PREDICTING THE SPATIAL DISTRIBUTION OF STOATS, SHIP RATS AND WEASELS IN A BEECH FOREST SETTING USING GIS

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ABSTRACT

Using trap data the Hawdon, Poulter and South Branch valleys, a spatial distribution model was created for Stoats (*Mustela erminea)*, Ship Rats (*Rattus rattus)* and Weasels (*Mustela nivalis*) in the North Branch of the Hurunui River. Ten spatial attributes were analysed in this thesis as potential spatial predictors of Stoats, Ship rats or Weasels; four of which were distance related measurements (*distance from ecotonal edge, distance from river, distance from river tributary and distance from trapping edge*); three were climate based variables (*mean maximum temperature, mean minimum temperature and mean precipitation*) and three were topographical based variables (*elevation, aspect and slope*). Relationships that existed between each spatial attribute and the number of Stoats, Ship Rats and Weasels caught were quantified by comparing the significance of the mean trapping rate with each spatial attribute and expressed spatially as maps in a Geographical Information System (GIS). Results from this thesis found elevation, aspect and distance from ecotonal edge as potential spatial predictors of Stoat populations. Elevation and aspect were found to be potential predictors of Ship rat and Weasel populations. GIS is able to predict the spatial distribution of pest species to a similar (or better) level compared to more formal associative models. The potential of GIS is however, restrained by the same limitations associated with these models. By using a larger trapping data set and identifying a number of social interactions between Stoats, Ship Rats and Weasels, one can improve the accuracy of spatially modelling each species within a Beech forest environment. Therefore, improve our understanding how landscapes influence the distribution of each pest species.

Keywords: Department of Conservation, Stoat distribution, Ship Rat distribution, Weasel distribution, distribution maps, Operation Ark, GIS, Ecological modelling, Hawdon valley, Poulter valley, South Branch, North Branch, Hurunui Mainland Island, Nothofagus, beech forest.

CHAPTER 1: INTRODUCTION

1.1 General Introduction

New Zealand's long isolation has had a profound effect on its wildlife (Lindsey and Morris 2000). Prior to the arrival of the Polynesians about 900 years ago, no terrestrial mammals were present except for three species of bat (Worthy and Holdaway 2002). However, since human arrival, 31 mammalian species were deliberately introduced into New Zealand as assets for sport, food, or fur, and have established themselves in the wild as feral populations (King 1990; 2001).The impact of introduced predatory mammals, especially rats (*Rattus* sp.), mustelids (*Mustela* sp.) and Feral cats (*Felis catus*), on the vertebrate fauna has been catastrophic, a situation that has been described as an "ecological collapse" (Towns and Atkinson, 1991).

Eradication of introduced mammals is not usually practicable on the New Zealand mainland, for financial, technical or social reasons (Atkinson 2001). Neverless, since 1975, there have been remarkable success in averting further extinctions of native fauna and rehabilitating these species habitats on offshore islands (Atkinson, 1988; Saunders and Norton 2001) and maintaining mainland populations of kokako at Mapara (Innes et al. 1999). In the last 5 to 10 years, these successes have stimulated interest in localized intensive control of mammal pests in selected areas of the New Zealand mainland. (Atkinson 2001).

Mainland restoration in New Zealand has become characterized by localized intensive control of several introduced mammal species together. This differs from mainland restoration in continental countries where native terrestrial mammals are part of the ecosystem (Atkinson 2001). Currently, pest mammals in New Zealand are managed for three broad purposes: to protect indigenous species and communities, to reduce vectors of bovine tuberculosis (Tb) and to protect production values depending on the species and where it live, these purposes may overlap (Parkes and Murphy 2003). Intensive pest control to limit the movement of pests into managed areas has been focused at forest-pasture margins (Saunders and Norton 2001).

The “Mainland Island” approach to ecological restoration had its inception with the creation of six intensively managed areas on the New Zealand mainland by the New Zealand Department of Conservation in 1995/96. Based on the imperatives for ecological restoration (Atkinson 2001), the “Mainland Island” approach provides habitats for threatened animal or plant-animal communities depleted of their original biological diversity. The “Mainland Island” approach is based on successes in removing herbivorous and carnivorous pests from offshore islands, and increasingly effective pest control programmes undertaken at other mainland sites (Saunders and Norton 2001). There are currently twelve major projects in the North Island and six in the South Island, initiated by the Department of Conservation and by private organizations or individuals (e.g. Wilson 1994).These projects total an area of 28,360 ha and range in size from the 117 Paengaoroa mainland island to the 6000 ha Hurunui Mainland Island (Atkinson 2001). The development of sustainable management regimes by which critical pests, in particular, introduced herbivorous and carnivorous mammals can be effectively controlled and their re-invasion limited to acceptable levels. This is a priority activity for these sites (Saunders and Norton 2001), A total of 17 animal pests (15 vertebrates and 2 vespulid wasps) are being intensively controlled at Mainland Islands, with up to eleven species targeted for control at one site (Saunders and Norton 2001). The Department of Conservation manages mammalian pests at an estimated annual cost of c. $40 million, or 23% of its budget in 2001/02 (DOC 2002).

Two primary considerations face agencies responsible for managing mammalian pests: no agency has adequate finance given the scale of the project, and a lack of co-ordination amongst agencies mean goals or mandates may differ. Unless the pest can be eradicated, measuring both pest densities and the condition of the resource directly would improve understanding of the pest-resource relationships, allowing unexpected results to be identified and interpreted in a way to improve management practices (Parkes and Murphy 2003).

Effective methods of controlling introduced animals and plants on the mainland can be expected to increase as new technologies are developed (Atkinson 2001). The use of Geographic Information Systems (GIS) applications such as spatial modelling of pest abundances is seen as a useful resource of information for pest management. Though the use of GIS applications has been considered by DOC as a ‘new technology’ for the last 10 years, GIS applications can give a better

understanding of the habitat requirements and environmental limits of pest species. GIS can also provide more detailed and area-specific estimates of densities that could be expected in the absence of control, and estimates of how long previously controlled pest populations might take to reach such densities (Fraser et al. 2004).

1.2 Thesis Aims and Objectives

The aim of this thesis was to investigate the spatial distribution of three introduced New Zealand pests; Stoats (*Mustela erminea*), Ship Rat (*Rattus rattus*) and Weasels (*Mustela nivalis*), and how these species can be predicted within a beech forest (*Nothofagus* sp.) setting using GIS. To achieve this goal, the research pursued five main objectives:

i. To investigate from recent research how the spatial distribution of Stoats, Ship rats, and Weasels varies on the temporal scale.

ii. To identify and graph the spatial distribution of Stoats, Ship rats and Weasels from trap data collected between 1997 - 2005 by the Department of Conservation (DOC) located within three intensively managed sites in the South Island of New Zealand;

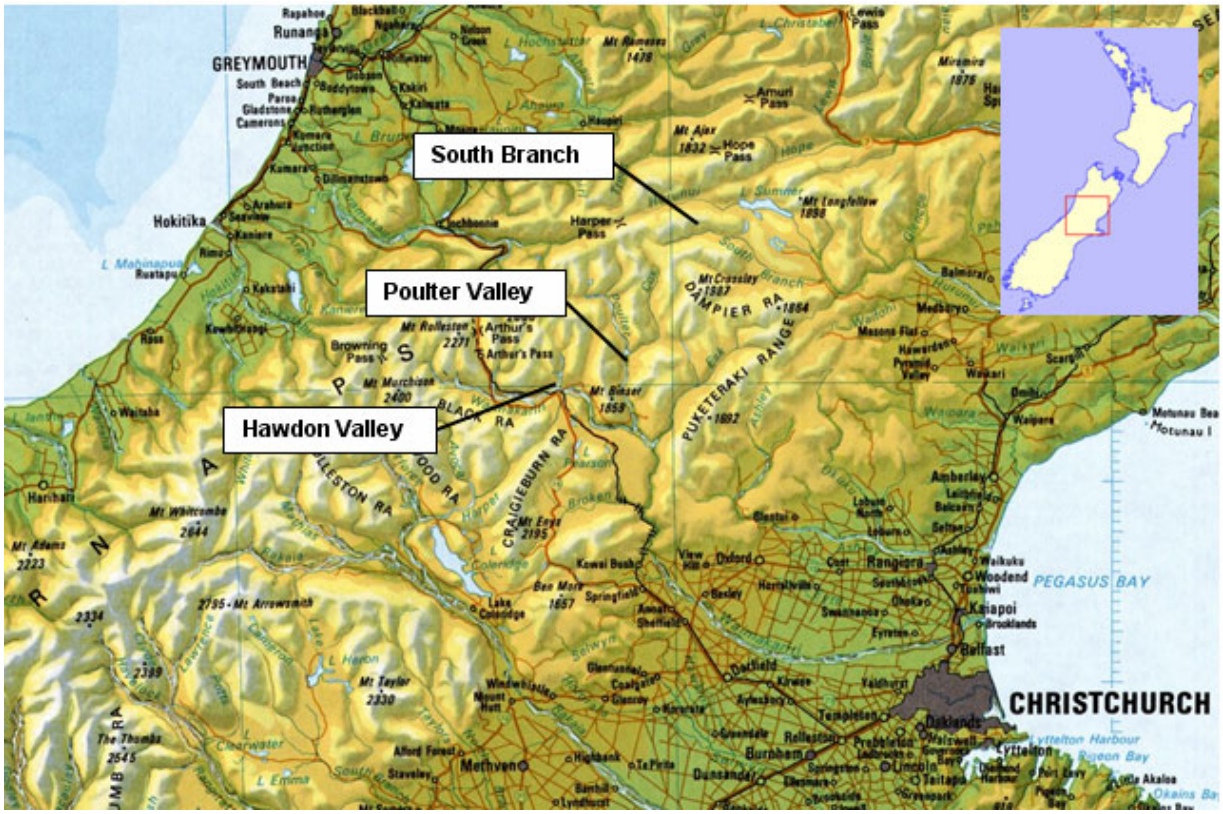
iii. To investigate what spatial attributes (i.e. elevation, distance from ecotonal edge etc.) account for a large percentage of variability of distribution between mustelids and rodents at each control site.

iv. To correlate the findings from (i) to (iii) and use these data to make a spatial prediction map for Stoats, Ship rats and Weasels in the North Branch of the Hurunui Mainland Island.

v. To discuss the potential use of GIS (Geographic Information Systems) in Stoat, Ship Rat and Weasel control

1.3 Study Sites

Three study sites were chosen for this thesis; the Hawdon and Poulter valleys, and the South Branch of the Hurunui River (Map 1), are all classed as intensive pest management areas by New Zealand Department of Conservation (DOC). Both the Hawdon and Poulter valleys are tributaries of the Waimakariri River; The South Branch is located within the headwater regions of the Hurunui River and is part of the Hurunui Mainland Island, the largest mainland island in New Zealand (12,000 hectares). Sections 1.3.1 and 1.3.2 details the location, topography, vegetation and conservation values of the Hawdon and Pouter valleys and South Branch valley of the Hurunui valley respectively.



Map 1.1: Locations of each study sites (New Zealand Map Sheet 1:1,000,000 scale)

1.3.1 Hawdon and Poulter Valleys (Maps 2 and 3)

Location

The Hawdon (Grid Reference: K33 08250) and upper Poulter (Grid Reference: K32 175140) valleys are both tributaries of the Waimakariri River, situated east of the Main Divide in the Arthur's Pass Region, The Hawdon valley is located within the Hawdon ecological region, which is part of the Arthur's Pass ecological district. The upper true left of the Poulter valley is also located within the Arthur's Pass ecological district, while the upper true right of the Poulter is located within the Minchin ecological district, which is part of the Hawdon ecological region. The lower Poulter valley is part of the Poulter Ecological District within the Puketeraki ecological region (DOC 2004a). Both valleys are administered by the Department of Conservation.

Topography

The Hawdon valley is approximately 12 kilometres long and less than 1 kilometre wide. The Polar Range on the true right of the valley rises to 2,035 m (Mt Wilson), while Mt Valiant in the Savannah Range on the true left of the valley rises to 1,847 m. The Hawdon valley floor rises from 600 m to 1,120 m near the head waters and is dominated by stony river flats, although small terraces are evident. The East Hawdon Stream is approximately 5.75 km in length and branches out to the North east 5.5 km up the main valley. (DOC 2004a)

The Poulter valley is approximately 19.5 km long and has an approximate area of 29,600 ha. On the true left of the valley, the Polar Range rises to a maximum height of 1740 m above the east Branch of the Poulter River with the Snow Cap Range reaching 1,720 m (Mt Morrison) between the Thompson and Minchin Streams. The main valley floor rises from 640m at its confluence with the east Poulter River, to 840 m below Worsely Pass and is dominated by stony fluvial river flats, boulders and gravels in the bed of the braided river; however large forested terraces exist above the valley floor (DOC 2004). Above the East Branch of the Poulter River, several large streams flow into the Poulter river including Ranger, Thompson, Minchin and Poulter stream on

the true left, and Casey, Trudge and Enchanted Stream on the true right. Lake Minchin lays approximately two kilometres up Minchin Stream at an altitude of 764 m (DOC 2004a).

Both the Hawdon and Poulter valleys are glacial in origin and both have a classic stepped walled profile with broken greywacke and scree fans extending from open ridge tops down below the bush line. Glacio-fluvial terraces on valley sides of and fertile outwash fans at the mouths of side streams have developed since the last major glaciation and large alluvial deposits have created the flat valley floors.

Vegetation

The lower terraces and main slopes of the Hawdon Valley are covered by typical montaine *Nothofagus* forest which rises sharply to the bush-line at 1,200-1,300 m. This forest is predominantly composed of mountain beech (*N. solandri* var. *cliffortioides*) with stands of red beech (*Nothofagus fusca*) at the toe of the steep slopes rising to mid slope (750 m). Occasional stands of silver beech (*N. menziesii*) are located upstream from the confluence with the East Hawdon stream. The under story is diverse and generally thick, particularly on the slopes where patches of regenerating beech are interspersed with bush lawyer (*Rubus* sp.), small leaved shrubs such as *Myrsine divaricata*, broadleaf *Griselinia littoralis*, *Coprosma* and *Pseudopanax* species. Above the bush line, extensive sub-alpine shrub lands, snow tussock and alpine herb fields grow. The frost prone valley floors are dominated by grasses, but Matagouri (*Discaria* tournatou) scrubland and scattered *Hebe* sp. are present (DOC 2004a).

