The effect of Rabbit

(*Oryctolagus cuniculus cuniculus*)

(Linnaeus, 1758)

Browsing on Seedling Survival.

A thesis presented in part fulfillment of the requirements

of the degree of

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in
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"From the extraordinary manner in which European productions have recently spread over New Zealand, and have seized on places which must have previously occupied, we may believe, if all the animals and plants from Great Britain were set free in New Zealand, that in the course of time a multitude of British forms would become thoroughly naturalized there and would exterminate many of the natives."

Darwin, Charles. The Origin of the Species. 1859.

ABSTRACT

The European rabbit, *Oryctolagus cuniculus* (Linnaeus 1758) is a small 2–4 kg eutherian mammal introduced into New Zealand from the United Kingdom in the mid 1800's. By the 1950's the range of the rabbit had covered nearly 95% of the available land resulting in millions of dollars of damage. It was noticed by the 1970's that some populations were stable without any control measures being applied, and with increasing research and a changing attitude towards pest management away from extermination to control, it became policy that the status of this pest was downgraded to a regional pest rather than a pest of national importance. Control became the responsibly of the landowner rather than a national body except where populations occurred in high densities.

However, even rabbit numbers at low densities do exert a pressure on vegetation, and in some bush remnants rabbits are blamed for the lack of regeneration that occurs even when larger herbivores are excluded.

Four bush remnants within the Manawatu-Rangitikei region of New Zealand, two in the coastal sand country and two inland at Marton, were studied for the causes of seedling mortality over five seasons from August 1999 to December 2000.

One hundred and fifty seedlings were identified and numbered to species level and were placed in five treatments and controls at each site, except Legg Estate bush remnant where ninety seedlings were used in unbalanced numbers in each replicate

The data were analysed using logistic regression with scores for rabbit densities and deaths of seedlings per bush remnant within the treatments and controls.

The analysis suggests that there is a seasonal effect ($P<0.0001$) and a treatment /control effect ($P=0.0002$) on seedling survival with treatments at Legg Estate bush remnant surviving consistently better over the five seasons.

At Himatangi Block Scientific Reserve seedlings in the treatment survived better than seedlings in the controls, except for winter 1999.

At Monkton's and Fulleton-Smith bush remnants, treatments survived better than in the controls.

Overall the treatment (protecting seedlings against rabbits by fencing) improves seedling survivability. This trial was conducted at a time of regionally low pest numbers because of the prior introduction of Rabbit Haemorrhagic Disease (RHD), and treatment results should be interpreted with this in mind.

Key Words: Rabbit, Treatment effect, Bush remnant, RHD, Exclosure, Seedling survival.

List of photographs

Unless otherwise stated photographs were taken by Mrs Cheryl Doyle

List of maps

List of diagrams

List of tables

List of graphs

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A remembrance of the memory of my child hood friend, teacher and hunting companion, my sheepdog Flynn (named after Barry Crumps dog of the same name in New Zealand's greatest work of fiction, A Good Keen Man), who taught me to rabbit, and in many ways laid the foundation work over thirty years ago, which has accumulated to date in this project.

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A SINCERE

THANK YOU!

Table of contents

Appendices

CHAPTER 1

General introduction and site data

1:1. Introduction

The New Zealand Botanical region consists of a group of over 660 islands, including the larger North and South Islands, within the latitudes of 160^0 to 180^0 East and longitudes of 30^0 and 50^0 South. Within these ranges New Zealand's indigenous flora and fauna has been in increasing isolation from the Gondwana landmass for the last 80 million years. This is reflected in the species that have evolved here, without the "destructive [1]" activities of grazing and predatory mammals (Cockayne, 1967) and these endemic species generally known to be "ancient", as many have roots back to the great southern landmass Gondwana.

The mammal species we know today evolved from ancestors living in the Oligocene period 37 to 24 Million Years before Present (MYBP). The already isolated New Zealand landmass was too distant for any significant species of land mammals to reach here, as no land bridges existed and rafting here was extremely unlikely. Only three native land mammals were known to exist here and these were members of the order Chiroptera (bats), and as these were capable of sustained flight it was likely they were blown or flew here (Daniel,1979). Influences upon the speciation of New Zealand from its drifting from Gondwana until the last 1100 years were its isolation, a maritime climate and the tectonic processes of volcanism and tectonic uplift.

In the last 1100 years human kind began to inhabit New Zealand in significant numbers and intentionally introduce exotic species, whose presence, once established, had a dramatic impact upon the now vulnerable fauna and flora. The Maori brought the Kiore *Rattus exulans*, Peale, 1848 and the Kuri or Maori dog *Canis familiaris,* Linnaeus, 1758 from their Pacific island origins.

[1] Destructiveness within this work is defined as consumption of indigenous and introduced plants unwanted organisms. There is currently a debate about the actions of Cervids and this is outside the scope of this work.

There is evidence of Kiore being present in New Zealand 2000Years Before Present (YBP)(Worthy & Holdaway, 2002).

The British explorer Captain James Cook was the first European to begin exotic introductions into New Zealand with pigs *Sus scrofa,* Linnaeus, 1758, and members of the order Rodentia, the norway rat *Rattus norvegicus*, Berkenhout, 1769, the ship rat *Rattus rattus,* Linnaeus,1758, & the house mouse *Mus musculus*, Linnaeus, 1758, all of which have proven to be economically and environmentally damaging.

These species were from Europe and in New Zealand found themselves in a relatively predator free, resource rich environment. The whalers and sealers that followed the Cook expeditions dramatically reduced many marine mammal populations and also stocked outlying islands with exotic mammals e.g. goats, as food sources for any shipwreck survivors.

Colonization of New Zealand by Europeans in the 1800's brought a rapid increase in the human population leading to one of the world's most dramatic modification of the existing vegetative cover by human kind in a relatively short period of time. Forests were felled or burned, swamps drained and many exotic species were imported into New Zealand as food or livestock or organisms familiar to the colonists (Stevens *et al*, 1988) As New Zealand was ceded to the English Crown by the Treaty of Waitangi in 1840, the prevailing thought of Mother England was, to stock the realm with exotic game species, to create diversity in the diet of Her Majesties subjects and provide sport for the gentry and industry for the new lands. The Lagomorph *Oryctolagus cuniculus cuniculus* (Linnaeus, 1758) or rabbit with nine species of Cervides (Deer) and three species of Bovides, thar, *Hemitragus jemlahicus*, Smith,1826, chamois, *Rupicapra rupicapra rupicapra,* Couturier, 1938, & goats *Capra hircus,* Linnaeus,1758, were a few of many species brought to New Zealand and released.

Rabbits were brought here from the 1840's onwards, and after several attempts at establishment, they quickly became a serious pest. The spread in the South Island was initially very rapid and coincided with the spread of pastoralism.

The spread in the North Island was at a slower rate but followed the clearance of standing forests, which all but ended in the 1950's. Today rabbits are still considered a pest, but their impact is mainly confined to regions in the South Island while in others areas it has a localized effect upon the landscape and vegetation. Most landowners feel that the removal of rabbits would be beneficial in the long term. During the initial invasion rabbits occupied areas that they are absent from today and its impact upon the landscape is vastly reduced. Nevertheless small increases in the population can have recognizable impact upon the existing vegetation.

The dramatic modification of the landscape which has occurred in the last 170 years, means that no forests on the mainland are in pristine condition. Little Barrier Island is now considered by some to be the largest area of unmodified forest left in New Zealand (Cometti, 1986). The modification seen in the mainland forests as a result of the exotic invaders, both animal and plants can be seen in all bush and bush remnants to varying degrees. Modifications of the physical environment have had a profound impact upon the survival of native species.

Some regions in New Zealand have lost nearly all of their original forest cover and much of the little remaining forest is highly modified, with most having only modest levels of protection against herbivores until quite recently. Human impact upon the landscape, flora and fauna within New Zealand has been nothing but disastrous, and it is now unlikely that the full impact of those modifications can be reversed. The likelihood is the significant threats that exist today can only be managed within broad limits.

It is with management of these risks that this research project was funded by Horizons mw.[tm]

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The aim is to assess whether rabbits has an impact upon regenerating bush remnants and under the Biosecurity Act 1993, to determine how High Value Conservation Areas (HVCA) may be managed.

The Manawatu Plains Ecological District has lost nearly all of its original forest cover, only about 2% of the original cover remains, all of which is highly fragmented and degraded, and which has become, recently, in need of some form of protection (Saunders J, 1995). Many remnants are on private land, and have been assessed by the Protected Natural Areas Programme as Recommended Areas for Protection (RAP), under the Reserve Act 1977 Section 3 (1) (b) or as HVCA's under the statute provisions of the Biosecurity Act 1993 for assessment of vertebrate and avian pest control. The status of bush remnants depends on how much similar bush remnant exists or what special features it has or unique species or species combinations exist.

In several bush remnants no regeneration has been recorded since several decades of stock exclusion (Sheep *Ovis aries*, Linnaeus, 1758, & Cattle *Bos taurus*, Linnaeus, 1758), while others bush remnants have reasonable strikes of seedlings and recruitment into the canopy, regardless of the presence of rabbits. To gain a better understanding of the impact rabbits has upon regenerating forest remnants, Horizons mw tm has sponsored a trial to quantify the effect rabbits have upon seedling survival. This research is required to help formulate policy on vertebrate pest control within bush remnants, as required under the Biosecurity Act 1993.

This is highlighted by one such bush remnant, Legg Estate bush remnant, which has received protection, but little active management (a bush remnant with little regrowth after 50 years of stock exclusion). This is a highly degraded bush remnant in the Manawatu sand country where the owners feel the impact of rabbits was significant, and that their exclusion would allow recognizable regeneration of seedlings.

This project should show any negative impact rabbits have upon seedling survival within the four chosen bush remnants and allow the remnant managers to help formulate control policies as part of the restorative programmes.

1:2:1. The Rabbit [1], History and Biology.

With the study of any organism or interactions of an organism with its environment, it is essential that an exact identification of that particular species in question be made. The rabbit, *Oryctolagus cuniculus cuniculus* is a small eutherian mammal, which has a typical r-strategy of survival. It has, over time, provided a source of food and clothing for many, sport as a small game species, is entwined in our folk law and extensively used in research as well as making a popular cuddly pet (Photograph I, page 6). Rabbits have also laid waste to the landscape and have done millions of dollars in damage, costing us much in control and associated research to mitigate this damage. In New Zealand alone, the national cost of rabbits and their control is at least $22 million per annum (Parks, 1995).

1:2:2. Classification.

The European rabbit *Oryctolagus cuniculus* (Linnaeus 1758) was originally known as *Lepus cuniculus* (Lepus-hare, cuniculus-rabbit) reflecting its similarity to members of the Lepus genus, but also recognizing distinction from other members of the genus Lepus, like *Lepus europaeus* (a Lagomorph common in New Zealand). When comparing *Oryctolagus cuniculus* with rabbits of the Americas Genus *Sylvilagus* (the cottontails) it was easily recognized as a distinct species.

The distinction of *Oryctolagus* from other genera in the Leporidae families is on biochemical and behavioral grounds, especially its nature of digging which is unique to this member of the Order Lagomorpha.

[1] Through this work all names of plants, where possible are in the binomial classification. Animals show initially their binomial and common name thereafter their common name is used. Appendix I, page 130 gives both the scientific and common names.

Photograph I: An nine-year-old adult male rabbit.

Lilljeborg coined the Latin *Oryctolagus* in 1874 and it was then placed as a sub genus of Lepus. *Oryctolagus*, means digging hare (Corbet, 1994). *Oryctolagus* is now considered a genus and is no longer a sub genus of *Lepus*. The Genus *Oryctolagus* is a monospecific genus with two distinct subspecies.

Classification is currently:

Class:	Mammalia
Subclass:	Eutheria
Order:	Lagomorpha
Family:	Leporidae
Genus:	*Oryctolagus*
Species:	*cuniculus*
Subspecies:	*cuniculus*
:	*huxleyi*

1:2:3. Ideal habitats.

Ideal habitat for rabbits is that of the Iberian Peninsula, essentially a Mediterranean climate, with rainfall of a 1,000 mm or less annually, short vegetation with well drained and loosely compacted soils that are easily dug or with secure refuges in near by scrub next to the feeding grounds.

This habitat is also ideal for agriculture and horticulture production and the creation of such habitat has enabled rabbits to greatly expand it range and density, in many instances to plague proportions. A warm sunny aspect is also preferred with cold wet conditions being avoided. Rainfall and soil type are important factors in the life cycle of rabbits as rainfall is a major determinate of vegetative growth, which affects the fecundity of does, and young survival, as many juvenile rabbits will drown in the burrows. Light soils are preferred over the heaver clay soils, for ease of digging and providing good drainage.

1:2:4. Life cycles in New Zealand.

New Zealand traverses a range of latitudes from 33° S to 53° S. This variation in latitude has an impact upon the seasons and hence breeding cycles of resident fauna and flora. For rabbits, the breeding season begins later in the year at higher latitudes, a trend noted in Europe as well as New Zealand. In central Otago (450° 15') the breeding season begins in August while in the Hawkes Bay (40° 00') breeding begins in late May. Litter sizes vary from 4.5 in June to 6.5 in October, with 50% of does pregnant in all months except March, April and May. Peak fecundity is reached in 9 to 12 months for does and 36 months and over for bucks.

In New Zealand the major natural influences of the populations of rabbits are predation of juveniles by introduced predators (King & Moody, 1982) (Fitzgerald, 1988), drowning of juvenile rabbits in their stops and disease.

Under some circumstances rabbits form vast multichamber warrens which may last for many years, with labyrinths of breeding chambers, tunnels and bolt holes, providing shelter from the weather, protection and escape from predators and a safe environment to raise their young. However rabbits will often live above ground seeking shelter in dense vegetation and breeding only in underground stops (Lloyd & McCowan, 1968).

1:2:5. Population fluctuations and its pest status within New Zealand.

With the successful introduction of a species into a new range, many varying factors aid in its success as an invader. In New Zealand, rabbits found a predator free land mass, human modified food and environmental resources with suitable climatic conditions, which were in many respects similar to their native Iberian Peninsular. The ideal conditions enabled rabbit's populations to erupt to plague proportions.

The plagues covered much of Canterbury, Southland and Otago causing several high country farms were abandoned, while production from many others remained low. Seventy seven sheep runs totaling 628 thousand hectares in Otago were abandoned from 1877 to1881 mainly due to rabbit's infections. After the initial establishment phase in the 1870's and 1880's rabbit eruptions after this period were thought to be influenced by climate (Robertshaw and Stafford-Smith, 1993). As with many species within a new environment they overshot their food supply and extend their range into areas that ultimately prove unsuitable. By the 1900's rabbit numbers began to stabilise and their range decreased. Rabbit now occupies approximately 56% of the New Zealand land area and is considered a serious pest in about 5% of this area. In addition to the North and South Islands they are found on 24 smaller islands. Rabbits can exceed 50 per hectare but most areas have less than 10 per hectare (Parks, 1995). Populations are subject to large seasonal and annual fluctuations and much of this is thought to be climate influenced. Dry weather allows high juvenile survival where as wet weather increases juvenile mortality. The nature of the fluctuations indicate how well rabbit populations can bounce back both from natural as well as human induced controls

1:2:6. The political history of the rabbit problem.

The huge increase in rabbit numbers in the late 1880's saw them regarded as a pest to which most control measures were seen as ineffective.

Fences to exclude rabbit were built in both North and South Islands failed to stop the spread of the pest, and the importation of mustelids as a biocontrol agents, the stoat *Mustela erminea* Linnaeus,1758, the weasel, *Mustela nivalis vulgaris,* Erxleben, 1777, the ferret *Mustela furo*, Linnaeus,1758, and the domestic cat, *Felis catus*, Linnaeus,1758, (McCaskill, 1969) also failed.

The importation of mustelids occurred despite widespread concern as to their effectiveness (King, 1971). These actions reflected the desperate situation faced by the farmers of early colonial New Zealand. This was repeated by the actions relating to the farmer's illegal release in 1997 of Rabbit Calicivirus disease (RCD) now called rabbit hemorrhagic disease (RHD). The introduction of RHD was thought to be the saviour of the high country in the late 1990s but in time, it is likely to be as much of a failure as the introductions of mustelids were a century earlier.

In the 1880's the need for control was initiated by the Rabbit Nuisance Act 1876 followed by the Rabbit Control Act 1886. Vast numbers of the pest were killed from the 1880's to the mid 1940's and industries sprung up based upon products produced from the kills.

In 1947 we saw the setting up of the Rabbit Destruction Council and the associated rabbit boards and the failed "Killer policy". This policy, using aerial poison drops of Sodium monofluoracetate (1080) was hugely successful, but was abandoned for a "Control Policy" in 1971. In 1967 the Agricultural Pest Destruction Act was passed and was expanded to include other vertebrate pests such as possum, seven members of the genus *Macropus*, the wallabies of which only four species now remain (Wodzichi, 1950, Wodzichi and Flux, 1967), and the rook *Corvus frugilegus*, Linnaeus,1758. This act set up the Technical Advisory Committee (TAC) to allow a more scientific and ecological approach to pest management.

Since scientific research on rabbits started in New Zealand it has been discovered that isolated populations of rabbits remained relatively stable, despite little or no controls and they do not erupt into the plagues seen a century beforehand.

The only areas where problems seem to exist are in Central Otago and Canterbury, where very large populations developed from the mid 1980's.

These major problems occurred because of a series of dry years and overgrazing by both domestic stock and rabbits alike.

The New Zealand Government asked the TAC to propose a system for realistic dispersal of its funds for pest control.

In 1983 the Agriculture Review Committee recommendations were:

- Rabbits be treated no differently than other farm pests
- Land be classified according to susceptibility
- Government funding should be phased out, except in areas of high susceptibility
- In non susceptible areas rabbit rates should not be levied

In 1988 the Minister of Agriculture commissioned a Rabbit and Land Management Task Force to establish the Rabbit and Land Management Programme (RLMP). This programme became operational with the establishment of the Regional Councils in 1989. The aim of the task force was to find a way to more sustainably manage of the environment in the long term and to redirect land usage to avoid creating the "ideal conditions" for rabbits.

It is worth noting that in areas with high rabbit proneness there are serious obstacles to achieving sustainable land management. The economic viability of some of the properties taking part in the RLMP is doubtful, and in these situations the presence of rabbits is likely to dictate the land management system, rather than vice-versa.

The Agriculture Pests (Exemption of Domestic Rabbits) Order 1980 came into law on 22 January 1980, enabling the keeping of rabbits as domestic animals.
Rabbits were now becoming a resource to be farmed, as has happened with other pest species, both in New Zealand and worldwide.

The then Minister of Agriculture, Honorable Duncan MacIntyre, was quoted as saying

"I personally see domestic rabbits as a resource through which we could increase our overseas funds by production and processing of furs and the export of meat".

Feral rabbits could be harvested for food and pet food, under stringent hygienic conditions to reduce the likelihood of disease transmission to humans and pets alike.

Public attitudes to rabbits were changing but today there are still heated debates about the animal and its control methods in New Zealand (Fraser, 2001).

In 1993 the Biosecurity Act came into effect, reducing rabbits from a pest of national importance to a pest of regional importance (Martin, 1996). This has enabled differential responses to feral populations depending upon the causes of the population increase and severity of infestations.

It appears that as our knowledge of the pest has increased out attitudes have changed to reflect the more achievable goals of maintaining low numbers of rabbits over most of the country with an increased response in the few areas of the country where this animal is a pest. We have gone from a policy of total extinction to managed populations in the similar time frame as the populations of this animal exploded across the landscape when first released to a local or almost individual farm problem. This also mirrors the human response to the problem, as at the time reflecting the knowledge and methods available to them.

1:2:7. Conclusions.

Rabbits have become a much widespread and disliked animal with the problems it has created being amplified but human kind's activities. Rabbits were confined to the Iberian peninsular by the last glaciation, where they found their ideal climatic conditions. Their distribution from here has largely been human assisted, where they now are widespread over the planet (Flux & Fullagar, 1983), and in many climates that are anything but Mediterranean.

Its arrival in new lands has in general been welcomed at first and cursed later. The problems it has created have led to some disastrous attempts at rectification and a flurry of political activity to govern this animal's control, most of which to date has been unsuccessful.

With time the animal's populations have stabilized and become a local or regional nuisance. Reduction of this impact has been in many places been aimed at vulnerable crops and areas, while other areas are left to themselves.

Overall this animal has been able to exploit the environments we have modified ourselves, and been in competition for the resources we use. In most instances some form of control is needed over large areas but special control or exclusions of this animal in high valued areas is the only method to mitigate these animals damaging activities.

1:3:1. Regional and site presence of rabbits.

By finding the indicators that a species is present in a given area is called field sign or just sign (Taylor, 1970).

Rabbits have a distinctive field sign, small scratches of dirt made by the animal looking for rootlets or bucks settling territorial disputes were often characterized with a spray of urine or a few droppings. Faecal pellets varied in size, color and consistency according to current diet. Rabbits use special dung heaps which were often seen on, open ground, where the animals congregated before dispersing to feed. They also served as olfactory information and may smell strongly of urine. Often these heaps have been built up over many years, nutrients have leached out from the pellets giving rise to a ring of strong plant growth. Field sign can be used to estimate the numbers present and the state of the population. By assessing the number of breeding holes present and their condition it was possible to gauge how many does were breeding, and by the color and texture of the faecal pellets showed what the animals are eating.

Depending upon the species in question, different methods were employed to assess the size of the population. Horizons mw [tm] staff used count lines to obtain indications of how rabbit populations were behaving and to assess any control work which had taken place.

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1:3:2. Methods.

This trial was designed to assess the impact of rabbits upon the bush remnant, so an indication of their presence required. Notes on the presence of field sign was made at each visit to each bush remnant, with searches made of the surrounding land for field sign from which the means are calculated per season and are presented in table 1, page 16.

Notes were made on the presence of field sign and this was then ascribed a value between zero to four, as follows

With

0 No field sign seen,
1 Two or less scratchings for rootlets,
2 Three or more scratchings seen
3 Scratchings and a single individual seen
4 More than one individual seen.

Blackbirds, *Turdus merula,* Linnaeus,1758 also made scratchings similar to rabbit while searching for food but they formed a wider base, were shallower and were confined to loose leaf litter and soil. The material spread over a wider area, but, where as rabbits scratchings were usually deeper, in firmer as well as sandy soil and are of a narrower base and the dug out material was more compacted and neater than that of blackbirds.

Rabbits are often crepuscular depending upon hunting and predatory pressure. The animals seen around the remnants during the trial when disturbed ran into the bush remnant.

Juvenile animals were seen frequently at Fulleton-Smith Bush and Legg Estate bush remnant during the day and what was assumed to be an adult doe were seen at Legg Estate in the vicinity of a fresh stop. These animals ran into the bush remnant when approached.

1:3:3. Rabbit numbers during the trial period.

During the period of the trial, numbers of rabbits varied through out the region, both geographically and seasonally.

Data were obtained from Horizons mw on the counts per kilometre for rabbits across the region and this was used to generate graph I on page 18. This showed how populations of rabbits were behaving at the time of the seedling survival trial.

An Analysis of Variance (ANOVA) was conducted comparing sites, seasons and rabbit seasonal scores (see table 1) to look for differences in rabbit populations at each remnant and season.

Season **Forest**	**Spring '99**	**Summer** **'99 -, 00**	**Autumn' 00**	**Winter '00**	**Spring '00**
Legg Estate	1	1	2	3	2
H.B.S.R.	0	1	2	2	1
Monkton's	1	0	0	0	0
F /S Bush	1	1	1	3	3

Table I: Score means of rabbit field sign per season of the four trial sites of the seedling survival trial in the Manawatu–Rangitikei region, North Island, New Zealand.

Within the Horizons mw region in recent years there have been some political changes that had impacted upon rabbit populations, specifically the introduction of the Regional Animal Pest Management Strategy (RAMPS) and the associated reduction of 41% in monies spent on rabbit control.

Another significant impact upon rabbit populations was the arrival of RHD in early 1998. RHD reduced animal numbers from about 13 animals per kilometre to seven and a half animals per kilometre, or 45 % but noting that animal numbers were up from pre RAMPS time from five animals per kilometre (Todd, 1998).

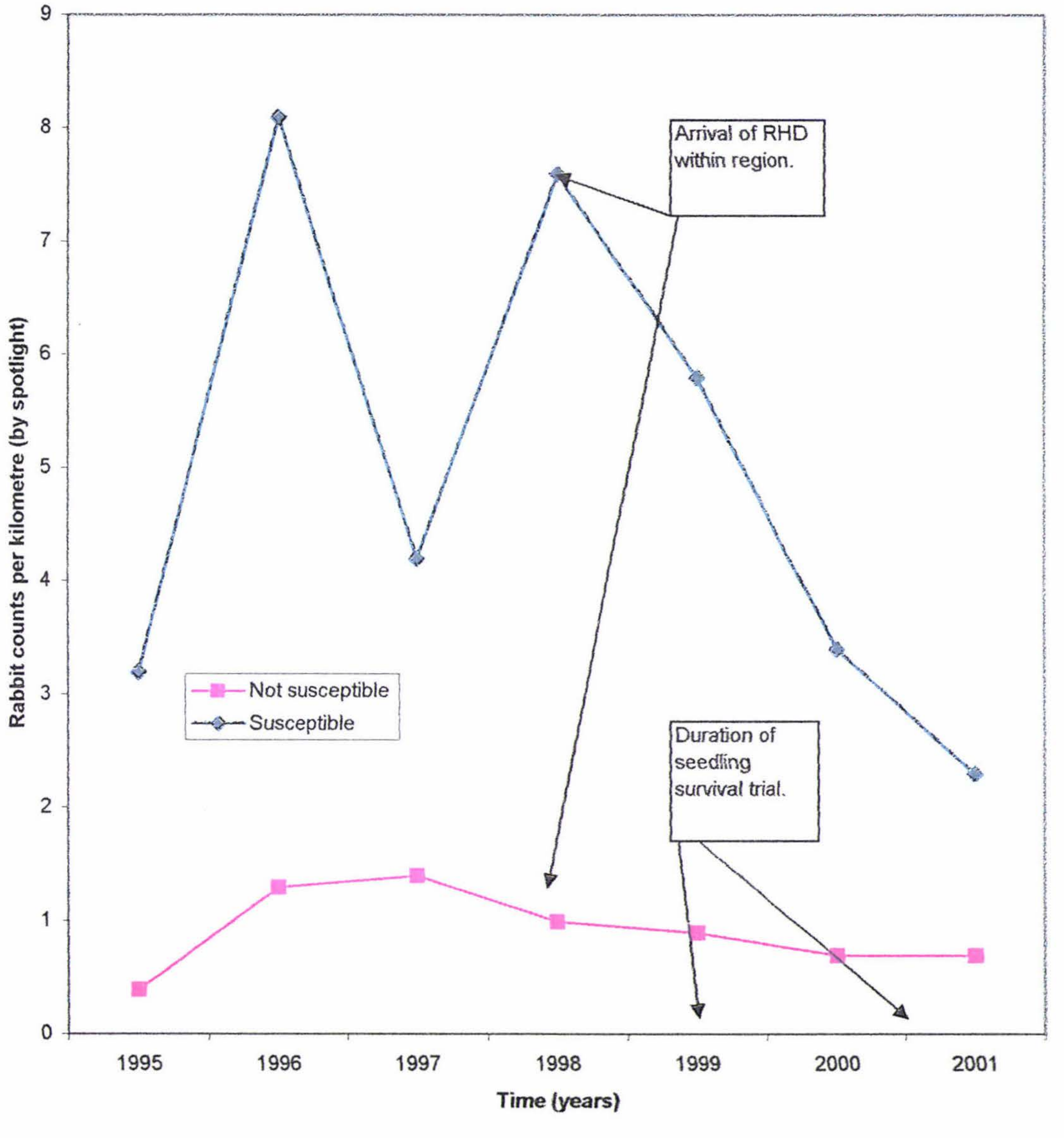
1:3:4. Conclusions and general remarks.

Several authors (Gilbert *et al*, 1987 & Gibb *et al*, 1985) have discussed the dynamics of rabbit populations and concluded that different populations were subject of differing factors responsible for the dynamic of that particular population and these factors are complex. A recent addition to rabbit population dynamics has been the introduction of RHD and its interactions are just starting to be understood.

The ANOVA analysis shows a significant site interaction P=0.017 but no significant seasonal interaction P=0.156. A Chi-squared analysis was conducted upon sites versus seasons but no useful results were obtained with many values under 0.

These results suggest that the sand country area had different population constraints acting upon the animals present compared with those of Monkton's and Fulleton-Smith bush remnants.

RHD has reduced rabbit populations especially in the sand country (see graph I, page 18). RHD effect had been present for a year at the time of the commencement of the trial and this could have had effected the impact of rabbits on seedling survival.



Graph I: Graph of rabbit numbers across the Horizons mw region. With the introduction of RHD in 1998 population reductions of 45% occurred and at the new lower levels the seedling survival trials commenced in August 1999 and concluded in December 2000.

1:4:1. Regional and site data for the four bush remnants.

