change and can be described as evidence of natural forest mortality. It is also worth noting that variation in the enclosures of the sampling periods is minor. This given they are non-palatable and their surrounding environment (despite some intrusions by goats) is protected can be expected especially in the larger size classes (Figures 5-10 and 5-11).

The lack of significant differences is mirrored in the results from the ANOVA tests of basal area. Each test returned a result greater than 0.05 indicating that there were no significant differences between treatment and year of sampling. This indicates that the trees that were tagged in 1985 have shown no negative change in basal area with the presence of goats. While this would suggest that goats are therefore not having a negative effect it is important to note that the trees tagged, were for the most part adult trees or juveniles of a reasonable size. As such, unless they are an easily climbed species such as *Griselinia littoralis* they are quite unlikely to have their leaves and shoots readily browsed by goats. Some mortality has occurred but despite this change in numbers of tagged trees over three sampling periods there is no significant change in growth that can be directly attributed to the presence of feral goats. This is further backed by Figure 5-12 which showed that overall tagged species changed minimally which was to be expected given that the majority of the species were adult species and often too large to have their foliage easily accessed.

However the ANOVA test of vegetation less than one metre did in fact return a notable significant difference between the treatments. This indicates that the presence of goats in the open plots is having an adverse effect on regeneration and recruitment. The enclosure plots have provided some adequate defense as it was possible to find juveniles of palatable species that had experienced no browse (Figure 5-16).

Figure 5-13 shows that there is no consistent correlation of percentage cover of species less than one metre. The enclosures are somewhat varied though still on a similar scale while

open plots in particular show no significant trend. As can be seen due to the wide spread along the axis's there is minimal similarity between the exclosures, the open plots and the new plots. However with the down weighting of rare species it is possible to see that there is significant correlation (Figure 5-14), and when viewed with the corresponding information in Table 5-3 it is possible to see that the correlation is centered around *Coprosma* species, some of which are noted as being less palatable to ungulates (Cochrane 1994). It is possible that their divaricating growth, considered a defense against moa (Greenwood and Atkinson 1977; Batcheler 1989; Bond, Lee et al. 2004) may also be providing enough protection to new growth



Figure 5-16 Juvenile *Griselina littoralis*, *Coprosma rhamnoides* in an exclosure and showing no evidence of browse (Photo by H. Berkett).

During the 26 years since the exclosure plots were erected it has become possible to note significant change in the understory composition of the forests in the reserve. Also observed was that goats are browsing species in the exclosures where growth has spread past the fence wire (Figure 5-16).



Figure 5-17 Browse of *Coprosma rotundifolia* on the edge of the Isolation Hut Exclosure (Photo by H. Berkett).



Figure 5-18 Brian Boru exclosure showing a heavily browsed understory outside of the exclosure compared to the well populated understory within the exclosure (Photo by H. Berkett).

Due to the presence of goats there is practically no understory of note in the majority of the plots as evidenced by the ANOVA results for vegetation composition of one metre or less. This was also visible (Figure 5-17) where it was possible to see the heavy undergrowth present in the exclosure while immediately adjacent to it is a heavily browsed open area. As is immediately apparent juvenile examples of highly palatable species are widespread, while in the open areas, despite having a comparable number of adult stems present there is practically no juvenile woody species which are essential for the forests continued existence.

This example further illustrates the effect that feral goats are having in the reserve is indeed serious and quite far along.

During the period of this study feral pigs were observed on multiple occasions, one such sighting involving a sow with a large litter, the other sightings being of individual pigs. On one occasion deer were heard roaring while at the Brian Boru enclosure, they were believed to be on the upper reaches of the reserve. While neither species were investigated for this study it is felt that their presence is minor compared to that of the feral goats, this being attributed to recreational hunters being more interested in shooting deer or pigs. While vegetation species that are important to the deer diet (Nugent 1990) are present in Isolated Hill Scenic Reserve (Cochrane 1994) and are similar to that of feral goats suggesting the potential for habitat competition their impacts appear limited in comparison to feral goats despite the fact that with similar diet preferences.