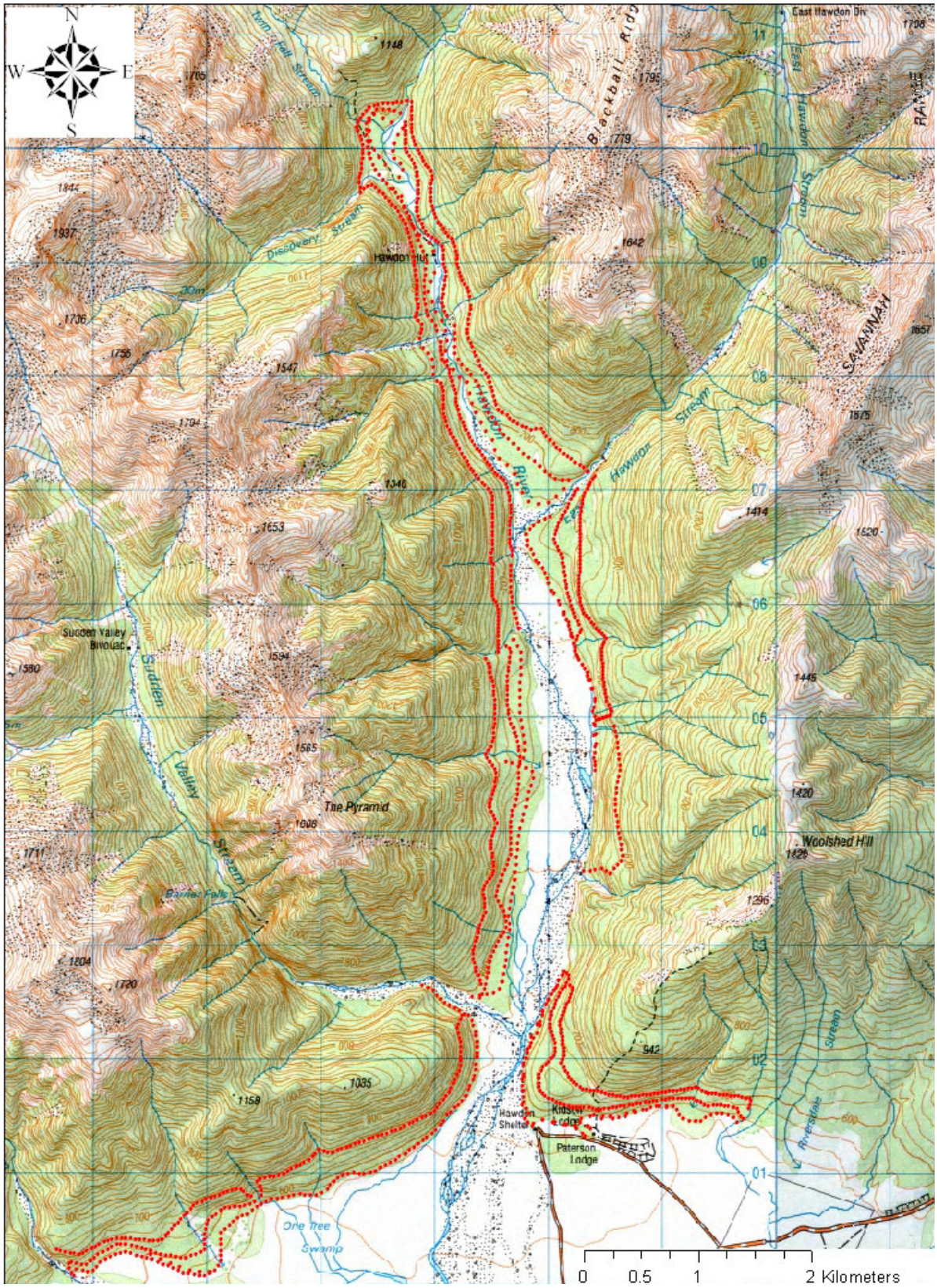
The Poulter valley has a mixed beech forest with predominantly mountain and red beech (*Nothofagus solandri* var. *cliffortioides*) and (*N. fusa*) with occasional areas of silver beech (*N. menziesii*) especially in Thompson stream, Tall stands of red beech are present below the Casey Hut on the true right of the Poulter and also on the true left above the confluence of Casey stream. The valley floor is characterised by grassy flats and a braided alpine river systems. Red tussock (*Chionochloa rubra*), Native broom (*Carmichaelia* sp.), Mountain totatoa (*Phyllocladus aspleniifolius* var. *alpinus*) and Dracaphyllm sp., are common at the head of Thompson Stream. Mountain toatoa (*Phyllocladus alpinus*), *Pseudopanax* sp., Manuka *(Leptospermum scoparium*), *Cosprosma sp.*, *Arcaria traversii*, pokaka (*Elaeocarpus hookerianus*), Bog pine (*Halocarpus*

bidwillii), totara (*Podocarpus hallii*) and Mountain cedar *(Libocedrus bidwillii*) are all common in several parts of the upper Poulter valley. Some Southern rata (*Metrosiderios umbellate*) is also present (DOC 2004a). Much of the under story is open; it consists predominantly of Beech saplings, Broadleaf, Lancewood (*Pseudopanax crassifolus*), Coprosma *spp* (Van Hall and Duncan 2003) and other small leaved shrubs. Further down the valley on the true left above the river are thick patches of regenerating beech and manuka scrub (DOC 2004a).

Conservation Values

The Department of Conservation has recognised the Hawdon and Poulter valleys as both having exceptionally high conservation values. The Orange fronted-parakeet (*Cyanoramphis* sp.) is known to exist only in the Hawdon, Poulter valleys and South Branch of the Hurunui. Breeding populations of Mohua (Yellowhead) (*Mohoua ochrocephala*) and Blue duck (whio) (*Hymenolaimus malacorhynchus*) are both present in the Hawdon and Poulter valleys although Blue duck has become uncommon in both valleys (DOC 2004b). The Hawdon and the Poulter valleys provide a suitable habitat for a diverse range of other birds and several endangered birds including Kea (*Nestor notabilis*), Kaka (*Nestor meridionalis meridionalis*), Rock wren (*Xenicus gilviventris*), Black-fronted tern (*Sterna albostriata*), Roroa (great spotted kiwi*)* (*Apteryx haastii*), Yellow-crowned parakeet (*Cyanorhamphus auriceps*),Long-tailed cuckoo (*Eudynamys taitensis*), and New Zealand falcon (*Falco novaeseelandiae*) (DOC 2004a).

The Hawdon and Poulter valleys headwaters also provide a habitat for the 'Nationally Endangered' plant *(Pittosporum patulum*). Two species of beech mistletoe (*Peraxilla tetrapetela* and *Alepis flavidus*), both which are gradually declining in New Zealand are present in both valleys (DOC 2004a).



Map 1.2 Topographical Map of the Hawdon Valley (NZ Map Sheet K33 08250)
(Red dots indicate the location of the 1436 traps located within the valley)

Map 1.3 Topographical Map of the Pouter Valley (NZ Map Sheet L33 275300)
(Red dots indicate the location of the 356 traps located within the valley)

Map 1.4 Topographical Map of South Branch of the Hurunui River (NZ Map Sheet L33 275300)
(Red dots indicate the location of the 982 traps located within the valley)

1.3.2 South Branch of the Hurunui River (Hurunui Mainland Island) (Map 4)

Location

The South Branch of the Hurunui River is an isolated valley which covers an area of 5,765 ha located about 40 km southwest of Hanmer Springs (Grid Reference: L33 275300). It is located south west of Lake Sumner National Park and lies within the Minchin ecological district. The South Branch is administered by the Department of Conservation under a larger ' Hurunui Mainland Island' which also includes the Upper North Branch of the Hurunui River (DOC 2004b).

Topography

Glacial in origin, the South Branch of the Hurunui River is about 18 kilometres long with a gentle sloping valley floor (≤0.5 km wide) rising from 700 m at its mouth to 940 m at the bush edge near the headwaters. The valley floor is dominated by stony river flats. The Crawford range on the true left of the valley rises to 1,745 m, the Dampier and the Studleigh Ranges on the true right reach 1,821m and 1,841m respectively (DOC 2004b).

Vegetation

Both valley sides of the South Branch are predominantly covered with mountain beech (N. *solandri* var. *cliffortioides*), with extensive red beech *(Nothofagus fusca*) mixed with silver beech (N. *menziesii*) on the river terraces and old alluvial fans. The under story is generally open with patches of regenerating beech, Mountain toatoa (*Phyllocladus aspleniifolius* var. *alpinus*), broadleaf *Griselinia littoralis* and various *Coprosma* and *Pseudopanax* sp. In some areas, extensive short tussock/ herb fields are located on the valley floor with relatively few areas of introduced grasses and virtually no weeds. Matagouri (*Discaria toumatau)* communities are present adjacent to the bush edge on both sides of the valley. Wetlands including spring fed seeps and streams, swamps and hit spring seeps provide a variety of wetland species. Above the bush edge, extensive shrub lands, Snow tussock, and alpine herb fields exist (DOC 2004b).

Conservation Values

The Department of Conservation has identified the South Branch of the Hurunui River as being an exceptional conservation site both on a regional and national context (DOC 2004b). The South Branch, Hawdon and Poulter valleys have been identified as the only sites where Orange-fronted parakeets (*Cyanoramphis* sp.) are known to exist in New Zealand; the South Branch is notably a key site in the recovery of these endemic birds. The South Branch is also a key site for the recovery of Mohua (Yellowhead) (*Mohua ochrocephala*) populations and includes one of the most significant populations of Great-spotted kiwi (Roroa) (*Apteryx haastii*). The South Branch provides a diverse array of other forest birds and several other threatened bird species including Kea (*Nestor notabilis*), Kaka (*Nestor meridionalis meridionalis*), Rock wren (*Xenicus gilviventris*), Grey Duck (*Anus superciliosa*), Black-fronted tern (*Sterna albostriata*), Banded dotterel (*Charadrius bicinctus*), Roroa (great spotted kiwi*)* (*Apteryx haastii*), Yellow-crowned parakeet (*Cyanorhamphus auriceps*), Long-tailed cuckoo (*Eudynamys taitensis*), and New Zealand falcon (*Falco novaeseelandiae*). The 'Nationally Endangered' plant *Pittossporum patulum* and two species of beech (*Peraxilla tetrapetela* and *Alepis flavidus*), which are nationally on a gradual decline are both present in the South Branch valley (DOC 2004a).

1.4 Structure of Thesis

This section of the thesis gives a brief introduction and describes the objectives for each chapter. Divided into five chapters; General Introduction, Literature Review, Methodology, Results, Discussion and Conclusion, each chapter discusses a broad range of topics in relation to how a spatial model for each pest species was conceived.

1. GENERAL INTRODUCTION (This Chapter)

Chapter One provides a general introduction into pest management in New Zealand with relevance to the Department of Conservation (DOC), the aim and objectives for the thesis, a detailed investigation in to the three study sites; Hawdon, Poulter and South Branch valleys and makes reference to the methodological approach and innovative aspect of the thesis. The

objective of this chapter was to provide the reader with information on previous and current methods in pest management in New Zealand as well as provide a general introduction about the thesis and what it hopes to achieve.

2. LITERERATURE REVIEW

Chapter Two discusses previous research on a number of topics about the ecology of Stoats, Ship rats and Weasels. The chapter also includes a comprehensive summary on previous pest operations conducted by DOC in the Hawdon, Poulter, and South Branch and previous research using GIS to spatially model different species within their environment. The objective of this chapter was to provide the reader with information on previous research on how each species interacts within a beech forest environment, to indicate what research DOC had conducted within each of the three study areas, and inform on previous uses of GIS in this field of expertise.

3. METHODOLOGY

Chapter Three discusses the process in which data were collected, processed and analysed within a GIS. The chapter also introduces the ten spatial attributes by outlining and questioning previous research and discusses the methodology behind each attribute. The objective of this chapter was to inform the reader on the process involved from data collection stage to the origin of each spatial attribute and the method used to create a spatial distribution model for Stoats, Ship rats and Weasels.

4. RESULTS

Chapter Four details the mean trapping rates of Stoats, Ship rats and Weasels in each of the trapping valley in relation to each spatial attribute, discusses the significance and variability of each result and determines what spatial attributes are useful in determining the spatial distribution of Stoats, Ship rats and Weasels. The chapter also details the process in which key spatial attributes were modelled within a GIS and how they are applied to the North Branch of the

Hurunui River. The objective of this chapter was to inform the reader of the findings of this thesis.

5. RECOMMENDATIONS AND CONCLUSIONS

Chapter Five discusses the benefits and limitations of associative modelling using a GIS. The chapter also provides some recommendations for the Department of Conservation based on the results of this thesis. The objective of this chapter is to inform the reader about issues relating to ecological modelling and how they relate to this thesis.

1.5 Methodological Approach

This thesis takes a quantitative approach in predicting spatial distribution of Stoats (*mustela erminea*), Ship rats (*Rattus rattus*) and Weasels (*Mustea nivalis*) in three beech (*Nothofagus* sp.) forest valleys in the South Island of New Zealand. By analysing the number of Stoats, Ship rats and Weasels caught relative to the number of traps located within pre-defined intervals set by each spatial attribute, a mean trapping rate can be calculated for each valley to show whether an increase or decrease per interval in the number of Stoats, Ship rats and Weasels exists. Spatial attributes that are chosen as predictors of Stoats, Ship rats and Weasels were based on the accuracy of the observed mean trapping rates and similarity of trapping rates between each trapping valley.

Ten spatial attributes were analysed in this thesis as potential spatial predictors of Stoats, Ship rats or Weasels, four of which were distance related measurements (*distance from ecotonal edge, distance from river, distance from river tributary and distance from trapping edge*); three were climate based variables (*mean maximum temperature, mean minimum temperature and mean precipitation*) and three were topographical based variables (*elevation, aspect and slope*). These attributes are described in further detail in Chapter 3.

1.6 Innovative Aspect

The innovative aspect of this research is that by incorporating a range of research disciplines (i.e., ecology, zoology, biology etc.) with current field work data one can apply new technologies to better predict patterns and help understand population dynamics between pest species. Secondly, this research provides conservation management with a more focused approach to make better and more cost effective decisions. Thirdly, a valuable predictive monitoring tool has been created for use on other conservation estates.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

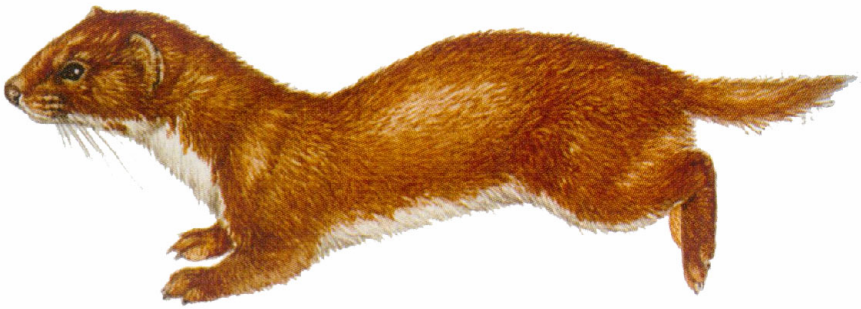
Stoats (*Mustela erminea*) and Weasels (*Mustela nivalis)* were first introduced into New Zealand after run holders pressured the government to introduce 'natural enemies' of the rabbit, given that previous attempts to control outbreaks of rabbit populations in the 1870's had failed (King 1990a). The first liberation of Stoats occurred in Palmerston in 1884 with further liberations occurring around the country in subsequent years (King 1990a). Within six years of the initial release, there were reports of Stoats spreading into the forests of Fiordland and other districts far from any known releases including places where there were, as yet, no rabbits present (Müller 1890; King 1990a). Weasels (*Mustela nivalis*) were first introduced in 1885 at a number of places around the South and lower half of the North Island (Thomson 1922). Historical studies suggest that Weasel populations in New Zealand erupted soon after the first releases, followed by a massive contraction in both numbers and range to become 'exceedingly rare' by the 1950's (Müller 1890; Woodzicki 1950; Guthrie-Smith 1969; King 1990a). Legal protection for Stoats and Weasels was removed by 1936 and further imports were restricted (King 1990a).

Ship rats (*Rattus rattus)* probably did not arrive by European sailing ships until the early in the 19th Century, but were restricted to towns and ports due to the already established Norway rat (Innes 1990). Historical records indicate that Ship rats did not spread in either the North or South Islands, until 1860 and 1890 (Atkinson 1973). By then Norway rats were common in all habitats, and Kiore were still present but declining on both main islands (Innes 1990).

This chapter comprises of three segments; the first segment discusses previous research on the ecology of Stoats, Ship rats and Weasels in relation to distribution, habitat, diet, social organisation and behaviour, home ranges, dens (nests), population dynamics and impact and control. The second segment discusses previous research conducted by DOC in the Hawdon, Poulter and South Branch, with the third segment discusses previous examples of the use of GIS in relation to spatial modelling. The objective of this chapter was investigate how the spatial

STOATS (*Mustela erminea)*

SHIP RATS (*Rattus rattus)*



WEASEL (*Mustela nivalis*)

PLATE 1. Portraits of Stoats, Ship Rats and a Weasel by Priscilla Barrett (King *2005)*

distribution of each pest species varies on the temporal scale, and provide previous examples on how GIS was used in this field.