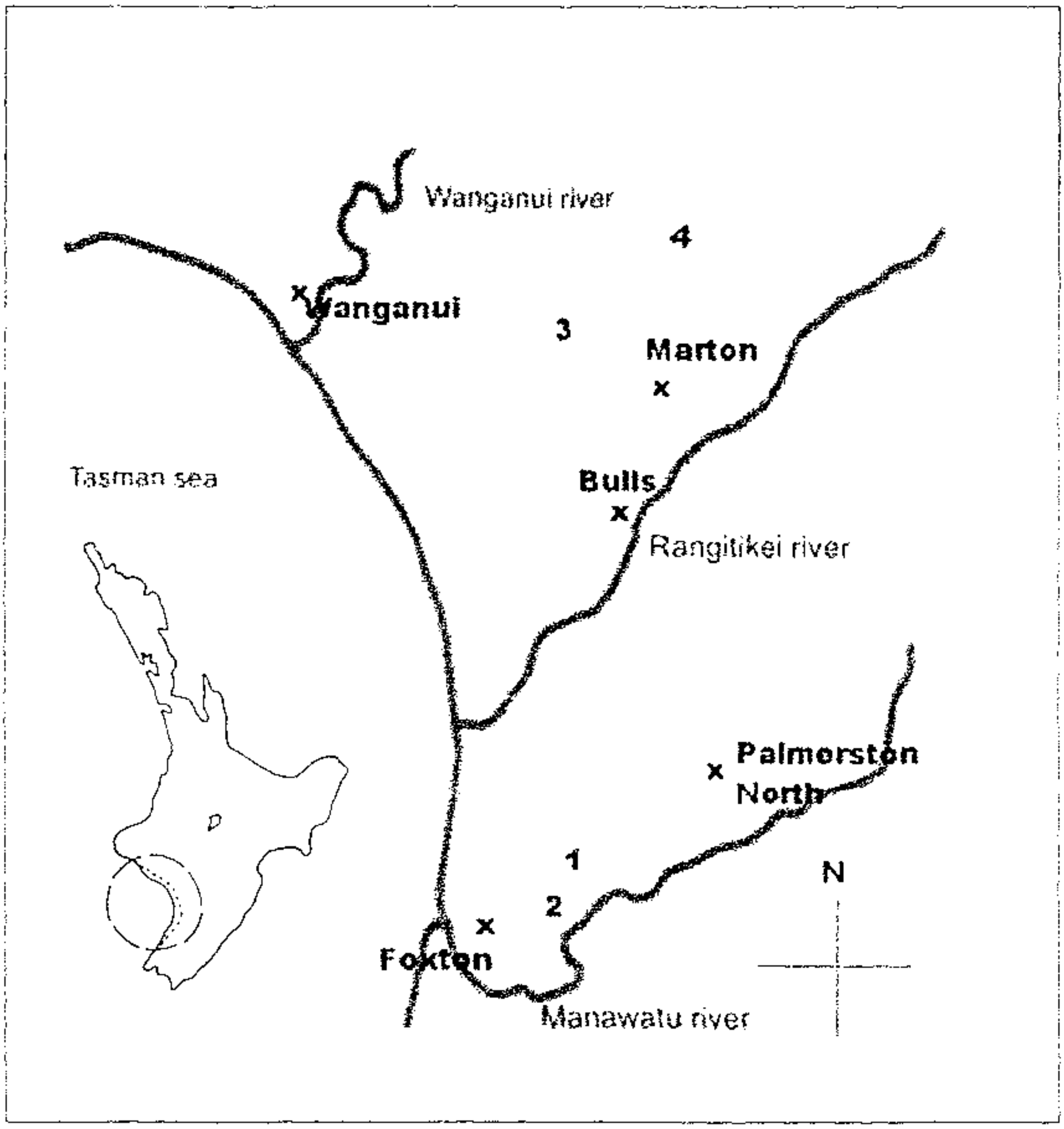
Four sites were chosen for this study in two differing areas of the Manawatu-Rangitikei region of New Zealand (See Map I, page 20), reflecting differing soil, climatic and population processes.

Two sites were in the sand country south of Palmerston North (Legg Estate bush remnant and Himatangi Block Scientific Reserve) in the Foxton Ecological District while the other two sites were to the North (Fulleton–Smith bush remnant) and West (Monkton's bush remnant) of Marton in the Manawatu Plains Ecological District of the Rangitikei region of the North Island, New Zealand. Both the Foxton and the Manawatu Ecological Districts are within the larger Manawatu Ecological Region.

1:4:2. Climate.

The climate of the two areas is similar, described by Esler (1978) as having moderate temperature, rainfall and hours of sunshine and considerable amount of wind. The windy nature of the Manawatu was influential in the formation of the sand dunes in the Foxton Ecological District.

Temperatures range from an average of 12.1° C at Marton to 13.6° C at Wanganui. Maximum temperatures are reached in February, with the highest temperatures recorded at Kairanga (to the north and east of the sand country sites) at 28.5 °C. Minimum temperatures are similar throughout the district, with July being the coldest month, and Marton recording the lowest average minimum of 3.5° C.



Map 1: Map of lower North Island showing the four bush remnants of the seedling survival trial. Legg Estate bush remnant (1) and Himatangi Block Scientific Reserve (2) are collectively known as the sand country sites while Monkton's bush remnant (3) and Fulleton-Smith bush remnant (4) and collectively known as the inland sites.

Rainfall, a crucial factor in juvenile rabbit survival varies from a regional low 896.06mm (n=29, SD=124.94mm, Max=1140.7 mm, Min=633.9) in the Himatangi area (period 1963 to 1992) to a high of 1057.99 mm.(n=9, SD=47.47mm, Max= 1325mm, Min=817.6mm) at the Marton filter station (period 1960 to 1989) (Data supplied by K. Tredrea, of National Institute of Water and Atmospheric Research, (NIWA).

1:4:3. The sand country sites.

1:4:3:1. Stratiagraphy.

The region has undergone three dune-building processes (Heerdegen, 1972) which have influenced the soil and vegetation types present. The older Foxton phase of 2 to 4000 years ago, the Motuiti phase of 500 years ago and the Waitarere phase of 120 years ago.

The Foxton dune phase formed when sands, which were thought to originate from the volcanoes of Taupo, Tongariro and Taranaki, blew in from the coast. This sand became dispersed over the flats leaving dunes a few metres high, which became stabilised by plants. A deep dark top soil then developed.

A similar process occurred in the Motuiti phase, but, unlike the earlier dune building process, the sand was not dispersed and consequently the vegetation fixed the dunes which were two or so meters high. The top soil has had less time to develop, so is not as deep or as dark.

The forests in this region had almost certainly been disturbed by the actions of the Maori burning (Esler, Greenwood & Atkinson, 1979).

At the time of the European settlement parts of the Foxton dune phase was still forested but no so the Motuiti phase, where drifting sands were impacting upon forest establishment.

1:4:3:2. Soils.

The soil of both sand country sites are recent yellow – brown sands (Cowie & Rijkes, 1977). These soils are formed by accumulation of windblown sand along the coasts and along lakes and rivers (Gibbs, 1980). The soils of part of the Manawatu exhibit an unusual property of being hydrophobic (water repellence) which makes these soils hard to wet. (Wallis,1987). In the Himatangi sand country this is considered a surface phenomenon.

1:4:4:1. Legg Estate bush remnant

1:4:4:2. Physical description.

This bush remnant (S 40°,23' 41"; E 175° 22' 44"), 22 kilometres south of Palmerston North on Bainesse Road is 1 hectare in size (see photograph II, page 23), some 500 meters long by 50 meters wide and is on the south face of a sand ridge which runs east – north east to west – south west. The slope of the sand ridge is about 25°. On the northern slope in the neighbouring property there was, at the start of the trial, a pine plantation, which was felled mid September 2000.

Photograph II: Legg Estate bush remnant as seen from the south.

This remnant was initially fenced in 1952 and again fenced in 1987 to include some of the farmed land to the south. The remnant is essentially long and narrow on well drained soils, bounded by a farm track to the south west, farmland to the north west and south east, and by Bainesse road to the north east. Across Bainesse road there is a smaller patch of similar bush, which could provide a source of seed for any further restoration at this bush remnant.

1:4:4:3. Vegetation.

The Ecological unit of this bush remnant is described as titoki-rewarewa (pukatea) forest on a sand ridge. At the base of the ridge there are *Laurelia novae-zelandiae*, *Cordyline australis* and *Dacrycarpus dacrydioides* present.

Macropiper excelsum is common at the south western end. There are several large *Alectryon excelsus* and *Melicytus ramiflorus* present. Ferns of the genus *Asplenium*, *Blechnum*, *Pteris* and *Pyrrosia spp.* are also present.

Three weed species that were noticeable are *Tradescantia fluminensis*, *Sambucus nigra*, and *Rubus fruticosus agg*. The *Tradescantia fluminensis* infestation covered over half the remnant while the other two weed species were patchy in distribution. A *Pinus radiata* plantation to the west of the remnant had, until it was harvested, provided a windbreak. Post harvest there was a noticeable increase in light intensity and wind movement within the bush remnant. Part of the pine plantation was to be included in the recommended area for protection (RAP) to act as a wind protection belt. Plantings of non-local sourced native trees has occurred on the land recently added to the reserve. These shrubs are doing well by comparison to self seeded plants within the remnant. Several large *Pinus radiata* trees still existed within the remnant, despite attempts to kill them. Several others had already been killed.

1:4:4:4. Legal status.

This bush remnant is a recommended area for protection, in private ownership. The land managers want to expand the area of this remnant to include the paddock to the south and plan to set up a trust to manage the area (Coulter, pers. comm.). They, like many land owners who have bush remnants upon their land are proud of their patch of old New Zealand, but have been unable to obtain the expertise to manage the remnants efficiently.

1:4:5:1. Himatangi Block Scientific Reserve.

1:4:5:2. Physical description.

This remnant was 18.76 hectares in size and was at the junction of converging sand dunes which run in a north-west south-east direction. The most westerly of those dunes was steep and up to 18 meters high which provides shelter from the prevailing winds. These were the sands of the Motuiti dune building phase while the other dunes are of the much older Foxton dune building phase and are only 3 to 5 meters high and are gentle sloping.

The remnant itself was (S 40° 26' 01"; E 175° 22' 37") and was 21.7 kilometers south of Palmerston North on Himatangi Block Road and Paranui Road (see photograph III, page 26) at some 14 kilometers from the coast and 4 kilometers from the nearby Manawatu river. It was 1000 meters in length and 200 meters wide, being part of the Himatangi 2A7A1 block in block III, lot 1DP 31864 of the MT Robertson Survey District.

Photograph III: Himatangi Block Scientific Reserve showing a dune of the Motuiti phase. On the ridge crest is *Hedycarya arborea, Knightia excelsa* and *Beilschmiedia tawa*, with a variety of introduced weeds and grasses in the foreground.

1:4:5:3. Vegetation.

The area in which the trial was conducted within this reserve was in the wet flats to the south side of the northern dune. This was a mixed broadleaf forest with *Hedycarya arborea*, *Pennantia corymbosa*, *Knightia excelsa* and *Beilschmiedia tawa*, with several *Pseudopanax crassifolius*, *Myrsine australis* and *Nestegis lanceolata*.

There was an understory of *Macropiper excelsum*, *Melictyus ramiflorus*, with several *Coprosma* species present (Esler *et al*, 1979). This under story was still recovering from years of stock grazing and several exotic grass species that had established e.g. *Holcus lanatus* and *Festuca arundinacea*.

From Paranui Road, local botanist Dr Michael Greenwood had established several plots in 1971 to determine how best to revegetate the pasture that was now established on the northern and western side of the reserve.

A sever drought in 1970 killed many of the adult trees and the understory was eaten out by stock. The bush remnant was fenced in 1972 although there have been several breaches of the fences, and sambar deer is thought to frequent this remnant.

1:4:5:4. Legal status.

In 1967, J. Cowie brought this forest remnant to the attention of the then Manawatu County Council while conducting a soil survey of the region. It was then in the hands of the Barber Estate, and one of the trustees a Mr. Harry Barber considered surrender of part of the property for reserve classification.

On the 17 April 1971 saw the signing of transfer documents and the completion of negotiations between the Crown and the Barber Estate for 18.766 ha and the Himatangi Block Scientific Reserve came into existence under the Reserves and Domains Act 1953 with gazetting as a scientific reserve (New Zealand Gazette 1984/ 4228) in 1984 (Esler *et al*, 1979).

1:4:6. The inland sites

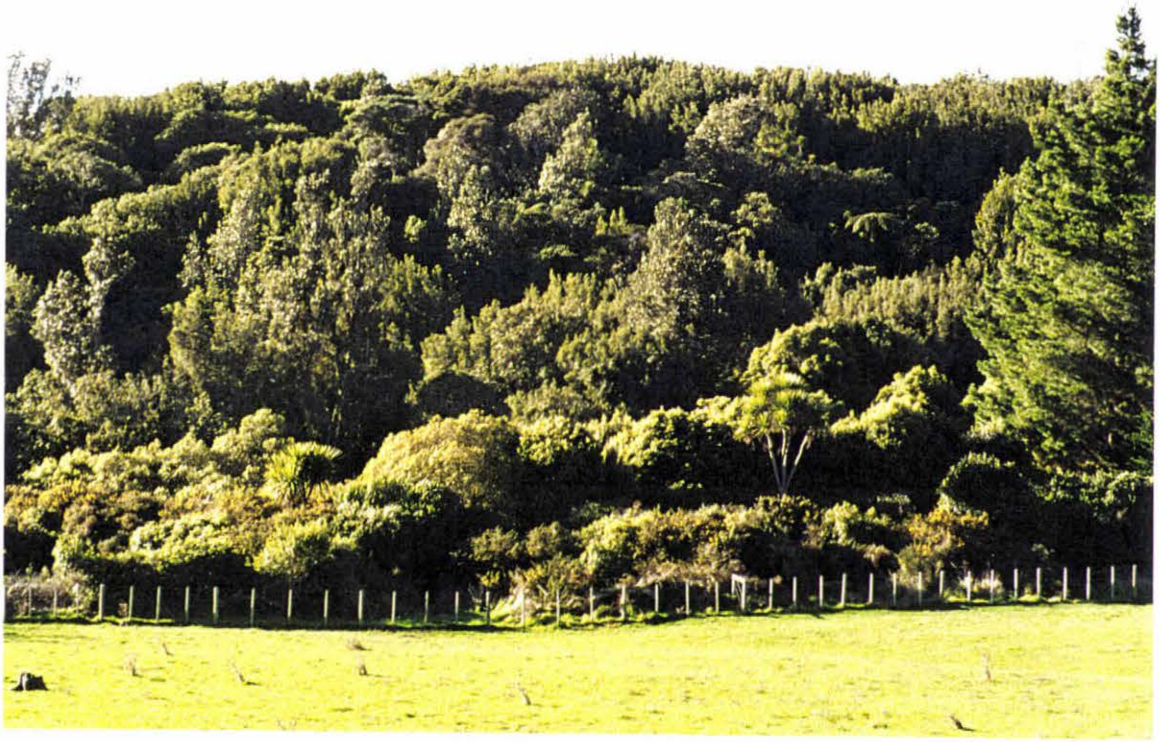
1:4:6:1. Stratigraphy

This landform was of low altitude and relatively recent with much being under water in the late tertiary period as the Wanganui Basin.

Uplifting had created a series of marine terraces, which had been modified by fluvial action, producing the gullies, river terraces, and alluvial plains, which are common in the Manawatu Plains Ecological District.

The underlying material of both remnants was laid down in the Pleistocene epoch (From 1.8 MYBP), Lower Hawera (0.4 MYBP) series and the influences upon its formation is considered partly marine.

The underlying Lithology of the Fulleton-Smith bush remnant is quartzite, greywacke and argillite gravel, with influences from the central north islands volcanos as ash and sand. These are known as the Kaiatea formation and are older than the lithology of the Monkton bush remnant. The Monkton bush remnants lithology is known as the Brunswick formation consisting of greywacke, quartzite and andesite gravel with marine sand, pumice, clay and sand.



Photograph IV: Monkton's bush remnant from the east. Scrub in the foreground is backed by a mixed podocarp / tawa forest.

1:4:6:2. Monkton's bush remnant.

1:4:6:2:1. Physical description.

This bush remnant (S 40° 03' 37", E 175 °18' 36") is oblong and 20 hectares in size, 11 kilometres to the west of Marton on Wanganui Road, surrounded by gently rolling farmland, being some 1100 meters long and 300 meters at its widest point at an altitude of 140 meters above sea level. (See photograph IV, page 29). The Omaha stream flows along the southern section of this bush remnant and empties into the Turakina River to the west. The north western bank of this stream is a steep embankment. This bush remnant was some 200 metres from the farm house. The eastern section of this remnant is not fenced and farm stock shelter at will under the titoki tawa forest here.

1:4:6:2:2. Soils.

Described as Central yellow brown earth, hill soils (Ravine, 1995[2]) part of the Halcombe hill series (Campbell, 1979)

1:4:6:2:3. Vegetation.

This remnant consisted of four Ecological units

1) Kanuka forest on terrace riser (4ha).
2) Mixed podocarp / tawa forest on terrace riser (6 ha).
3) Mixed podocarp/ titoki-tawa forest on terrace riser (5 ha).
4) Titoki – tawa forest on terrace tread (5ha).

There was some evidence of logging having occurred when the surrounding farmlands were cleared. *Dacrycarpus dacrydioides*, *Beilschmiedia tawa*, *Knightia excelsa*, *Pseudopanax crassifolius*, *Hoheria populnea* and *Pittosporum eugenioides* are present. Over twenty species of fern were recorded as well as native climbers and epiphytes.

Tradescantia fluminensis was becoming a problem towards the southern end. *Ulex europaeus*, a primary colonisation species was also present on the eastern side in a gully but this is being slowly crowded out by the regenerating bush remnant.

Several herbaceous annuals are present along the forest margins including *Buddleia alternifolia*, *Cirsium arvense* and *Cirsium vulgare*.

1:4:6:2:4. Legal status.

Mr John Monkton and his family privately have owned the property for over eight years. There was financial input from the Department of Conservation with monies for the cost of fencing. The landowner carried out pest management with shooters shooting possums on a monthly basis.

1:4:7. Fulleton-Smith bush remnant.

1:4:7:1. Physical description.

This bush remnant is 9 hectare in area (S 39° 59' 05"; E 175° 24' 22") at an altitude of 280 meters above sea level, 9 kilometres north of Marton on Galpins Road. It is L-shaped with a smaller arm to the north and the majority of the forest to the western arm. (Photograph V, page 32) There was a small stream coming into the north-eastern part of this bush remnant and exiting on the south side.

Photograph V: Fulleton-Smith bush remnant showing many large examples of native trees with a good understorey. Rabbit field sign was common in the pasture in the foreground.

The bush gradually rises from the south–west to the northeast. Through the western section of this remnant there is a driveway and this section backs onto the family garden. The bush remnant had been invaded by garden escapers who were planted earlier last century by the then land owners, but are now creating a serious weed problem.

This bush remnant is some 630 meters long and some 450 meters wide. The base of the L was broken by the drive way to the family residence which sat behind the back of the L. The base of the L was bordered by the family flower garden.

1:4:7:2. Soils.

The soil type at the bush remnant was described as an intergrade between a Yellow-brown earth and a Yellow- brown Loam (Ravine, 1995[1]) as part of the Kiwitea series (Campbell, 1979).

1:4:7:3. Vegetation.

This bush remnant consists of two Ecological Units:
1) Mixed podocarp and mixed broadleaf forest (6ha).
2) Kahikatea forest on terrace tread (3 ha).

The bush remnant had been milled many years ago, probably to build the original homestead. Originally this forest would have been a rimu rata forest. *Melictyus ramiflorus*, *Hoheria populnea*, *Lophmyrtus bullata*, *Hedycarya arborea*, *Macropiper excelsum*, *Cordyline australis*, *Nesregis cunninghamii* and several *Coprosma* species were present. *Ripogonum scandens*, *Tetrapathea tetrandra*, *Rubus cissoides* and Clematis and a variety of ferns, epiphytes and spleenworts were also present.

Several invasive weed species exist. *Passiflora mollissima*, *Selaginella krussiana*, *Cobaea scandens*, *Hedera helix*, *Vinca major* which present major management problems were prevalent at the driveway end.

The kahikatea forest at the southern end of the remnant had been milled over to a greater extent than the northern part and was now mainly regenerating *Dacrycarpus dacrydioides*. There are several emergent podocarps and *Metrosideros robusta* of which many were over 30 meters tall.

1:4:7:4. Legal status.

This bush remnant was in private hands belonging to several generations of the Fulleton-Smith family, which are a well-known family within the Marton and Rangitikei area. They had, over the years invested many thousands of dollars into the upkeep of the remnant and were proud to have it on their property (Fulleton-Smith, pers. comm.) Department of Conservation manages this remnant, with a substantial weed control programme being undertaken.

The land owner had contracted out possums control using talon [tm] bait stations, which also keeps numbers of rats down, as several dead animals were found while data recording was in progress. All bait stations in the bush remnant in this trial were pulse fed. A task force worker from Works and Income was carrying out upkeep for a six-month period from February 2001. Horizons mw [tm] staffs were also carrying out weed control at this property.

1:4:7:5. Impressions and conclusions.

In selecting the sites for this trial I chose sites that had similar backgrounds of soil, underlying lithology and management and influences upon the existing rabbit populations.

The sand country has nearly all of the original forest cover removed and what remains has been highly degraded.

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There has been major environmental modification by draining the land which was originally swampy. Here also were the highest populations of rabbits in the Horizons mw region.

The inland sites had lower average population levels of rabbits compared with the sand country, and also had more bush remnants nearby. In the Mount Curl region near Fulleton-Smith bush remnant there were several large tracts of bush remnants that were not as degraded as the sand country sites.

Monkton's bush remnant had very high seedling growth along the edge which had recently been fenced and was responding to domestic stock exclusion.

There was much more native bird life in the inland bush remnants by comparison with the sand country bush remnants which were generally quiet. Overall the inland bush remnants had more diversity and seemed, visually, to be doing better than the sand country sites. A general summary of all relevant data is shown in table II, page 36.

Forest Data	**Legg Estate**	**Himatangi Block**	**Monkton's Bush**	**Fulleton-Smith**
Size	1 ha	18.76 ha	20 ha	9 ha
Region	Sand country	Sand country	Inland sites	Inland sites
Soil Type	Yellow brown sand	Yellow brown sand	Yellow brown earth /loam	Yellow brown earth / loam, hill soils
Vegetation Type	Mixed broadleaf forest	Titoki-rewarewa forest On sand ridge	Mixed podocarp. Kanuka forest	Mixed podocarp-mixed broadleaf
Rainfall ****	Approx. 938mm.	Approx. 938mm.	Approx. 1061mm.	Approx. 1061mm.
Sunshine Hours	1968.28 **	1968.28 **	2071.28 ***	2071.28 ***
* **Rabbit Proneness**				
(Horizons mw)	High.	High.	Low.	Low.
(Kerr et al 1991)	Low.	Low.	Negligible.	Negligible.

Table II: Environmental data on the four trial sites in the Manawatu-Rangitikei region, New Zealand.

- Comparisons are made between the Horizons mw assessment of rabbit densities within it's confines and a nation wide system of defining rabbit densities.

** Data supplied by NIWA from Kairanga 1970 to 1988.

*** Data supplied by NIWA from Ohakea 1954 to 1991.

**** Data supplied by NIWA

1:5:1. The problem defined.

Under the Biosecurity Act 1993 section 88.1 (b), Regional Councils are required to conduct reviews of the pest management strategies every five years. For Horizons mw [tm] this was carried out in 2001. This called for submissions from interested parties such as farmer groups, Department of Conservation, Forest and Bird, Deer Stalkers, SPCA and members of the public to determine the status of species, which are a pest or could be included in the strategy. Rabbits are, of course mentioned in this strategy.

A draw back of the Biosecurity Act is that it targets detrimental species rather that the restoration of the entire ecosystem (Todd, pers. comm.). When one species is targeted other species that impact upon forest health may be ignored. Possums are currently targeted as an animal health and conservation pest for its omnivorous activities, consuming eggs, nestlings and a variety of insects and molluscs, while also acting as a vector spreading *Mycobacterium tuberculosis* or Bovine tuberculose (TB) to other animals including livestock. Rat species, which also consume a similar range of resources and could also be a reservoir of TB and aid in spreading it to other mammal species, are currently not targeted by the pest management strategy. Targeting of possums with no corresponding reduction in rat numbers would likely be of little value as rats will consume some of and other the resources not consumed by possums.

To determine the detrimental effect a species has upon the environment evidence of impact is required. To this end, Horizons mw funded this trial to determine if there was any negative impact by rabbits upon High Value Conservation Areas which had been fenced to exclude domestic stock.

Replicates of a treatment and a control were used at four forest remnants to determine and effect of the exclusion of rabbits. The information could indicate

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whether it would be advantageous to have monies made available to control or exclude rabbits from these high value conservation areas.

Four bush remnants were chosen for this study, two sites in the sand country and two bush remnants inland at proximity to Marton.

Chapter one is a general introduction chapter. Background information is given on the rabbit and the four bush remnants used in the trial. Information on rabbit populations, at the four trial sites and within the regional council boundaries is presented. Another introduced mammal species found in the region that could affect seedling survival, the sambar deer is also discussed.

Chapter two looks at light levels at treatments and controls are recorded for each plot and readings were measured in unobstructed light as a control. Mean values were calculated for each season and A Chi-squared analysis was conducted on these values.

Moisture levels at OA horizons levels at each site over four months during the summer months of 2000 / 2001. A split plot design with five replicates of two exclusion and two access plots with half of these being irrigated on a three day basis.

A two sample T-Test was carried out on the irrigated verses non irrigated plots to see if that addition of water made a difference to the moisture levels in the OA horizons. Seedling counts and moisture levels were recorded and a Chi-squared analysis was conducted on seedling numbers for each treatment.

Chapter three looks at the results of the germination of 500 grams of OA horizons material with the identification of the species and numbers of each species produced. A Chi-squared analysis was conducted upon the numbers of native seedlings and weeds and grasses at each bush remnant.

Seed rain was collected in large funnels and a Chi-squared analysis looks at the types and numbers of each type collected.

Chapter four is in two parts. Part one looks at the growth of seedlings of each plant species at each site within the treatments and controls. Part two looks at the logistical modes looking at bush remnants, season, rabbit presence and seedling survival within a treatment and control environment.

Chapter five draws all the results from the different trials and experiments and presents a conclusion with a discussion on how the results could be applied to some bush remnant managements. A section is included on the Legg Estate plots which were not removed and enabled a seedling survival count in spring 2003.

This trial is a snapshot of only fifteen months in ecosystems which have functioned for far longer, and with other cycles that run in periods of time far longer than the study period. Also the trial period is a time of artificially low rabbit numbers as a result of the introduction of RHD.

1:5:2. Objectives.

I hoped to see if the treatment seedlings had a higher survival level than that of the control seedlings, indicating that it would be beneficial for seedling survival to exclude or reduce the incidence of rabbits even below the lowered population levels by the introduction of RHD before the trial had begun. As varying populations of rabbits had varying influences acting upon them, this may have impacted upon seedling survival at the four different bush remnants within the two distinct regions. An assessment of rabbit incidence was carried out on a monthly basis at all sites.

By looking at seed rain, soil seed bank, light levels within and outside each remnant and rabbit's presence at each site I hope to show that some differences exist between each of the four trial sites within the two regions.

Overall I hope of demonstrating that excluding rabbits from bush remnants will have a positive effect on seedling survival and that this could influence how some bush remnants are managed in the future.

1:6:1. Sambar deer in the Rangitikei-Manawatu region.