The browsing of the forest understorey is the most noticeable effect by feral goats. Vegetation that is subject to browse can be classified as highly palatable, moderately palatable or low palatability. As can be observed by the results of the ANOVA test on vegetation of one metre or less it is clear that the majority of the vegetation present in Isolated Hill Scenic Reserve is mixed high and medium palatable species. This is in keeping with the results of McKinlay (2000) and both Cochrane (1994) and Cochrane (1999) all of which indicated that the understorey vegetation provided a desirable food source for goats and other ungulate browsers present.

Despite being a heavy contributor browsing may not necessarily be the only influencing factor behind the absence of regeneration as gaps in the canopy and site conditions (McKinlay 2000) are also potentially responsible for decreased regeneration. However the site conditions are most likely a result of continued browse and the presence of feral goats in the reserve. In areas of adult palatable species litter fall provides an option of foraging that is readily engaged in by feral goats (Daniel 1975; Cowan, Waddington et al. 1985), but also reduces the likelihood of regeneration through the removal of leaf matter, and the degradation of soil conditions.

With the presence of enclosure plots it is possible to note specific vegetation changes in the forests of Isolated Hill Scenic Reserve and with the results of the data it indicates that this is a result of goat diets.

The regeneration that can be seen in the three exclosure plots across the reserve provides visual evidence of the occurrence of heavy browse. In the exclosure plots the presence of juvenile regenerating palatable species, such as the highly palatable *Griselinia littoralis* and *M. Ramiflorus* is a positive indication that goats are significantly changing species composition as outside of the reserve it is rare to find juvenile examples of these species. Therefore it is plausible to conclude that goat browsing is still occurring as it was in earlier studies (Hayward 1985; Cochrane 1994; McKinlay 2000) and that regeneration is significantly restricted across almost all species.

Cochrane (1994) indicated that spatial heterogeneity will influence the browsing behaviour of feral goats and therefore vegetation change. Spatial heterogeneity in an environment suggests that in the case of Isolated Hill Scenic Reserve, the utilisation of the feral goats will vary spatially depending on their location and barriers they may encounter (Adler, Raff et al. 2001). As Isolated Hill Scenic Reserve is very spatially heterogenous then utilisation and the associated impacts will also vary depending on area (Cochrane 1994). Areas of less palatable species, such as red beech and mountain beech (*Nothofagus fusca* and *Nothofagus solandri* var. *cliffortioides*) are less susceptible to changes influenced by feral goats than areas of podocarp forests and the secondary seral forests. Vegetation change is primarily occurring in these two forest types however this is only indicated by the presence of the exclosure plots (being in secondary seral forests) and therefore this statement while true of the observations is not necessarily accurate. Given the time span of which browse has occurred and the vegetation changes that have been wrought, predominately understorey loss, it is entirely feasible that the utilisation of less desired beech forests will occur due to a lack of preferred species.

5.5 Isolated Hill Scenic Reserve, an uncertain future

Despite organised pest control and recreational hunters the continued presence of feral goats, with other introduced herbivores means the modification of forest composition first reported in Cochrane (1994) is continuing. Major changes have occurred to the composition and cover of the vegetation component (McKinlay 2000) due to feral goats in the 17 year time period (Cochrane 1994) and the 26 year time period (Hayward 1985). Saplings and seedlings of palatable species are heavily browsed and removed, such as *C. serratus*, *G. littoralis*, *M. australis*, and *M. ramiflorus* (McKinlay 2000). As indicated by the previous studies of Cochrane (1994; 1999) and McKinlay (2000) the dominant palatable canopy species are not regenerating a dominant understorey with the presence of goats. Therefore the understorey vegetation becomes dominated by lower preference less palatable species though their existence is often still limited leading to an open understorey due to occasional browse and trampling, a secondary effect of the introduced ungulates. The ordination analysis in Chapter 2 further supports this as it supports the notion that while there is some selectivity of more palatable species overall selectivity by introduced mammals of browsed species is minimal. This indicates that while more palatable species will be browsed first as availability of forage decreases then less favoured species will enter the diet. This would account for the lack of palatable species and reduced presence of non-palatable species in the understorey of the open plots across the reserve. While non consumptive effects of goats such as trampling (Laforteza, Coomes et al. 2010; Stritar, Schweitzer et al. 2010) contribute significantly to the reduced presence of non-palatable species in the understorey the evidence presented in Figure 2-1 and Figure 2-2 indicate that the potential for browse over a wide variety of species is evident.