2.2 Prior Stoat Research

Distribution

Stoats (*Mustela erminea*) are present on both the North and South Island of New Zealand. Stoats were never taken to offshore islands and remain absent from many of these islands, except those close proximity to the mainland (i.e. Resolution and Maud Island) where stoat populations have colonised unassisted (King 1990a).

Habitat

Stoats live in any habitat in which they can find prey (King 1990a). In New Zealand they can be found anywhere from beaches to remote high country, at any altitude up to and beyond the tree line, in any kind of forest, native or exotic, in scrub, dune land, tussock grassland and farm pastures (Gibb and Flux 1973). Stoats can tolerate both extremely wet (>6000 mm/yr) conditions in parts of Westland and Fiordland, and moderately dry conditions (<1000mm/yr) in Otago and Canterbury (King 1990a). Murphy and Dowding (1994) found Stoats avoided roads though were able to cross fast flowing rivers.

In open country, Stoats keep undercover as much as possible in scrub filled gullies, ditches, piles of brush left after clearing and so forth. Stoats are less common in open country than ferrets (*Mustela furo*) but more common in forests (King 1990a; Smith and Jamieson 2005). In South Island beech *(Nothofagus* sp.) forests, Stoats are the most common mammalian carnivore where it becomes periodically numerous (King 1983a; Prudey et al. 2004).

Diet

Stoats are active hunters and search for prey through all possible cover, down every accessible hole and up every likely tree (Moors 1983a). Male Stoats, on average, will consume 75 g/day of food while females consume only 30 g/day except during lactation, when food requirements of breeding females increase by 200-300% (Müller 1970). Killing behaviour is independent of hunger. If the opportunity arises, a stoat will kill any suitable prey it can and store the surplus for future use (King 1990a).

Stoats prey generally on birds, rats, possums and lagomorphs (i.e. rabbits and hares) (King 1990a; King et al. 1996a; Murphy et al. 2004). In all seasons, female Stoats consume more small prey (e.g. Mice, Wetas) than males, though, like males, are still capable of taking lagomorphs, rats, and birds (King 1990). Large prey provides most nutritional needs of both sexes because small preys frequently eaten contain relatively little net food value (King 1990a). The proportion of each prey type eaten depends among other things on habitat, sex (but not age) of the stoat, season and even year, so generalisations are difficult (King and Moody 1982).

Differences in diet between habitat types and/or seasons often reflect real changes in the availability of prey. On riverbeds, the primary prey of Stoats is lagomorphs (Pierce 1987; Dowding and Elliot 2003; Murphy et al. 2004). In beech forest -grassland areas more lagomorphs are eaten by male Stoats, compared to mixed podocarp-hardwood forests where possums are largely eaten, this reflects the reciprocal distribution of these species (King 1990a). Rats are more eaten all year in mixed podocarp-hardwood forests while mice are eaten all year in both forest types, but usually at the end of the breeding season in beech forests, which again reflects the distribution of the prey (King 1990a). Insects contributed a significant proportion of the items taken by Stoats in beech forests even though insects provided little nutritive biomass for Stoats (Rickard 1996).

Birds are the most frequently taken class of prey in all seasons and forest types, especially during summer, but there was a sudden drop in autumn corresponding to the seasonal increase in consumption of mice (King 1990a). Predation on birds by Stoats decreases when there is plenty

of alternative food sources available (King and Moody 1982; King 1983a; Murphy and Dowding 1995; Dilks et al. 2003). However there might be an increased danger in beech forests from Stoats temporarily switching to bird predation when mice populations decline (Rinely et al.1959), though this fact is still hard to establish among wild Stoats (Prudey et al. 2004). Stoats might also respond to a decrease in mice by switching to lagomorphs (Murphy and Dowding 1995).

Social Organisation and behaviour

Stoats (*mustela erminea*) can be seen at anytime of the day or night (King 1982). Daily activity is usually divided into short hunting periods then resting in one of several dens throughout their home range (Erlinge 1979). Activity only increases when prey is scarce (King 1990a). Males search for females actively during the breeding season (Sept-Nov) but do not establish a pair bond and play no part in rearing the young (Erlinge 1979). Young disperse from late as October to early February (King 1982; King and McMillian 1982)

Home Ranges

Adults live on separate home ranges for most of the year (King 1990a) and will defend these ranges against the opposite sex (Powell 1979). Males are dominant over females except when females are rearing their young (King 1990a), A male stoat's home range may include several females during the winter season (King 1990a). Socially subordinate animals tend to use different habitats (Erlinge 1977; Sandell 1986). Cuthbert and Sommer (2002) suggest behaviour of juvenile Stoats may represent spatial avoidance of the adult males, whose home range overlaps with the subordinate juveniles.

Home range size of Stoats is related to the density of prey (Glitterman and Harvey 1982; King 1990a; Cuthbert and Sommer 2002; Prudey et al. 2004). Small home ranges (<60 ha) have been found in beech (*Nothofagus* sp.) forests in years of high prey abundance following an eruption in mouse numbers (King 1975a; Murphy and Dowding 1995; Smith and Jamieson 2005) and in areas of high prey density around mainland colonies of yellow eyed penguins (*Megadyptes antipodes*) and sooty shearwaters (*Puffinus griseus*) on the Otago Peninsula (Alterio et al. 1998).

Large home ranges of between 100-250 ha have also been recorded for Stoats in beech forests in years of low prey abundance (i.e non mast years) (King 1975a; Murphy and Dowding 1994; Alterio 1998; Smith and Jamieson 2005). Alterio (1998) suggests that Stoats might even become non-territorial when their primary prey is at high densities. However little is understood of the territorial behaviour of Stoats in beech forests (Prudey et al. 2004) except that their activity tends to be concentrated near the valley floors (Murphy and Dowding 1994; Dilks and Lawerence 2000; Dilks et al. 2003; Smith and Jammieson. 2005).

Dens

Stoats do not make their own nests, but rather take over those of other animals, such as rats, rabbits or possums (King 1990a). Den sites may include holes up the trunks and in roots of trees (Murphy and Dowding 1994), or in piles of logs, ditches and isolated patches of scrub in open habitats (King 1989a). A warm nest is important for survival even in a mild climate owing to the long thin shape and short fur of Stoats (King 1990a).

Population Dynamics

Stoats have the general characteristics of an opportunistic species: small size, short life span and high and variable rates of birth and death, which result in unstable populations whose density and distribution are controlled primarily by food (King and Moors 1979; King 1983a, 1983b). In beech *(Nothofagus* sp.) forests, after a heavy seed fall, a predictable sequence of events is set off; this is known as a beech mast cycle (Wardle 1984; Murphy and Dowding 1995; King 2002). The beech mast cycle is set off with an increase in the numbers and/or availability of mice over the winter and early spring after a heavy seed fall. This is followed by an eruption of young Stoats in summer (8-9 months after the seed fall which declines in autumn (Riney et al. 1959; King 1981, 1983a; O'Donnell et al. 1996; Lawrence 1997). However there is little evidence that these relationships are causal (King 1983a; Efford et al. 1988).

Stoat captures are recorded using the trap-catch index which assesses the relative density of a species. It is calculated as [Captures/ (traps set- half no. of traps sprung)] x nights set x 100. Essentially, the trap-catch index calculates the number of animals caught per trap per 24 hours, corrected for unavailable traps (Nelson and Clark 1973). The trap-catch index of Stoats in New Zealand Beech forests varies between 0-9.3 C (captures) /100 TN (trap nights) (King 1980, 1981, 1983a, 1996a). Standardised trap lines set in beech forest in the Eglington Valley and the Cragieburn Forest Park between 1973- 1979 (King 1980a,1981,1983a), have recorded a regular average seasonal rate of less than 1C / 100TN per 3 months in winter and spring, to 2 C/100 TN per 3 months in summer. Irregular summer variation of 1-2 C/100 TN - 5-6 C/100 TN has also been recorded per 3 months after a post seed period. This additional input in number caught are all newly independent young which quickly disappear over the winter, and by the following spring the normal low density is restored (King and McMillan 1982).

The life expectancy of Stoats in New Zealand forests is less than two years though a few can live to between 6-8 years old. The sex ratio of a stoat at birth is 1:1 (Müller 1970; Ternovsky 1983); this ratio is unlikely to be affected by post seed fall years in beech forests (King 1990a). Stoats born during a post seed fall bonanza of mice growths are larger but suffer higher mortality in their first year than those born in non seed fall years (Powell and King 1997). Those that do survive their first breeding season achieve lower breeding success or even none at all (King et al. 2003). Increases of local bird populations (both endemic and introduced); migrating birds (e.g. finches [*Passeriformes* sp.]), and invertebrates may also contribute to higher numbers of Stoats in the year following a seed fall (Murphy and Dowding 1995). The timing of stoat breeding is controlled by day length, resulting in an influx of young Stoats at the same time each year (King 1989a). Thus, from late November large numbers of juvenile Stoats are present in beech forests (known as a 'stoat population irruption') (Dilks et al. 2003).

The mortality rate of Stoats in a beech forests is extremely high (>80% in the 1st year), then reduces to between 20-30% in sequential years (King 1990a). Powell and King (1997) found that first year mortality rate varied between 0.55 and 0.92.

Impact and Control of Stoats

The introduction of Stoats is commonly regarded as one of the worst mistakes ever made by European colonists in New Zealand (King 1990a). Stoats have contributed to the loss of 5 out of 135 extinct species of native birds including the extinction of the South Island subspecies of the bush wren (*Xenicus l. longpipes),* New Zealand Thrush (*Turnagra c. carunculatus*), Laughing Owl (*Sceloglaux a. albifacies*), Saddleback (*Philesturnus c. carunculatus*) and Kokako (*Callaeas c. cinerea*) and perhaps aided the already advance decline of the Kakapo (*Strigops habroptilus*), Takahae (*Notornis mantelli*) and Little Spotted Kiwi (*Apteryx owenii*) (King 1990a).

The periodic increases in predation by Stoats after beech mast years may explain why the South Island kokako disappeared while the North Island Kokako (*Callaeas cinerea wilsoni*), living mostly in non beech forests, has so far survived (Clout and Hay 1981). Several threatened beech forest species are seriously damaged by predation for short periods during a heavy beech mast including Kaka, Mohua and Yellow-crowned Parakeet (Efford and Morrison 1991; O'Donnell 1996). Endemic birds might be expected to be more vulnerable than introduced birds though the losses are about the same for each (Moors 1983a, 1983b). In non beech forest habitats, populations of Stoats are generally higher and more stable, but the consequences of their predatory activities cause concern for much longer periods of the year in most years (King et al. 2001).

The numbers and distribution of Stoats can be affected by interference competition from larger predators (King 1989b). Stoats are liable to be killed by falcons (*Falco navaseelandiae*) and wekas (*Gallirallus australis*) (Thompson 1922; King 1982b) and Feral cats (Gibb and Flux 1973; Fitzgerald and Karl 1979). However the main predator of Stoats as elsewhere is man (King 1990a). Stoats are incidentally killed by traps or poisons laid for rabbits and possums, though the general numbers of Stoats are not affected by predation, trapping or accidental deaths (King 1990a).

Stoats are naturally short-lived and can rapidly be replaced; therefore a reduction greater than 80% every year is needed to kill a high enough proportion of the resident population of Stoats

(King and Moors 1979; King and McMillan 1982). The only practical control method over wide areas at present is the humane Fenn traps, set in tunnels and baited with hen eggs or meat (Dilks et al. 1996; Lawrence and Donnell 1999). 1080 (sodium monofluroacetate), cholecalciferal and diphacinone, (a second generation anticoagulant) have all have been tried with mixed results (Miller and Elliot 1997; Spurr 1999; Dilks and Lawrence 2000). Predator proof fences, repellents, fertility control and manipulation of disease are also under investigation as means of controlling Stoat populations (King et al. 2001).

2.3 Prior Ship Rat Research

Distribution

Ship rats (*Rattus rattus*) are by far the most uniformly distributed of the three rat species on the New Zealand mainland (Innes 1990). They are found throughout the North, South and Stewart Islands, virtually wherever suitable habitat is found (Innes 1990).

Habitat

Ship rats (*Rattus rattus)* are found in the wild in forests and in a wide range of other habitats, ranging form the coast to the tree line, but are scarcer at higher latitudes (Innes 1990; King and Moller 1997). Ship rats are most abundant (< 22C/100TN) in mature, diverse, lowland podocarp-broadleaved forests, and are absent or vary scarce (<0.5C/100TN) in pure beech (*Nothofagus* sp.) forests (Innes 1990; King et al. 1996a; King and Moller 1997; Innes et al. 2001).

Social Organisation and Behaviour

Ship rats are nocturnal and have excellent senses of smell, touch, hearing and taste (Innes 1990). Like Norway Rats (*Rattus norvegicus*), Ship rats display a strong exploratory drive within their home range (Barnett 1975). Ship rats spend most of their time on the ground (Hooker and Innes 1995; Murphy and Dowding 1994), perhaps because ground cover is dense and the sub canopy sparse (Murphy and Dowding 1994). Trapping studies and nest observations show Ship rats are

not colonial, but rather individuals or family groups are dispersed evenly through the available habitat (Ewer 1971; Daniel 1972; Innes 1977). This behaviour is also seen in populations of Norway rat populations in New Zealand (Moors 1990).

The social organisation of Ship rats can be explained as food-determined female dispersion with male promiscuity, which accounts for the larger home ranges of males (Hooker and Innes 1995). No long-term associations between males and females were reported by Hooker and Innes (1995), although rats were reported forged together in close proximity in the Puketi Forest (Murphy and Dowding 1994).

Diet

Ship rats are omnivorous generalists, yet can be very selective feeders (Clark 1981). In native forests, Ship rats eat both plant and animal foods all year round (Innes 1990), with animal foods predominantly consumed in spring and summer and plant foods in autumn and winter (Daniel 1973; Innes 1979). The main animal foods are arthropods, especially Wetas, but also Beetles, Spiders, Moths, Stick insects and Cicadas (Best 1969; Daniel 1973; Innes 1979; Gales 1982). Other prey items of conservation significance are native snails (Daniel 1973; Meads et al. 1984), slugs (Best 1969) and lizards (Whitaker 1978).

Ship rats are probably the most known rodent predator of birds' eggs and their young (Atkinson 1978, 1985; Innes 2001). Birds however are a minor diet item for Ship rats living in established mainland populations, and the significance of their predation on contemporary mainland populations remains unclear (Moors 1983; King 1984). In laboratory trials, adult Ship rats eat about 15 g or 10% of their body weight of dry food a night (Bhardwaj and Khan 1974). Ship rats prefer to feed under cover and often carry food items to sheltered places rather than eat their prey immediately (Ewer 1971).

Home Range

Adult females tend to occupy exclusive areas in the breeding season (Innes and Skipworth 1983; Hickson et al. 1986; Dowding and Murphy 1994), though males tend to have larger home ranges (Innes 1990). Foot print tracking shows that forest-dwelling rats may traverse most of their home range at night (Innes 1990). Ship rats know their neighbours well; if one disappears, invading Ship rats will invade their home range within days (Innes 1990).

In beech forest of the Eglington Valley (Fiordland) during the summer of 1999-2000, three radio tracked Ship rats moved up to 700 m from their dens in one night before returning, whereas the only tracked female remained within 100 m of her capture site (Dilks et al. 2003). Other studies have recorded movements of Ship rats ranging between 0-200 m between successive captures (Daniel 1972; Innes 1977; Murphy and Dowding 1994; Hooker and Innes 1995) depending on sex and habitat of the ship rat.