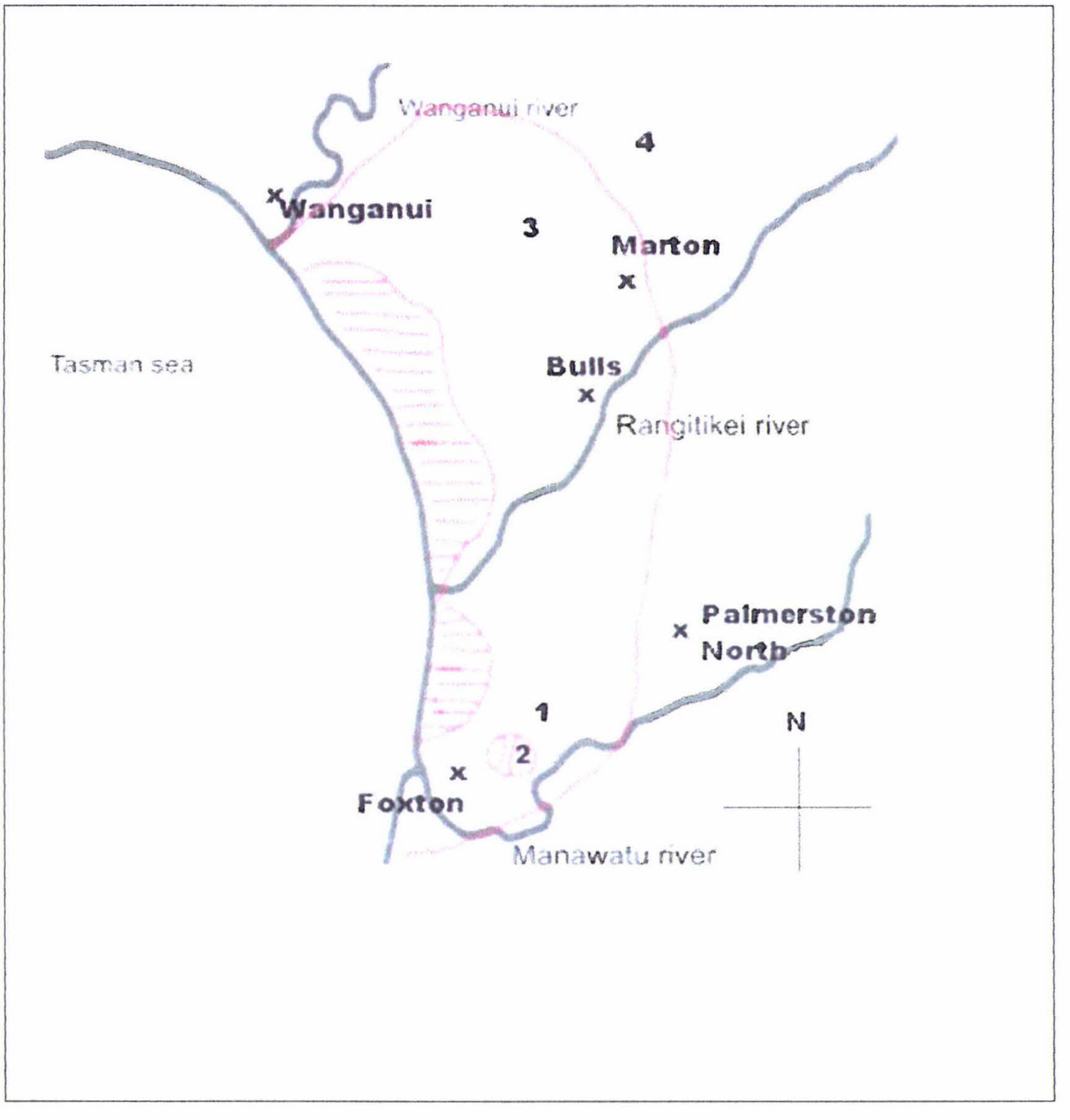
On the west coast of the North Island a long a thin strip of coastal land from Wanganui in the north to Levin in the south there is a scattered population of sambar deer *Cervus unicolor unicolor* (Kerr1792,) (see Photograph VI, page 41). This species was first introduced to the Rangitikei area in 1875 from the now Sir Lanka (Doone, 1924). The herd survived and thrived in the then swampy and under developed swamplands along the Manawatu-Rangitikei coast (see Map II, page 42). Illegal hunting and land development reduced the herd size until protective measures came into effect in 1893 under the Animal Protection Act 1880. There have been varying levels of protection applied since, currently they are a managed herd.

Three of my study sites fall within the range of this animal as described by Douglas (Douglas, 1983), and it is highly likely that they have had an influence upon the regrowth of the understorey in the study sites.

I have seen hoof prints of sambar deer in Monkton's Bush, Marton (Identified as such by M. Todd, Horizons mw). Cheryl Doyle confirms seeing hoof prints in both Monkton's bush remnant and Himatangi Block Scientific Reserve, similar to the description by Kelton (Kelton, 1981). At times in Monkton's Bush there was a definite "m*usk*" smell noticed when scoring plots one and two. These plots were near a small hillside, which was covered in *Ulex europaeus,* which would provide ideal cover for sambar. Because of the proximity to human dwellings, and the free ranging of the family dogs, it is unlikely, but not impossible that sambar deer would be found intermittently at Fulleton-Smith bush, but very likely that they could be in the local area.

Photograph VI: An adult male sambar deer.

Wildlife Fact File. Pub. by Partworks International Ltd.
Hong Kong, 1996. Number 317.



Map II: Ranges of sambar deer in the Rangitikei–Manawatu region. The outline shows the range (red outline) now thought to be occupied from discussion with a deer stalker compared with its officially recognised range (hatched). The seedling survival trial sites are 1) Legg Estate bush remnant, 2) Himatangi Block Scientific Reserve, 3) Monkton's and 4) Fulleton-Smith bush remnants.

A bush remnant, Soler bush, five kilometres away from Fulleton-Smith bush has deer present (Soler, pers. comm.) and there are reports from the Marton reservoir (S 40° 02' 44"; E 175° 21' 33') of these animals being sighted here, in the early 1970,s.

Also, in discussion with the landowners of Legg Estate, they felt that this animal has on occasions been in their remnant, as when they have been there they have sometimes heard a large animal crashing through the remnant (Legg & Coulter, pers. comm.). Mrs. Legg feels very strongly that the intermediate visits by sambar deer to this remnant is responsibly for the lack of regeneration seen. Mrs. Legg feels that until this is resolved there is little point in spending any monies to help restore this remnant (Legg, pers. comm.) as it would be a waste of money.

The research for this thesis did not set out to quantify damage by sambar deer, the potential for damage to seedlings caused by this animal's behaviour and distribution would indicate that this was highly likely.

1:6:2. Relevant biology and behaviour.

Sambar deer feed after dark, ranging some distance from their hides if necessary, to suitable food sources and returning to these hides before dawn.

Signs of their browsing are scattered, as these animals are selective feeders feeding while on the move. They feed on *Phormium tenax*, *Festuca arundinacea*, *Rubus fruticosus*, root and pastoral crops are included in their diet as well as bark and shoots of *Pinus radiata*, and as there are large plantations along the coast they cause some financial loss. Damage is localised and seasonal as they do not yet cause a level of economic damage like that of possums.

Sambar deer frequent underdeveloped areas including pine forests, scrub lands isolated gullies and bush remnants. Small bush remnants (Legg Estate and Himatangi Block Scientific Reserve) provide sufficient cover to hide during daylight hours up and is often adjacent to developed lands and pastures that would provide some of their nutritional requirements. They are drawn to swampy areas and small streams where their footprints are often seen.

Adults can attain a standing jump of 1.5 meters with little effort, which is sufficient to clear most stock fences in the region, including all the fences in and around the four bush remnants in the seedling survival trial.

Deer stalkers I have spoken to (Morton, pers. comm.) describe this deer as a very secretive animal that could exist in an area for an extended period of time without detection, and also has a range far greater than officially recognised, although the animal may not be present in all areas of the range as shown in map II, page 42 (Fraser *et al*, 2004).

They have been known to bed down in very close proximity to rural workers, and when they perceive danger to melt quietly away into the surrounding vegetation.

1:6:3. The deer hypothesis.

I believe that it is highly likely that sambar deer periodically visit these bush remnants and their grazing habits would have a negative impact upon seedling and sapling survival. In the sand country, where seedling survival appears to be affected by moisture fluctuations and browsing by small mammals, deer impact would be minimal. Solving or mitigating the factors that reduce successful seedling strike could provide a standing crop of plants that then would be consumed by these deer when present in bush remnants. To exclude deer would be helpful in remnant restoration, although I have no experimental evidence from my trial duration of any damage these deer have caused.

1:6:4. Implications for the trial.

With all bush remnants on mainland New Zealand, it is important to realise that they are modified to some varying degree, and it would be difficult to establish weather these animals are destroying seedlings that would, otherwise, survive long enough to be recruited into the canopy forest.

Sambar deer undoubtedly consume selectively some shrubs and ferns within their browsing range. For the seedlings in the two sand country bush remnants, considering the other environmental influences currently acting upon them, these animals are another element to factor into the equation of seedling survival.

I have no direct proof of any negative impact done by any deer at any of the study sites during the course of my trial. This does not mean that they do not affect the regeneration of native bush remnants, but it suggests that deer did no damage during the time of the trial. I have evidence of some historical damage in the sand country sites and circumstantial evidence of their existence at one site at Marton (Miss Monkton, pers. comm.) and anecdotal evidence of their existence in the proximity of the other bush remnant at Marton.

The very secretive nature of these animals indicates that they could exist within an area for extended periods of time without detection and there would be little doubt in the minds of most people that they would impact upon existing native and other vegetation in that area.

As this trial was of short duration a much longer trial might have detected an impact by this species although the exclusion fences would require modification to exclude these animals.

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CHAPTER 2

Light levels and the irrigation experiment

2:1:1. Light Levels.

Growth within a well or gaps (See photograph VII, page 53) within a bush remnant canopy occurs in response to an increase in light levels and soil moisture from increased rain and light reaching the remnant floor. Most species that grow rapidly in response to these gaps and are known as primary colonisors and survive well in the increasing light regimes, while the canopy forest represent species that tolerate high light regimes in their adult phase but require low light intensities in their juvenile stage provided by the shade of the primary colonisers.

The growing plants in these gaps become a resource for phytophagous organisms, it is here that one would expect to see and consequently be able to measure the impact of their activity. In the seedling survival trial this is exactly what we have done.

With increased numbers of seedlings within light well or breaks by comparison with areas where there are no light wells it is easy to realise how some introduced mammals grazing these light wells could affect the canopy recruitment by selectively consuming the germinating seedlings.

This destruction could have a negative impact upon remnant growth and ultimately alter canopy recruitment, as the more palatable species would be eliminated before the less palatable species, there by shifting species composition of the bush remnant long term.

Light levels in Lux[1] was collected at each of the 5 replicates within each bush remnant per season is presented in Table IV page 55. A balanced analysis of variance was conducted upon this data to determine if any differences existed between the treatments and controls of the seedling survival trial.

[1] Lux (lx) a unit of illumination equivalent to one lumen per square meter of surface when measured at right angles to the direction of light.

Photograph VII: A typical light-well within a bush remnant. This photograph was taken in Legg Estate bush remnant.

2:1:2. Materials and methods.

To gain an indication of the light levels inside and outside the bush remnant a series of observations were made using a light meter (Li-210SA Photometric Sensor [tm]).

As every treatment and control plot had a marker peg, these pegs were used to provide consistency when taking light readings. Light readings in Lux were taken monthly.

Technical problems and the unavailability of the light meter lead to an incomplete data set. These unavoidable events have impacted upon the presentation of the data as set out below. To obtain values for the data, a mean was taken using the last value for the previous and the first value for the following season.

2:1:3. Results of light levels at the remnant floor.

With the data collected, mean values per treatment and control were calculated per season are shown in Table IV page 55. Where a season had missing values because of the technical problems mentioned above, the last value from the previous season and the first value of the next season were used from which a mean value was calculated.

The data in Table IV page 55 show a check to see how reliable this method is. The data used is from the last values in spring and first values in autumn at Monkton's bush remnant. The values are a mean of the replicates at this bush remnant.

[tm] trade mark.

Plot	Last spring mean value	First autumn mean value	Calculated summer mean	Actual summer mean
Treatment	139	205.04	172.02	127.58
Control	64.8	39.1	51.95	55.3

Table III: Checks to determine the accuracy of the method of calculating missing values for Lux readings at treatment and controls of the seedling survival trial.

Table III shows how accurate this method was in providing missing values for the times when the light meter was not functioning. Although the difference between the actual and calculated mean for the treatment is 44.44 Lux. A reading of 44.44 Lux is quite dim and would be of little significance. The difference between the actual and calculated mean for the control is 3.35 Lux.

		Spring 99	Summer	Autumn	Winter	Spring 00
Legg Estate	**T**	109.54	128.51	38.59	57.88 *	25.28
	C	96.36	116.74	39.60	50.92 *	23.75
HBSR	**T**	64.38	44.55	70.23	17.46*	22.78
	C	79.99	42.47	71.90	18.5*	18.56
Monkton's	**T**	78.96	127.58	110.69	44.67 *	181.66
	C	128.31	55.3	31.66	42.89 *	185.02
F/S Bush	**T**	105.83	57.80	33.78	41.23 *	75.76
	C	81.26	51.26	26.22	39.37 *	82.01

* Values calculated as mean from last value in autumn and first value in spring.

Table IV: Mean values for Lux reading at the four bush remnants involved in the seedling survival trial. T and C represent the values obtained for treatments and controls respectively.

2:1:4. Results.

The balanced analysis of variance was conducted on the light readings at the four bush remnants showed significant results between bush remnants (P=0.015), season (P=0.036) but no differences between treatments and controls (P=0.489) within the bush remnants using an alpha level of 0.05.

2:1:5. Conclusions.

The results indicate that there are differences between the bush remnants and between the seasons but no differences between the treatments and controls. This is important as we can eliminate the light levels at the remnant floor as a variable affecting seedling survival. Therefore the analysis of the results for treatments and controls could be conducted without taking different levels of light into account.

2:2:1. Results for canopy light levels.

Light readings were taken monthly at an unobstructed site close to the bush remnant to give an indication of light falling upon the bush remnant canopy.

A balanced analysis of variance was conducted on the data form the five seasons at the four bush remnants giving insignificant differences between the four bush remnants (P=0.824) but significant differences between the five seasons (P=0.016) with an alpha level at 0.05

Table V page 57 was generated using the mean values calculated per season per bush remnant.

Remnant Season	Spring 99	Summer	Autumn	Winter	Spring 00
Legg Estate	15966	3768.6	534.4	714.2*	1248.267
HBSR	5268	16029	97.8	2024	4518
Monkton's	15611.5	12569.33	1703.15	917.15*	3296.133
F/S Bush	3956	9624	3903.5	2944.5*	4309.333
Regional Mean	10200.37	6494.55	1559.71	1649.96	3342.93

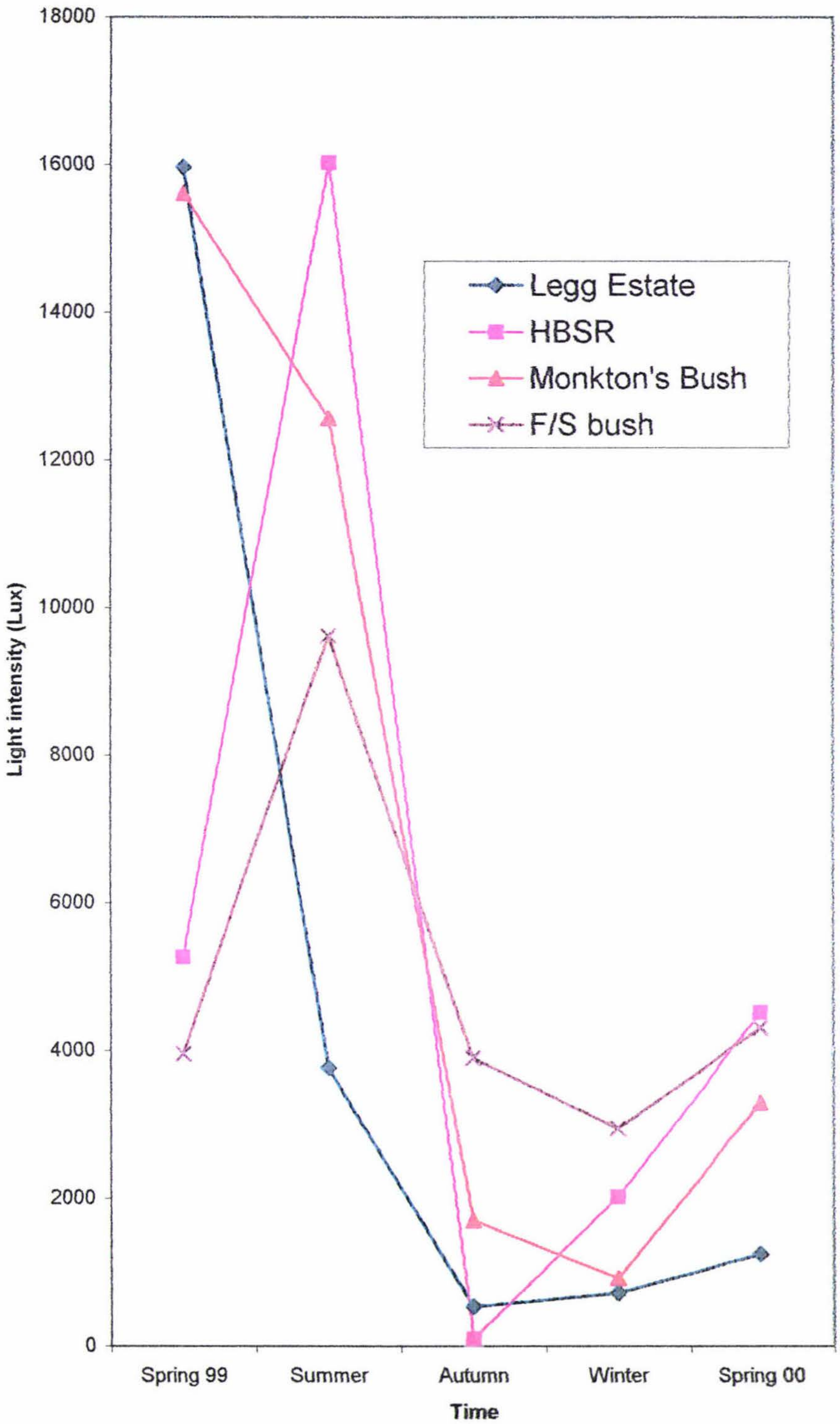
* Values calculated from mean of last value in autumn and first value in spring 00.

Table V: Calculated seasonal and a regional means for unobstructed sunlight light in units of Lux taken as part of the seedling survival trial conducted at four bush remnants in the Manawatu-Rangitikei region.

2:2:2. Conclusions from canopy light level results.

There is little differences between the results obtained for the four bush remnants overall. This is to be expected, as the distances from the most northerly to the most southerly bush remnant is rather short, at almost fifty kilometres. The data does show that there are variations between the seasonal values and as New Zealand lies in the mid latitude zones (Allen,1982) and that there is huge variation seen in seasonal values as the suns angle of attack shifts through a relatively range, giving large seasonal differences in the insolation at the earth surface (Strahler and Strahler,1987).

The data for spring 1999 does have a rather large spread in comparison with the other four seasons. I put this down to the readings been taken on unusually bright days realising that readings were taken only on one day per month for three months at a maximum and an average of these values were taken. Consequently the values used are open to debate for the accuracy of the results they portray. Graph II page 58 shows the values per site per season.



Graph II: Mean values per season in Lux of unobstructed sunlight in units of Lux at four bush remnants in the Manawatu-Rangitikei region from spring 1999 to spring 2000.

2:3:1. OA horizons soil moisture.

Within the sand country bush sites, especially Legg Estate bush remnant, I noted that there was often a carpet of seedlings at the cotyledon stage, but no noticeable progress beyond this stage. Considering that Legg Estate bush remnant had had stock excluded for over 50 years, one might expect more of an under storey than was present. Rabbits and possums have been blamed for the lack of regrowth. By comparison Munro's bush (S 40°, 23', 07"; E 175°, 36', 40"), (a badly degraded bush remnant with a serious *Tradescantia fluminensis* on the Massey University hill behind Agresearch, Palmerston North) has regenerated saplings to 1 to 1.5 metres tall, with ferns spreading along the remnant floor after weed removal. Rabbits are present at both sites.

Seedling strike does not seem a problem at any of the four sites in this study (and also Munro's bush remnant) but the sustainability of the germination in the sand country sites does appear to be a problem. This suggests very high seedling mortality after germination in the sand country and I postulated that moisture fluctuations in the germination zone could be responsible, especially at the two-cotyledon leaf stage. This could be compounded by the hydrophobic nature of soils in the sand country.

The sand country remnants were once swamp land (Esler, 1978) and during the 1920's and 1930,s was drained as part of the Manawatu Drainage scheme (Evans, 1964). The lowering of the water table by drainage could contribute to place vital water resources out of the reach of the germinating seedlings and this might account for, in part the lack of sustained seedling regeneration in the sand country bush remnants.

The soil seed germination trials yielded one native shrub *Solanum aviculare* that, when planted by myself within the remnant near irrigation plot 1, had done very well at the time of clearing away of the irrigation trial in March 2001. Upon returning to the bush remnant in September 2002 this seedling had disappeared.

2:3:2 Materials and methods.

At all four sites, thirty samples of OA horizons material (The zone of seed germination) were taken randomly at monthly intervals within the vicinity of the seedling survival trial.

The samples were collected in plastic film canisters, weighed and dried within six hours of collection. Samples were weighed on a Wiltons1212 MP™ electronic balance, to two decimal places, dried in an Atlas Neptune™ oven for ninety minutes at 150 degrees Celsius.

Percentage of moisture present was calculated using the following equation.

Percentage Composition = (initial weight – cup weight) - (final weight – cup weight) / (Initial weight- cup weight) x 100

The paper cup is a heat resistant corrugated paper-cooking cup available at most supermarkets (used for making cupcakes) and the two hundred cups used in these trials had an average weight of twenty-six grams. The value of twenty-six grams was used as a constant for all OA horizons moisture calculations.

2:3:3:1. Calibration of the neptune oven.

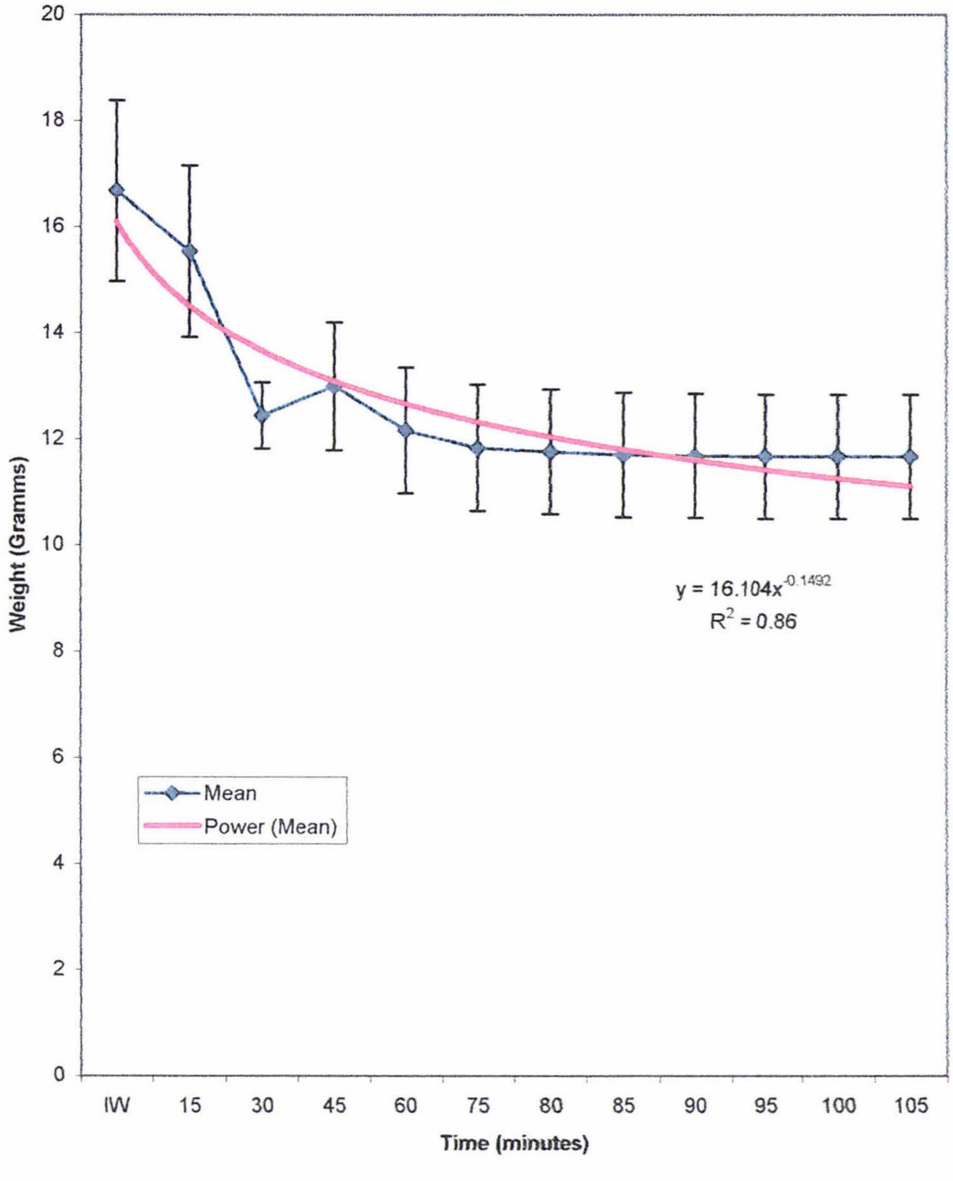
To ensure that the samples were processed to give an absolute value for material moisture percentage, five replicates of irrigated soil, an Ashurst Silt loam, (stony

Phase) (Cowie, 1978) from the property lot 57 DD 2626 (S 40° 21' 25''; E 175° 32' 21''), obtained from an Etrex™ hand held GPS by Garmin™ within Palmerston North City were sampled. The soil had been irrigated for twenty minutes prior to sampling with a Plassay™ garden irrigator. Any pebbles present in the samples were also removed prior to drying. Samples were collected in plastic film containers, and placed in the cooking cups as for collection of bush remnant samples and dried at 150° C with weights to two decimal places taken every 15 minutes for the first seventy five minutes and every five minutes thereafter, until three consecutive constant weights were obtained for all five samples (appendix IV, page 136). The mean and standard errors are shown in table VI, page 61. This shows that a constant weight is obtained at 95 minutes. All irrigation trial and samples from the four bush remnants were dried for 95 minutes.

Time (Minutes)	Mean	Standard Error	Time (Minutes)	Mean	Standard Error
Initial weight	16.684	1.701598	**80**	11.76	1.176878
15	15.542	1.614926	**85**	11.704	1.174185
30	12.446	0.618207	**90**	11.686	1.67989
45	12.998	1.205791	**95**	11.688	1.169451
60	12.166	1.18272	**100**	11.688	1.169451
75	11.834	1.190613	**105**	11.688	1.169451

Table VI: The mean and standard error for drying time for five replicates of irrigated Ashurst silt loam, (stony phase), at 150° Celsius for the calibration of an Atlas Neptune™ oven for optimal drying times of OA horizons samples.

tm Trade mark



Graph III: Mean weights of five replicates of Ashurst Silty Loam (stony phase) verses drying time in an Atlas neptune tm at 150^{O} Celsius to obtain three consistent weights. This time was assumed to be optimal drying time for OA horizons material from the irrigation trial and background OA horizons moisture levels at the four sites of the seedling survival trial North Island, New Zealand.

2:3:4:1. Irrigation experiment at Legg Estate bush remnant.

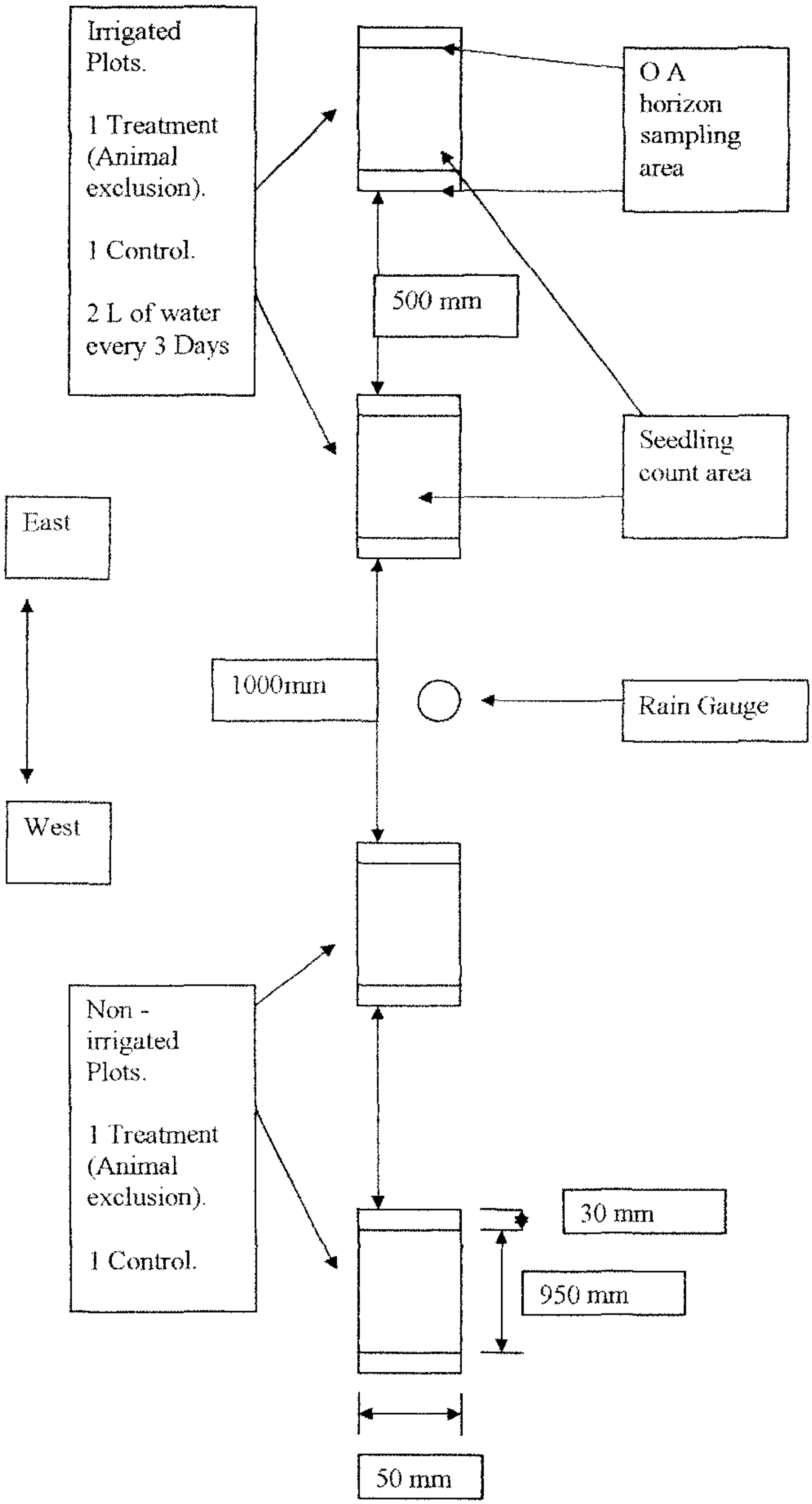
2:3:4:2. Materials and methods.