The three exclosure plots provide an example of the successful regeneration of palatable species when browsing is removed as a pressure on the forest. Previous research (Cochrane 1994; McKinlay 2000) concluded that the forest is being replaced by species resistant to browsing, typically with a high proportion of less palatable species. However trampling effects and the loss of soil stability due to the loss of plant species via browse has resulted in a more open environment in the understorey. On the assumption that intensive browsing occurs at the same rate by feral goats the amount of forest degradation depends on the life

span, and the occurrence of disturbances, such as windthrow, erosion or fire, that could deplete the canopy (McKinlay 2000).

Areas of heavy modification due to browse are at this stage, quite likely to disappear. This would result in a loss of matai forest and broadleaf species that would be irreplaceable and their decline would in turn have far reaching consequences for the reserve. This is inclusive of canopy species that are too large to be browsed in an adult state because with the progression of natural mortality there will be no succeeding individuals to replace those gone due to the removal of regeneration. Areas of less palatable species will experience less modification though overall diversity will be reduced with the loss of palatable species in the understory (Cochrane 1994) but a mostly intact canopy can be expected.

With regards to the regeneration of the more favourable plant species, such as *Griselinia littoralis* and *Melicytus ramiflorus* which are present in the canopy are not successfully regenerating in the ground and understorey layers. If the upkeep of the current plant communities is used as a target for conservation as a tool to monitor goat control and therefore regeneration success then it is apparent that success is still elusive in Isolated Hill Scenic Reserve (Cochrane 1994). Successful upkeep will involve the establishment and successful growth of all species currently recorded in the reserve otherwise the forest will be considered modified.

Notable vegetation changes are present in the secondary seral forests of the reserve and are indicative of palatable species to feral goats. With the exception of the three exclosure plots sapling and seedlings of *Griselinia littoralis* and *Melicytus ramiflorus* are rarely found in the reserve. This can be attributed directly to the presence of feral goats as *Griselinia littoralis* seedlings are abundant through areas of vegetation exclosures monitored by the Department of Conservation and in cases where feral goats are unable to gain entry to an area seedlings and saplings of both species have been recorded (Cochrane 1994). In the exclosures regeneration is occurring at what can be considered natural rates further indicating that with the absence of goats the forest continues in a healthy state.

Cochrane (1994) modified the two models of the relationship between vegetation modification and feral goats (Moore and Cranwell 1934; Atkinson 1964) which described the future vegetation change that could be expected in Isolated Hill Scenic Reserve at that time.

Areas where heavy modification had occurred by feral goats (matai forest and broadleaf forest) were deemed as having an uncertain future (Cochrane 1994). The findings at the time indicated that palatable species, inclusive of the canopy will eventually disappear from the majority of these areas. Disturbance events will be an influencing factor in the rate of canopy species removal and the encroachment of shrub and grass land as will the natural mortality of the stands (Cochrane 1994; McKinlay 2000). The occurrence of fragmentation will also accelerate the rate of erosion (Laforteza, Coomes et al. 2010) particularly on areas of Isolated Hill.

Areas where less impact has been observed (kanuka forest, Hall's totara and red beech) will continue, however palatable understorey species will be removed thus change the diversity present in these forest types, however these less preferred species will continue regeneration enabling the continuation of a relatively enclosed canopy (Cochrane 1994).

Future patterns of vegetation change have been described in Table 5-3 which provides a model based upon the research into vegetation change perpetrated by goats in Isolated Hill Scenic Reserve. This model reflects the nature of the terrain and is built on both visual observations made by the author as well as an analysis of data. This allowed for a realistic approach to defining a model that accurately represents the change occurring. The two earlier models proposed by Moore and Cranwell (1934) and Atkinson (1964) while accurate representations of goat induced vegetation change models are not accurate in Isolated Hill. The proposed model addresses the steepness of the terrain and the associated run-off and erosion potential that this encompasses with the occurrence of inclement weather.