Nests

Ship rats build their nests in epiphyte clumps or in tree hollows (Innes 1990). If these are not available they may build sparrow like nests in young trees or hedges (White 1897; Innes 1977). Ship rats used, on average, between 3 to 4 dens during a 5-week study at Puketi Forest (Murphy and Dowding 1994), with up to three rats (males and females) sometimes denning together.

Population Dynamics

Winter food supply and predation are suggested as the determining factors in limiting Ship rat populations (Daniel 1972, 1978; Blackwell et al. 1998). Recorded abundances of Ship rats in New Zealand have ranged between 2.9-7.1/ ha depending on the season and habitat (Murphy and Dowding 1994; Hooker and Innes 1995; Brown et al. 1996; Blackwell et al. 2002). Capture rates of Ship rats in beech (*Nothofagus* sp.) can remain at low levels after seed fall years (±1.5 C/100TN), though become more abundant after moderate to heavy seed fall years (King 1983; King and Moller 1997; Alterio et al. 1999).

Ship rats generally breed from mid spring until autumn (September to April) while winter pregnancies are infrequent and only have been recorded after a heavy seed fall (Daniel 1972, 1978; Best 1973; Innes 1979; Innes et al. 2001). This seasonal breeding of Ship rats causes a corresponding change in density, from low numbers in spring-summer to a peak usually in autumn (Daniel 1978; Moors 1978; Innes et al. 1996; Blackwell et al. 2002). Seasonal breeding and recruitment creates a cycle whereby rapid disappearance of each annual cohort will be blurred by fluctuations both in breeding season and rat longevity, the exact timing and extent of these peaks and troughs in Ship rat density varies between years and habitats (Innes 1990; Innes 2001). Early born juveniles mature about 3-4 months after their birth (Watts and Aslin 1981), Recruitment of young Ship rats was more effective in the forest interior (King et al. 1996b).

Control and Impact of Ship Rat

Since their introduction in the 19th century, Ship rats have more or less coincided with the decline of a number of New Zealand birds (Atkinson 1973; Innes 1990; Clout et al. 1995; Innes et al. 1996; Brown 1997). By reducing the abundance of native birds through predation on eggs, chicks and adults, Ship rats are expected to have detrimental effects on the dispersal of many forest plants even if they are known to be a seed disperser themselves (Clout and Hay 1989; Williams et al. 2000; Wilson et al. 2003).The impact of Ship rat predation on the complex mainland ecosystems of New Zealand still remains unclear. Widespread and significant impacts of Ship rats on other fauna and flora are suspected but documented by few published studies (Innes 1990, 2001).

Predators of Ship rats include Stoats (*Mustela erminea*), Ferrets (*Mustela furo*), Weasels *(Mustela nivalis*); Feral Cats (*Felis Catus)* (Daniel 1972, 1978; Fitzgerald and Karl 1979; King and Moody 1982; Murphy and Bradfield 1992; King et al. 1996a; Rickard 1996; Murphy et al. 1998, 1999), and Moorporks also prey on Ship rats though very rarely (St Paul 1997). Predators may be able to slow, but cannot prevent a rodent population eruption of Ship rats and House mice (*Mus musculus*) following a large energy input (i.e. heavy seed falls), and cannot truncate the peak population, nor can they hasten the rate of decline of crashing prey populations (Blackwell et al.

2002, 2003). This indicates that Ship rat populations may be more likely to be limited by food (Blackwell et al. 1998).

Active control of Ship rats over thousands of hectares of forest at some mainland locations have increased during the 1990s, stimulated by changes to the problem at hand rather than technology (Innes 2001). Ship rats have been controlled to very low levels in forests (< 4000 ha) by aerial and ground poisoning and trapping (Innes et al. 1995; James and Clout 1996; Saunders 2000). Sodium monofluoroacetate (1080) and broadifacoum are the most common poisons used to control ship rat populations, though broadifacoum is now restricted to mainland sites due to concern over its persistent use (Innes 2001). Snap trapping and Foot print indexing techniques are still considered today as accurate ways in which to monitor population trends of Ship rats over time (Fitzgerald 1978; King and Edgar 1977; Innes 1990; Innes et al. 1995; Blackwell et al. 2003).

2.4 Prior Weasel Research

Distribution

Weasels (*Mustela nivalis*) have patchy distribution over most of the two main islands of New Zealand, except in the south west of the South Island (King 1990b). Weasels are not known to have reached any other islands (King 1990b).

Habitat

Weasels seem to prefer more disturbed habitats, from suburban gardens to agricultural land, in scrub and cutover or exotic forest, or at the margins between these and open country. Weasels prefer these habitats as they are more likely to harbour more mice and insects than undisturbed native forest (King 1990b; King et al. 1996a, 1996b).

Diet

The daily food requirements of Weasels are about 40 g/day for males and 20 g/day for females except during lactation when a female's food requirement greatly increases (King 1990b). Weasels generally consume small prey, mostly mice, insects, lizards and birds (King and Moody 1982; King et al. 1996a; Murphy et al. 1998). About 40% of a Weasel's diet is mice, 30% is birds, while the remaining 30% comprised of bird's eggs, lizards and invertebrates (King and Moody 1982). Weasels can, and do, kill rabbits, mostly juveniles but less than 10% of the time (King 1990b). The feeding behaviour of Weasels is generally like that of Stoats, except that Weasels are more closely adapted to the exploration of small rodents and less capable of taking larger prey (King 1990b).

Social Organisation; Behaviour and Home Ranges

The social organisation of Weasels in New Zealand is unknown (King 1990b). Small rodents are usually scarce in New Zealand, so the home range of Weasels may be large for most of the time (King et al. 2001). In Europe, the two sexes live on separate home ranges. On average, males live on larger ranges (5-25 ha) than females (1-10 ha) (though these ranges increase when their primary prey is scarce) and have activity and schedules and systems of social hierarchy and communication (i.e. mutual avoidance) much like those of the Stoat (Lockie 1966; King 1975b; Powell 1979; Jedrzejewski et al. 1995). Captive Weasels are tolerant and of each other and of other mustelids while immature, but antagonistic when adult (King 1990b).

Population Dynamics

Weasels share with Stoats the general characteristics of opportunistic species. However the breeding success of Weasels is more strongly influenced by fluctuations in the supply of small rodents and their lifespan is shorter (less than 1 year) (King 1990b). Capture rates of Weasels in the Pureora in the Forest Park by King et al. (1996a) found the mean density of Weasels to be between 0 -1.15 C/100TN. This capture rate can rise significantly after eruptions in the population of mice (41.4 C/100 TN).

In beech forests, the population of Weasels, and their prey, fluctuates by periodic seed falls, this cycle is similar to Stoats except that the details of the reproductive response of Weasels and Stoats are different (King et al. 2001). In patchy and variable environments, Weasels are always able to find, breed in and disperse from places where rodents are locally common, and are able to avoid confrontations with Stoats (King 1990b).

Weasels are vulnerable to attack by large predators, especially Feral Cats, Stoats, Ferrets and Harriers (King 1989b). However predation alone can not control the numbers of Weasels (King 1990b). The mortality rate for Weasels is very high (>0.75 in all ages and both sexes) with the principal agent of mortality being availability of food (King 1990b).

Local populations of Weasels are subjected to rapid fluctuations in numbers and distribution including local extinctions, correlated with the distribution and abundance of food (King et al. 2001). The key survival strategy of Weasels in colder climates of surplus killing and caching does not work in warmer climates (Jedrezejewski and Jedrezejewska 1989). The consequent unfavourable energy conditions and interference from Stoats in New Zealand might help explain their general rarity (Erlinge and Sandell 1988; King et al. 2001).

Impact and Control of Weasels

Weasels are currently the rarest of the three types of mustelid. Hence its effect in the New Zealand environment is the smallest (King 1990b). It is still unclear how Weasels in New Zealand have survived so long in complete absence of their traditional prey (mostly small animals and birds) (King 1990b). Presently, Weasels pose no known threat to the survival of any native species on the mainland, except on the local scale, when they can decimate small local populations of a species such as the Whitakers Skink (Miskelly 1997). If unaided, Weasels are unlikely to reach any off shore islands (King 1990b, King et al. 2001). Their populations are naturally unstable and liable to frequent local extinctions. Most of New Zealand offers, at best, only marginal habitat for Weasels, in which their survival is less than certain than that of the

remaining native species with which they co exist (King 1990b). Weasel populations do not carry Mycobacterium bovis (Anon 1989) and therefore pose no threat to domesticated livestock.

2.5 Pest Control in the Hawdon, Poulter and South Branch valleys

In September 2003, an initiative to protect South Island populations of Orange-fronted Parakeet (*Cyanorhamphus malherbi*), Mohua (Yellowhead) (*Mohoua ochrocephala*) and Blue Duck (kowhiowhio) (*Hymenolaimus malachorhynchos)* was launched by the Minister of Conservation. Known as "Operation Ark", several high priority sites were selected for protection based on capability and suitability assessments evaluated against weighted criteria. Because Orange-fronted Parakeet, Mohua and Kowhiowhio are all present in the Hawdon and Poulter valleys and the South Branch of the Hurunui River, these sites are ranked as the top two sites for Operation Ark nationally (DOC 2004a; 2004b).

Ship rats (*Rattus rattus*) and Stoats (*Mustela erminea*) are currently targeted for control in the Hawdon, Poulter and South Branch. The effects of predation by Stoats and Ship rats on native fauna is deemed by DOC to be the primary cause of the declining Orange-fronted Parakeet and Mohua populations in Canterbury (DOC 2004a, 2004b). Brushtail possums (*Thrichosurus vulpecula*) are also targeted for control in the South Branch only. However they are considered a low priority given the unknown impact possums have to the decline of these endangered birds (DOC 2004a, 2004b). This section firstly details the establishment of trapping grids in the Hawdon, Poulter and South Branch valleys, discusses the current strategy of stoat and rat control by DOC and presents beech seed fall and trapping data over the last ten years.

2.5.1 Establishment of Trapping Grids/Blocks

Hawdon and Poulter Valleys

Stoats were first trapped in the Hawdon Valley in 1989, It was not until 1999 that a more intensive on-going trapping programme was initiated involving 220 stoat trap boxes located at 100 metre intervals along the bush edge of the valley floor, and has been ongoing since then

(DOC 2004b). In 1995/96, Stoats were poisoned using diphacinone (liquid concentration) as part of a field trial (Spurr 1999, DOC 2004a). In 2004, a similar stoat trapping grid consisting of 356 traps was also established in the Poulter valley

Since 2003, a rat trapping regime consisting of 1,191 single entry/exit core flute tunnels set with either a single Mk. IV Fenn trap or Victor Professional Rat Trap has been operational in the Hawdon Valley (DOC 2004a). These trap stations are spaced at 50 m intervals along lines 150 metres apart. Three trap lines run up both sides of the Hawdon Valley, the lowest on the bush edge, and the others are approximately 150 m and 300 m above the first and extend along both the eastern and western faces parallel to the Waimakariri River (DOC 2004).

South Branch of the Hurunui River

Stoat control was initiated in the South Branch in 1995/96, when 272 wooden tunnels were placed at 100 m intervals along the bush edge and up all major side creeks in the South Branch of the Hurunui. Stoats were originally controlled using two hens eggs injected with 1.0 ml of 0.1% 1080 solution, but have now been replaced with Mk. Fenn IV traps (DOC 2004b).

Prior to 1999, Ship rats (*Rattus rattus)* had never been recorded in the South Branch since the Hurunui Mainland Island programme had begun in 1995. Rats were first recorded in November 1999 with the first indication of a rat eruption in 2000/01. In 2002/03 a grid of 667 trap stations (each with a single Mk. Fenn IV trap) was established in attempt to control rats. The lines were set 150 m apart with trapping stations every 50 m. The Rat trapping block containing several smaller trapping grids extends approximately 11 kilometres up the valley from the valley floor bush edge to approximately 200 m above the base of the valley sides where terrain will allow. Each grid is a discrete trap areas which are defined by major streams or other significant landscape features (DOC 2004b).

2.5.2 Current Strategy to Stoat and Rat Control (Department of Conservation)

Stoat Control

Stoat Populations are controlled and maintained at <10% tracking tunnel index using the existing network of approved traps placed along the bush edge of the valley floor at 100 m intervals extending up all the major creeks for 200-300 m. This approach will allow all Orange-fronted Parakeet and Mohua populations to recover (DOC 2004a, 2004b).

Stoat traps are checked weekly between October and March, and monthly in April and September. Stoat trap rates are expected to rise (especially in a beech mast year) in December, during the breeding season when the young leave their nests, and to lesser degree in April with immigration of juveniles into the area. If stoat and/or rat densities increase, the inspection regime of traps in each valley may be increased at the Field Supervisors discretion. This is vitally important during a rat eruption when a large proportion of Stoats traps catch rats instead of Stoats (DOC 2004a, 2004b).

All traps are currently baited with two white eggs, one pricked and one unpicked. The pricked egg is discarded monthly while the second egg is pricked and a new egg is added. All trapped animals are removed and the traps are reset. If any animals are alive they are dispatched of swiftly and humanely. If, however any protected wildlife is caught it must be released as soon as possible (DOC 2004a, 2004b).

Rat Control

Ship rat populations are controlled and maintained to below a threshold density that allows Orange-fronted Parakeet and Mohua populations using the existing rat trapping regime in the Hawdon and South Branch valleys (DOC 2004a, 2004b). The extensive rat trapping grid already in place in the South Branch of the Hurunui has been reported by DOC to be sensitive to low rat densities and provides data on rat densities, spatial data on rat distributions and information on the change in rat densities over time. As such it is a very valuable predictive monitoring tool (DOC 2004b).

All stations are baited with 3 white chocolate buttons contained in film canisters which are drilled with 5mm holes and placed in an upright position at the end of the non entry end of the box (stations are re-baited monthly). All trapped animals are removed and traps are reset, if any animals are still alive they must be dispatched of swiftly and humanely. If any protected wildlife is caught it must be released as soon as possible (DOC 2004a, 2004b).

When a rat is caught, traps within a 250 m radius of the capture are to be checked twice weekly until there are two contiguous nights with no rat captures. This strategy will manage rats at a local level by increasing the trapping effort in 'hot spots' where localised outbreaks of increased rat intensity are occurring. If this process fails to suppress rat numbers, the control will progressively move into a wider block (sector) based control regime, followed by a global control regime where control is carried out by the deployment of rodenticides will be deployed in bait stations (brodifacoum) and/or bait bags (coumatetralyl) throughout the entire valley(s). This regime increases in intensity and methodological variety in a step-wise manner to meet increases in rat populations. If trapping in conjunction with ground-based poisoning fails, aerial 1080 is used (DOC 2004a, 2004b).

Historically, Ship rat population eruptions have only occurred approximately once every 10-30 years in South Island beech forests, therefore uncertainty remains as to when intensified rat control is needed. Rat eruptions have only been recorded in the Hawdon and South Branch following a beech mast event.

2.6 Previous Research (Department of Conservation)

This section discusses previous research conducted by DOC on the temporal changes of beech seed fall, and variations in number of House mice, Ship rats, Stoats and Weasels caught in the Hawdon and Poulter valleys between 1999-2005 and the South Branch valley between 1993-2005. By reviewing field data, a better understanding and appreciation of how populations of Stoats, Ship rats, and Weasels interact in a beech forest environment can be achieved.

2.6.1 Beech Seed fall

Beech (*Nothofagus* sp.) seed fall was collected by DOC in both the Hawdon valley between 1995-2004 and in the South Branch of the Hurunui River between 1995-2005 respectively. Beech seed was also collected in the North Branch of the Hurunui River from 2001 onwards. These data have not been included into this report as the data collection was not as comprehensive as other collection areas. Figure 1.1 shows ten years of beech seed fall research in both the Hawdon and the South Branch (some data has been modified to correspond with the associated months).