At Legg Estate bush remnant, to determine if soil moisture stress was having a detrimental effect upon seedling survival, a split plot design, with five replicates was been set up orientated east west. Placement within Legg Estate bush remnant was random within the rear half of the remnant. A heavy infestation of *Tradescantia fluminensis* has prevented nearly all regrowth in the front half of this bush remnant, which rendered this area unsuitable for this experiment.

Each replicates consisted of four plots: two of which were irrigated (the treatment) and two received no irrigation (the control) Each plot are 500 millimetres apart, the treatment and control are separated by 1000 millimetres and each cage is 500 by 950 millimetres (see diagram I, page 64).

Within each irrigated and non-irrigated plot, one plot is caged to exclude rabbits while the other is exposed to all herbivores including rabbits. Samples of OA horizons were taken in plastic film containers before irrigation occurred and dried within six hours of sampling. The OA horizons samples were taken from outside the area in which seedling numbers were being recorded. A rain gauge was placed between the irrigated and non-irrigated plots and a rain gauge was also placed external to this bush remnant in a full-unobstructed position in order to gain an indication of background rainfall. Samples of OA horizons material, rain gauge readings and the irrigation of the respective plots were made at three days intervals. Two litres of water was applied evenly over each irrigated plot using a watering can, after the OA horizons samples were collected.

Diagram I: The set up of a replicate in the Irrigation experiment at Legg Estate bush remnant shows distances between each cage, placement of the rain gauge and the areas irrigated and where the samples were taken. All replicates were of an east-west orientation.


Irrigated Plots.
1 Treatment (Animal exclusion).
1 Control.
2 L of water every 3 Days
O A horizon sampling area
500 mm
Seedling count area
East
West
1000mm
Rain Gauge
Non - irrigated Plots.
1 Treatment (Animal exclusion).
1 Control.
30 mm
950 mm
50 mm

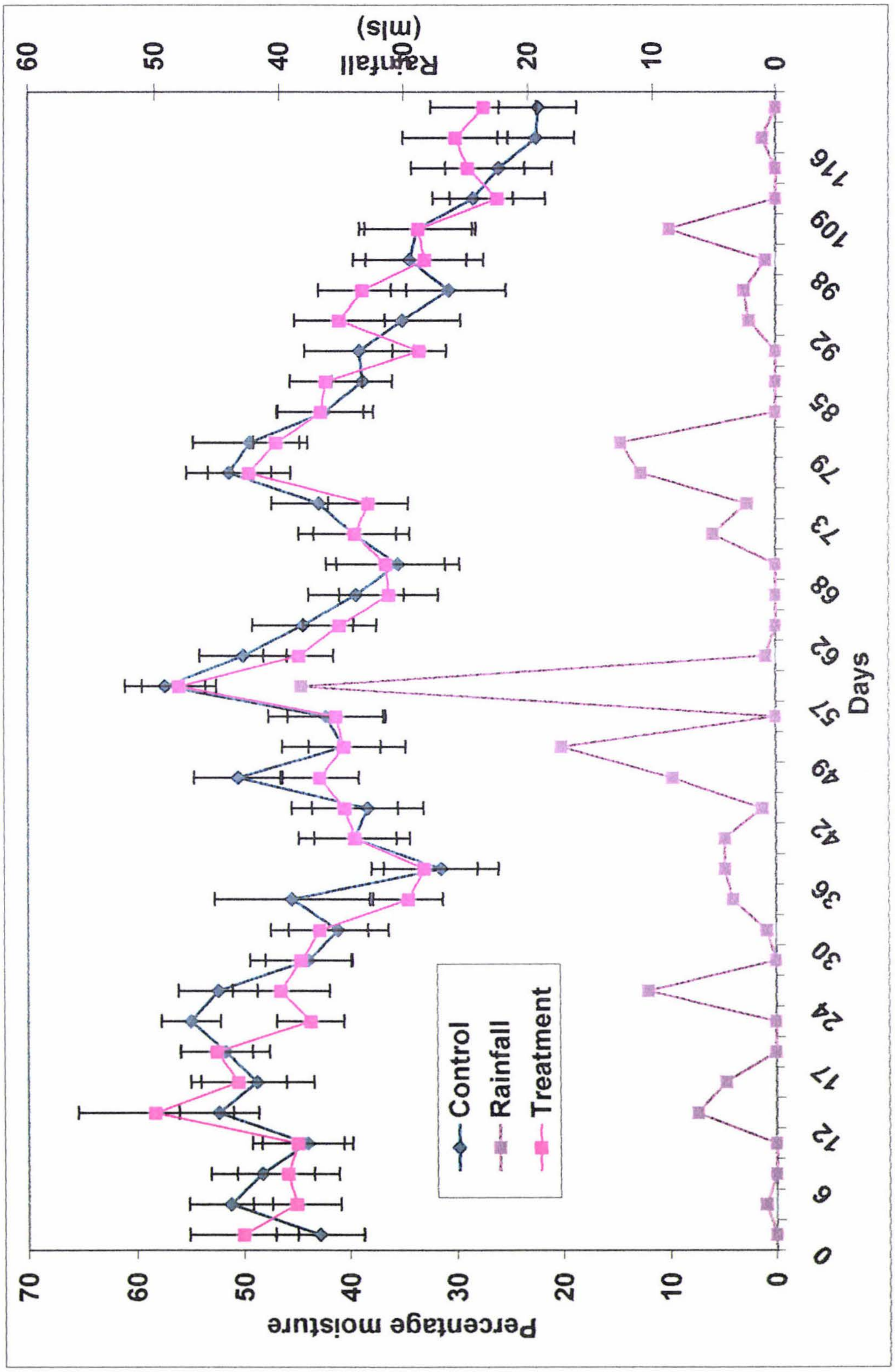
The readings from the external rain gauge were considered inaccurate because of yearling heifers licking the rain gauge from the post and a hight evaporation rate from the rain gauge between readings. Out of bush remnant rainfall values (appendix III, page 135) were obtained from a Mr and Mrs Eddie Millard's climate station seven hundred metres from the bush remnant edge. The data collected by Mr Eddie Millard are supplied to NIWA for part of the national climate data collection scheme. This data was used to produce graph IV page 66.

Seedlings present in each treatment were counted at the start of the experiment and on seven other days throughout the experiments duration. This data is used to generate Table VII, page 65. As non whole numbers were calculated for some day treatment cells there were rounded up if greater than 0.5 or down if less than 0.5.

Day/Treatment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Run day	1	15	30	52	79	92	112	119
Control Irrigation	21	28	57	37	28	35	33	26
Treatment Irrigation	10	15	22	23	17	16	9	6
Control Non Irrigation	30	39	57	57	54	71	45	33
Treatment Non irrigation	10	14	16	9	2	1	0	0

Table VII: Mean numbers of seedlings present from the five replicates of the irrigation experiment at Legg Estate bush remnant, Palmerston North, New Zealand.

Graph IV: (Opposite). OA horizon moisture levels of treatment (water addition) and controls (no water addition) at five replicates as part of the irrigation experiment at Legg Estate bush remnant, Palmerston North from 15 October 2000 (Day 1) to 11 February 2001 (Day 119). The unobstructed rainfall shown for this bush remnant was obtained from a climate station 700 metres from the bush remnants edge.


Percentage moisture
Rainfall (mls)
Days
Control
Rainfall
Treatment

Noting that the treatment has less moisture then the controls would suggest that there are fundamental errors in sampling or result processing. After all the addition of moisture should in theory increase the moisture content. By looking at rainfall and comparing the moisture after treatments and controls we see there is an increase in both treatments and controls. When adding the two litres of water the first time, I did observe how easily it did bead and flow from some of the plots. To offset this loss from the experimental area I applied the water more slowly to allow uptake at the O A horizons.

When it rained the interception store was the first to fill, followed by the soil store and thirdly the surface store. While the water was in the interception store it could dissolve waxes and oils from the leaves, which could aid in infiltration and retention within the soil. As I applied potable water (tap water) this may not have these waxes and oils present and this could have influence the results obtained (Springett, pers. com.).

2:3:4:2. Results.

A Chi-squared analysis was conducted on the seedlings present for the eight days seedlings were counted versus the four treatment types. A calculated Chi-squared statistic of $X^2 = 80.415$, DF=21, $P < 0.001$ was obtained. A tabulated result of 32.670 (appendix II, page 134) indicates that there is an association between each of the treatments and their effects upon seedling survival, but this does not show which treatments have these differences.

I looked at the effect of excluding rabbits from the irrigated and non-irrigated plots to see if there was the means for each seedling population was similar and found a calculated $X^2 = 23.234$, DF=7, $P = 0.002$ compared with a tabulated Chi–squared value of 14.067 this indicates that is an association between the plots weather irrigation is applied or not and rabbits is excluded.

When looking at the plots that allow access of rabbits and other grazers we get a X^2=23.234, DF=7, P=0.002 with a tabulated result of 14.067 indicates that there is an association between irrigation and the non irrigation plots with access by rabbits.

A two sample T- test on the OA horizons moisture levels between irrigated and non irrigated plots gave a T-value of 3.64 with a P- value of 0.0001 with DF of 64. A tabulated result (appendix V page 137) of 3.232 shows that the application of 2litres of water every 3 days did change the OA horizons moisture levels.

2:3:4:3. Conclusions.

The results of the irrigation trial indicate that there are fluctuations in the OA horizons moisture and that these fluctuations may impact upon seedling survival show (graph IV, page 66) that a significant rainfall event is required to produce a detectable rise in the moisture levels at the OA horizons and that the increase was of a short duration.

When additional of the two litres of water was applied every three days, little or no effect was observed and even moderate rainfall events showed no increase in moisture levels.

The varied moisture results and seedling survival results suggest that the chemical nature of these soils could have a significant impact upon seedling germination, and survival in the Legg Estate bush remnant and possibly also at Himatangi Block Scientific Reserve (and other bush remnants on these soils).

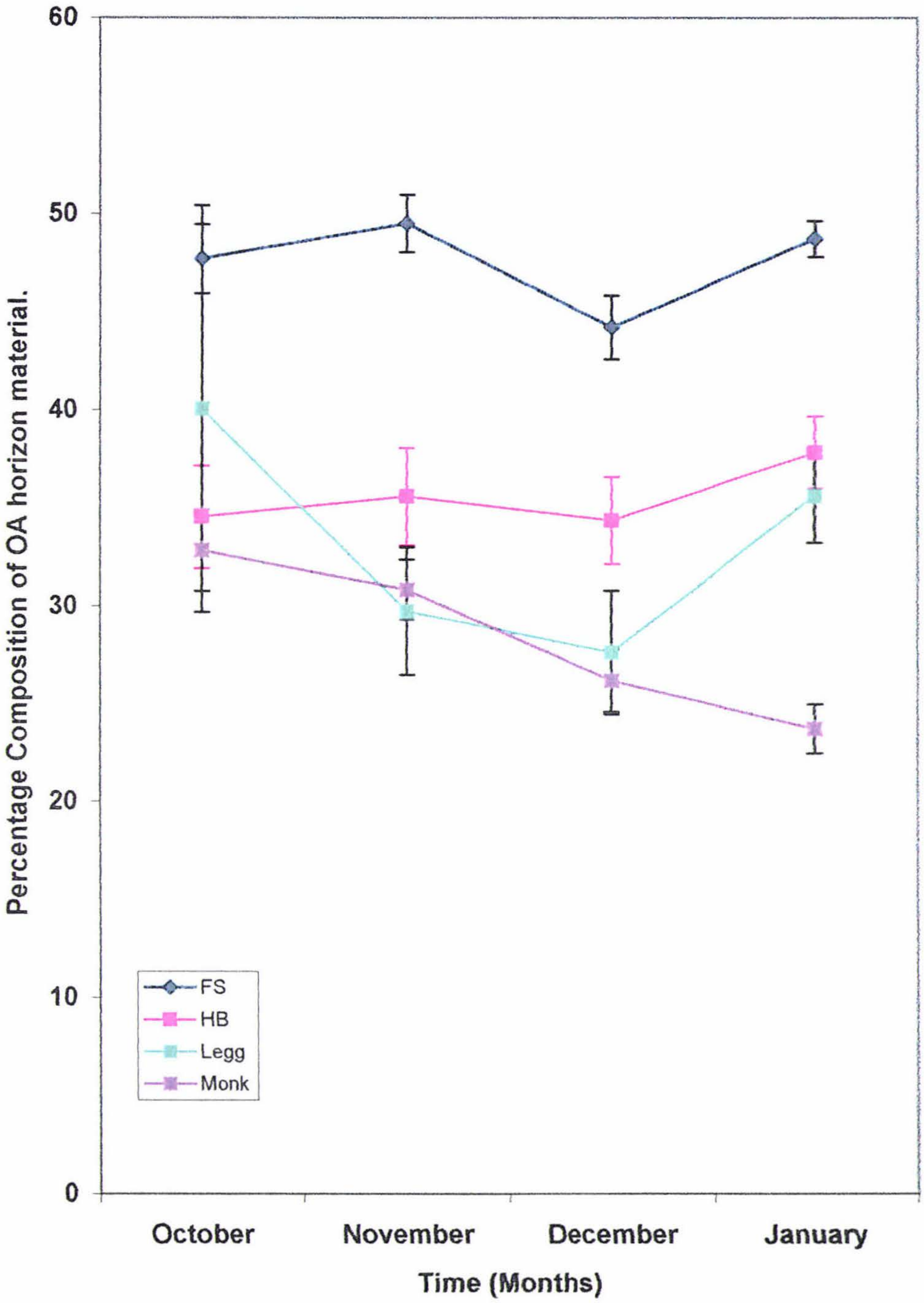
When looking at the OA horizons material of each of the five replicates in the trial there was significant visual differences between the replicates and even significant visual differences across the southern end of the forest remnant depending upon ones position within the remnant. Visually there was more organic matter at the base of the sand ridge than out by the edge of the remnant next to the pasture with a decreasing level of leaf detritus from the sand ridge to the pasture side.

I conclude that the amount of water added was not enough to bring about an increase in moisture levels in the irrigated plots sufficient to have a positive impact on seedling germination and subsequent survival.

The plot of soil moisture (graph IV, page 66) shows fluctuations about a decreasing mean over the summer period. These fluctuations however slight could be sufficient to cause the death of these seedlings unlike the hand planted saplings on the outside of the bush remnant. The hand planted saplings on the exterior of this forest, have survived well with few losses, probably because the roots of these plants were at a greater depth than the roots of seedlings in the interior of the bush and likely to have access to more constant water supplies than the naturally germinating seeds.

The rainfall at the coast is lower than that of the inland sites and as moisture is one important factor in seedling growth this may account for some variances obtained for seedling survival and growth between the sites as shown in graph V, page 70.

Graph V, page 70 shows moisture values for four months (November – February) and uses values from samples collected on one day per month. Samples were collected randomly from the forest floor in the vicinity of the seedling survival plots. Legg Estate bush remnant shows a drop of some eight percent of soil moisture over the four-month period.



Graph V: OA horizons percentage moisture content at the four bush remnants of the seedling survival trial from October 2000 to January 2001. The data for Legg Estate bush remnant were independent of the irrigation experiment.

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CHAPTER 3

Seed production and seed rain

3:1:1. Seed production.

Most plants on earth including those within all four bush remnants would set seed of some sort through out their life cycles. This seed caries the genetic blue print for an individual of its particular plant species in some future time. The amount of seed produced could give an indication to the viability of each remnant as to weather it could be self sustaining in viable seed production and capable of maintaining the life cycles of most if not all of its species. Within many remnants unwanted species (weeds) are present and any germination trial will have to allow for their presence.

3:1:2. Materials and methods.

Seed fall can be intercepted and seeds present counted and identified to a species level. This was done at all four trial sites but initial identification was on morphological type with later identification to species where possible.

Insect fall traps were used to intercept and retain the seed rain and other biological material (See Photograph VIII, page 73). Three were set up in each remnant site within close proximity of the plots for the seedling survival trial.

The traps were cleared fortnightly when visiting the sites for other data collection and sorted into their morphs / species. No replicates were used as all three trap catch material was pooled.

Analysis was done using a Chi-squared test for similarity of plant species between all four bush remnants and a separate analysis was done on reach region again testing for any similarity with plant species present within each region.

Photograph VIII: An insect fall trap used to collect the seed rain. In the background is a seedling survival control plot. This photograph was taken in Legg Estate bush remnant.

3:1:3. Results.

The results obtained from this trial included the total numbers of seeds per species, and in presenting the results I had values for all species recovered. Species six, nine, ten and twelve were, because of there low or no showings at a few or one of the trial sites were dropped from the analysis. The count of seeds recovered, was the sum from the samples recovered per species for the duration of the trial from early April 2000 through to the last collection in early January 2001. Total seed counts that are used in the final analysis are shown for the sand country sites and the inland sites in tables VIII, page 76 and IX, page 77.

Diagram II on page 75 shows the seeds collected for the individual morphological types used in the calculations.

The Chi-squared statistic generated gives a result of (X^2 = 885.724, DF= 21, P=0.05) with a tabulated result of 32.67. There were three cells with expected values less than zero. Chi-squared analysis are adequate when the average expected cell count is greater than five and all individual expected counts are greater than one (Moore & McCabe, 1993). To over come this, bush remnant one (Legg Estate bush remnant) was dropped from the calculation because of poor showing on most species, the calculations with bush remnants two three and four give the following results (X^2=761.06, DF=14, P=0.000) compared with a tabulated result of 23.68.

By looking at bush remnants from the sand country and the inland sites we get a tabulated result for the sand country of (X^2 =71.169, DF=6, P=0.05) with a tabulated result of 12.592 while for the inland bush sites we get a calculated results of (X^2=388.544, DF=5, P=0.05) and a tabulated result of 11.070. This indicates a huge variation between Monkton's and Fulleton-Smith bush remnants.

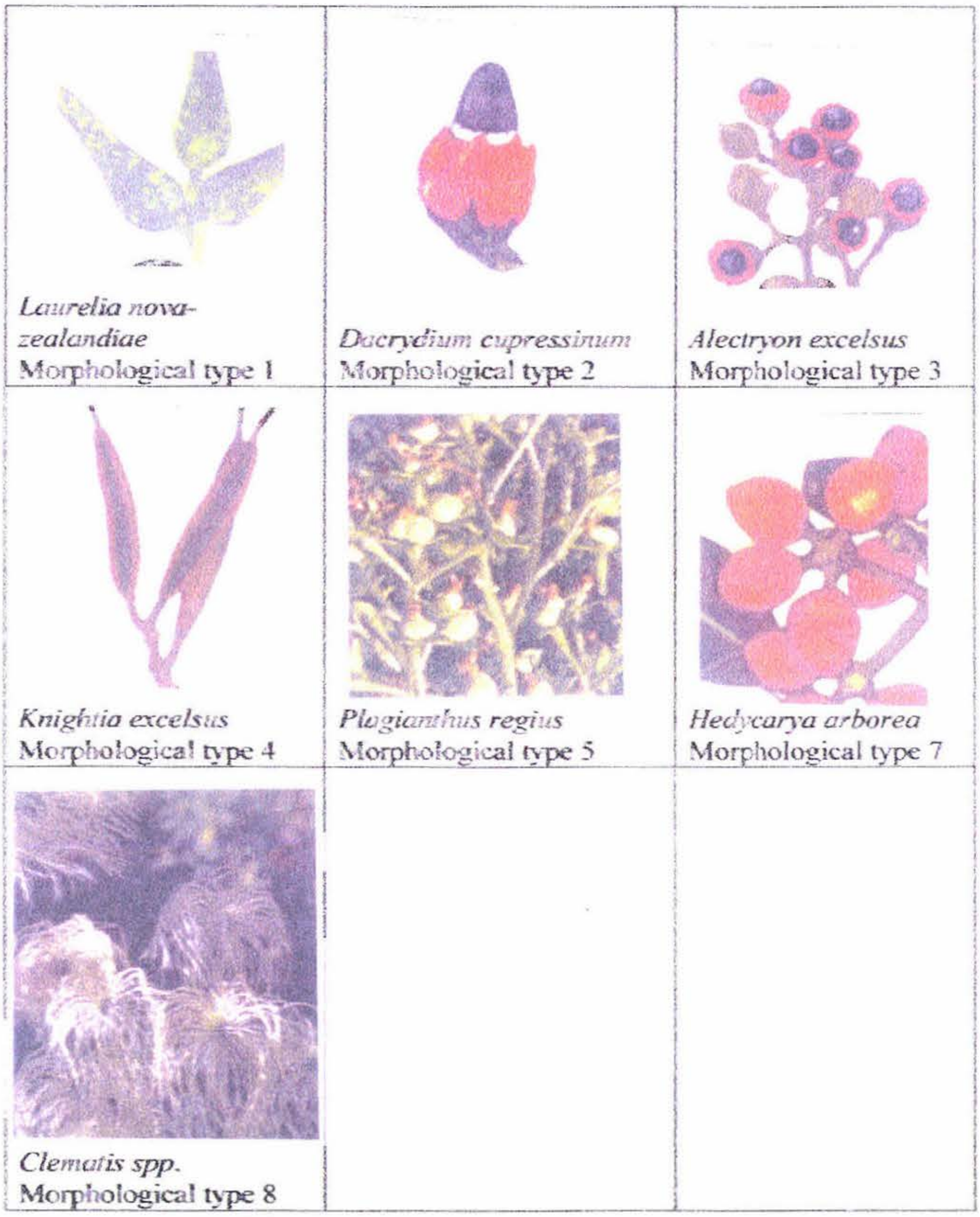

Diagram II: Drawings of seeds of the native plant species used for the Chi-squared calculations, showing the morphological number and their species name.

Note: Drawings of morphs 1,2,3,4 and 7 are sourced from "The Fiat book of New Zealand Trees" By N. M Adams (1967), pages 35,25,71,39 and 33 respectively.

Morph 5 is from "Native Trees of New Zealand" J.T Salmon (1980) page 185.

Morph 8 is from "Native New Zealand flowering Plants " By J.T. Salmon (1990) page 30.

Sand country bush remnants	Morph. / Species		Count
Legg Estate bush remnant	(1)	*Laurelia nova-zealandiae*	8
	(2)	*Dacrydium cupressinum*	1
	(3)	*Alectryon excelsus*	9
	(4)	*Knightia excelsa*	3
	(5)	Unidentified type	0
	(7)	*Hedycarya arborea*	1
	(8)	*Clematis spp.*	0
	(11)	Unidentified type	0
Himatangi Block Scientific Reserve	(1)	*Laurelia nova-zealandiae*	12
	(2)	*Dacrydium cupressinum*	0
	(3)	*Alectryon excelsus*	2
	(4)	*Knightia excelsa*	16
	(5)	Unidentified type	57
	(7)	*Hedycarya arborea*	37
	(8)	*Clematis spp.*	0
	(11)	Unidentified type	5

Table VIII: Individual counts of seeds collected as seed rain from Legg Estate bush remnant and Himatangi Block Scientific Reserve south of Palmerston North, in the Manawatu region, New Zealand from April 2000 to January 2001.

Marton bush remnants	Morph / Species		Count
Monkton's bush remnant	(1)	*Laurelia nova-zealandiae*	2
	(2)	*Dacrydium cupressinum*	194
	(3)	*Alectryon excelsus*	9
	(4)	*Knightia excelsa*	0
	(5)	Unidentified type	31
	(7)	*Hedycarya arborea*	0
	(8)	*Clematis spp.*	50
	(11)	Unidentified type	1
Fulleton- Smith bush remnant	(1)	*Laurelia nova-zealandiae*	0
	(2)	*Dacrydium cupressinum*	0
	(3)	*Alectryon excelsus*	33
	(4)	*Knightia excelsa*	0
	(5)	Unidentified type	186
	(7)	*Hedycarya arboreoa*	0
	(8)	*Clematis spp.*	0
	(11)	Unidentified type	22

Table IX: Individual counts of seeds collected as seed rain from Monkton's and Fulleton-Smith bush remnants near Marton in the Rangitikei region, New Zealand from April 2000 to January 2001.

3:1:4. Conclusions.

The results of the statistical analysis show that there is huge variation between the four sites for the seed rain collected. Even with some of the conditions for the statistical calculations being violated the calculated statistic is still very large.

By examining the standard residuals calculated as part of the Chi-squared statistic (See table X, page 78) and looking at the ranges of this value per species over each site. By having very small values over all four sites we see that despite there being significant differences in each forest there could be some species which would be similar at differing sites. From the results calculated there is no evidence for any similarity of any of the species over all the four sites.

Species	**1**	**2**	**3**	**4**	**5**	**7**	**8**	**11**
Forest								
L.E	8.63	-2.12	5.56	3.04	-2.98	-0.21	-1.27	-0.95
H.B.	3.83	-6.09	-2.54	6.52	0.69	11.08	-30.8	-0.14
M.	-2.39	12.29	-2.83	-2.83	-7.88	-4.01	6.28	-3.15
F.S	-2.79	-8.32	3.27	-2.60	9.00	-3.67	-4.21	3.83
Range	11.42	20.61	8.39	9.35	16.88	15.09	10.49	6.98

Table X: Standardized Residuals calculated from seed rain for eight plant species at the four seedling survival trial sites in the Manawatu–Rangitikei region, North Island, New Zealand.

Over all the data collected and analysed there is, despite some problems with the statistic set up, a confirmation of the differing bush types as shown in table I, page 36, and that these bush remnant species mix are substantially different. These differences are reflected in the seed production and ultimately in the trees producing them. The varying mixes of species in the adult phase are reflecting the differing environmental histories and the human management techniques that have been applied over the past few centuries.

3:2:1. OA horizons soil seed bank.

As plants set seed in the course of their lifecycle, many of the seeds are either not viable, consumed by seed eating organisms or fall upon unproductive sites. Some fall upon potentially sites and under ideal circumstances will germinate and of the many viable seed set only very few if any from any one years set will actually make it into the canopy as an adult specimen.

To get an indication for the species producing seeds and the amount produced and found in the OA horizons, a germination trial using OA horizons material was conducted on material obtained at all four bush remnants sites.

3:2:2. Material and methods.

Approximately 500 grams of OA horizons material was collected from within each bush remnant, in proximity to the seedling survival trial plots. The material for each remnant was mixed at the surface of a germinating tray in Yates potting mix and placed under a cloche with a north facing aspect. Sampling was destructive except for a native seedlings species from Legg Estate and Himatangi Block Scientific Reserve material. The native plant seedlings of Himatangi Block were surrendered to Department of Conservation as part of the permit requirements to access this Crown land, while the only native seedling grown from Legg Estate bush remnant material was planted back into this bush remnant in December 2000.

Sampling of the germinating seeds was done at irregular intervals, but sufficient time elapsed between each sampling to allow adequate growth of the plants being sampled and to ensure accurate species identification. Sampling was destructive, but care was taken in the root removal to reduce the loss of potting mix material, which was likely to contain seeds yet to germinate.

Replacement of germinating trays within the cloche was done at random to reduce the chances that growth was a function of placement or watering technique within the cloche. Watering was carried out over a two-day cycle, each plot receiving one litre of tap water. Hands and harvest equipment were washed between each tray when sampling occurred to prevent any cross transfer of seed material. Care was taken to safeguard the integrity of each germinating tray.

3:2:3. Results.

Twenty-three species were grown from the total of the four bush remnants, seven species were native while sixteen species were weeds and grasses. A total of two hundred and ninety five individual seedlings in total were germinated. Native species made up a total of 33.9 % (100 out of 295) with weeds and grasses making up 66.1 % (195 out of 295) of the species germinated.

Legg Estate bush had the smallest number of natives at a small 1.2 %, while weed and grass species make up the bulk of seedling germinated at 98.8 %. The one native species germinated *Solanum aviculare* does not appear in the seedling survival trial (see table II, page 36).

Himatangi Block Scientific Reserve native species germinated make up 27 % while weed and grass species make up 73 %. The two native species germinated *Coprosma spp.* and *Pittosporum eugenioides* are not present in the seedling survival trial (see table II, page 36).

Monkton's bush has two native species germinate. *Hedycarya arborea* and *Leptospermum scoparium* make up 27.7 % and weeds and grasses make up 72.3 % of the totals germinated. *Leptospermum scoparium* does not appear in the seedling survival trial (see table II, page 36) but *Hedycarya arborea* does with 18% of the seedling survival at this bush remnant in this trial being this species.

Fulleton-Smith bush remnant has six native species making up 60 % of the total seedlings germinated with the balance of 40 % being weeds and grasses. *Coprosma spp, Knighta excelsia, Parsonia heterophylla* and *Hedycarya arborea* are present in both trials (see table II, page 36) while *Solanum aviculture* and *Pittosporum eugenioides* are present in only the germination trial.

Tables XI to XIV on pages 82 to 85 show native and weed plant species germinated per bush remnant.

Species / Date	5/8	21/8	24/9	10/11	29/12	Total Percents
Solanum nigrum	42	0	8	0	1	60
Taraxacum afficinate	17	0	0	0	0	20
Cirsium vulgare	1	0	0	0	0	1.2
Hypochaeris radicata		2	0	0	0	2.3
Conzya spp.			8	1	0	10.6
Amaranthus powelli				3	1	4.7
Solanum aviculare					1	1.2
Total						100

Table XI: Plant species germinated from approximately 500 grams of OA horizons material sampled from Legg Estate bush remnant, Bainesse, Palmerston North, New Zealand. Native plant species are shown in bold type and account for 14.3% (1 out of 7) of the species present and 1.2 % (1 out of 85) of individual germinated.