This is a far more accurate model for describing the relationship between vegetation modification and feral goats in Isolated Hill Scenic Reserve, however in the intervening 17 years I feel some changes and additions can now be made to this model following my own observations.

As previously mentioned by Cochrane (1994) heavy modification will occur in areas of preferred species with notable losses of palatable juvenile species and the potential for significant losses of adult members of these species. The heavy browse on both adults and juvenile examples will lead to a decrease in regeneration due to i) adults having reduced fecundity from heavy browse, and ii) juveniles being predominantly consumed whole or

dying off due to excessive damage. This will result in the forest being unable to develop replacement growth as natural mortality occurs.

Less palatable species will show an increase while soil quality (nutrients, stability, drainage etc.) will decrease with the decrease in palatable species. This decrease is attributed to the reduction in plant bio mass entering the nutrient cycle as litter fall of palatable species is often consumed. A reduction in stability and drainage is correlated with a loss of the understorey cover with the decreasing numbers of palatable species present. While less palatable species will show increased growth they will not grow at a rate to immediately fill areas previously dominated by palatable species. At this point large adult trees will remain relatively unaffected due to their size.

Further decreases in palatable species occur with continual heavy browsing, as does the degradation of soil quality. With the decrease in soil conditions less palatable species start to experience a decrease as well due to nutrient loss and an increased occurrence of erosion due to the ever decreasing understorey. Regeneration decreases for both palatable and non-palatable species due to browse and soil loss via erosion. Browse of less palatable species can be expected as palatable species become fewer. This evidenced in the results and discussion of Chapter 2 which indicate that while most of New Zealand's introduced herbivores have preferences in browse species they can also be considered ranked generalists. This diet structure can lead to significant changes in vegetation composition as fewer species will be able to regenerate as time progresses due to a lack of surviving adults.

As natural mortality progresses adult trees begin to die off (Coomes, Duncan et al. 2003; Coomes and Allen 2007), with a resulting increase in grass and sedge species. Even in areas of less palatable species regeneration is slow with only especially hardy species surviving. Fragmentation occurs, with large open areas dominated by grass species and open slopes being bare and highly susceptible to significant erosion events. Over the entire reserve the understorey is either severely depleted or nonexistent in areas where forest remains.

Given the progression of vegetation change that has been observed during the course of this study, both analytically and by direct observation, Isolated Hill Scenic Reserve in its current state, involving the notable presence of feral goats and the vegetation types will continue to diminish in diversity as indicated by previous studies (Cochrane 1994; Cochrane 1999; McKinlay 2000). The modification of the seral forests will continue (Stewart, Wardle et al.

1987) and in particular the podocarp/matai/broadleaf communities will suffer heavily. Unfortunately given the effects already noticeable it is quite likely that even with the removal of feral goats and other introduced ungulates will not necessarily allow the forests to return to their original state as vegetation change is both temporal and spatial.

Management plans devised for the reserve should highlight the need for the rapid removal of feral goats. Plans should also consider the changing nature of forests under the presence of ungulates and identify corridors that will allow adequate regeneration of original vegetation species while understanding the change of forest composition that spatial and temporal changes may bring.

5.6 Limitations

The primary limitation is the validity of the data, the exclosure plots were erected in 1985 and initial DBH measurements occurred this point. Therefore it is felt that this would make that data invalid for the first year of records as it would have realistically been representative of the forest under the current (for the time) conditions (goat presence and forest structure). Therefore it is felt that the differences between data sets from 1994 (Cochrane) and 2011 (the author) would show more useful results given the extended period of time (17 years) between them.