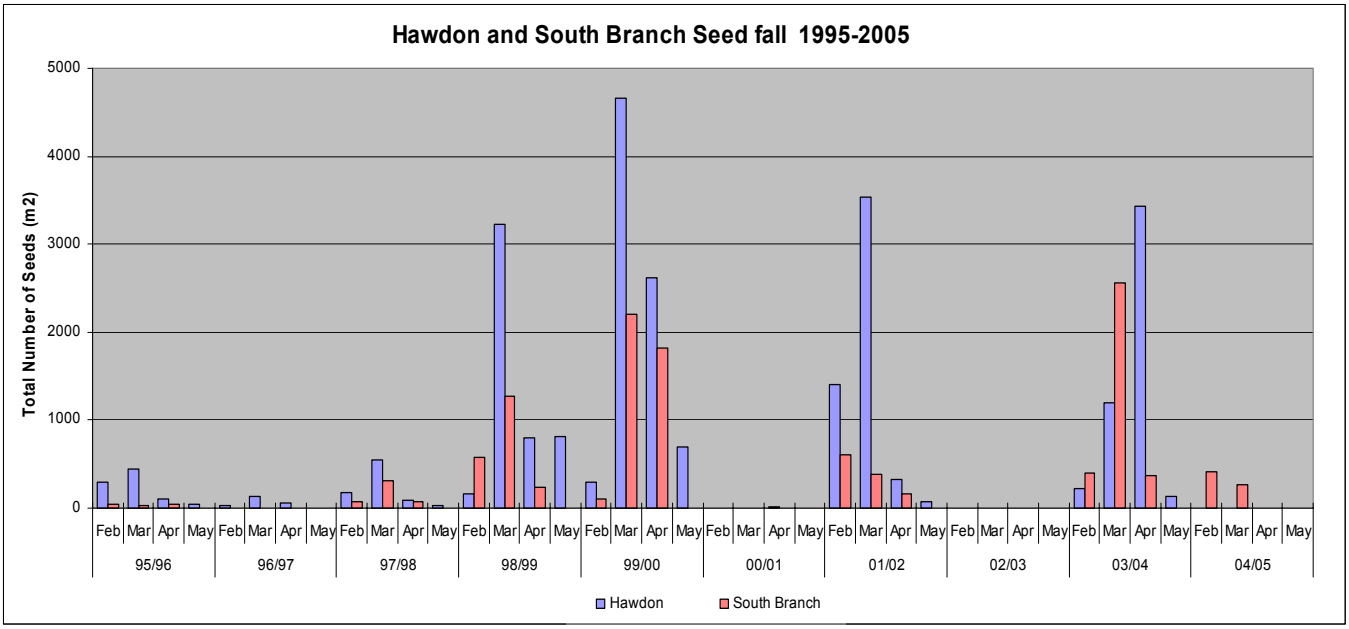


Figure 1.1: Collection of Beech seed (per sq. metre) from 8 sites in both the Hawdon and South Branch valleys during the summer and autumn months of 1995 to 2005. Each collection site was spaced at 25 metre intervals under red, mountain and silver beech forest. Each site consisting of a cordura funnel with a collecting surface of 0.5 sq.m and a collecting receptacle at the bottom.

Seed mast events were recorded in both the Hawdon and South Branch in 1998/99, 1999/00 and 2003/04, with the Hawdon recording another mast event in 2001/02. The largest mast event for the Hawdon occurred in the season of 1999/00, while the season of 2003/04 proved to be the largest for the South Branch. A consecutive beech mast event during the seasons of 1998/99 and 1999/00 in both valleys is considered to be an unusual occurrence as it departs from the usual

pattern of a major mast occurring every 5+ years (DOC 2004a, 2004b). The magnitude of 1999/00 is clearly seen in both valleys to be larger than that of 1998/99. Small amounts of seed were produced in both valleys in the seasons of 1995/96 and 1997/98, with a relatively small amount recorded in the Hawdon in 1996/97. No seed was produced in either valley during the seasons of 2000/01 and 2002/03.

2.6.2 Mice Catches

Mice (*House Mouse)* were caught by DOC in Hawdon Valley from 1993-2005, Mice were also caught in both the North and South Branches of the Hurunui River from 1995-2005. In total 320 and 449 mice were captured in the Hawdon and the South Branch respectively. Figure 1.2 shows the number of mice captures in both the Hawdon and South Branch between 1993-2005.

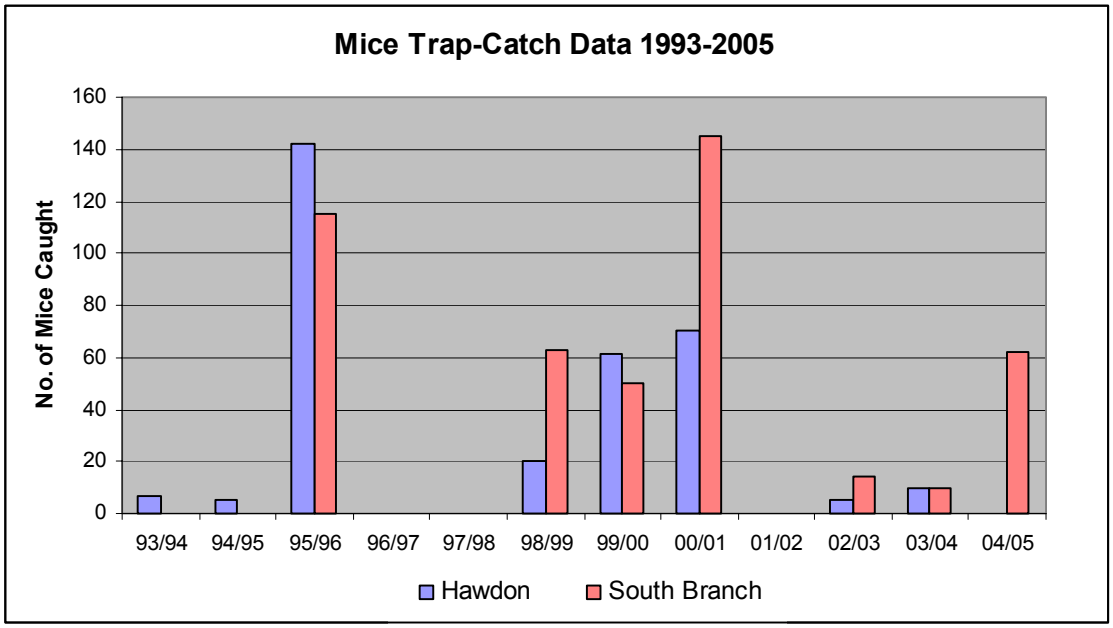


Figure 1.2: Mice caught in the Hawdon and South Branch valleys from 1993-2005

Previous mouse population eruptions have occurred in both the Hawdon and South Branch valleys during 1995/96 and 2000/01. Mouse populations remained high in both valleys during 1998/99 and 1999/00 with another high record in the Hawdon in 2004/05, though they are not considered by DOC to be of 'plague proportions' (DOC 2004a, 2005b). Three successive seasons

with high mice numbers were recorded between 1998-2001, the result of two large beech masts during 1998/99 and 1999/00 (Figure 1.1). Mice were recorded at low levels in both valleys in 2001/02 and 2003/04 with the Hawdon Valley recording two more low readings in 1993/94 and 1994/95. Figure 1.3 shows the Trap-catch index (TCI) of mice in the North and South Branch of the Hurunui River between 1995-2005. Trap-catch indexes are able give an accurate picture of population trends over time especially in relation to mustelids and rodents.

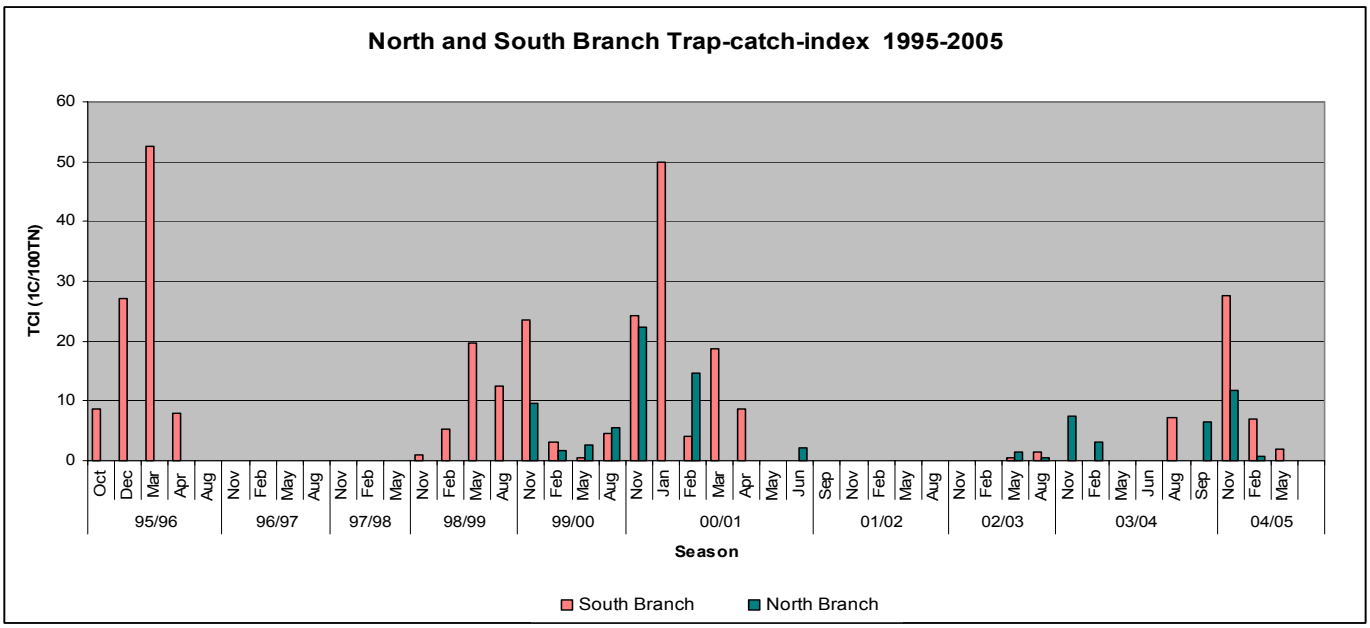


Figure 1.3: Trap-catch-index of mice from the North Branch (1998/99-2004/05) and South Branch (1995/96-2004/05). Trap-catch-index assesses relative density of a species, It is calculated as [Captures/ (traps set- half no. of traps sprung)] x nights set x 100. Essentially, TCI calculates the number of animals caught per trap per 24 hours, corrected for unavailable traps (Nelson and Clark 1973).

The TCI data (Figure 1.3) show mouse population populations were high in 1999/00, 200/01 and 2004/05 in both valleys of the Hurunui River. Prior to 1998/99, the South Branch recorded, high population of data during 1995/96 and 1998 /99. During the consecutive beech mast during 1998/99 and 2000/01, mice were being caught during the winter months of 1998 and 1999. This scenario, where a mouse population is present over the winter months and into the next spring and summer months, has been documented by Fitzgerald 1978, King 1983a, Fitzgerald et al 1996, Choquenot and Ruscoe 2000 and Ruscoe et al. 2004.

2.6.3 Ship Rat catches

DOC began trapping for Ship rats (*Rattus rattus*) in the South Branch of the Hurunui River in January 2001 after reports of the local rat population being 'numerous and widespread' (DOC 2004b). In the Hawdon Valley, rat trap-data are available from November 2003 onwards. In total 335 rats were caught between the seasons of 2000/01 and 2004/05 in the South Branch, and 470 rats were caught between the season of 2003/04 and 2004/05 in the Hawdon valley. No rat trap grid exists in the Poulter Valley.

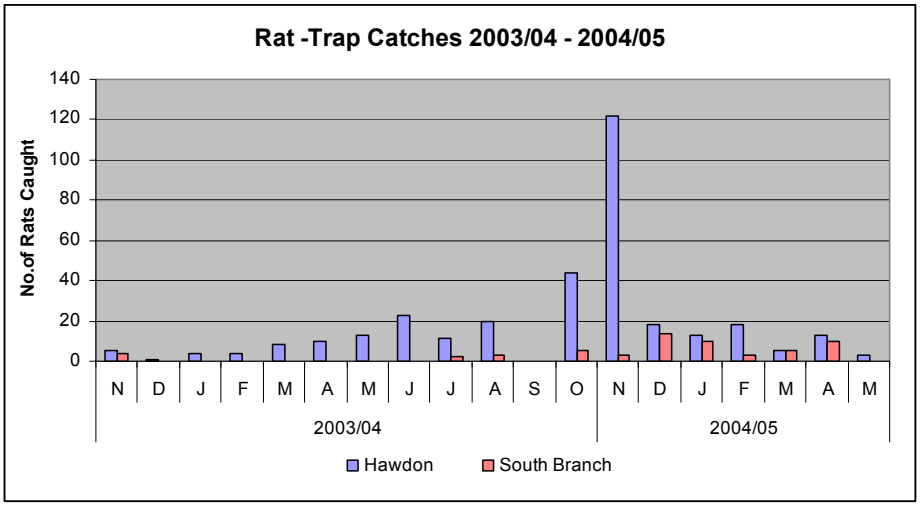


Figure 1.4: Rat trap-catch data between November 2003 and May 2005.

Figure 1.4 shows a trend of increasing Ship rat captures in the Hawdon and South Branch valleys during the 2003/04, climaxing between November and December 2004. The timing of these increases is associated with the beech mast event of 2003/04. The difference in the number of Ship rats caught could be related to age of the two operations (Hawdon (2003), South Branch (2001), suggesting that the Hawdon results are influenced by a pre-control rat population in existence when this when this data was collected.

Figure 1.5 shows the high Ship rat trap-catch levels reported in 2000/2001 season. Most of these catches were recorded in the stoat treatment block. By the end of 2001, Ship rat catches had diminished with low catches reported in 2001/02, 2002/03 and 2003/04. Ship rat captures increased in 2004/05, after the 2003/04 beech mast which was the highest on record (Figure 1.1)

with most catches caught in the rat block. High Ship rat captures in the summer of 2000/01 were probably in response to consecutive beech masts of 1998/99 and 1999/00 (Figure 1.1). Interestingly, Ship rat captures in the stoat non treatment block are highest in the autumn and winter months in 2000/01, and again in 2001/02 and 2002/03. These data suggest that these captures are related to an immigrating juvenile Ship rat population moving into the valley after the breeding season which occurs between September and April (Miller and Miller 1995; King et al. 1996b; Miller 1999).