Species \ Date	**5/8**	**21/8**	**24/9**	**10/11**	**29/12**	**Total Percents**
Solanum nigrum	15	0	0	0	0	40.6
Holcus lantatus	1	0	0	1	0	5.4
Hypochaeris radicata		2	0	0	0	5.4
Carex spp.					2	5.4
Conzya spp.			4	0	1	13.5
Buddleia alternifolia					1	2.7
Coprosma spp.					1	2.7
Pittosporum eugenioides					9	24.3
Total						100

Table XII: Plant species germinated from approximately 500 grams of OA horizons material sampled from Himatangi Block Scientific Reserve, Bainesse, Palmerston North, New Zealand. Native plant species are shown in bold type and account for 25 % (2 out of 8) of the species present and 27 % (10 out of 37) of the individual germinated

Species \ Date	**5/8**	**21/8**	**24/9**	**10/11**	**29/12**	**Total percents**
Solanum nigerum	41	0	0	0	0	49.4
Cirsium vulgare	1	0	0	0	0	1.2
Cirsium arvense	1	0	0	0	0	1.2
Polygonum spp.	6	0	0	0	0	7.2
Stellaria media			6	0	0	7.2
Digitaria sanguinalis					1	1.2
Ameranthus powelli				1	1	2.4
Buddleia alternifolia					1	1.2
Carex spp.					1	1.2
Hedycarya arborea				1	0	1.2
Leptospernum scoparium				19	3	26.6
Total						100

Table XIII: Plant species germinated from approximately 500 grams of OA horizons material sampled from Monkton's bush remnant, Fern Flats, Marton, New Zealand. Native plant species are shown in bold type and make up 18.2 % (2 out of 11) of the species present and 27.7 % (23 out of 83) of the individual germinated.

Species \ Date	5/8	21/8	24/9	10/11	29/12	Total Percent
Solanum nigrum	17	0	0	0	0	18.9
Cirsium vulgare	1	0	0	0	0	1.1
Senecio vulgaris		1	0	0	0	1.1
Buddleia alternifolia					5	5.6
Coprosma spp.			2	2	0	4.5
Knighta excelsia					1	1.1
Parsonia heterophyalla				1	0	1.1
Pittosporum eugenioides					30	33.3
Hedycarya arborea			29	0	0	32.2
Solanum aviculare				1	0	1.1
Total						100

Table XIV: Plant species germinated from approximately 500 grams of OA horizons material sampled from Fulleton-Smith bush remnant, Mount Curl, Marton, New Zealand. Here native plant species are shown in bold type and account for 60 % (6 out of 10) of the species present and 73.3 % (66 out of 90) of the individual germinated.

Solanum nigerum was the most common of all species both natives and weeds and grasses making up 42 % (124 out of 295). Of the remaining 24.1 % weed and grass species *Taraxacum afficinate* made up 5.76 % (17 out of 295), with *Conzya spp.* at 4.75 % (14 out of 295), *Buddleia alternifolia* making up 2.37 % (7 out of 295) and *Amaranthus powelli, Polygonum spp.* and *Stellaria media* making up 2.04 % (6 out of 295) each. The remaining 5.13 % is made up from seven species *Holcus lantatus* 1.35 %, *Hypocharir radicata* 1.35 %, Carex *spp.* 1.01 %, *Cirsium vulgare* 1.01 %, *Cirsium arvense* 0.67 %, *Digitaria sanguinalis* 0.33 % and *Senecio vulgaris* 0.33 %.

Three Chi-squared analyses were done on data for the species germinated in this trial. Because of low showing or showing in one site only weed and grass species seven, eight, nine, ten, twelve and fifteen along with native species seventeen, twenty one and twenty three were excluded.

1) The first analysis was done on all four sites including both natives and weeds and grasses giving a result of (X^2=264.207, DF=39, P<0.000). This is an extremely large value with tabulated results of 114.364, indicating that there is an association between the numbers of seedlings and species from within each bush remnant.

   When considering native seedlings only at all four sites we get a calculated result of (X^2=144.049, DF=9, P<0.000), while we would expect a tabulated result of 16.919, again showing a significant difference between the native seedlings germinated from the four bush remnants.

2) As the trials were set up to include two blocks that were similar, each with two representees. This has been done and we have the sand country and inland sites. We would expect that within the sand country blocks considering their close approximation (Four and a half kilometres in a straight line) there would be some close results to be obtained for native plant species.

3) The calculations give results of $X^2 = 10.00$, DF=3, P<0.000 and a tabulated values of 7.815. This shows that there is an association between species present and the two regions in which the trials were run.

4) The inland sites although further apart (16 kilometres in a straight line) with differing factors operating upon them, shows differing results for native species. A Chi-squared result of $X^2 = 78.174$, DF=3, P<0.000. The tabulate result of 7.815 showing an association between bush remnants and the native species present at each bush remnant.

The final Chi-squared analysis is done upon the species present in the seedling survival trial. The species listed in table XV, page 95 species number eight, ten, twelve, thirteen and fourteen were dropped because the appeared in a few or one bush remnant and when appeared were at very low levels. The calculated results of $X^2 = 263.872$, DF=24, P=0.000 has a tabulated result of 36.415 indicates an association between species present in the seedling survival trial and the bush remnant from which they were drawn.

This series of analysis also confirms the percentage calculations carried out on the seedlings germinated in this trial.

3:2:4. Conclusions.

When looking at the distribution of the native species verses weeds and grasses Legg Estate bush remnant has the lowest germination rate at 1.2 %. Himatangi Block Scientific Reserve at 27 % and Monkton's bush remnant at 27.7 % are next respectively while Fulleton- Smith bush has the highest native seedling germination at 60 %.

Legg Estate bush remnant is long and narrow with places most of the remnant within meters of the exterior coupled with little diversity in the mature specimens and having a poor seedling survival rate once germination has occurred. Over half the bush remnant floor is covered in *Tradescantia fluminensis* and to the southern end there is a high number of *Macropiper excelsum* which is a primary coloniser and would have grown up after disturbances breaking the canopy.

Himatangi Block Scientific Reserve and Monkton's bush remnants have had their understory grazed until recently, but they do show in places a lot of seedlings present, are relatively large by comparison (18.76 ha and 20 ha respectively) with Legg Estate bush remnant (1 ha.) and have more species and numbers of different species present.

Fulleton-Smith bush remnant has the highest percentage of native seedlings present at 60 %. This bush remnant has the longest history of some sort of management (Fulleton–Smith pers. comm.), with a large number of mature specimens and a good mix of species. Despite being smaller (9 ha) than Himatangi Block and Monkton's bush has close proximity to other bush remnants as well as the seed distributing the wood pigeon, *Hemiphaga novaeseelandiae*, Gmelin, 1789 (Dawson & Lucas, 2000) are very common in this bush remnant and the other remnant they were seen in was Monkton's bush remnant.

When comparing the results of the species used in the seedling survival, realising this is an insitue germination trial, the seeds that germinated were not restricted to seeds that had fallen into the traps.

These traps, by their design limited the seeds that fell into them by the requirement of being at one metre above the ground and falling into the funnel.

Seeds from plants at distance from the trap may not have fallen into the trap but could fall at close proximity to the trap. The traps by design created a bias for seeds the were released either directly over or very near the funnel and were blown into the funnel.

Over all every bush remnant has a distinct mix of weeds and grasses and native seedlings produced in both the seed bank trial and the seedling survival trial.

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CHAPTER 4

Seedling growth and survival

4:1:1. Seedling growth.

With the colonisation of New Zealand from the late 1840's onwards began the clearance of existing vegetation to make way for pastoralisation. For a variety of reasons small pockets of remnants survived in many areas, and in recent years many have been fenced to exclude most large herbivores (Domestic stock and large feral ungulates). This fencing however, does not exclude the smaller herbivores, omnivores and carnivores, which would still have access to these remnants and their presence, could impact upon the bush remnant health. In recent times the development of total exclusion fences was allowing some forests on the mainland to begin to return to a less non-indigenous modified state.

By using enclosures that excluded a specific or several species in combination, and tracking the growth of selected plant material in both the treatments and the controls, it was possible to gauge the impact some exotic species have had upon existing vegetation. From this one could draw some conclusions upon removal or control of the species, and the possible impact their control will have upon the remnant health. These trials in the four bush remnants looked at exclusion of rabbits.

4:1:2 Materials and methods.

To determine the impact of rabbits upon these bush remnants I followed the layout of a block design, consisting of a treatment (fenced to exclude rabbits) and a control (access to all herbivores, including rabbits) which was replicated five times within each bush remnant. The exception was Legg Estate bush remnant where, due to insufficient seedling numbers, four unequal replicates were used. [(1x 20 seedlings per treatment and control) + (2 x 10 seedlings per treatment and control) + (1x 5 seedlings per treatment and control)]

Within each block selection of treatment or control was random. The treatment plot was fenced with chicken wire, which was pinned into the ground at the base and slightly buried to stop rabbits from burrowing under and was of a sufficient height to prevent rabbits from jumping over.

There was no evidence of rabbits gaining access to the treatments, as none of the wire was lifted or any tags knocked down and no rabbit faecal pellets were sighted within the treatments. Possum faecal pellets were found in replicate three at Monkton's bush remnant, Marton. This facial material appeared to have fallen into the plot rather than being deposited by the actual animal within the plot. This exclusion system was based upon a system used successfully to exclude rabbit from Santoft legume evaluation trials by a Dr Grant Douglas of Agresearch, Palmerston north. Although these fences looked flimsy, they proved to be more than adequate for the duration of this trial.

Placement within each forest was based upon the following criteria.

1) Within a light well or break in the forest canopy (see photograph VII, page 53).
2) Access was assured for rabbits.
3) Seedlings were of sufficient size and number to allow tracking for the time of the trial.

These seedlings were numbered and identified to a species level, Legg Estate bush remnant because of a lack of sufficient seedlings, was limited to a total sample size of ninety. This affected the presentation of the results for analysis, requiring data on survival to be presented as percentage of total in each replicate. The removal of the chicken wire some eight weeks into the trial destroyed a replicate and partly destroyed the seedlings in another treatment within Himatangi Block Scientific Reserve. This reduced the number of seedlings for analysis within Himatangi Block

Scientific Reserve to four replicates, again the analysis reflected this unfortunate destruction. Four seedlings in the treatment in replicate one, numbers six, nine, thirteen and fourteen although destroyed were not considered in the final analysis giving replicate one a total of eleven seedlings. The control has fifteen seedlings. No seedlings were destroyed during the period from the fence removal and its replacement fourteen days after discovery.

Hight measurements were recorded at four weekly intervals in millimetres. These measurements were able to provide two sets of data. The first growth per season per plant, the second, losses from the treatments and the controls.

To gain some indication of seedling fate, present / absence scores were also taken at four weekly intervals but two weeks after the height measurements were made.

The trial data was collected for five seasons upon the following definitions.

Summer: The period between the summer solstice and the autumn equinox, 22nd December to 21st March (Clark, 1990[1]).

Autumn: The period between the autumn equinox to the winter solstice, 22nd March to the 21st June (Clark, 1990[2]).

Winter: The period between the winter solstice to the spring equinox, 22nd June to 21st September (Clark, 1990[3]).

Spring: The period between the spring equinox to the summer solstice, 22nd September to the 21st December (Clark, 1990[4]).

The first season of the trial was spring 1999 and followed the plants through to spring 2000 giving the trial a total of 15 months over five seasons.

At Legg Estate, Monkton's and Fulleton-Smith bush remnants there was a collection of data in winter 1999. These values were not considered in the analysis, because of delays in getting permission from Department of Conservation for Himatangi Block Scientific Reserve data collection which started on 3rd October 1999.

As varying species involved in this trial, there distribution per site are shown below in Table XV page 95.

Species used in trial	Species No.	Legg Estate	H.B.S.R.	Monkton's bush	F/S bush
Alectryon excelsus	1	42	*	12	23
Hoheria populnea	2	21	4	20	*
Macropiper excelsum	3	9	31	35	5
Beilschiedia tawa	4	6	18	26	45
Lophomyrths obcordata	5	3	*	6	*
Knightia excelsa	6	2	*	5	*
Hedycarya arborea	7	2	54	27	63
Laurelia nova-zealandiae	8	1	*	*	*
Coprosma grandifolia	9	*	*	12	5
Myrsine australis	10	*	*	*	2
Parsonia heterophyalla	11	*	4	5	1
Lophomyrtus bullata	12	*	1	*	*
Prumnopitys taxifolia	13	*	*	*	1
Nestegis cunninghammi	14	*	1	*	*
Destroyed		*	5	*	*
To Identify /Dead		4	2	2	5
Total		90	120	150	150

- Not present in the trial at the specific remnant, but could be present elsewhere in that specific bush remnant.

Table XV: Species distribution and totals plant species count per site for the seedling survival trial sites in the Manawatu-Rangitikei area, North Island, New Zealand.

For each season, a growth rate in millimetres was calculated by the following equation.

$$SGR = (S_2 - S_1)$$

Where S.G.R = Seasonal Growth Rate, S_2 = final measurement per season and S_1 = initial measurement per season.

Some height measurements at final and or initial measurements were missing so the next available measurement was used. Some results were negative indicating that some type of phytophagous activity or destruction by natural means had occurred.

Tables XIX to XXII, pages 96 to 101 shows the mean growth changes per species per season per treatment and control for each bush remnant. Because in some species the sample size changes with time and as sample size is a factor in the calculation of standard error both sample size and standard error are also shown. Only species, which had two or more individuals in both the treatments and the controls, were used to generate tables XVI to XIX, page 96 to 101 and the corresponding graphs VI to XV on pages 104 to 113.

Differing species are present at differing numbers, and this was reflected in the species composition that made up the species mix of the bush remnants.

This heterogeneity of species was described by Watt (1947) as "patterns and processes", noting here that the influence of previous farm owners selecting certain individuals species for harvest had altered the species mix post harvest. The heterogenesis of species was reflected in the species distributed through the remnants and plots, with some bush remnants having only a few individuals of a species in the trial while other species are very commonly represented within in the trial. This presents a problem when looking at growth as a function of species, season and treatment / control.

Table XVI: (Opposite) Means growth per season, sample size and standard errors of individual native plant species within treatments and controls in the seedling survival trial at Legg Estate bush remnant, Palmerston North, New Zealand from August 1999 to December 2000.

Species	Data	Spring 99	Summer	Autumn	Winter	Spring 00
Macropiper excelsum **T**	Mean	57	31.66	48.33	20	62.66
	Number	3	3	3	3	3
	SE	60	16.41	57.32	28.93	36.70
Macropiper excelsum **C**	Mean	48	47.5	-66.66	31.66	-78.66
	Number	4	4	3	3	3
	SE	21.77	25.36	56.96	9.93	96.22
Hoheria populnea **T**	Mean	82.16	43.16	0	0.83	28
	Number	6	6	6	6	6
	SE	29.48	30.39	22.39	10.67	19.39
Hoheria populnea **C**	Mean	42.06	36.33	21.42	49.76	11.08
	Number	15	15	14	13	12
	SE	26.06	17.63	25.95	31.31	15.35
Alectryon excelsus **T**	Mean	2.21	18.10	0.64	3.35	13.68
	Number	19	19	17	17	16
	SE	4.26	3.98	7.45	6.66	6.64
Alectryon excelsus **C**	Mean	4.47	7.41	-2.93	5.26	4.66
	Number	17	16	15	15	12
	SE	5.12	3.16	6.59	5.52	8.62
Beilschmiedia tawa **T**	Mean	29	-94.25	11	-8.25	17.25
	Number	4	4	4	4	4
	SE	6.48	115.47	11.90	17.31	20.18
Beilschmiedia *tawa* **C**	Mean	195.5	47.5	27.5	46.5	20.5
	Number	2	2	2	2	2
	SE	127.5	50.5	12.5	8.5	139.5

Table XVII: (Opposite) Means growth per season, sample size and standard errors of individual native plant species within treatments and controls in the seedling survival trial at Himatangi Block Scientific Reserve, Palmerston North, New Zealand from August 1999 to December 2000.

Species	**Data**	**Spring 99**	**Summer**	**Autumn**	**Winter**	**Spring 00**
Hedycarya arborea **T**	Mean	-5.63	15.61	-6.17	4.33	-5.83
	Number	20	18	17	15	12
	SE	4.50	3.78	6.12	2.78	5.56
Hedycarya arborea **C**	Mean	4.20	8.66	-9.76	-2.91	-13.43
	Number	34	27	26	24	23
	SE	3.14	2.57	7.69	2.84	8.26
Parsonia heteraphyalla **T**	Mean	12.5	-5	0	10.5	43
	Number	2	2	2	2	2
	SE	14.5	15	20	9.5	8
Parsonia heteraphyalla **C**	Mean	50	40	10	39	21.5
	Number	2	2	2	2	2
	SE	38	10	10	21	.5
Macropiper excelsum **T**	Mean	2.41	12.2	-10.5	-7.4	-8.6
	Number	12	11	10	10	10
	SE	5.70	3.98	11.21	19.16	8.85
Macropiper excelsum **C**	Mean	0	3.72	0.88	19.18	11.64
	Number	19	18	18	16	15
	SE	6.34	7.98	12.86	16.50	11.57
Beilschmiedia tawa **T**	Mean	-12.09	8	-8.88	-0.12	-3.83
	Number	11	10	9	8	7
	SE	4.58	6.84	4.62	5.72	7.68
Beilschmiedia tawa **C**	Mean	14.28	5.85	16.66	-12	18.2
	Number	7	7	6	5	5
	SE	13.65	5.79	19.56	4.38	17.87

Table XVIII: (Opposite) Means growth per season, sample size and standard errors of individual native plant species within treatments and controls in the seedling survival trial at Monkton's bush remnant, Marton, New Zealand from August 1999 to December 2000.

Species	Data	Spring 99	Summer	Autumn	Winter	Spring 00
Macropiper excelsum **T**	Mean	78.86	10.45	5.18	-0.22	8.36
	Number	22	22	22	22	22
	SE	10.48	4.58	6.49	6.34	8.69
Macropiper excelsum **C**	Mean	10.15	-17.58	-4.54	-5.27	12.88
	Number	13	12	11	11	9
	SE	5.51	8.02	10.03	5.02	13.91
Beilschmiedia tawa **T**	Mean	12.53	-0.92	10.53	26.23	4.84
	Number	13	13	13	13	13
	SE	5.11	4.06	9.28	17.96	25.07
Beilschmiedia tawa **C**	Mean	23.61	4.69	-12.15	-15	0.3
	Number	13	13	13	12	10
	SE	11.14	3.41	4.70	3.57	5.71
Coprosma grandifolia **T**	Mean	39	4.6	9.2	14	112.8
	Number	5	5	5	5	5
	SE	11.86	4.08	5.58	5.73	35.48
Coprosma grandifolia **C**	Mean	36	1.14	-7.85	1	18
	Number	7	7	7	6	6
	SE	18.78	5.36	13.88	10.13	17.26
Hoheria populnea **T**	Mean	25.75	-5.83	17.72	39.72	6
	Number	5	5	5	5	5
	SE	10.72	9.95	15.67	17.40	15.36
Hoheria populnea **C**	Mean	28.62	-9.75	-11.37	13.87	-19.42
	Number	8	8	8	8	7
	SE	11.91	10.84	6.95	8.50	47.58

Species	Data	Spring 99	Summer	Autumn	Winter	Spring 00
Alectryon excelsus **T**	Mean	19.62	-7.37	-16.25	-1.25	7.16
	Number	8	8	8	8	6
	SE	4.97	2.65	13.61	7.47	6.20
Alectryon excelsus **C**	Mean	11.75	3.75	-12.5	-18	21.66
	Number	4	4	4	4	3
	SE	8.94	5.52	3.22	9.65	9.35
Knighta excelsa **T**	Mean	117.5	45	-55	31	152
	Number	32	2	2	2	2
	SE	37.5	45	45	58	28
Knighta excelsa **C**	Mean	12	-4.66	0	2.5	13
	Number	3	3	3	2	2
	SE	30.61	36.74	36.74	58	28
Lophomyrtus obcordate **T**	Mean	49.66	11.66	30.	-29	29.33
	Number	3	3	3	3	3
	SE	22.55	1.66	35.11	15.53	27.84
Lophomyrtus obcordate **C**	Mean	37.66	-5	-3.33	-5	-38.66
	Number	3	3	3	3	3
	SE	29.86	12.58	21.85	37.11	39.49
Hedycarya arborea **T**	Mean	9.42	-8.57	-4	19.28	39.66
	Number	7	7	7	7	6
	SE	9.33	23.15	6.83	6.44	13.65
Hedycarya arborea **C**	Mean	10.1	3.1	-5	-7.27	-17.4
	Number	20	20	19	18	15
	SE	4.14	3.21	2.7	7.22	20.07

Table XVIII: (Opposite) Means growth per season, sample size and standard errors of individual native plant species within treatments and controls in the seedling survival trial at Monkton's bush remnant, Marton, New Zealand from August 1999 to December 2000.

Species	**Data**	**Spring 99**	**Summer**	**Autumn**	**Winter**	**Spring 00**
Hedycarya aborea **T**	Mean	3.90	2.68	-0.58	6.4	9.06
	Number	32	32	31	30	30
	SE	3.74	2.13	6.0	4.02	3.88
Hedycarya aborea **C**	Mean	7.03	-4.96	-12.93	-2.18	2.86
	Number	32	30	30	28	23
	SE	4.63	4.6	5.59	2.32	2.06
Alectryon excelsus **T**	Mean	13.8	8	-10.5	0.66	8.77
	Number	10	10	10	9	9
	SE	6.67	5.59	4.72	5.41	19.19
Alectryon excelsus **C**	Mean	5.15	8.92	-7.6	-2.33	-4.6
	Number	13	13	10	9	5
	SE	7.34	9.38	7.11	6.81	6.05
Belschmiedia tawa **T**	Mean	-0.47	-6.30	-7.42	-3.3	-1.7
	Number	23	23	21	20	10
	SE	4.35	1.82	2.63	3.92	3.07
Belschmiedia tawa **T**	Mean	9.31	2.5	-12.72	-14.57	5.06
	Number	22	22	22	21	5
	SE	6.76	3.32	9.35	6.29	8.25

Analysis was done in Minitab V13.30 using a General Linear Model (GLM) to see if there was any relationship between growth and bush remnant, season, treatment, control and rabbit score. The data was split into ten groups by species to see if individual species were affected by the factors being tested.

To overcome species with a few or one representative in the trial, two categories were created for the analysis, depending upon how many of these plants existed in both treatment and controls.

Category 1: Species with more than five but less than ten from all bush remnants. This category is identified in the calculations as plant nine and consists of the species *Lophomyrtus obcordate* and *Knightia excelsa*.

Category 2: Species with less than five individuals in all remnants. This category is identified in the calculations as plant ten consisting of the species *Nestegis cunninghamii*, *Lophomyrtus bullate*, *Myrsine australis*, *Prumnopitys taxifolia* and *Laurelia novae-zelandiae*.

Species one in the calculations consisted of individuals that were consumed, died or destroyed (by wire removal in Himatangi Block Scientific Reserve) before accurate identification were possible. This species group were not discussed in the results and conclusion sections.

4:1:3. Results.

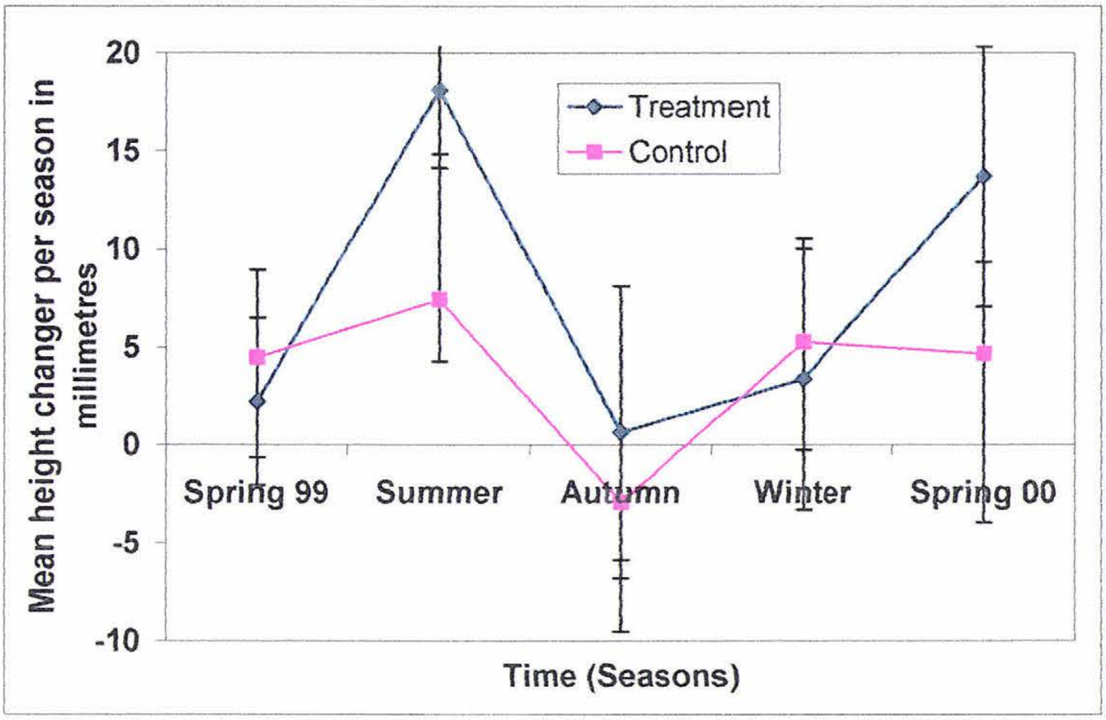
For species two (*Coprosma grandifolia*) (Graph XIII, page 111) there were no significant rabbit (P=0.075) effect but a significant season (P=0.000), Treatment and control effect (P=0.000) and a significant bush remnant effect (P=0.008)

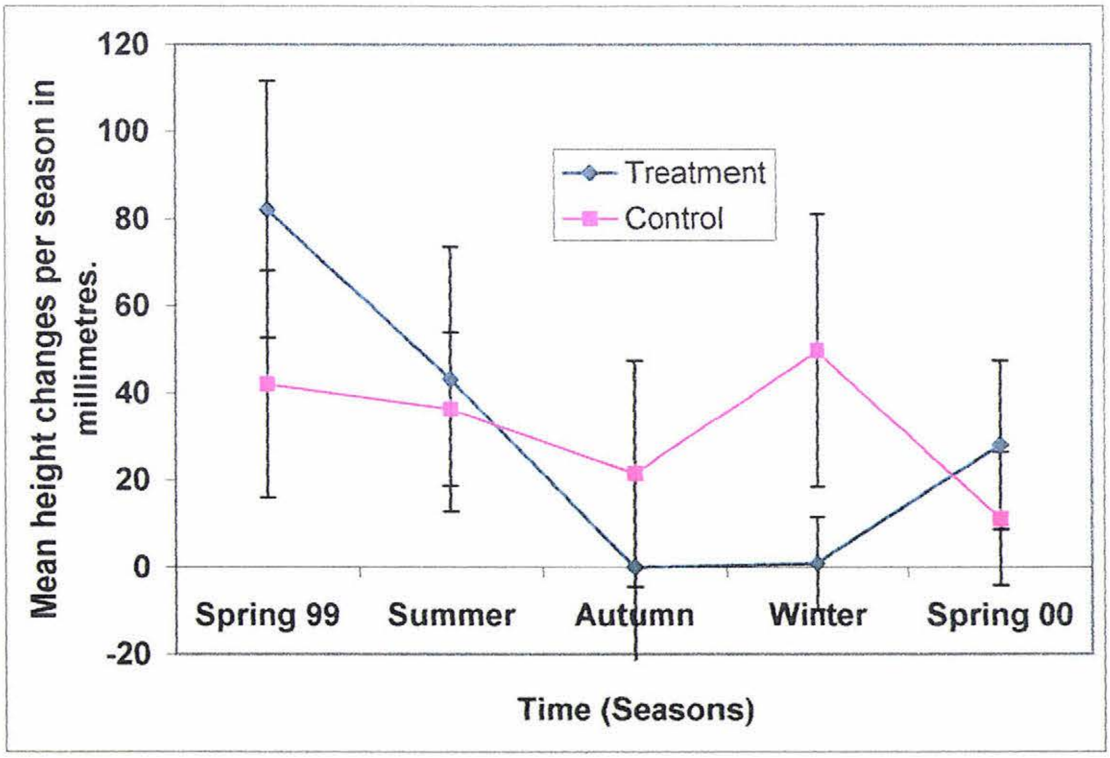
Species three (*Macropiper excelsum*) (Graphs VII, VIII & X, pages 105, 106 &108), species four (*Hoheria populnea*) (Graphs VI,XII, pages 104 & 110), species six (*Hedycarya arborea*, Graph IX, XI & XIV, page 107, 109 & 112)) and species eight (*Alectryon excelsus*) (Graphs VI, XII & XIV, pages 104, 110 & 112) all have significant results for bush remnant, rabbit, treatment / control and season (P=0.000) while species five (*Parsonia heteraphyalla*) (Graph IX, page 107) has no treatment / control effect (P=0.056) or bush remnant effect (P=0.224) but show a rabbit and a season effect (P=0.000).