A further limiting factor for the accurate assessment and comparison and contrast with open plots of the reserve is the number of exclosure plots implemented in 1985. The three exclosure plots were constructed for the purpose of browse analysis by feral goats on the secondary seral forests of Isolated Hill Scenic Reserve (Hayward 1985) and provide a useful insight into the changes that have occurred in the reserve. While the three exclosures are spread well over the reserve and subsequently represent a broad swath of the forest types present they are still somewhat limited. Ideally at least an additional three exclosures would be implemented with an additional four open plots 100metres to a 150metres from each of the four exclosure edges. These four additional plots could also be implemented on the existing exclosures. This would then provide one exclosure, or natural state plot to provide comparison with four immediately associated open plots and 18 other open plots. It would also allow for a broader comparison of exclosures across the reserve.

These plots would also serve to analyse the forest to a greater extent and not just the seral communities therefore allowing a greater understanding of what changes are taking place.

6 Bibliography

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7.0 Appendices

7.1 Flora Species

<i>Acaena media</i>	<i>Blechnum fluviatile</i>
<i>Acaena sanguisorbae</i>	<i>Blechnum minus</i>
<i>Aciphylla</i> spp.	<i>Blechnum penna-marina</i>
<i>Agrostis</i> spp.	<i>Blechnum procerum</i>
<i>Alepis flavida</i>	<i>Brachyglottis bidwillii</i>
<i>Alseuosmia macrophylla</i>	<i>Brachyglottis repanda</i>
<i>Alseuosmia pusilla</i>	<i>Cardamine</i> spp.
<i>Alsophila smithii</i>	<i>Cardiomanes reniforme</i>
<i>Anisotome antipoda</i>	<i>Carex</i> spp.
<i>Anthoxanthum odoratum</i>	<i>Carmichaeliaspp.</i>
<i>Anisotome filifolia</i>	<i>Carpodetus serratus</i>
<i>Anisotome haastii</i>	<i>Cassinia vauvilliersii</i>
<i>Anisotome latifolia</i>	<i>Celimisia</i> spp.
<i>Anisotome pilifera</i>	<i>Cerastium fontanum</i>
<i>Archeria traversii</i>	<i>Chionochola flavescens</i>
<i>Aristoleia serrata</i>	<i>Chionochola lyallii</i>
<i>Aristoleia fruticosa</i>	<i>Chionochloa pallens</i>
<i>Asplenium bulbiferum</i>	<i>Chionochloa rigida</i>
<i>Asplenium flaccidum</i>	<i>Chionochola rubra</i>
<i>Asplenium obtusatum</i>	<i>Cirsium</i> spp
<i>Asplenium polydon</i>	<i>Clematis</i> spp.
<i>Astelia</i> spp.	<i>Collospermum hastatum</i>
<i>Auricularia polytricha</i>	<i>Coprosma areolata</i>
<i>Beilschiedia tawa</i>	<i>Colobanthus</i> spp.
<i>Blechnum capense</i>	<i>Coprosma brunnea</i>
<i>Blechnum chambersii</i>	<i>Coprosma ciliata</i>
<i>Blechnum colensoi</i>	<i>Coprosma cuneata</i>
<i>Blechnum discolor</i>	<i>Coprosma foetissima</i>

Coprosma grandifolia
Coprosma linariifolia
Coprosma lucida
Coprosma petriei
Coprosma propinqua
Coprosma pumila
Coprosma rhamnoides
Coprosma rotundifolia
Coprosma serrulata
Coprosma tenuifolia
Cordyline australis
Cordyline indivisa
Coriaria angustissima
Coriaria arborea
Coriaria sarmentosa
Cotula spp.
Cyathea smithii
Cyathodes juniperina
Cytisus scoparius
Dacrydium cupressinum
Dacrydium bidwillii
Dacrycarpus dacrydioides
Deyeuxia avenoides
Dicksonia squarrosa
Digitalis purpurea
Discaria toumatou
Dracophyllum longifolium
Dracophyllum traversii
Dracophyllum uniflorum
Durvillea antarctica
Dysoxylum spectabile
Elaeocarpus dentatus
Elaeocarpus hookerianus