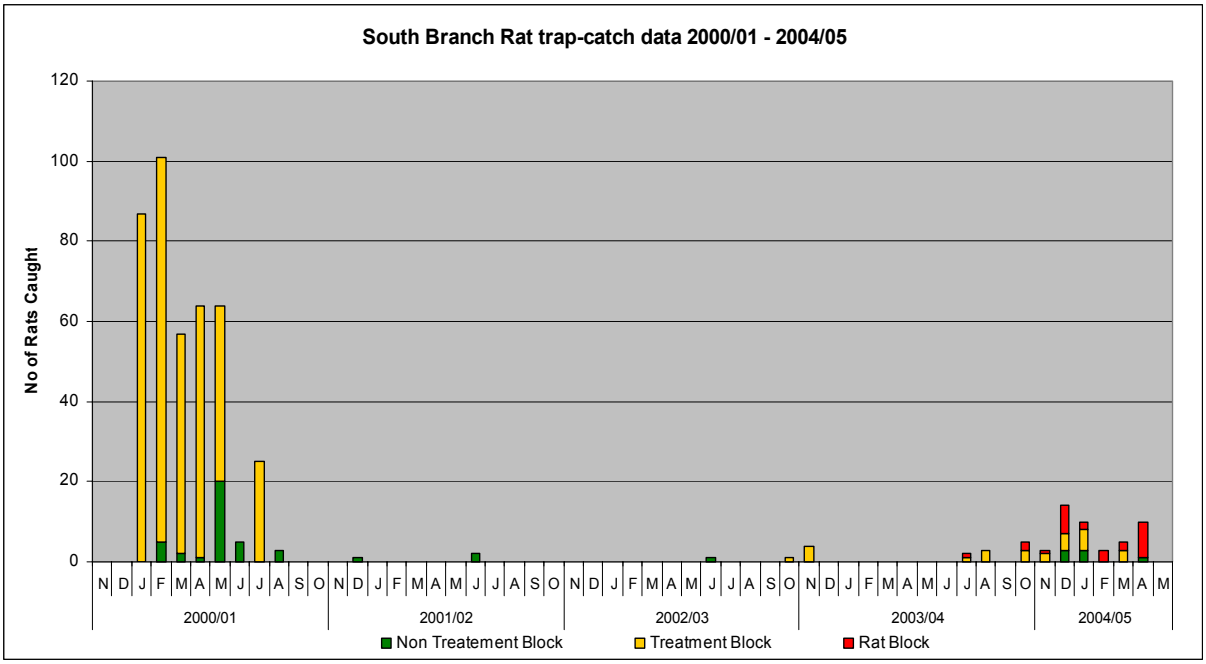


Figure 1.5: Rat trap-catch data from 2000/01 season through to 2004/05 season based on trap type

2.6.4 Stoat Catches

Stoats (*Mustela erminea)* have been caught by DOC in the South Branch from 1995/96 onwards. The data used in this report date from 1996/97 through to 2004/05. Stoats were also caught in the Hawdon valley from 1999/00 onwards. The data used in this report dates from between 2003/04 and 2004/05. More recently, Stoat trap-catch data from the Poulter valley have become available, with trap-catch data from 2004/05 have being used in this report. Between 1995-2005, 110 Stoats were caught in the Hawdon valley, 186 in the Poulter valley and 509 in the South Branch valley

respectively. Figure 1.6 shows stoat trap-catch data from the Hawdon and South Branch between the seasons of 2003/04 and 2004/05.

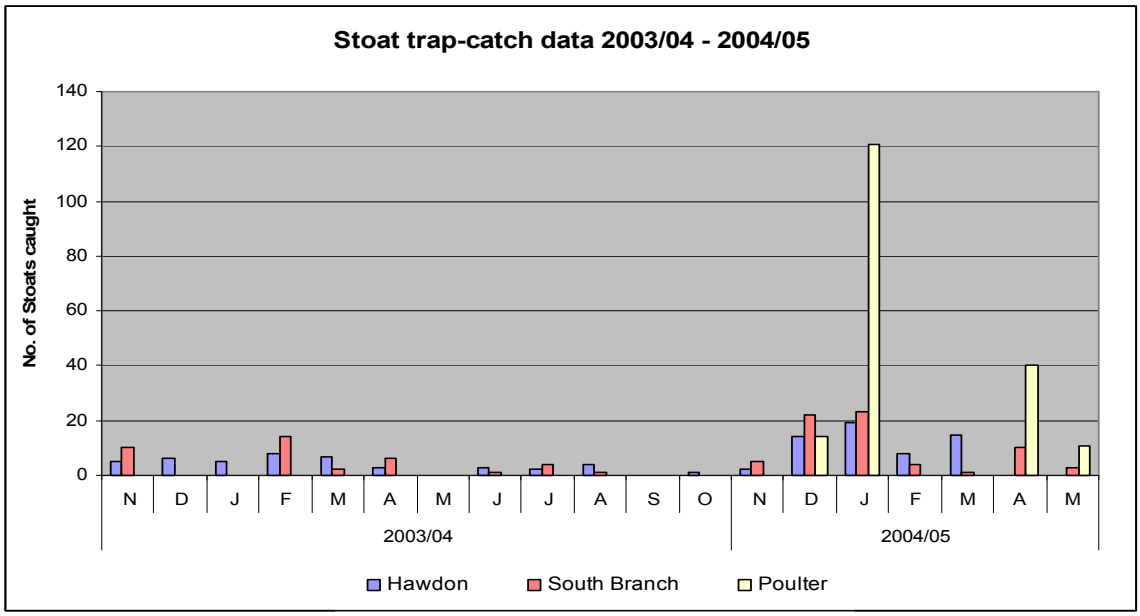


Figure 1.6: Stoat trap-catch data from the Hawdon, and South Branch from 2003/04 to 2004/05 and Poulter from 2004/05.

Figure 1.6 shows a stoat population eruption in all three valleys during the 2004/05 season. Stoat eruptions were also recorded in 1999/00 and 2000/01 in both the Hawdon and South Branch valleys, and again in 1995/96 in the South Branch. This increase is more prevalent in the Poulter valley, as it was the first season in which Stoats were trapped in the valley, hence a large proportion of stoat populations being caught in that season. This first season trend has previously been seen in the Hawdon and South Branch valleys with mice and rats (Figure 1.2 and 1.4), and have all occurred one year after a large beech seed event (Figure 1.1). Like the 2004/05 season, a small increase in both the Hawdon and South Branch valleys was reported during the 2003/04 season owing to the availability of mice during the large beech seed mast of that year. Stoat numbers are higher in seasons following a large beech mast event owing to the large input of young Stoats born during this time (8-9 months after the post-seed bonanza) (Powell and King 1997). Figure 1.7 shows the stoat-trap catch data in the South Branch from 2000/01 to 2004/05

High Stoat captures associated with the 2000/01 season (Figure 1.7) follows on from consecutive seasons of high stoat catches starting in 1999/00 (DOC 2004b). These consecutive seasons are possibly the result of the two consecutive beech seed masts of 1998/99 and 1999/00 (Figure 1.1) that caused increase in both House mouse and Ship rat populations between 1999/00 and 2000/01 (Figure 1.3 and 1.5). The 2000/01 eruption was reported by DOC as being 'significant and of a similar magnitude' as the last stoat eruption that occurred in 1995/96 (DOC 2004b), probably for the same reason as the 2000/01 eruption. The 2000/01 season was also unusual in that Stoats were still being caught well after March, compared to past seasons where stoat activity fell away quickly during February and March (DOC 2004b). It is suggested that the consecutive beech mast of 1998/99 and 1999/00, and resulting fluctuations in both rat populations possibly caused an evident stoat population being reported in the autumn and winter months. Figure 1.7 also shows other smaller eruptions in stoat population occurring in the 2001/02 and 2004/05 for reasons similar to those previously mentioned. Interestingly, with the introduction of the rat block in 2002/03 season, we see a greater proportion of Stoats being caught in these traps. A greater proportion of Stoats is also being caught in the non-treatment stoat block, especially during seasons that fell after large beech mast events, indicating a larger proportion of migrating Stoats (especially males searching for females) caught during the breeding season (Sept-Nov) (Erlinge 1979), and again in the summer and early autumn by juvenile Stoats (King 1982; King and McMillian 1982).

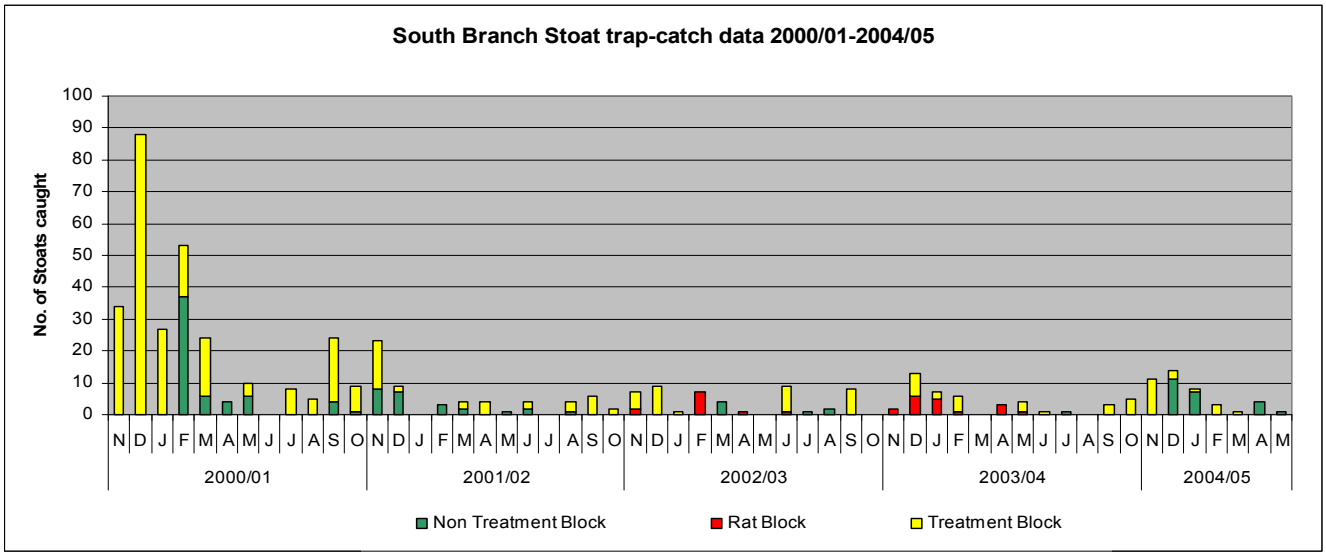


Figure 1.7: Stoat trap-catch data by trap type from 2000/01 to 2004/05. Stoats have been caught in the South Branch of the Hurunui River since 1995/96 (DOC 2004b).

Egg taken by Stoats between 1995/96 - 2002/03 shows a decreasing trend of Stoats caught in the years after a major beech mast event. In the 2000/01 season, when Fenn trapping replaced toxic eggs in bait stations, the rate of eggs taken or Stoats trapped / per station / per day dropped from a rate of 0.0075 to 0.0003 by 2002/03. With no record of this rate after the 2002/03 season, it is predicted that the rate would increase in 2004/05, a year after the 2003/04 beech mast event and decline over the intervening years before the next major beech mast.

2.6.5 Weasel Catches

Weasels (*Mustela nivalis*) are not considered by DOC to be a major pest and do not pose a serious threat to any New Zealand fauna. Weasels that are caught were recorded as by-catch on the established stoat and rat trapping grids in the Hawdon, Poulter and South Branch. In total, 27 Weasels were caught in the Hawdon between October 2004 and August 2005. Only 7 Weasels were caught in the Poulter between January and May 2005, and 63 Weasels were caught in the South Branch between 2000-2005. Figure 1.8 shows the trap-catch data from these three valleys during the 2003/04 and 2004/05 seasons.

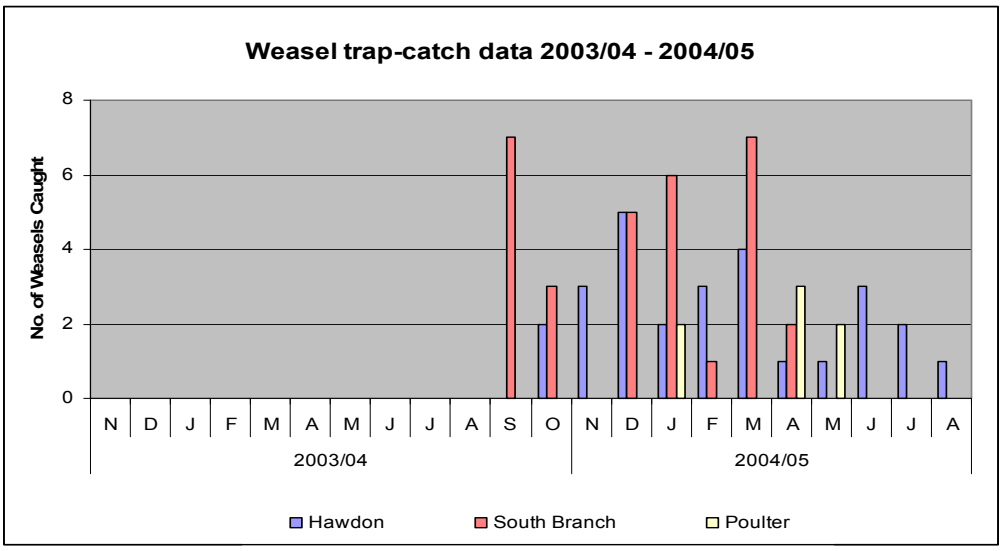


Figure 1.8: Weasel trap- catch data from the Hawdon, Poulter and South Branch between 2003/04 and 2004/05 seasons

Figure 1.8 shows Weasel catches recorded during the 2003/04 and 2004/05 seasons. These catches are likely to have resulted from increased rodent populations caused by the beech mast event of 2003/04. The numbers of Weasels caught in each valley remained low, on average 1-3 Weasels caught per month in the Hawdon and Poulter valleys during the summer and autumn months of 2005. On the other hand, in the South Branch the average number of Weasels caught per month is higher (1-7 per month) than the Hawdon or Poulter. It is suggested that this result is owing to the decline of the Weasels competitor; Stoats (*Mustela erminea)* after 10 years of trapping. This unsubstantiated view requires further research. Figure 1.8 shows Weasels being caught in the Hawdon valley well into the winter months suggesting that after a beech mast event, Weasels were still being caught though until the height of winter. Figure 1.9 shows weasel trap-catch data from the South Branch between the season of 2000/01 and 2004/05.

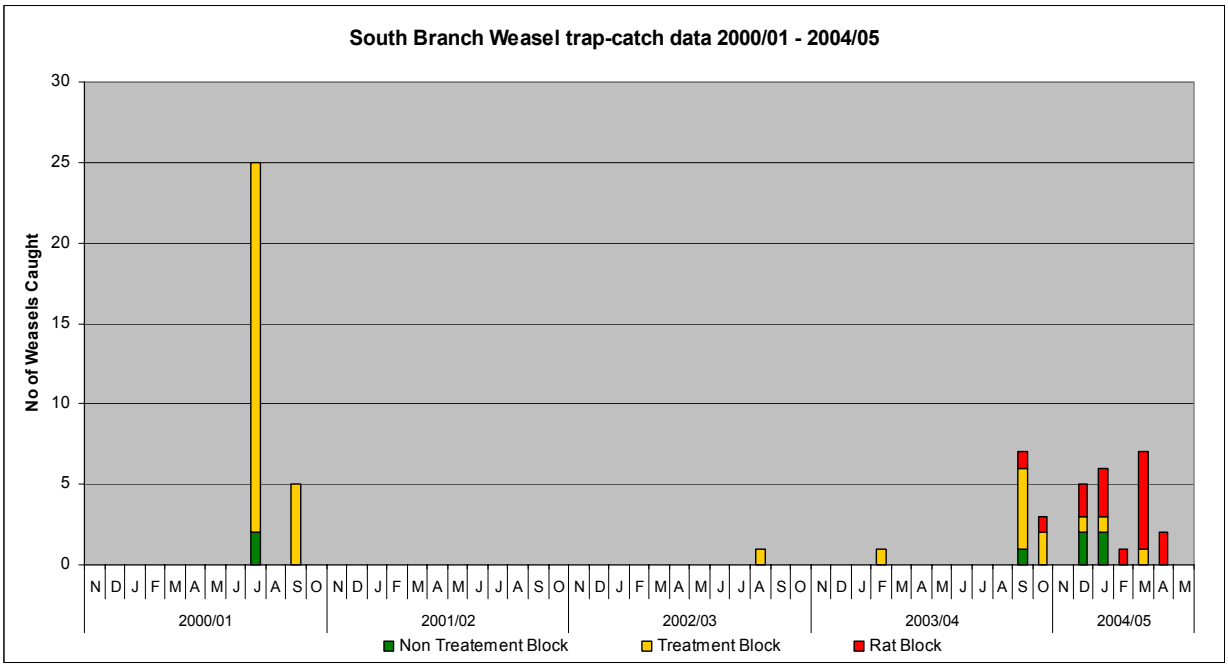


Figure 1.9: Weasel trap-catch data by trap type from 2000/01 to 2004/05.