Species seven (*Beilschmiedia tawa*) (Graphs VII, VIII XIII, & XV, pages 105, 106, 111 & 113) show a rabbit (P=0.012) bush remnant and season (P=0.00) respectively but no treatment / control effect (P=0.585).

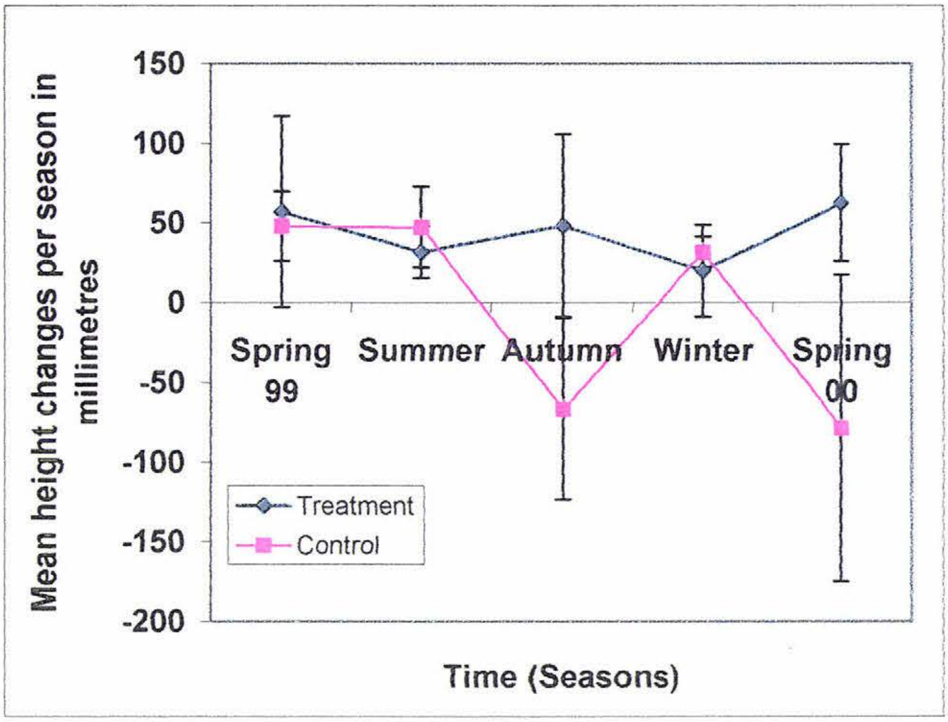
Species group nine (*Knightia excelsa* (Graph X, page 108) & *Lophomyrtus obcordate*, (Graph XI, page 109)) shows no rabbit effect but does show an effect for bush remnants (P=0.043) and a season and treatment / control effect (P=0.000) respectively.

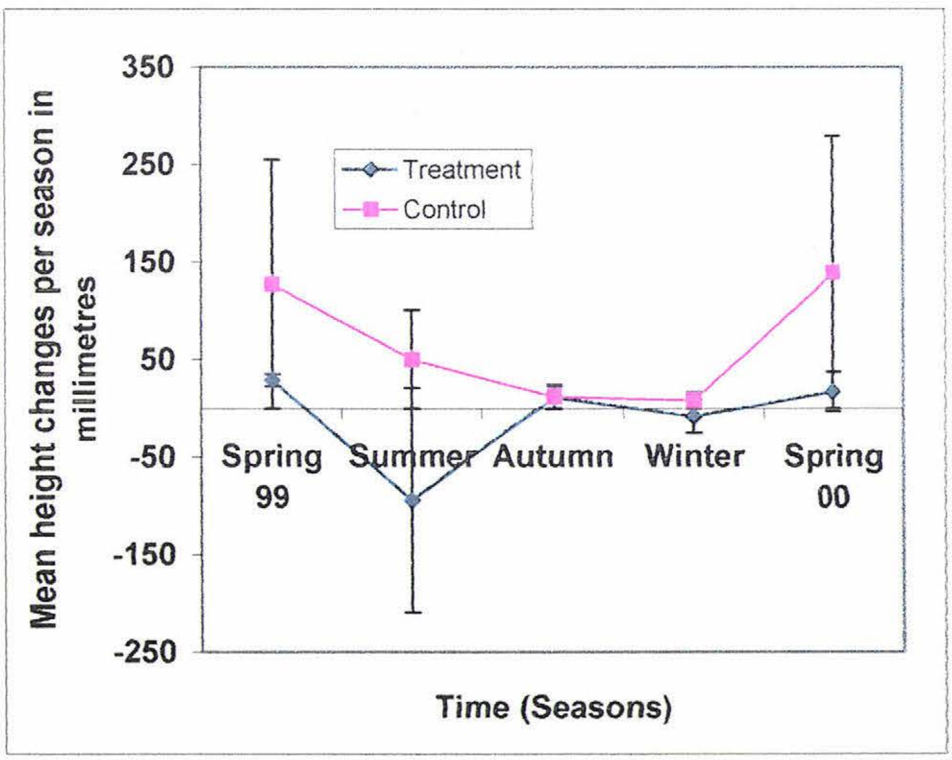
Minitab was unable to perform a calculation on the data for species group ten.



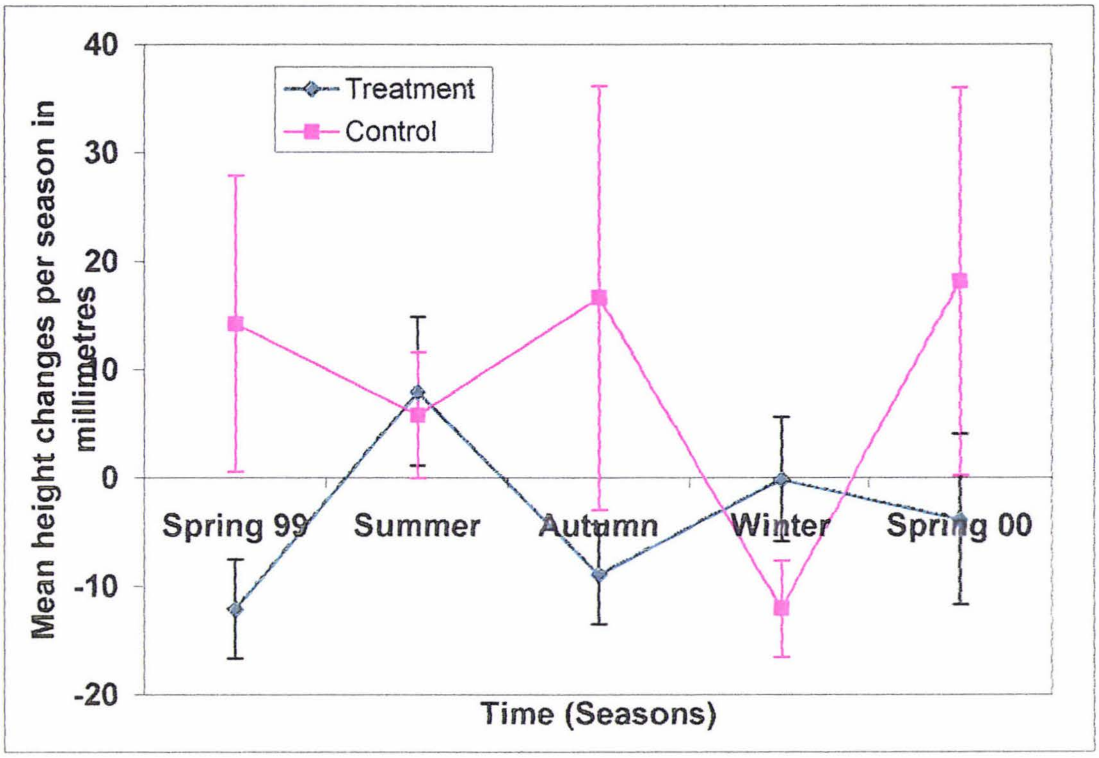


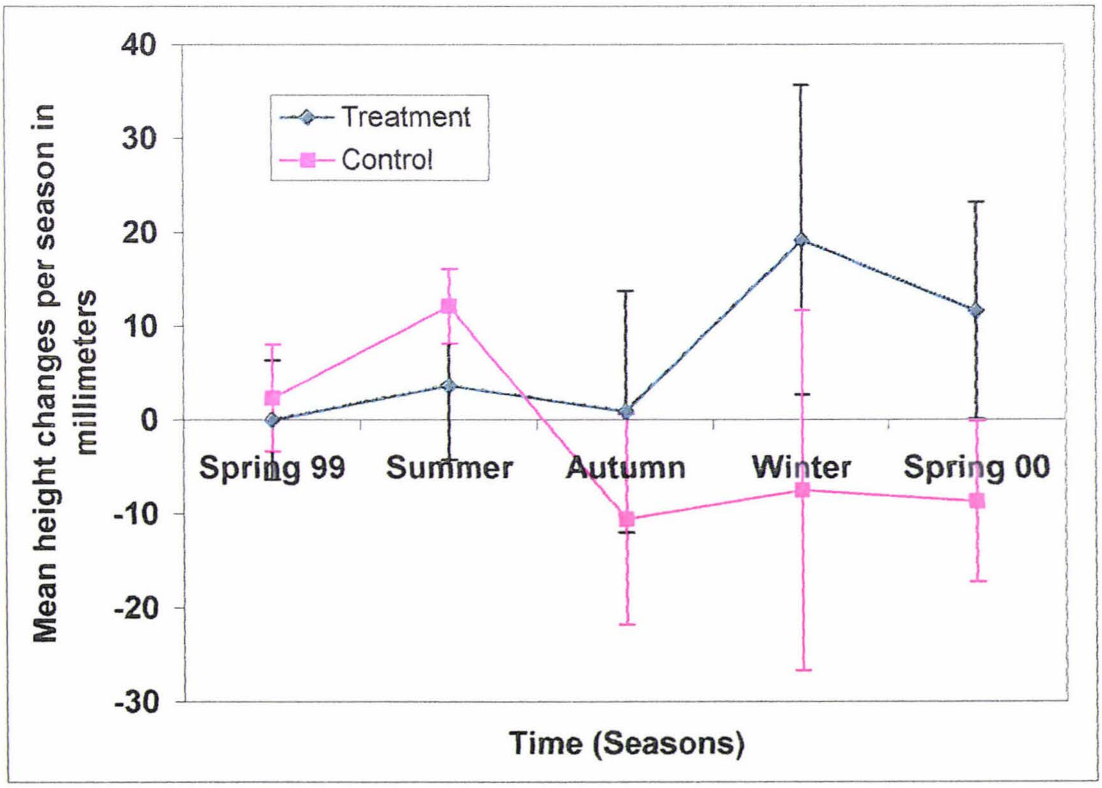
Graph VI: Seasonal growth changes for *Alectryon excelsus* (top) *and Hoheria populena* (bottom) at Legg Estate bush remnant in the seedling survival trial August 1999 to December 2000.



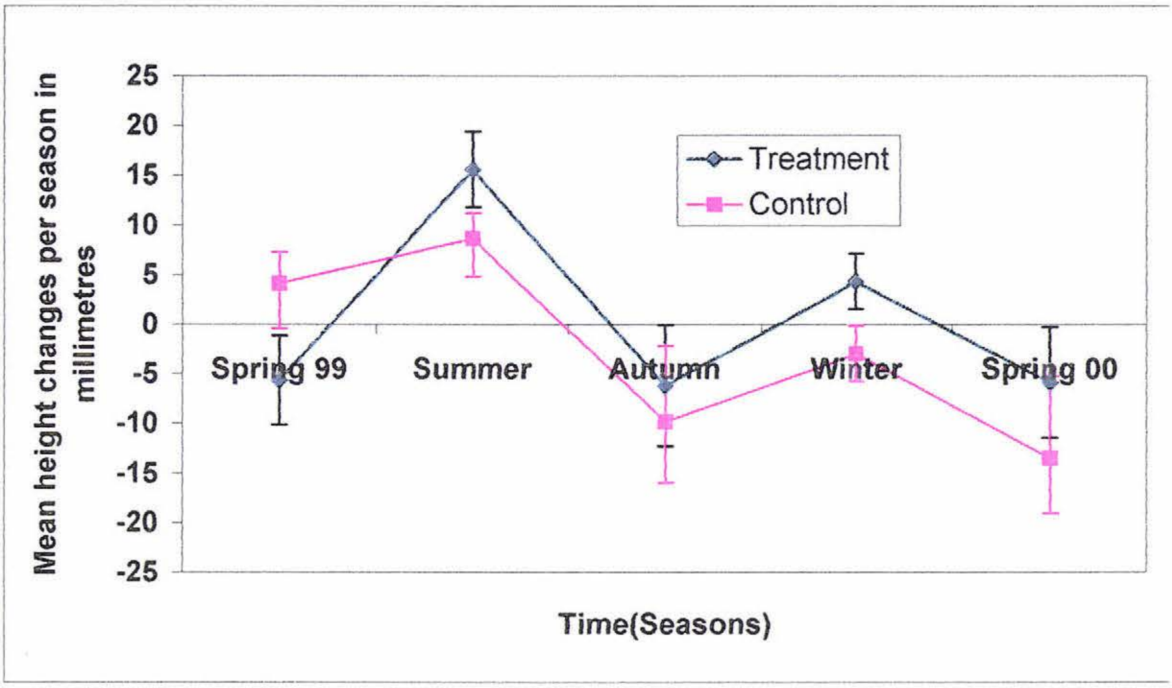


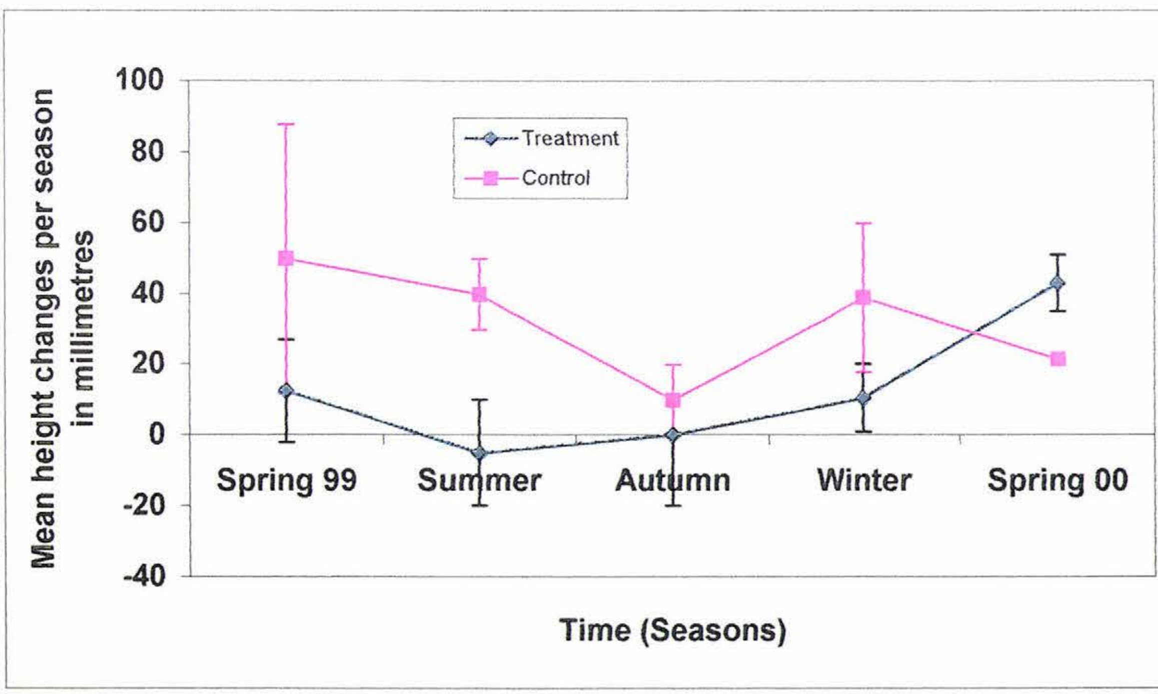
Graph VII: Seasonal growth changes for *Macropiper excelsum* (top) and *Beilschmiedia tawa* (bottom) at Legg Estate bush remnant in the seedling survival trial August 1999 to December 2000.



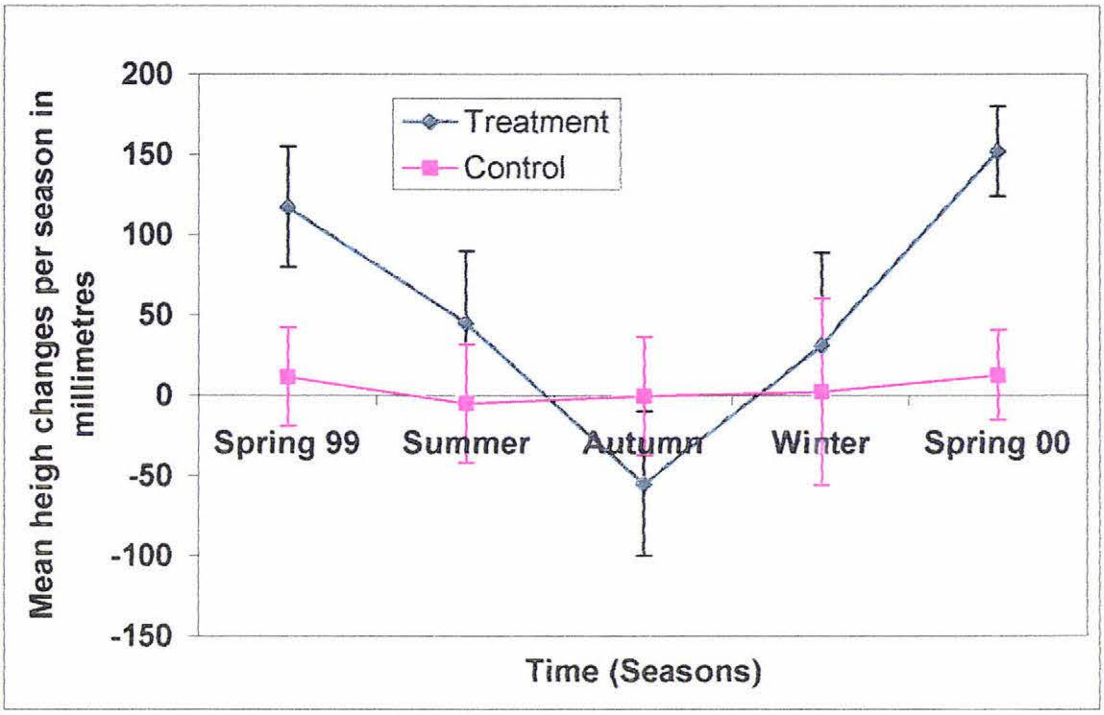


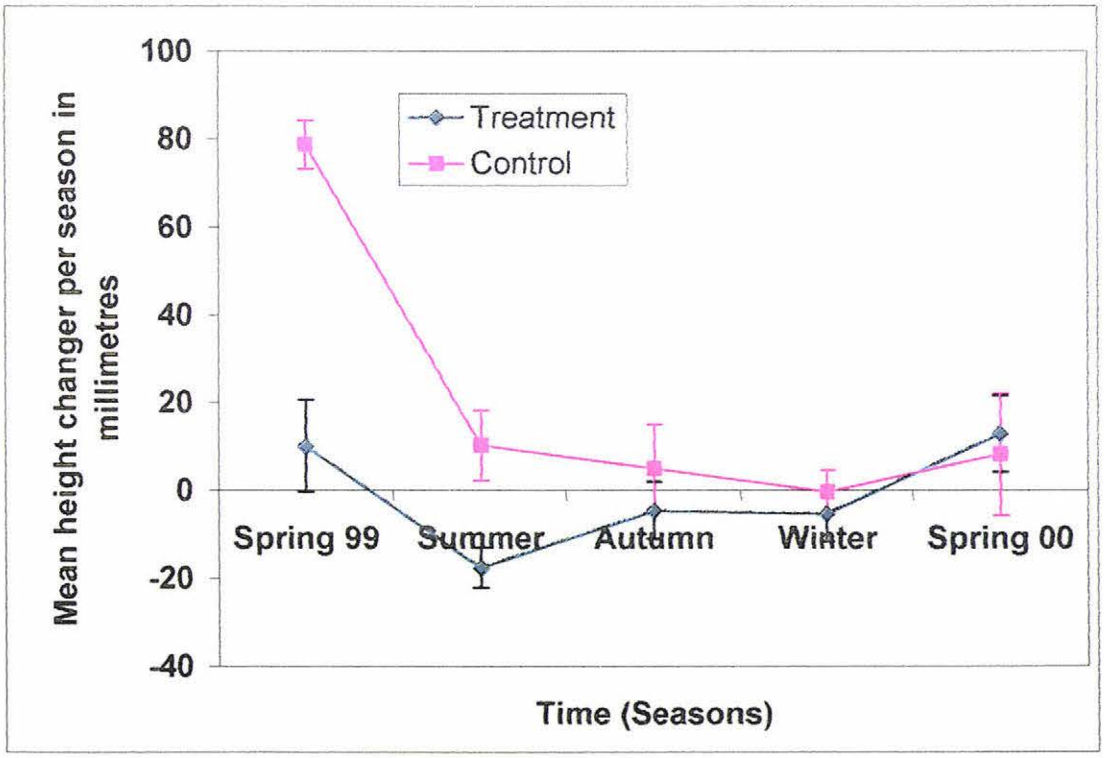
Graph VIII: Seasonal growth changes for *Beilschmiedia tawa* (top) and *Macropiper excelsum* (bottom) at Himatangi Block Scientific Reserve in the seedling survival trial August 1999 to December 2000.



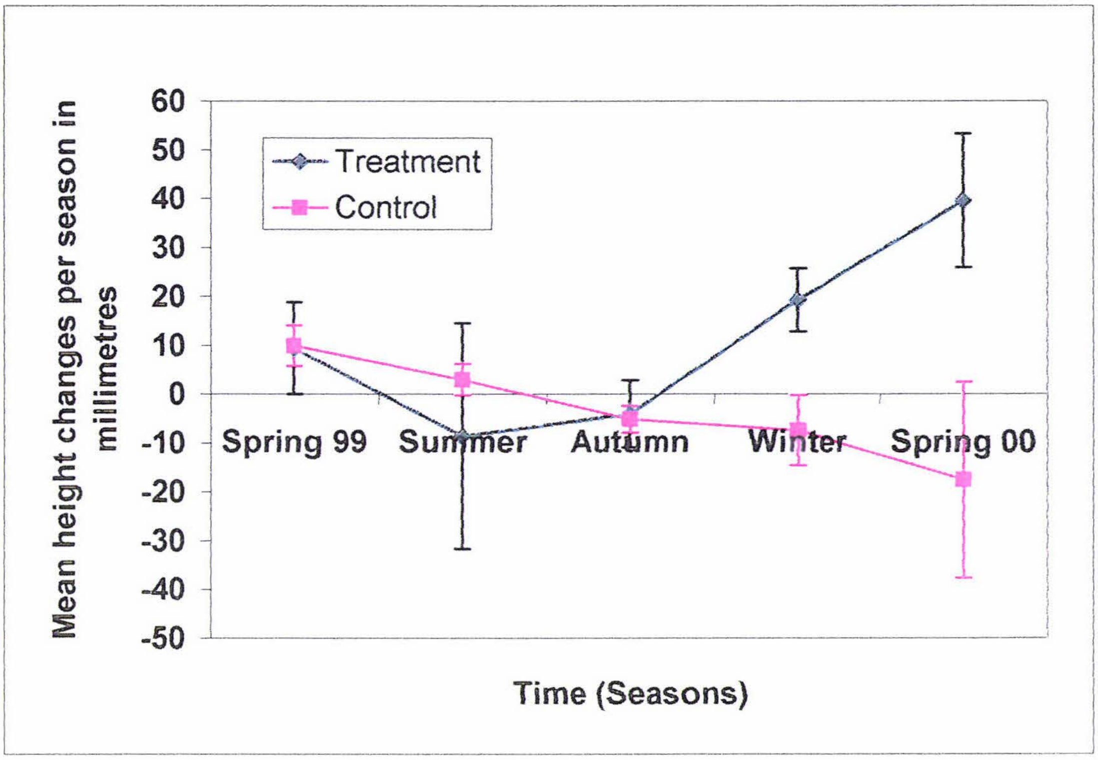


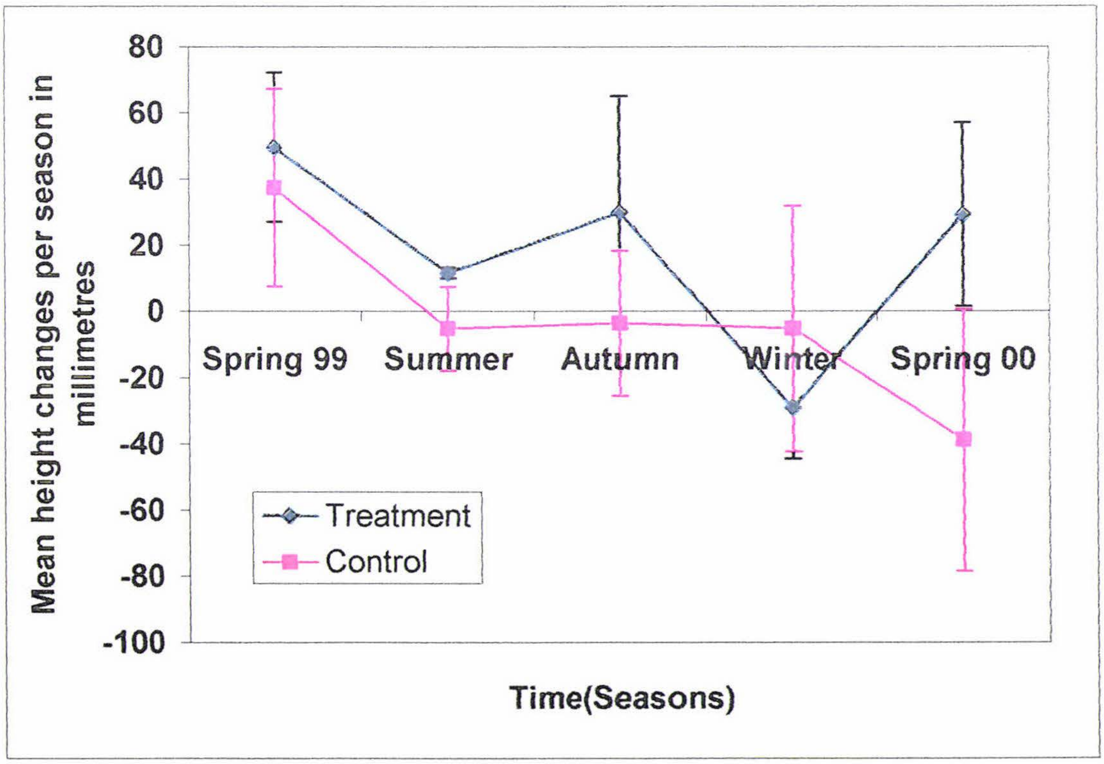
Graph IX: Seasonal growth changes for *Hedycarta arborea* (top) *Parsonia heteraophyalla* (bottom) at Himatangi Block Scientific Reserve in the seedling survival trial August 1999 to December 2000.