Epilobium spp.
Freycinetia banksii
Fuchsia excorticata
Galium aparine
Galium erythraea
Galium propinquum
Gaultheria antipoda
Gaultheria depressa
Gaultheria crassa
Gaultheria rupestris
Geniostoma ligustrifolium
Griselinia littoralis
Gunnera monoica
Hebespp.
Hedycarya arborea
Helichrysum bellidioides
Helichrysum selago
Hieracium spp.
Hierochloa spp.
Histiopteris incisa
Hoheria angustifolia
Hoheria glabrata
Hoheria lyallii
Holcus lanatus
Hydrocot. Spp.
Hymenanthera alpina
Hymenophyllum spp.
Hypolepis spp.
Ileostylus micranthus
Ixerba brexioides
Knightia excelsa
Kunzea ericoides
Lastreopteris glabella

Laurelia novae-zelandiae
Leontodon spp.
Leucogenes grandiceps
Leptospermum scoparium
Leptopteris hymenophylloides
Leptopteris superba
Leycesteria divaricata
Leycesteria formosa
Leuucogenes grandiceps
Libocedrus bidwillii
Libertia ixioides
Linum catharticum
Lotus angustissimus
Lotus major
Lotus pedunculatus
Luzula rufa
Lycium ferrocissimum
Lycopodium fastigiatum
Macropiper excelsum
Melicytus lanceolatus
Melicytus ramiflorus
Melilotus spp.
Metrosideros diffusa
Metrosideros fulgens
Metrosideros kermacencensis
Metrosideros perforata
Metrosideros robusta
Metrosideros umbellata
Microlaena avenacea
Microsorium pustulatum
Montia fontana
Muehlenbeckia australis
Muehlenbeckia axillaris

Myoporum, laetum
Myosotis spp.
Myrsine australis
Myrsine divaricata
Myrsine nummularia
Myrsine salicina
Myrtus pedunculata
Neomyrtus pedunculata
Neopanax arboreum
Neopanax simplex
Nertera ciliata
Nertera depressa
Nertera villosa
Nothofagus fusca
Nothofagus menziesii
Nothofagus solandri. Var
cliffortioides
Nothopanax arboreum
*Notospartium*spp.
Olearia ilicifolia
Olearia rani
Oreomyrrhis colensoi
Ourisia lactea
Parsonsia spp.
Pellaea rotunafolia
Pennantia corymbosa
Peraxilla colensoi
Peraxilla tetrapetala
Phormium colensoi
Phormium cookianum
Phorium tenax
Phylocladus alpinus
Phymatosorus diversifolius

Phymatosorus pustulatum
Pimelea spp.
Pittosporum divaricatum
Pittosporum eugenioides
Pittosporum patulum
Pittosporum tenuifolium
Plalanthus betulinus
Plantago triantha
Podocarpus ferrugineus
Podocarpus totara
Podocarous hallii
Podocarpus nivalis
Podocarpus spicatus
Polypodium diversifolium
Polystichum vestitum
Pomaderris phyllicifolia
Potamogeton suboblongus
Prumnopitys ferruginea
Prumnopitys taxifolia
Pseudopanax arboreus
Pseudopanax colensoi
Pseudopanax crassifolius
Pseudopanax edgerleyi
Pseudopanax simplex
Pseudowintera colorata
Pteridium esculentum
Pratia arenaria
Pyrrosia serpens
Quintinia acutifolia
Quintinia serrata
Ranunculus spp.
Raoulia tenuicaulis
Raukua edgerleyi

Raukua simplex
Ripogonum scandens
Rosa rubiginosa
Rubus cissoides
Rubus fruticosus
Rubus schmidelioides
Rumex acetosella
Senecio bidwillii
Senecio monroi
Senecio reinoldii
Schefflera digitata
Schoenus pauciflorus
Solanum lacinatedum
Solanum nigrum
Sophora microphylla
Stellaria decipiens
Stellaria media
Sticta spp.
Suttonia australis
Taraxacum spp.
Tetrapothea tetandra
Tillaea moschata
Trifolium arvense
Trifolium ambiguum
Trifolium repens
Ulex europaeus
Uncinia spp.
Urtica ferox
Urtica incisa
Viola cunninghamii
Wahlenbergia albomarginata
Weinmannia racemosa
Monocotyledons

Fungi

Lichen

Herbs