Figure 1.9 shows that the majority of Weasels trapped in the South Branch have occurred the year after a beech mast event, (see Figure 1). Prior to the establishment of the rat block in November 2003, the majority of Weasels were caught in the stoat treatment block. Since November 2003, the rat block has caught a larger proportion of Weasels compared to the other two blocks. The small number of Weasels being caught in the stoat non-treatment block has also increased during

the 2004/05 season, possibly indicating a small immigrating weasel population moving either in or out of the valley during the breeding season (spring) and subsequent dispersal of juvenile Weasels in summer and autumn months.

2.3 Spatial Modelling applied to pest and forest distribution in New Zealand

Abstracts from three recent research papers that provided a fundamental basis for this thesis have been listed below. The first paper by Frasier, Overton, Warburton, and Rutledge (2004) details the methods for modelling and predicting abundances for the brushtail possum (*Trichosurus vulpecula*) on a national level. The second paper by Newell and Leathwick (2003) details the methods and results of predicting the spatial distribution of forest distribution in the North Branch and South Branches of the Hurunui catchment using cluster analysis The third paper summaries research that I conducted in 2004 on predicting areas of high areas brushtail possum (*Trichosurus vulpecula*) activity by spatially mapping the chemical properties of soils within the North Branch of the Hurunui Mainland Island using GIS.

Research Paper One:

Frasier, K.W; Overton, J.M; Warburton B; Rutledge, D.T. (2004): Predicting the spatial pattern of animal pest abundance: a case study of the brushtail possum (*Trichosurus vulpecula*). Science for Conservation 236. Department of Conservation, Wellington, New Zealand.

Methods for modelling and predicting abundances of animal pest species throughout New Zealand were developed, using brushtail possum (*Trichosurus vulpecula*) data in generalised regression analysis and spatial prediction (GRASP techniques to develop models describing the spatial relationships and statistical relationships between trap-catch-indices (TCI's) of possum abundance and key environmental factors (e.g. land cover, climate). TCI data from monitoring surveys of uncontrolled possum populations were tested as predictors of relative possum abundance at 'equilibrium' (with tested uncertainties) through out New Zealand. The GRASP model accounted for 50% of the variation in TCI's and identified seven spatial variables significantly correlated with TCI. This model also produced 'correction graph' for converting

between TCI values in January and June and between raise-set and ground set trapping. Post control trap-catch data, together with control history information, were then used to predict the relative abundance of possums under different control scenarios. These models accounted for 1-30% of the variation in pest control TCI's, suggesting that a statistical modelling approach to predicting spatial patterns of abundance can provide important and useful information for pest / conservation management. However priority should be given to improving the uncontrolled model.

Research Paper Two:

Newell, C and Leathwick, J.R. (2003): Mapping local forest community distribution, using computer models: a pilot study. Landcare Research Contact Report LC0202/179

Data from permanent forest plots were used to model the spatial distribution of forest vegetation in the North Hurunui, one of two major catchments in the Hurunui Mainland Island. Nine vegetation communities were identified within five broad vegetation classes using cluster analysis. Relationships between environmental parameters and both vegetation classes and communities were quantified using classification tree analysis and expressed spatially as maps in a GIS. The distribution of *Griselina littoris*, an important food species for rare birds in the Hurunui Mainland Island, was modelled using logistic regression. Differences between individual vegetation classes and communities related closely with temperature and rainfall. Similarly, variation in *Griselina* abundance related to temperature, rainfall, and vapour deficits. The vegetation class, community, and *Griselinia* models were tested in a nearby catchment using permanent-forest plot data set from the South Hurunui catchment. The models did not accurately predict the proportion of plots in each vegetation class and community, nor the distribution and abundance of *Griselinia* in the South Hurunui. These discrepancies may in part relate to shortcomings of the environment data used, the absence of site scale factors in the models and the underlying differences in the past and present environment between the North and South Hurunui Catchments

Research Paper Three:

Lough, H.G.C (2004): Predicting areas of high areas brushtail possum (*Trichosurus vulpecula*) activity by spatially mapping the properties of soils within the North Branch of the Hurunui Mainland Island using GIS. Unpublished University of Canterbury fourth year paper.

Data sourced from Landcare Research (NZ) was combined with spatial GIS data locating soil plots in the North Branch of the Hurunui River. The spatial distribution of Carbon, Nitrogen, and Phosphourous, Exchangeable calcium, magnesium, potassium and sodium was derived by subsetting elevation in relation to changes of each soil property. The objective of this project was to see if certain soil properties can predict areas of high possum activity.

The study supported previous research by Payton (1989), which reported on increases increase nitrogen, phosphorous, and potassium concentrations in regrowth foliage which may provide a rational explanation for the repeated browsing of individual trees by possums. The study found that analysing soil samples can indeed indicate possum activity in areas, although is restrained by a number of limitations. By using higher precision techniques from greater range and locality of data points and a higher, more precise interpolation method, it was possible to overcome the limitations on quality, accuracy and precision of these results.

Summary

Classification tree and regression analysis which were used to predict the spatial distribution of possum and forest vegetation species was associated with limited success in the first two papers. The third paper, which used applications within a GIS to model the spatial distribution of soil properties, introduced a new concept to spatial modelling that could possibly provided better levels of accuracy. The methodology used in this paper provided a basis of research for this thesis.

2.4 Conclusion

This chapter has reviewed previous research literature on the ecology of Stoats, Ship rats and Weasels in a beech forest environment and pest management data collected by the Department of Conservation (DOC). Both sources of information have identified the beech mast cycle as the predominant factor responsible for temporal fluctuations of Stoats, Weasels and Ship rats in a beech forest environment. These fluctuations occur about every 3-5 years, and result in an increase in trap-catch rates in the Hawdon, Poulter and South Branch valleys.

Trapping data collected from DOC in the Hawdon and South Branch valleys have also indicated that the number of Stoats, Ship rats and Weasels is generally high in the first trapping year following a beech mast cycle compared to subsequent years. Consecutive beech mast years recorded in 1998/1999 and 1999/2000 also resulted in a large increase in the number of Stoats, Ship rats and Weasels caught. Predicting the spatial distribution for each pest species must take into account whether any major trapping operations have been conducted in the area that is spatially modelled and when the last significant beech mast occurred.

The chapter also introduced three spatial models that have been applied to pest and forest distributions in New Zealand. Each model recorded a limited success rate in predicting each spatial distribution, which needs to be considered when predicting the spatial distribution of Stoats, Ship rats and Weasels in a beech forest environment.

CHAPTER 3 METHODOLOGY

Chapter Three details the quantitative approach of this thesis from beginning to end product in which spatial distribution models for Stoats, Ship rats and Weasels in a beech forest environment were created. This chapter is divided into five sections; 1) Data Collection; which discusses data acquisition, conversion into a GIS and the creation of a DEM for each study site, 2) Spatial attributes; which introduces each spatial attribute in detail, 3) Creation of Interval Boundaries; which discusses the process used to define intervals for each spatial attribute; 4) Regression analysis; which describes procedure of regression analysis of trap data and (5) Creating a Model of High Pest Abundance which describes the method used to model the spatial distribution of Stoats, Ship rats and Weasels in a Beech forest environment.

3.1 Data Collection

Trap data from the Hawdon, Poulter and South Branch valleys were provided in electronic format by the Department of Conservation Canterbury Conservancy Office on 26 July 2005. Additional trap data were later transferred from the Department of Conservation Waimakarri Area Office on the 25th November 2005. Table 3.1 shows those files that were received on 26th July which have all been incorporated into the thesis.

	File Name	Code	Description
1	alltrapdatachcco-67910.xls	CHCCO-67910	Database containing all stoat and rat block trap data from Hawdon between 2003/04 - 2004/05 and South Branch between 1995/96 - 2004/05 (inc. analysis of results).
2	poustoatchcco-69626.xls	CHCCO-69626	Database containing all stoat trap data from the Poulter during the 2004/05 season.
3	alltrapsfiefds.shp	-	Point Shape file containing the locations of all Stoat and Rat traps in the South Branch in a GIS
4	all_traps2.shp	-	Point Shape file containing the locations of all Stoat and Rat traps in the Hawdon in a GIS
5	poultertrap_3.shp	-	Point Shape file containing the locations of all Stoat and Rat traps in the Poulter in a GIS
6	eggtakesCHCCO-24595.xls	CHCCO-24595	Spreadsheet containing data on poison eggs taken by Stoats from 1995/96 - 2000/01 and Stoats caught in Fenn traps from 2000/01 - 2004/05 in the South Branch (inc. analysis of results)
7	micetrapsbchcco-50.xls	CHCCO-507	Spreadsheet containing Mouse Index Trapping data in the South Branch from 1995/96 - 2004/05
8	sbseedchcco-30807.xls	CHCCO-30807	Spreadsheet containing Seed fall data from the South Branch from 1995/96 - 2004/05 and North Branch from 2001/02 - 2004/05
9	waimakseedwmkao-249.xls	WMKAO-249	Spreadsheet containing Seed fall data from the Hawdon from 1995/96 - 2004/05

Table 3.1: Data files collected from the Department of Conservation which were source of information for this type of research. (.xls indicates that the data concerned was formatted using the Microsoft Excel© Spreadsheet application. All shape files were created using the GIS application; ArcGIS©).

Files 1 and 2 (Table 3.1) contain the essential trapping data from the Hawdon, South Branch and Poulter Valleys conducted by DOC over the last 10 years. When an animal is caught in a trap, the date, season number, trap code, species type, sex and age of the animal and location are all recorded. Date is recorded as day/month/ year.

Files 3 to 5 are all point shape files, when run in a GIS application such as ESRI's ArcGIS©. These shape files display the location of each coded trap positioned by a single XY coordinate pair within geographical space. Each trap site within each valley was recorded as a point in using GPS (Global Positioning System). These data provided the basis for this type of research and were fundamental in analysing the spatial distribution of Stoats, Ship Rats and Weasels in each of the valleys.

File 6 contains data on poison egg takes by Stoats (per season) from 1995/96 - 2000/01 and Stoats caught in Fenn traps from 2000/01 - 2004/05. These data were used to describe the long-term temporal trend of stoat populations in the South Branch.

File 7 contains data on mice trap indexing in the South and North Branch of the Hurunui River and was used to describe the short- term temporal trend of mice (*Mus musculus*), which may give an insight to population trends for Ship rats and Stoats during beech mast and non mast seasons. Only one mouse trapping line exists in the Hawdon and South Branch. These lines don't control mice populations, though provide data on mouse populations which constantly fluctuate depending on season and seed availability.

Files 8 and 9 contain beech seed fall collection data in the Hawdon, South Branch and North Branch between 1995/96 - 2004/05. Beech seed fall (per sq. metre) is collected from eight sites located within each of these valleys during beech mast and non mast seasons (Oct-April), and is considered the first phase in the beech mast cycle.

Weasel data from the Hawdon valley was accessed separately on the 25 November 2005 coded WMKAO-8079 and contained weasel trap data from the established stoat and rat block in the Hawdon valley between 2003/04 and 2004/05. This file was formatted in a similar manner to files 1 and 2 (Table 1), providing information on time location, age and gender of captured Weasels.

3.1.1 Conversion of trap-catch data into a GIS

In order to spatially analyse the distribution of Stoats, rats and Weasels in the Hawdon, South Branch and Poulter Valleys, each trap that recorded a catch of a stoat, rat or weasel was sorted, separated and transferred into a new spreadsheet. This resulted in the creation of three new files for Stoats and Weasels and two files for Ship rats based on their location within any of the three valleys. (Note: No rat trapping grid/block exists in the Poulter Valley). Each new file was then checked for bad trap code entries. Where the trap code had been entered incorrectly, measures were adopted to identify the cause of the bad entry (e.g. bad spelling or incomplete trap code), and if possible, rectify the mistake or delete the entry all together. In total, 8 files where removed from the Hawdon Rat data and 2 files from the Poulter Stoat data.

As discussed previously, when an animal is caught within the Hawdon, South Branch or Poulter valleys, the record of its capture was categorised chronologically. This posed a problem where there were numerous instances of the same trap code being recorded. If the situation was prevalent when joined with spatially referenced data within a GIS environment, only one record would be read, while duplicate records with the similar trap code would be dismissed and unaccounted for. To overcome this problem a new column of data ‘freq’ or ‘frequency’ was created in each pest file to account for the number of Stoats, Ship rats or Weasels caught per trap over the extended study period for each valley.

To become compatible with the ArcGIS application, each spreadsheet file containing edited data on Stoats, rats and Weasels in the Hawdon, South Branch and Poulter valleys was formatted from a Microsoft Excel© Spreadsheet format to a Database IV format. Each file was then joined to the table to its corresponding point shape file; for example, Hawdon Stoat, Rats and Weasel Database

IV files were joined with the Hawdon point shape file 'alltraps2.shp' (Table 1). Each trap-catch record is now related to its corresponding spatially referenced point within the point shape file and provides the pivotal data to spatially map the distribution of Stoats, rats and Weasels in each valley based on numbers caught per trap. Essentially these data alone can show variations of population density per pest across each valley from areas of traps that register a high levels of animals caught (> 2 caught per trap) to low levels or absence of animals caught.

3.1.2 Creating a Digital Elevation Model (DEM)

A Digital Elevation Model (DEM) is a quantitative model, defined by mathematically defined surfaces or by point or line images that shows the variation of surface elevation over an area of the earth's surface (Burrough and Mc Donnell 2000a). DEMs are modelled within a GIS either by regular grids (altitude matrices) or triangular-irregular networks (TINs). Altitude matrices are the most common form of discretised elevation surfaces and are commonly produced by interpolation from irregularly or regularly spaced points, while TINs use a sheet of continuous, connected triangular facets based on a Delaunay triangulation of irregularly spaced nodes or observation points (Burrough and Mc Donnell 2000a). Both forms of DEM are useful in deriving information about the surface of the landform including slope, aspect, solar irradiance (hill shade) and surface topology.

An altitude matrix DEM was used in this research to obtain information on surface topology and hill shade, display spatial data in the Hawdon, South Branch and Poulter over the underlying landform, as well as calculating slope and aspect. Altitude matrix DEMs were chosen for their simple data structure and data entry, as well as their ease with which matrices can be handled within a computer. Though TINs are considered to provide the more efficient, accurate data storage of elevation data, they do this with the expense of introducing a triangular discretisation that may hinder some kinds of spatial analysis such as the derivation of surface topology and geometry (Burrough and Mc Donnell 2000a). As three valley areas were modelled in this research, the option to use an altitude matrix DEM was based on avoiding any complexity in data structure or hindrance associated with TINs that may slow down research.

An altitude matrix DEM was created for each of the three valleys by selecting and subsetting contours from arc shape files sourced from the New Zealand Digital Topographic Database, which was accessed from the University of Canterbury Geography Department. Based from maps sourced from Land Information New Zealand; NZ Map Series 260 (Scale 1:50,000), contours were selected and subsetted from the arc shape file 'L33' for the South Branch and Poulter valleys, while a combination of 'L33' and 'K33' were used for the Hawdon valley. Each subsetted contour arc shape file was then converted into a point coverage file where the contour line was systematically broken up into points. Each point recorded an elevation based from the original contour line attribute table. Each coverage file was then created into a new point shape file. An inverse distance method of interpolation with a neighbourhood or search radius of 12 data points was used to calculate each DEM, combining the ideas of proximity espoused by Theissen polygons with the gradual change of the trend surface. Inverse distance methods of interpolation assumes that the value of an attribute z, in this case, 'elevation', at some unvisited point is a distance weighted average of data points occurring within a neighbourhood or window surrounding the unvisited point (Burrough and Mc Donnell 2000a). Each DEM is saved as a Raster grid with a cell output size of 15 metres.