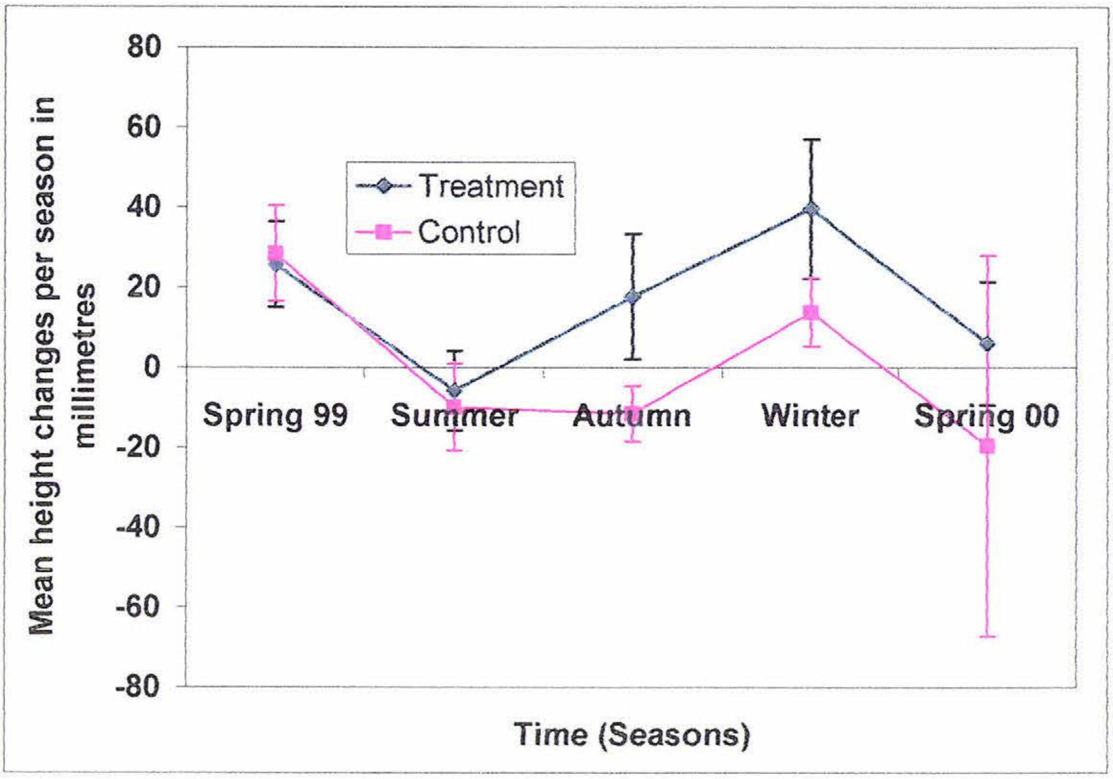


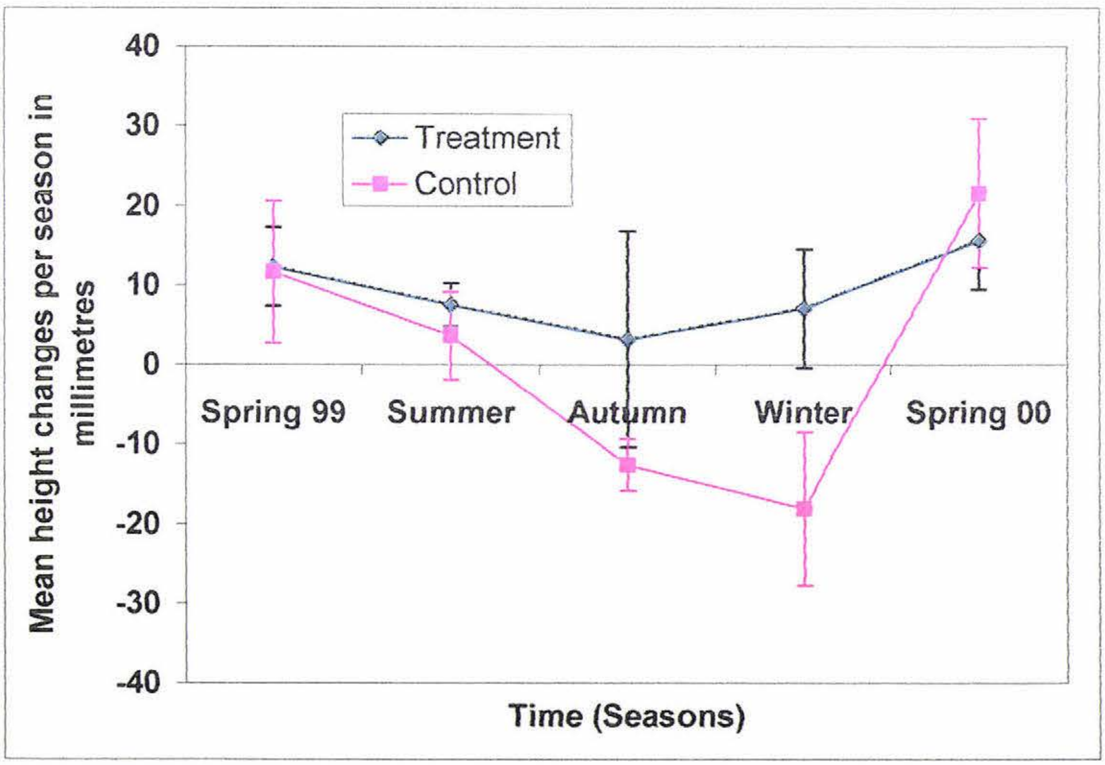
Graph X: Seasonal growth changes for *Knightia excelsa* (top) and *Macropiper excelsum* (bottom) at Monkton's bush remnant in the seedling survival trial August 1999 to December 2000.



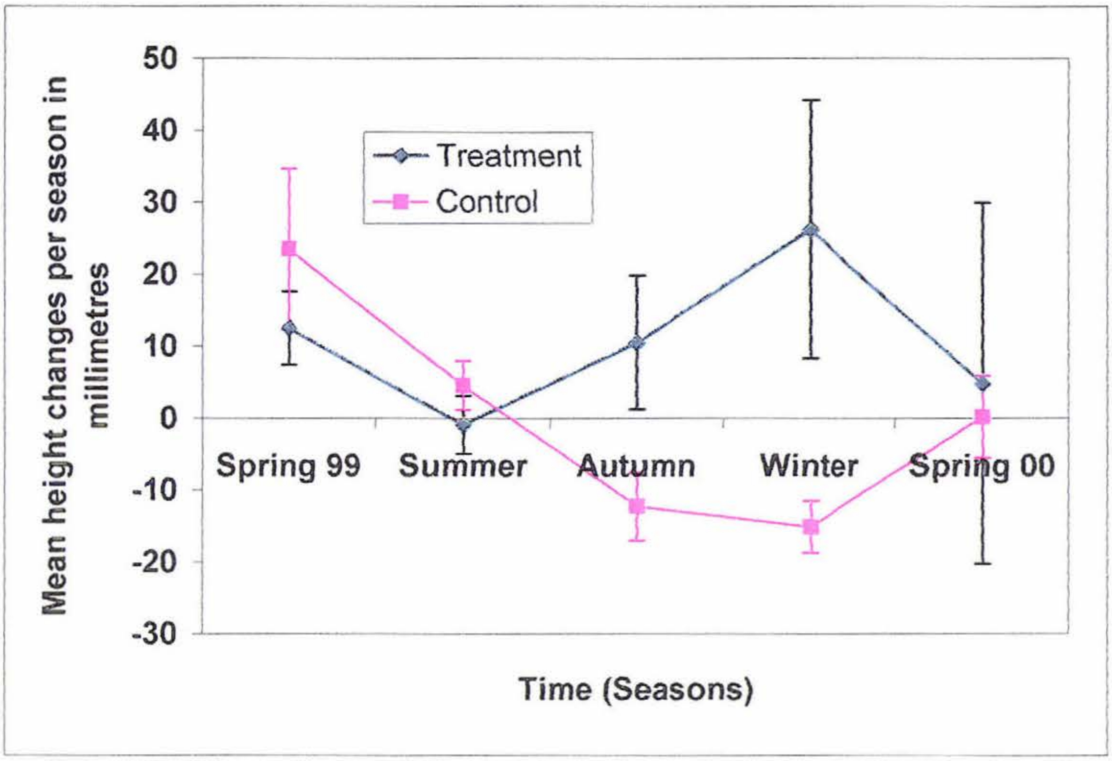


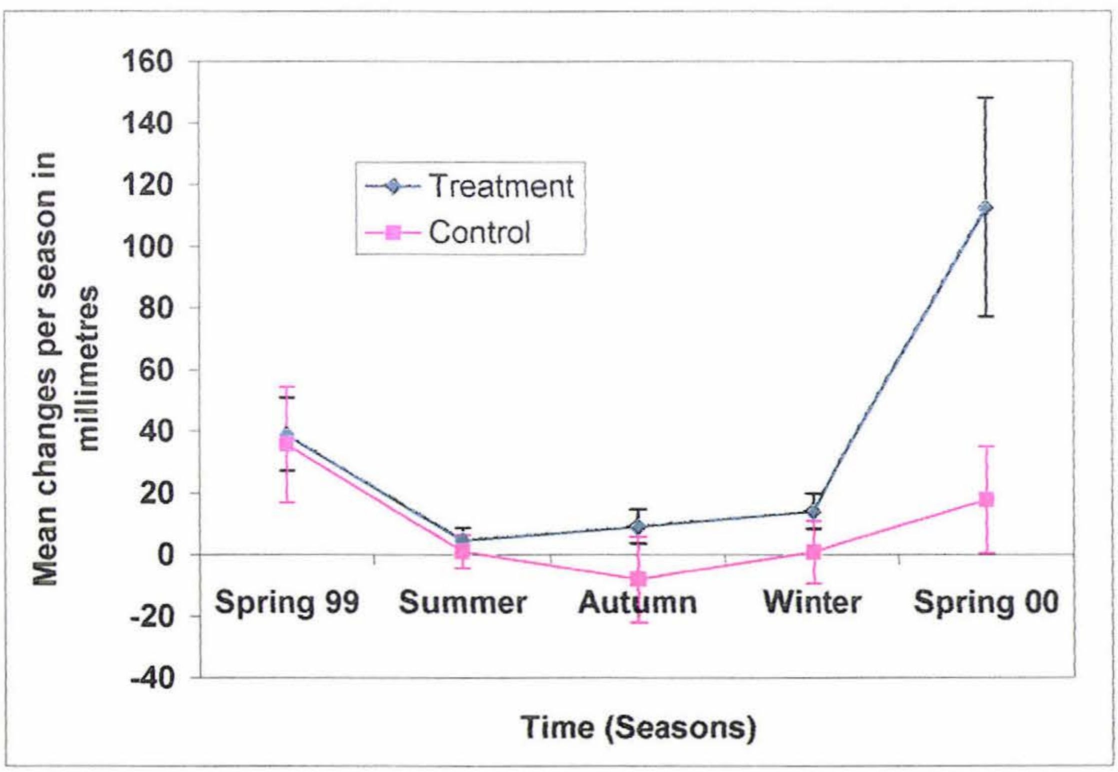
Graph XI: Seasonal growth changes for *Hedycarya arborea* (top) and *Lophomyrtus obcordate* (bottom) at Monkton's bush remnant in the seedling survival trial August 1999 to December 2000.



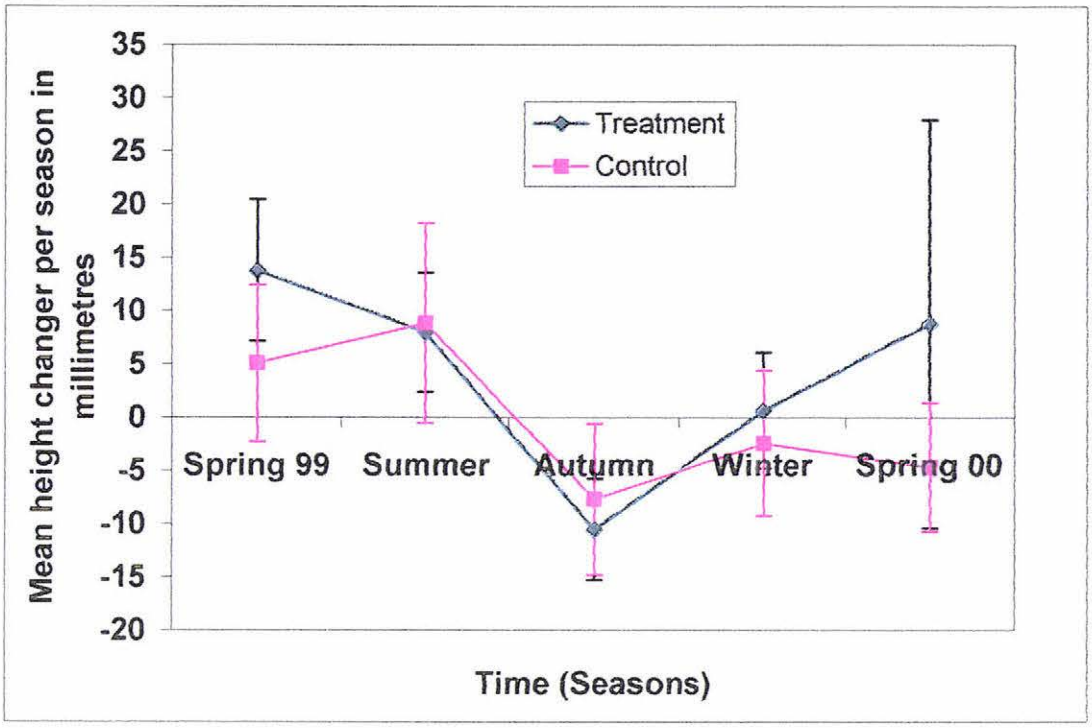


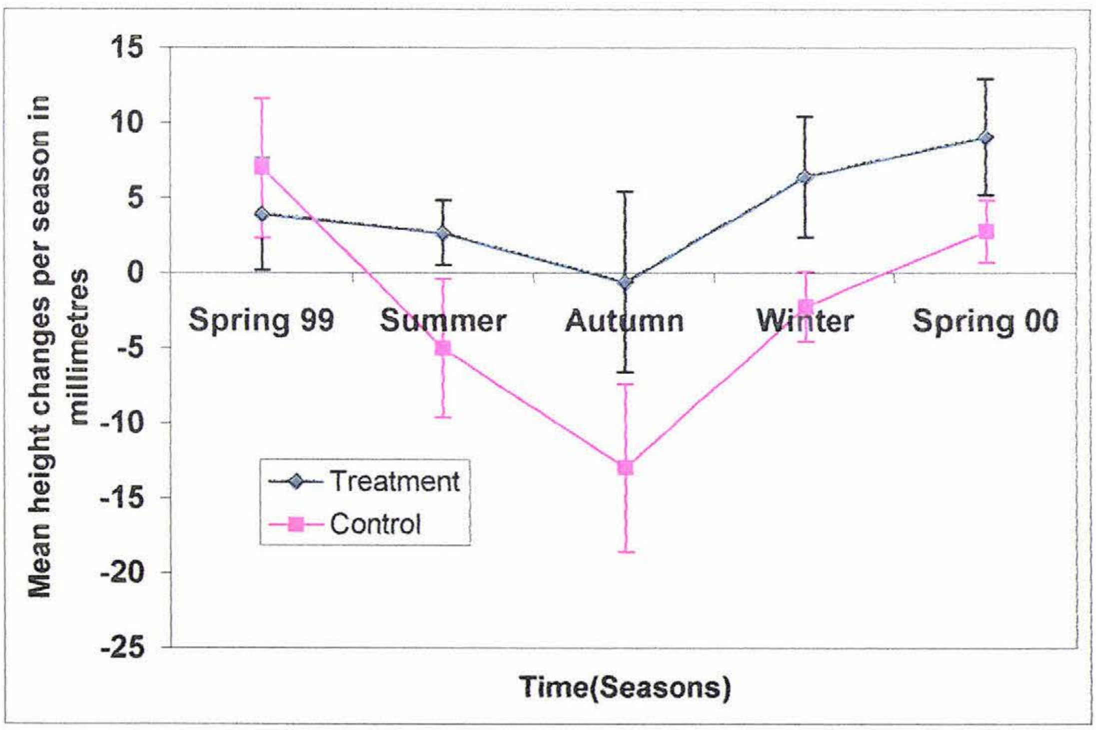
Graph XII: Seasonal growth changes for *Hoheria populnea* (top) and *Alectryon excelsus* (bottom) at Monkton's bush remnant in the seedling survival trial August 1999 to December 2000.



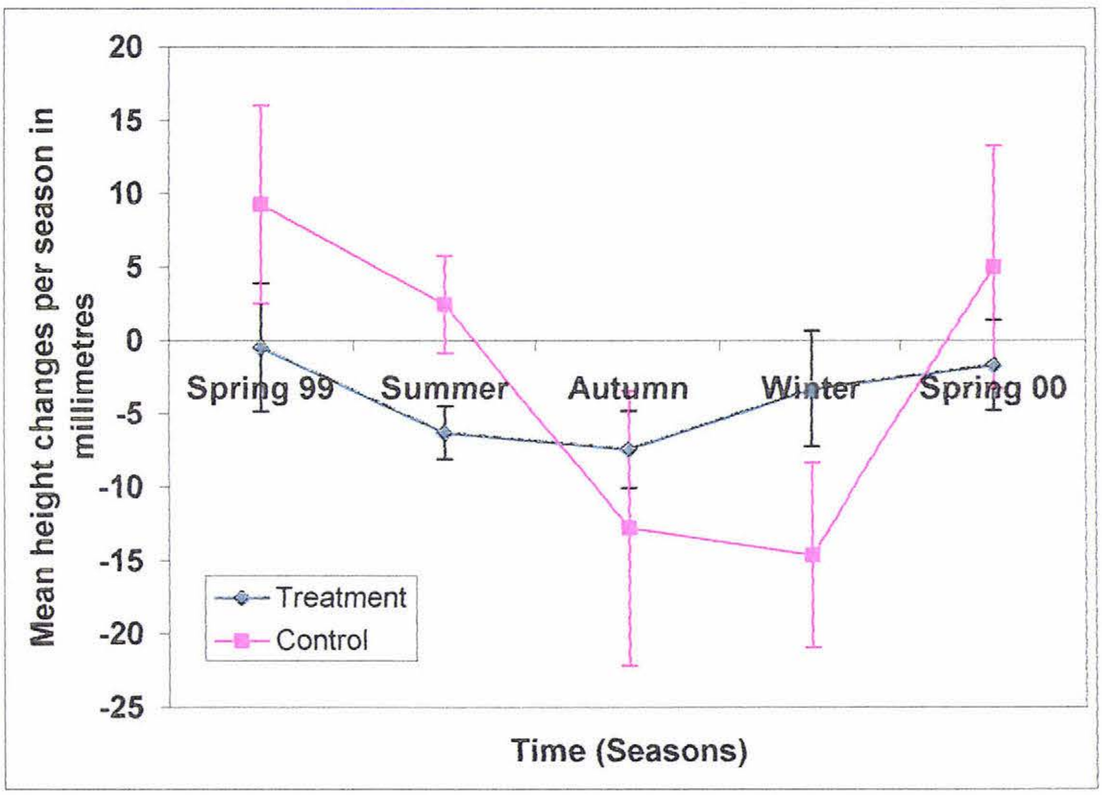


Graph XIII: Seasonal growth changes for *Beilschmiedia tawa* (top) and *Coprosma grandifolia* (bottom) at Monkton's bush remnant in the seedling survival trial August 1999 to December 2000.





Graph XIV: Seasonal growth changes for *Alectryon excelsus* (top) and *Hedycarya arborea* (bottom) at Fulleton-Smith bush remnant in the seedling survival trial August 1999 to December 2000.



Graph XV: Seasonal growth changes for *Beilschmiedia tawa* at Fulleton-Smith bush remnant in the seedling survival trial August 1999 to December 2000.

4:1:4. Conclusions.

The analysis of the data was able to show trends in growth over the four bush remnant sites within the five seasons and show trends of growth within species as function of rabbit grazing.

The general linear model looked at the growth per season in each bush remnant and with rabbit scores and whether each plant was in a treatment / control and weighted this against the varying numbers of each species and how they were distributed over the four bush remnants and through the treatments and controls within each bush remnant.

The assumption is that all remnants, seasons, treatment / control and rabbit date is equal at all sites. With P values greater than 0.05 that indicated that although there are some variations between the variables being tested they were not enough to reject the hull hypothesis and accept the alternate hypothesis (Moore & McCabe, 1993) and with P values less that 0.05 show that there are significant differences and we accept that the tested variables are different over the four bush remnants.

As each species had varying patterns of distribution within each forest and between each forest this affected its probability and quantity of inclusion within the treatment or control, its physiological make up was likely to affect its palatability to rabbit and its survivability through the varying conditions within each season at each of the four bush remnants.

As each bush site had been classified as a different type (Table I, page 36) and as each had differing histories of degradation coupled with varying levels of rabbit these variations show up in the results.

The size of the remnants also varied as do the species composition and number of members of species.

These differences showed up in the results and explained the differences seen and the results that deviate from the null hypothesis.

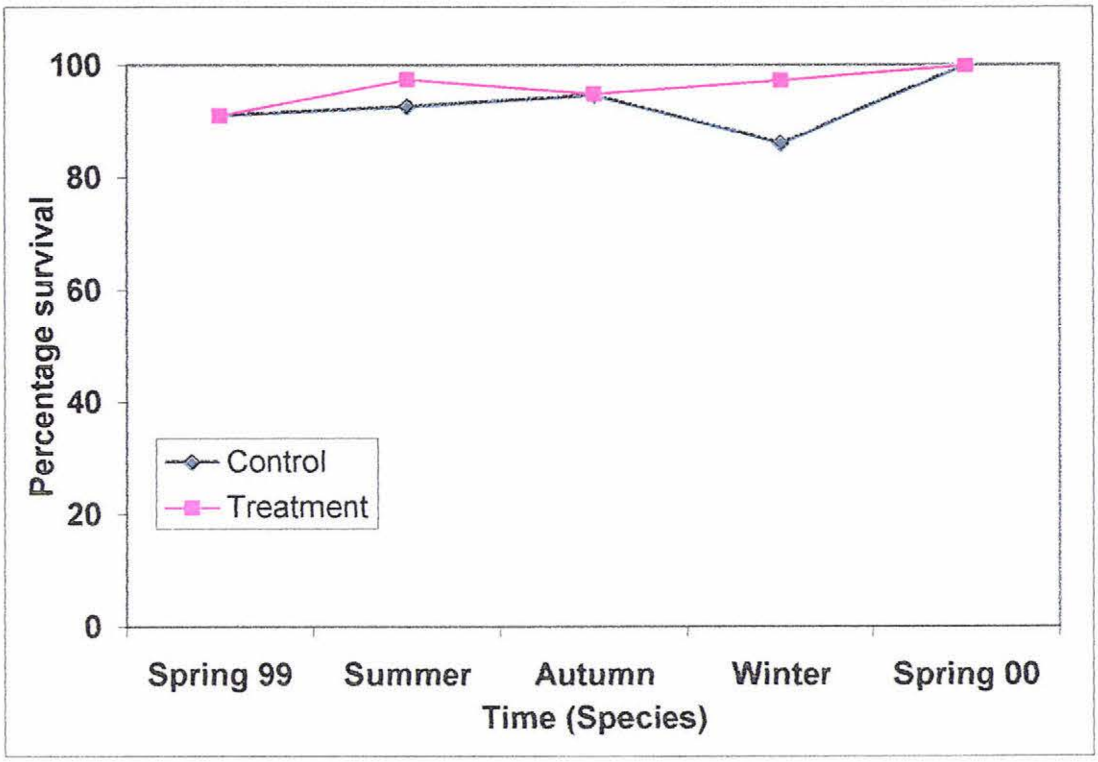
Species three (*Macropiper excelsum*) was a primary coloniser and presented in all four sites in high numbers, there was no effect to the four variables being tested by the model. Its presence was usually evident in disturbed bush remnants and established a cover for the germinating seedlings that will form the mature canopy. These species are important in the repair of slip faces and breaks in the remnant and in new lands which the forest was colonising and will given time become extinct within the interior of long standing remnants but will be common at the exterior of most bush remnants.

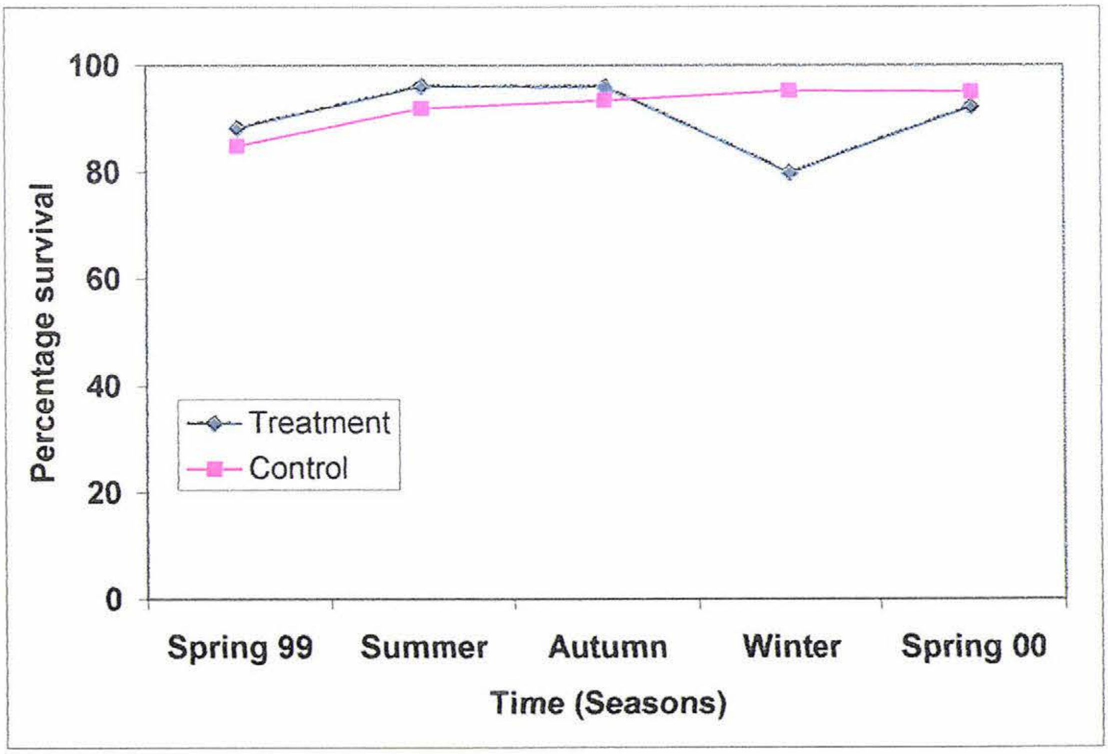
4:2:1. Seedling survival.

This model was looking at seedlings deaths per season within the treatments and controls. Results for each season were treated as a separate trial with the survival at the end of one season being rolled over to the start of the next season. As there were four bush remnants nested within two regions this also was incorporated in the model. Values for rabbit per season (see table I, page 16) were also included within the model

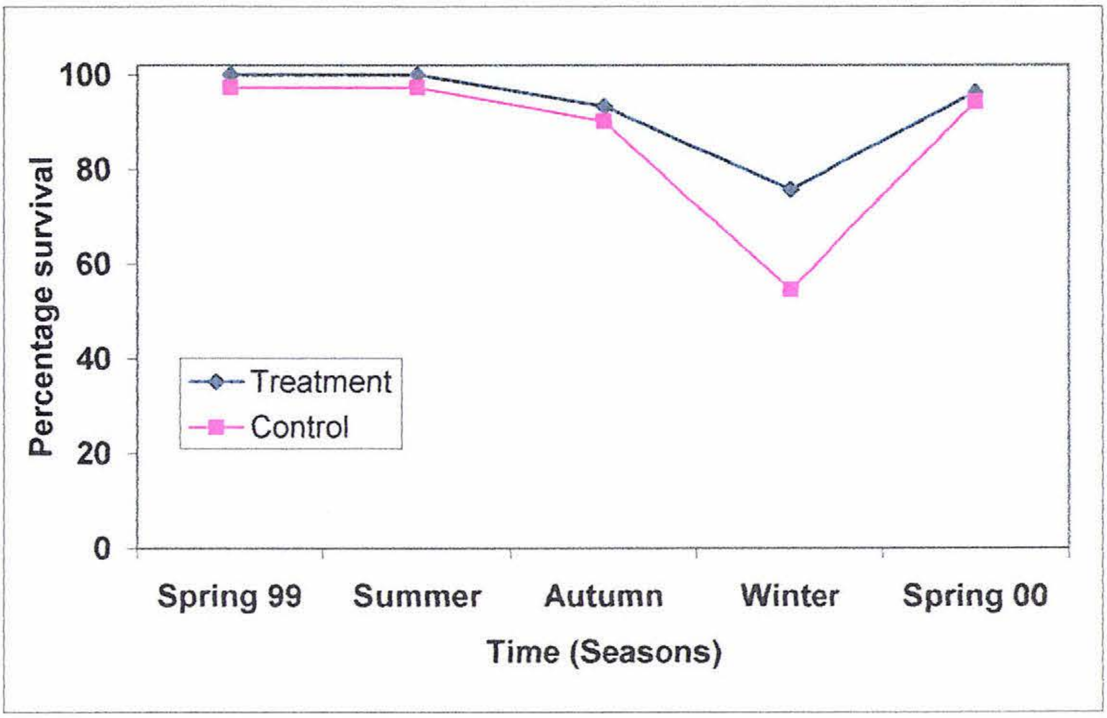
4:2:2. Results.

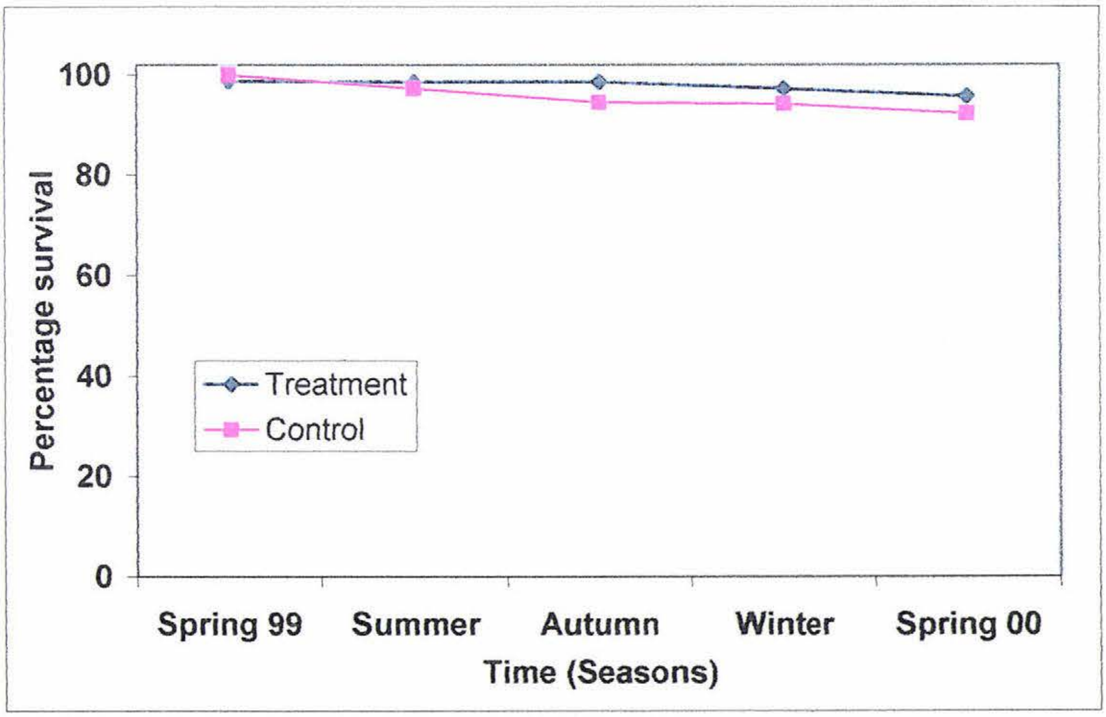
A logistical regression was run in SAS version 8.2 and showed significant results for season ($P<0.0001$), treatment and controls ($P=0.0002$) and bush remnants nested within regions ($P=0.0050$). There appears to be no region effect ($P=0.6405$) or rabbit effect ($P=0.9438$). Treatments appear to do better than controls when displayed graphically. Graph XVI, page 117 shows treatment versus controls for the sand country sites while graph XVII, page 118 shows results for the inland country sites.





Graph XVI: Seedling survival per season at Legg Estate bush remnant (top) and Himatangi Block Scientific Reserve (bottom) in the sand country area in the Manawatu region, North Island, New Zealand from spring 1999 to spring 2000.





Graph XVII: Seedling survival per season at Monkton's bush remnant (top) and Fulleton-Smith bush remnant (bottom) at the inland sites the Rangitikei region, North Island, New Zealand from spring 1999 to spring 2000.

4:2:3. Conclusions.

The use of a treatment enhances seedling survival. At Legg Estate bush remnant treatments do better than controls and this is consistent over the five seasons. There are major losses from the controls during winter at a time when rabbit scores are at their highest (Table I, page 16). At Himatangi Block Scientific Reserve treatments do better than controls except of winter and spring 2000 where treatment survival falls below control survival. As rabbits do not have access to the treatments we cannot explain this result on rabbits. Table I, page 16 shows a relatively constant rabbit presence from summer 2000 to spring 2000.

At the inland bush remnants where there are different values for rabbit presence treatments do do better than the controls. At Fulleton-Smith bush remnant the differences are constant through each of the five seasons reflecting relatively constant rabbit presence values for each of the seasons. The first three seasons score a value of one while the last two seasons score values of three. This indicates rabbit pressure is constant through the seasons. The presence of the family dogs would deter most of the feral predators. My own experiences on my guardians' farm show the rabbits and dogs do coexist very well together and that our house cat often made little difference to the adult rabbit's presence around the farm buildings. I had often shot rabbits within metres of the dog kennels and from the back door step of my guardians' house. I caught no feral cats around my guardian's house, they were caught from some four hundred metres from the nearest farm buildings.

Monkton's bush remnant is surrounded by tidy paddocks and is at some 200 metres from the family farmhouse where their dogs are chained up when not in use. Compared with Fulleton-Smiths dogs which are off the chain when not working and the surrounding country side has many bush remnants and scrub on hill sides as it is more hilly and has many isolated pockets of vegetation and fallen branches which are used by rabbits for shelter and breeding.

My own experiences hunting on my guardians' farm support this as most rabbits shot and trapped were in the messy weedy eastern section of the farm. Few rabbits were shot on the clean and tidy pastures on the western side of the farm. Here mainly hares were shot and note that hares were seen frequently around Monkton's bush remnant and noting the behaviour of one animal, I assumed it was a doe with young. Feral cats were seen in daylight at Monkton's bush remnant in spring 1999 and personal conversations with farm staff indicate resident feral cats within the remnant.

My own experiences in pest control suggest that constant pressure on rabbits is essential to maintain them at low levels. With the HVCA bush remnants on private land incentives to reduce rabbits to low levels could improve seedling survival. Control of other phytophagous mammal species would also provide benefits and as possum control is in place at three of the remnants, the exclusion of sambar deer could provide benefits in the longer term. Whatever method is used to control pest species it would have to be adapted to suit the landscape, the numbers of pests present as well as the numbers of predators present.

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CHAPTER 5

Final discussion

5. Discussion.

The aim of the seedling survival trial was to see if rabbits did impact upon seedling survival and to try to get an indication of the magnitude of this impact. Other factors were also investigated that had a bearing upon seedling survival.

The fate of seedlings is determined by many factors acting in unison. These factors can be divided into two groups, biotic or abiotic. The biotic factors considered in this work are the production of seed, seed strike, post strike growth and rabbit grazing. The abiotic factors considered were light availability within and on the bush remnants, and moisture at the zone of seedling germination.

This trial was run during a time of low rabbit numbers brought about by the introduction of RHD within the region. This certainly had an impact upon the results obtained especially at the sand country sites and would give results that would not necessarily reflect the processes operating in the pre RHD period when the original concerns about the activities of rabbits were expressed.

The trial was set up within two distinct soil types and four vegetation types. The sand country soil type is a recent yellow-brown sand (Cowie & Rijkes, 1977) while in the inland sites the soil type was yellow-brown loams (Campbell, 1979), indicating a longer time in development than the sand country soil. Each bush remnant was of a different vegetation type. It is very likely that human harvesting has played an important part in the development of the climax communities in each bush remnant, rather than their being the result of differing natural processes operating through time. Soil types, existing vegetation, climate, human activity and predator pressure will have an impact on existing rabbit populations. Within the four trial sites, an ANOVA test indicates that there are three different rabbit populations within the trial areas.

The sand country sites and each of the inland sites appear to have differing constraints acting upon the resident rabbit populations.

Parts of the sand country area are Tb vector control areas and are subject to the control of ferrets and feral cats as vectors of Tb. This has the negative spin off, of higher rabbit survival (Hocking, pers. comm.) as, under normal circumstances predation here could act as, top down control of the rabbit populations (Reddiex, 2003).

The sand country soil drains easily, which is ideal for juvenile rabbit survival but also drains moisture out of the zone of germination to the detriment of seedling survival. Compounding this is the hydrophobic nature of the sand country soils (Wallis, 1978) which directly affects seedling strike and survival. This phenomena places vital water resources out of reach of, the seedlings resulting in a high seedling death rate.

The inland sites have good rainfall but the soils are heavier and older than that of the sand country sites. Both bush remnants have a good seedling strike along the remnant edge. This is very evident at Monkton's bush remnant where the western end was fenced seven years ago and the seedling strike here is very high by comparison to the eastern end where livestock still have access to the remnant for shelter. By contrast Fulleton-Smith bush remnant has had many decades of stock exclusion and there are dozens of trees several meters tall unlike Monkton's bush remnant where none of this height are present.

With all ecosystems, many factors contribute to observed trends and it is wise to be cautious in, ascribing a culprit, for, 'lack of regeneration'. There is no doubt that rabbits do impact upon seedling survival but to how much and whether this varies across the region was what I set out to discover. The treatment effect does improve seedling survival, but whether the trial is significant enough to warrant being used as a management tool is debatable.

Compounding this are new lower levels of rabbit numbers across the region especially the sand country, as a result of the introduction of RHD. Rabbit exclusion may now not be a viable option, but using selective control measures at the appropriate time be able to mitigate seedling loss. The data seem to suggest that this would be effective during the winter months and would be most appropriate at Legg Estate and Monkton's bush remnants. Appendix 6, page 138 shows presence absence scores until December 2004 for the Legg Estate bush remnant. These results are not discussed within the body of the test but as a supplement.

As for other pest species, I collected no data on possum and sambar deer presence or set up any trial to gain indications of their impacts. Possum is present in all four bush remnants and with regional controls on this species it is very unlikely that they would be at carrying capacity at three of the four bush remnants. Monkton's bush remnant did not have a pulse-poisoning programme for possums during the time of the trial, but could have farm staff shooting as a recreational activity.

Sambar deer was or are present at three of the four sites and no doubt feed within these bush remnants as well as hiding up during the day.

OA horizons and soil moisture levels are a concern for the sand country sites and although the OA horizons trial did not yield any significant data from which management decisions could be made. Fluctuating moisture levels especially rapidly fluctuating but decreasing moisture levels in the OA horizons over the late spring, summer and early autumn would leave seeds in initial stages of germination with insufficient moisture to survive. Even larger seedlings at about a year of age would face serious survival problems during this period of moisture stress. This is what I feel is the case at Legg Estate bush remnant, compounded by rabbits presence, remnant size and shape and the intermittent visit of sambar deer.

In the sand country bush remnants removal of seeds and small seedlings to be grown up artificially and then transplanting back into the remnant would be of some benefit. These plants then provide resources for the rabbits and deer. There is some discussion by the Legg Estate land owners (Coulter, pers. comm.) to get money to exclude sambar deer. Exclusion of rabbits is viable but expensive but mammal exclusion would only mitigate the mammal impact and not deal with the soil moisture deficit which is a serious concern during the summer months. At Monkton's bush remnant, possum control would help along with hare shooting and exclusion of sambar deer. Rabbits seem to be a problem at Fulleton-Smith bush remnant and at the family flower garden (Fulleton-Smith, pers. comm.) and here the best control would be shooting as judging by the number of wads and shattered disks seen next to this bush shooting is something the family enjoy.

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APPENDICES I -VI

APPENDIX I

Plants used in the trial

Kanono	*Coprosma grandifolia*
Kawakawa	*Macropiper excelsum*
Lacebark	*Hoheria populnea*
Maire	*Nestegis cunninghamii*
Mapau	*Myrsine australis*
Miro	*Prumnopitys taxifolia*
New Zealand Jasmine	*Parsonia heterophyalla*
Pigeonwood	*Hedycarya arborea*
Pukatea	*Laurelia novae-zelandiae*
Ramarama	*Lophomyrtus bullata*
Rewarewa	*Knightia excelsa*
Rohutu	*Lophomyrtus obcordate*
Tawa	*Beilschmiedia tawa*
Titoki	*Alectryon excelsus*

Other Plants Mentioned

Bush Lawyer	*Rubus cissoides*
Cabbage Tree	*Cordyline australis*
Clematis	*Clematis spp.*
Coprosma	*Coprosma spp.*
Flax	*Phormium tenax*
Kahikatea	*Dacrycarpus dacrydioides*
Kaikomako	*Pennantia corymbosa*

Lemonwood	*Pittosporum eugenioides*
Lancewood	*Pseudopanax crassifolius*
Manatu	Plagianthus regius
Manuka	*Leptospermum scoparium*
Mahoe	*Melicytus ramiflorus*
Monterey Pine	*Pinus radiata*
New Zealand Passionfruit	*Tetrapathea tetrandra*
Rata	*Metrosideros robusta*
Rimu	*Dacrydium cupressinum*
Supplejack	*Ripogonum scandens*
Poroporo	*Solanium aviculare*

Weeds

Banana Passionfruit	*Passiflora mollissima*
Blackberry	*Rubus fruticosus agg.*
Buddleia	*Buddleia davidii*
Californian Thistle	*Cirsium arvense*
Cats Ear	*Hyochaeris radicata*
Cathedral Bells	*Cobaea scandens*
Chick Weed	*Stellaria media*
Dandelion	*Taraxacum officinale*
Elder	*Sambucus nigra*
Fleabane	*Conzya spp.*
Groundsel	*Senecio vulgare*
Gorse	*Ulex europaeus*
Nightshade	*Solanum nigerum*
Ivy	*Hedera helix*
Periwinkel	*Vinca major*
Red Root	*Amaranthus powelli*

Scotch Thistle	*Cirsium vulgare*
Sedges	*Carex spp.*
Tall Fescue	*Festuca arundinacea*
Wandering Jew	*Tradescantia fluminensis*
Willow Weed	*Polygonum spp.*
Yorkshire Fog	*Holcus lanatus*
Summer grass	*Digitaria sanguinalis*
Selaginella	*Selaginella krussiana*

Mammals

Brown Hare	*Lepus europaeus occidentalis*
Cat	*Felis catus*
Chamois	*Rupicapra rupicapra rucipapra*
Cattle	*Bos taurus*
Dog	*Canis familiaris*
Ferret	*Mustela furo*
Goats	*Capra hircus*
House Mouse	*Mus musculus*
Human	*Homo sapiens sapiens*
Possum	*Trichosurus vulpecula*
Pig	*Sus scrofa*
Rabbit	*Oryctolagus cuniculus cuniculus*
Rat - Norway	*Rattus norvegicus*
- Native	*Rattus exulans*
- Ship	*Rattus rattus*
Sambar Deer	*Cervus unicolor unicolor*
Sheep	*Ovis aries*
Stoat	*Mustela erminea*
Thar	*Hemitragus jemlahicus*
Weasel	*Mustela nivalis vulgaris*

Birds

Blackbird	*Turdus merula*
Native Woodpigeon	*Hemiphage novaeseelandiae*
Rook	*Corvus frugilegus*

Insects.

Rabbit Flea	*Spilopsyllus cuniculi*

Bacteria.

Bovine Tuberculosis	*Mycobacterium tuberculosis*

Scientific and common names of species mentioned in this work.

APPENDIX II

p / ν	0.995	0.99	0.975	0.95	0.10	0.05	0.025	0.01	0.005	0.001
1	.0000	.0002	.0010	.0039	2.706	3.841	5.024	6.635	7.879	10.828
2	.0100	.0201	.0506	.1026	4.605	5.991	7.378	9.210	10.597	13.816
3	.0717	.1148	.2158	.3518	6.251	7.815	9.348	11.345	12.838	16.266
4	.2070	.2971	.4844	.7107	7.779	9.488	11.143	13.277	14.860	18.467
5	.4117	.5543	.8312	1.145	9.236	11.070	12.833	15.086	16.750	20.515
6	.6757	.8721	1.237	1.635	10.645	12.592	14.449	16.812	18.548	22.458
7	.9893	1.239	1.690	2.167	12.017	14.067	16.013	18.475	20.278	24.322
8	1.344	1.646	2.180	2.733	13.362	15.507	17.535	20.090	21.955	26.125
9	1.735	2.088	2.700	3.325	14.684	16.919	19.023	21.666	23.589	27.877
10	2.156	2.558	3.247	3.940	15.987	18.307	20.483	23.209	25.188	29.588
11	2.603	3.053	3.816	4.575	17.275	19.675	21.920	24.725	26.757	31.264
12	3.074	3.571	4.404	5.226	18.549	21.026	23.337	26.217	28.300	32.909
13	3.565	4.107	5.009	5.892	19.812	22.362	24.736	27.688	29.819	34.528
14	4.075	4.660	5.629	6.571	21.064	23.685	26.119	29.141	31.319	36.123
15	4.601	5.229	6.262	7.261	22.307	24.996	27.488	30.578	32.801	37.697
16	5.142	5.812	6.908	7.962	23.542	26.296	28.845	32.000	34.267	39.252
17	5.697	6.408	7.564	8.672	24.769	27.587	30.111	33.409	35.718	40.790
18	6.265	7.015	8.231	9.390	25.989	28.869	31.526	34.805	37.156	42.312
19	6.844	7.633	8.907	10.117	27.204	30.143	32.852	36.191	38.582	43.820
20	7.434	8.260	9.591	10.851	28.412	31.410	34.170	37.566	39.997	45.315
21	8.034	8.097	10.283	11.591	29.615	32.670	35.479	38.932	41.401	46.797
22	8.643	9.542	10.982	12.338	30.813	33.924	36.781	40.289	42.796	48.268
23	9.260	10.169	11.689	13.090	32.007	35.172	38.076	41.638	44.181	49.728
24	9.886	10.856	12.401	13.848	33.196	36.415	39.364	42.980	45.558	51.179
25	10.520	11.524	13.120	14.611	34.382	37.652	40.646	44.314	46.928	52.620
26	11.160	12.198	13.844	15.379	35.563	38.885	41.923	45.642	48.290	54.052
27	11.808	12.879	14.573	16.151	36.741	40.113	43.194	46.963	49.645	55.476
28	12.461	13.565	15.308	16.928	37.916	41.337	44.461	48.278	50.993	56.892
29	13.121	14.256	16.047	17.708	39.087	42.557	45.722	49.588	52.336	58.302
30	13.787	14.954	16.791	18.493	40.256	43.773	46.979	50.892	53.672	59.703
40	20.707	22.164	24.433	26.509	51.805	55.758	59.342	63.691	66.766	73.402
50	27.991	29.707	32.357	34.764	63.167	67.505	71.420	76.154	79.490	86.661
60	35.535	37.485	40.482	43.188	74.397	79.082	83.298	88.379	91.952	99.607
70	43.275	45.442	48.758	51.739	85.527	90.531	95.023	100.425	104.215	112.317
80	51.172	53.540	57.153	60.391	96.578	101.879	106.629	112.329	116.321	124.839
90	59.196	61.754	65.647	69.126	107.565	113.145	118.136	124.116	128.299	137.208
100	67.328	70.065	74.222	77.929	118.498	124.342	129.561	135.807	140.169	149.449

Chi-squared distribution.

APPENDIX III

Date	**15/10/00**	**18/10**	**21/10**	**24/10**	**27/10**	**30/10**	**2/11**	**5/11**	**9/11**
Day	0	3	6	9	12	15	17	20	24
Rainfall	0	1	0	0	7.4	4.7	0	0	12.1
Date	**12/11**	**15/11**	**18/11**	**21/11**	**25/11**	**27/11**	**30/11**	**3/12**	**6/12**
Day	27	30	33	36	40	42	45	49	52
Rainfall	0	.9	4	4.8	4.8	1.3	9.8	20.2	0
Date	**11/12**	**13/12**	**16/12**	**19/12**	**22/12**	**25/12**	**27/12**	**30/12**	**2/01/01**
Day	57	59	62	65	68	71	73	76	79
Rainfall	44.6	1	0	0	0	5.9	2.7	12.7	14.7
Date	**5/01**	**8/01**	**11/01**	**14/01**	**17/01**	**20/01**	**27/01**	**31/01**	**3/02**
Day	82	85	88	92	95	98	105	109	112
Rainfall	0	0	0	2.5	3	1	10.1	0	0
Date	**7/01**	**11/01**	**16/01**						
Day	116	119	124						
Rainfall	1.3	0	5.5						

Rainfall (in mls) recorded at Bainesse, 700 metres from Legg Estate bush remnant, Palmerston North.

APPENDIX IV

Time (Minutes)	Replicate 1 Weight g.	Replicate 2 Weight g	Replicate 3 Weight g	Replicate 4 Weight g	Replicate 5 Weight g
Initial weight	13.13	16.63	13.70	23.77	16.19
15 m	12.20	15.50	12.89	22.33	14.79
30 m	11.26	14.50	11.88	20.97	13.62
45 m	10.20	13.42	10.98	19.35	12.51
60 m	9.37	12.37	10.55	17.88	11.49
75 m	9.19	11.64	10.53	17.05	10.91
80 m	9.19	11.50	10.51	16.90	10.81
85 m	9.18	11.33	10.50	16.79	10.79
90 m	9.18	11.25	10.50	16.75	10.79
95 m	9.18	11.16	10.50	16.71	10.79
100 m	9.18	11.16	10.50	16.71	10.79
105 m	9.18	11.16	10.50	16.71	10.79

Drying times in minutes of five replicates of saturated Ashurst silty loam (stony phase) soil for the calibration of an Atlas neptune ^{tm} oven to optimise the drying times for the samples of the irrigation experiment.

APPENDIX V

df	Tail probability p											
	.25	.20	.15	.10	.05	.025	.02	.01	.005	.0025	.001	.0005
1	1.000	1.376	1.963	3.078	6.314	12.71	15.89	31.82	63.66	127.3	318.3	636.6
2	.816	1.061	1.386	1.886	2.920	4.303	4.849	6.965	9.925	14.09	22.33	31.60
3	.765	.978	1.250	1.638	2.353	3.182	3.482	4.541	5.841	7.453	10.21	12.92
4	.741	.941	1.190	1.533	2.132	2.776	2.999	3.747	4.604	5.598	7.173	8.610
5	.727	.920	1.156	1.476	2.015	2.571	2.757	3.365	4.032	4.773	5.893	6.869
6	.718	.906	1.134	1.440	1.943	2.447	2.612	3.143	3.707	4.317	5.208	5.959
7	.711	.896	1.119	1.415	1.895	2.365	2.517	2.998	3.499	4.029	4.785	5.408
8	.706	.889	1.108	1.397	1.860	2.306	2.449	2.896	3.355	3.833	4.501	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.398	2.821	3.250	3.690	4.297	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.359	2.764	3.169	3.581	4.144	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.328	2.718	3.106	3.497	4.025	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.303	2.681	3.055	3.428	3.930	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.282	2.650	3.012	3.372	3.852	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.264	2.624	2.977	3.326	3.787	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.249	2.602	2.947	3.286	3.733	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.235	2.583	2.921	3.252	3.686	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.224	2.567	2.898	3.222	3.646	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.214	2.552	2.878	3.197	3.611	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.205	2.539	2.861	3.174	3.579	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.197	2.528	2.845	3.153	3.552	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.189	2.518	2.831	3.135	3.527	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.183	2.508	2.819	3.119	3.505	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.177	2.500	2.807	3.104	3.485	3.768
24	.685	.857	1.059	1.318	1.711	2.064	2.172	2.492	2.797	3.091	3.467	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.167	2.485	2.787	3.078	3.450	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.162	2.479	2.779	3.067	3.435	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.158	2.473	2.771	3.057	3.421	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.154	2.467	2.763	3.047	3.408	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.150	2.462	2.756	3.038	3.396	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.147	2.457	2.750	3.030	3.385	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.123	2.423	2.704	2.971	3.307	3.551
50	.679	.849	1.047	1.299	1.676	2.009	2.109	2.403	2.678	2.937	3.261	3.496
60	.679	.848	1.045	1.296	1.671	2.000	2.099	2.390	2.660	2.915	3.232	3.460
80	.678	.846	1.043	1.292	1.664	1.990	2.088	2.374	2.639	2.887	3.195	3.416
100	.677	.845	1.042	1.290	1.660	1.984	2.081	2.364	2.626	2.871	3.174	3.390
1000	.675	.842	1.037	1.282	1.646	1.962	2.056	2.330	2.581	2.813	3.098	3.300
∞	.674	.841	1.036	1.282	1.645	1.960	2.054	2.326	2.576	2.807	3.091	3.291

t distribution.

APPENDIX VI

Post script – Legg Estate in spring 2003 and 2004.

As the remnant managers at Legg Estate bush remnant were keen to get on top of the problem at their remnant, I left the plots set up after the rest of the trial as discontinued at the other three sites in early 2001. This enabled further data recording to be made at future dates to see what changes have occurred that could influence the decisions making process on future management practices.

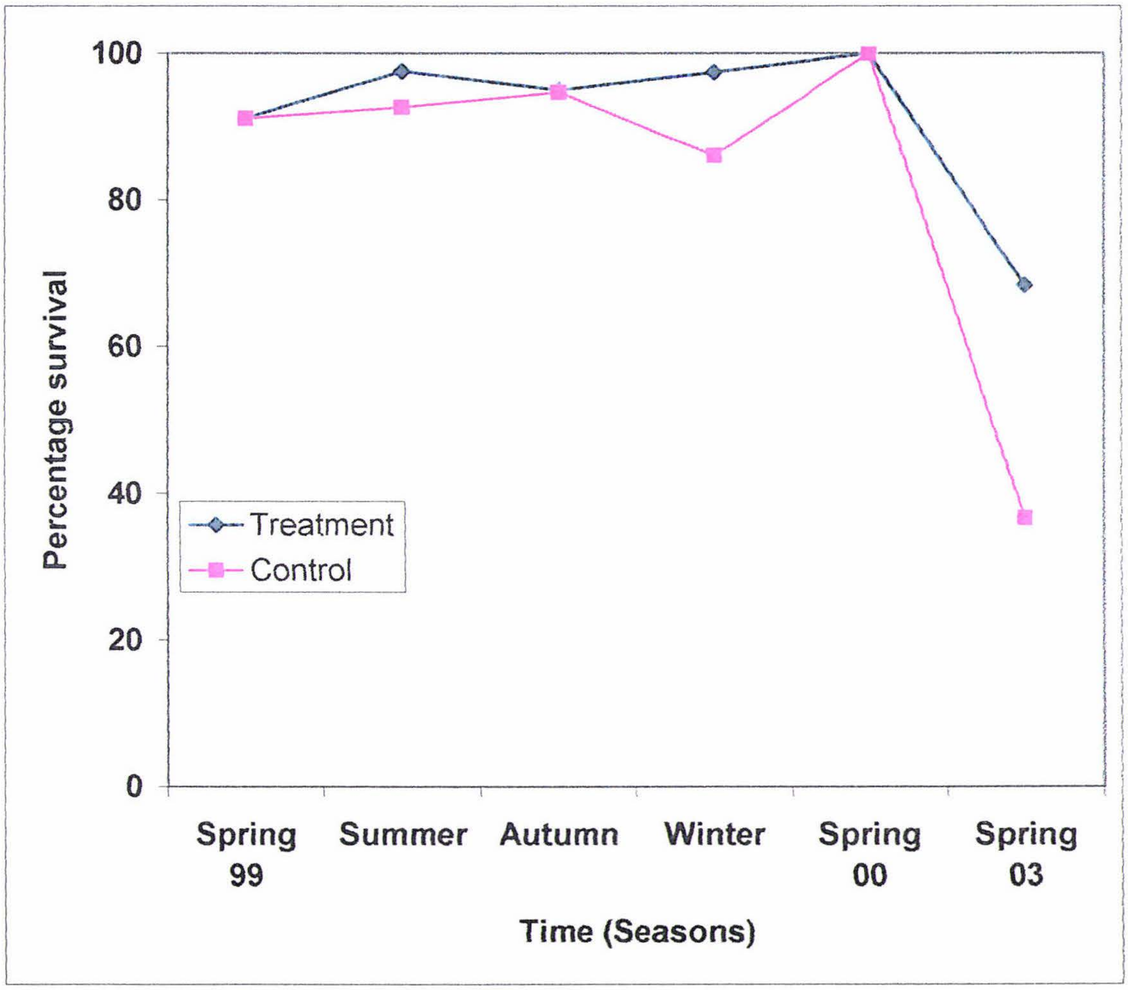
Materials and method.

A present absence score was carried out on 25th November 2003. Seedlings that had survived the final survey in December 2000 were scored as either present or absent. No growth data was collected. Only seedlings that were reported as present from the last recording in January 2001 were involved in this snapshot. I did not include any seedlings, if any whose leaves and stems were grazed as to give an absent reading but now giving a present reading. From my own experience some seedlings grazed by rabbits will regrow at a later date. A score of rabbit presence was also carried out.

Results.

The value for rabbit presence of four was gained. The bush remnant and neighbouring were checked and rabbit sign was found to be plentiful. Photograph IX, page 140 in the treatment replicate two shows scratchings, faecal pallets and a urine squirt. The treatments had a survival rate of 68.4% comparing with the controls which have a survival rate of 36.6% showing a big jump in the treatments survival over the controls survival (see graph XVII, page 141).

Photograph IX. Field sign of rabbits seen in Legg Estate bush remnant in November 2003. Scratchings in the sandy soil, faecal pellets and a urine squirt are clearly present. Rabbit field sign similar to this was plentiful within and around Legg Estate bush remnant at this time.



Graph XVII: Seedling survival in Legg Estate bush remnant from spring 1999 to spring 2003. The trial was an extension of the seedling survival trial, which left set up at the request of the landowners to provide ongoing data for management decisions on this bush remnant's restoration.

2004 Survey.

A survey on 5 December 2004 yielded no usable data as the trial has now reached the end of its usefulness. Many control tags were knocked out. There was a deep layer of leaf litter within the remnant and rabbit sign was very plentiful. A buck heap was present in the control of replicate one. Replicate fours control was destroyed although some plants were within its boundary but I was unable to identify them as being part of the trial. Only replicate one had a good showing of plants but these were saplings now nearly two metres high. The treatments of replicates four and five were intact and a wall of green. Some plants survived within replicate two's treatment while no seedlings survived within the control.

Conclusions.

The use of fenced enclosures to protect germinating seedlings, from the data obtained in spring 2003 does aid in survival and fencing the entire remnant using wire mesh (McKillop. *et al*, 1989), could be of some value. By summer 2004 the only usable data was a visual assessment and this supports the fencing concept. Rabbit score here was a three as rabbit sign was very plentiful. This has been discussed with the landowners and they appear keen to do this, funds depending. Any gains fencing out rabbits would be off set by periods without rain made worse by the chemical nature of the soil, and intermittent visitations by sambar deer. Sambar deer exclusion could be very expensive for such a small patch of remnant by comparison for the cost of rabbit exclusion. The raising of seedlings exsitue and transplanting back at a later date is one option considered to increase the seedling survival. This has been done in the past with poor results as most seedlings died over the summer autumn dry periods. Using large wad of loan soil when planting seedlings could improve moisture retention and hence survival during the periods of low OA moisture levels. As a sufficient large area is required to allow for sufficient numbers and variety of species and this will need to be self sustaining and I feel this reserve does not meet these requirements at present, consequently an ongoing management programme will be required. As with nearly all remnant restoration this will require a ready supply of money and trained willing people with the commitment to ongoing involvement. Currently seedlings are being removed grown up past their vulnerable stage and at a future date to be transplanted back into the remnant. The head horticulturalist feels that the seedlings will require protection from the rabbits as quoted

'I am happy to do this work but as long as they are adequately protected as I do not want to feed rabbits as this is a waste of my time' (Southgate, pers. comm.).

Bibliography:

McKillop, I. G., Butt, P., Lill, J., Pepper, H. W. & Wilson, C. J. (1989). Long term effectiveness of fencing to manage European wild rabbits. Crop Protection 17(5) July, 393-400.