Shaded Relief Maps (Hill shades) were created for each DEM to improve the visual quality of each map, particularly with respect to portraying relief differences in hilly and mountainous areas (Burrough and Mc Donnell 2000b). Hill shades are based on a model of what the terrain would look like if illuminated from a singular source at a given position. Each created hill shade adopts the default setting of light source illuminating at a 45 degree angle to the NE. Each hill shade is saved as a Raster grid with each cell obtaining a reflectance value which is displayed in grey scale, with light colours representing areas which are 'illuminated' and dark colours which are not. Each hill shade then is draped over the DEM, where elevation values from the DEM are calculated in relation to height, with an exaggeration factor of 1.5. This final step shows the 2D hill shade raster grid in three dimensional spaces.

3.2 Spatial Predictors

Ten spatial attributes were analysed in this thesis as potential spatial predictors of Stoats, Ship rats or Weasels; four of which were distance related measurements (*distance from ecotonal edge, distance from river, distance from river tributary and distance from trapping edge*); three were climate based variables (*mean maximum temperature, mean minimum temperature and mean precipitation*) and three were based on the topographical based variables (*elevation, aspect and slope*). This section introduces each spatial attribute and discusses them in detail.

3.2.1 Distance from Ecotonal Edge

Ecotonal edges of native and exotic forests provide a preferable habitat for Stoats and Weasels. The ecotonal edge of a forest is associated with dense ground cover which harbour high densities of mice (*Mus musculus*) (Murphy and Pickard 1990), which are frequently eaten by both Stoats and Weasels in beech forests. Dense ground cover also provides cover for both terrestrial and avian predators such as Feral cats (*Felius Catus*) and falcons (*Falco novaesseelandiae*) and from each other. Ship rat populations are more determined by winter food supply and predation and so their numbers are spatially varied throughout beech forest areas. Determining their spatial relation to the ecotonal edge of forests may give some insight if a relationship between species exists.

The ecotonal edge of beech forests in the Hawdon, Poulter and South Branch was defined by a polygon shape file characterised by forest location, area and type was sourced from the New Zealand Digital Topographic Database. Based on the similar process, on which contour lines were selected and used to create each DEM, each shape file was chosen in relation to the location of each valley. Each polygon was firstly selected by attribute to separate polygons classed as 'beech forest' from other polygons. These data were saved under a new file and selected and saved again based on their location in relation to trap locations in each valley.

The next stage in creating the ecotonal boundary involved editing polyline shape files based on the original forest polygon shape file. Each polyline was selected based on location with the final

selected polygon shape file and saved to a new file. This newly created polyline shape file was edited manually to select lines that represent the ecotonal boundary between beech forest and river flat. The purpose of this was to disregard the ecotonal boundary which exists at the tree line, which marks the transition between beech forest and alpine tussock. The final polyshape file shows the ecotonal boundary of beech forest located on both sides of the valley floor which includes all major gaps in the beech forest associated with alpine streams and tributaries up to a specified point.

Distance from the ecotonal edge was calculated in 50 m intervals (i.e. 50,100,150…etc.) from the ecotonal edge up to an interval where the furthest trap was located within each valley. Distance was calculated using the spatial analysis toolbox located within ArcGIS. Each calculation created a raster cell grid that was manually set to show the maximum distance on both sides of the ecological boundary based on the distance of the furthest trap location, and with a cell out put of 15 m correlated to the size of each DEM.

3.2.2 Elevation

Elevation of the surrounding terrain plays a limiting factor for each species spatial distribution in any environment. Ship rats are found from the coastline to the tree line in mountainous areas, but much less often in higher elevations, and never in alpine tussock areas (Innes 1990). Stoats are able to live in any habitat in which they can find prey; from coastal areas to remote high country; at any elevation up and beyond the tree line (King and Murphy 1990). It is presumed that with the unavailability of Stoats main sources of prey (birds, mice, and lagomorphs) at higher elevations, Stoat numbers will fall with height above sea level, especially up beyond the tree line. The relation of Weasels with elevation is unclear; being a close relation to the stoat, it is apparent that their distribution might be similar.

Elevation was calculated in 50 m intervals (i.e. 500m, 550m, and 600m) from the lowest to highest interval containing trap locations. The DEM of each valley provided the raster cell grid which was used to create these interval boundaries.

3.2.3 Slope

Slope is defined by a plane tangent to the surface as modelled by a DEM at any point and comprises two components namely, gradient, the maximum rate of change of altitude (measured in degrees), and aspect. King et al. (1996) reported that traps set on warmer, steeper sites in the Pureora Forest Park caught the most number of Ship rats. Stoats are active hunters and can search through all possible cover, down every accessible hole and up every likely tree (Moors 1983), whether steeper slopes are a deterrent for Stoats or Weasels to actively hunt rats remains unclear. Slope was calculated in 10 degree intervals (e.g. 10, 20, 30… etc.) for each valley using the spatial analysis toolbox located within ArcGIS. Each calculation created a raster cell grid with a cell size of 15m, correlated to the size of each DEM.

3.2.4 Aspect

Aspect relates to the compass direction in which the terrain faces. The relationship between aspect of the surrounding terrain to Stoats, Weasels and Ship rats remains unclear. Little or no research into how the distribution of each pest in New Zealand beech forests or in any other forest types, in respect to aspect was discovered when researching this topic. Aspect was calculated in degree intervals based on compass direction (e.g. East [67.5°-172.5°]) for each valley using the spatial analysis toolbox located within ArcGIS. Each calculation creates a raster cell grid (based on the pre-defined specifics mentioned above) with a cell size of 15 m, which correlates to the size of each DEM.

3.2.5 Distance from Water (*Distance from river* and *distance from river tributary*)

Water is essential for life. Every living organism on earth must have access to water in some form in order to survive. Hence populations of Stoats, Weasels and Ship rats must be in close proximity or include a certain water sources (e.g. stream, river, spring etc.) within their home range. It is hypothesised that the population density of each pest will decline with distance from water. Two Spatial predictors; distance from the main river body (i.e. Hawdon, South Branch and Poulter) and Distance from river tributary were tested in this report.

The location of each valley's river system and their tributaries was derived from a polyline shape file characterised by river location and length was sourced from the New Zealand Digital Topographic Database. Based on the similar process on how contour lines were selected to create each DEM, each polyline shape file was chosen in relation to the location of each valley. A polygon shape file showing larger areas of river that can not simply be defined as a simple line was also sourced and selected. Both the polyline and polygon river shape files were then combined by manually editing the river arc to include tracings of the boarder of each river polygon; this was achieved using the ArcGIS 'Editing toolbar' located within the Arc Map application. In order to analyse each spatial predictor separately, the edited polyline shape file went through a process of manual selection where arcs representing the main river body of each valley were selected and saved into a new arc shape file. The tributaries of each valley's river system were derived differently; selected by location in relation to the newly created river body polyline shape file, each polyline that did not match the designated river body polylines were separated and saved in a new polyline file.

Both spatial predictors; (*distance from main river body and distance from river tributary*) were calculated in 50 m intervals (i.e. 50,100,150…etc.) from up to a distance of 400 m. Distance for each spatial predictor was calculated using the spatial analysis toolbox located within ArcGIS. Each calculation created a raster cell grid that was manually set to show the maximum distance on both sides of the river/tributary, with a cell out put of 15 m correlated to the size of each DEM.

3.2.6 Climate Variables (Mean Max and Min Temperature, Average Rainfall).

Climate plays a limiting factor for the distribution of rats and Weasels. As mentioned before, both species prefer thick ground cover, so favour overgrown patches of any habitat including scrub and cutover forest (King et al. 1996a), or the margins between these and open country. In beech forests and other forest types, these margins (or ecotonal edges) near the tree line are controlled by climate, representing the ecological limit in which forests can grow. Climate does not limit the distribution of Stoats as they are able to tolerate both extremely wet (>6000 mm

rain/year) conditions in parts of Westland and Fiordland and moderately dry (< 500mm) conditions in parts of Otago and Canterbury (King 1990). Determining a relationship between climate and pest abundance may give some insight in to the spatial distribution of each pest.

Climate data were derived from research conducted by Leathwick, Wilson and Stephens (1998) in interpolating climate parameters measured over an irregularly-spaced network of climate stations in New Zealand. Mean maximum temperature, mean minimum temperature and precipitation were converted from a raster grid with a 1 kilometre resolution output to a 15 metre resolution output. This was achieved by converting each 1 kilometre cell in each original climate map into a point shape file and interpolated using an Inverse distance method. Mean maximum and minimum temperature was calculated in single degree (°C) intervals, and precipitation was calculated in 25mm intervals.

3.27 Distance from Trapping Edge

Established trapping grids such as the Hawdon, Poulter and South Branch experience a higher catch of each pest near the boundary of each grid; especially on the valley floor. This observation is caused by migrating pest populations entering into the trapping grid from other areas. Stoats and Weasels disperse when they are young, to form their own home ranges or in the search for food (King 1990a). Forest dwelling Ship rats do not form territorial, hierarchical colonies as commensial rats (Ewer 1971). Instead, individuals or family groups are dispersed rather evenly through available habitat (Daniel 1972; Innes 1977; Hooker and Innes). Understanding how this trend changes over distance from these boundaries might give another aspect on the spatial distribution of Stoats, Weasels and rats.

Distance from trapping edge was calculated in intervals based on geographical location of either the X (Easting) or Y coordinate (Northing), based on the New Zealand Map Grid. The X and Y coordinates of each trap point were derived by entering a 'Pre-Logic VBA script code' using the Field Calculator, located in the attribute table of each trap point file. Each code populates new or existing attribute fields with a points x, y and/or z coordinate component. Details on how this code works can be found on the ESRI support webpage (ESRI 2006). Based on the orientation of

each valley, X coordinates were chosen for the South Branch valley (West-East orientation) and Y coordinates used for both the Hawdon and Poulter valleys (North-South orientation). Each trap points X or Y coordinate and number of pest caught per trap were copied from each attribute table into Microsoft Excel. Each trap point was then sorted into intervals of 1000 based of the last 4 digits of the X/Y coordinate. Section 3.3 describes the next stage of data analysis (Regression analysis).

Representing these interval boundaries within ArcGIS required a different process. A new polyline shape file containing two lines was created for each valley using the 'Editing toolbar' located within the ArcMap application. These lines, located near the last trapping point(s) on both sides of each valley represent the border (or edge) of each trapping grid (both stoat and rat). Distance from each edge was calculated using the spatial analysis toolbox located within ArcGIS. Each calculation created a raster 15 m cell grid (correlated to each DEM) that was manually set to a range where distance intervals from both edges merge at the centre of each valley. Each distance calculation was then clipped to a polygon (created in a new shape file) representing the trapping area of each valley. Including a barrier, in this case a polygon, restricts analysis of distance intervals within the margins based on the pre-defined location of the polygon. Determining the spatial trend between each interval will correlate back to trend shown by X/Y regression analysis results.

3.3 Process involved in creating Interval boundaries for each spatial attribute

Interval boundaries for each spatial predictor were calculated using the Spatial Analysis toolbox located within the GIS application; ArcGIS. Each raster cell grid was then separated out into their pre-defined intervals (e.g. 50m, 100m, 150m… etc) using the Raster Calculator, a tool within Spatial Analysis toolbox which calculated each interval using Boolean logic. To avoid cross-over between elevation intervals, the highest of the two intervals, used in the equation was recorded 0.001 less than the initial figure used to define the interval boundary (e.g. 500 m became 499.999 m; 650 m became 649.999 m) Each Boolean calculation was then converted to a polygon shape file by using the 'Raster to Feature' option in the Conversion toolbox, another component within

ArcGIS. Each newly created polygon within the polygon shape file then went through a process of selection where those polygons with the 'GRIDCODE' or cell value of 1 were separated and copied into a new file. Trap points that were situated within any polygons with a cell value of '1' were separated into a new point file. Each group of segregated trap points represented the number of traps located within each distance interval, which provides the essential data needed for the next important stage trap data in analysis; regression analysis.

3.4 Regression Analysis of Trap Data

Once intervals became established for each spatial predictor, the number of pests caught, per interval is then obtained from each spatial predictor's attribute table located within ArcGIS and copied into a Microsoft Excel Spreadsheet. The mean number of pests within each interval ('Trap mean') was then calculated by the total number of pests caught divided by the number of trap records per interval.

Each interval mean was then graphed on a scatter graph against each attribute, and a simple regression analysis using linear or second or higher order polynomial trend lines was conducted to obtain an equation that best fits the trend of the data. A Pearson product moment correlation coefficient (r^2) was also recorded. To identify an increase or decrease in uncertainty of each mean trapping rate, a standard deviation is calculated between sets of two interval points. This is shown as a 'dashed' line for each recorded mean trapping rate.

It was decided that the mean number of pests per interval data for each attribute was not going to be converted to a Trap-catch index, a common technique used by DOC and other pest operators to assess the relative density of a particular pest. The trap data collected by DOC did not originate from one continuous pest control period, rather many seasonal based operations based over a number of years in each valley.

3.5 Creating a Model of High Pest Abundance

Once a number of spatial attributes have been determined as potential predictors in determining the spatial distribution of Stoats, Ship rats and Weasels in a beech forest environment, a model using ESRI's Model builder was developed to combine these spatial attributes into a spatial prediction map for the North branch of the Hurunui River.

CHAPTER FOUR: RESULTS

Chapter Four discusses the results and significance of each spatial attribute, before deciding on a combination of spatial attributes that are considered potential spatial predictors of Stoat, Ship rat and Weasel populations. Issues of uncertainty within the data and comments on the procedure of modelling each pest species in the North Branch of the Hurunui are also discussed. Chapter Four is divided into three sections; 1) Understanding the spatial distribution; 2) Identifying key Spatial Attributes and 3) Creating Spatial Distribution Maps. Each section is based on objectives 2-5 mentioned in Chapter One.

4.1 Understanding the Spatial Distribution

To understand the distribution of Stoats, Ship rats and Weasels in a beech forest valley setting, an appreciation of how the distribution of each pest varies between the Hawdon, Poulter and South Branch valleys must be recognised before one can create universal spatial distribution map for each pest. This section discusses and compares each spatial attribute result, and investigates why Ship rat mean trapping rates are different in the Hawdon and South Branch valleys.

4.1.1. Analysis of Results

Distance from Ecotonal Edge (Template 1)

The mean trapping rate of Stoats, Ship rats and Weasels was analysed to a total distance of between 400-500 m from the ecotonal edge in the Hawdon and South Branch valleys. A smaller distance range was analysed for Stoats (300 m) and Weasels (<100 m) in the Poulter valley due the small size of the trapping grid. All 1436 traps in the Hawdon valley, 356 traps in the Poulter valley and 982 traps in the South Branch were used to calculate the mean trapping rate of each species.

Stoat captures were recorded to a distance of between 250- 300 m away from the ecotonal edge in the Hawdon, Poulter and South Branch valleys. A decline in mean trapping rate was recorded in

both valleys, with high trapping rates recorded in close proximity to the ecotonal edge. A similar decline in mean trapping rate was recorded in the Poulter valley to a distance of 250 m away from the ecotonal edge. It is suggested that beyond this distance, the mean trapping rate declines, reaching a zero between distances of 300-400 m.

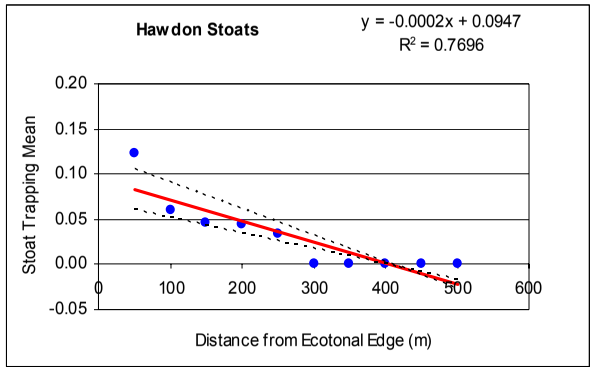
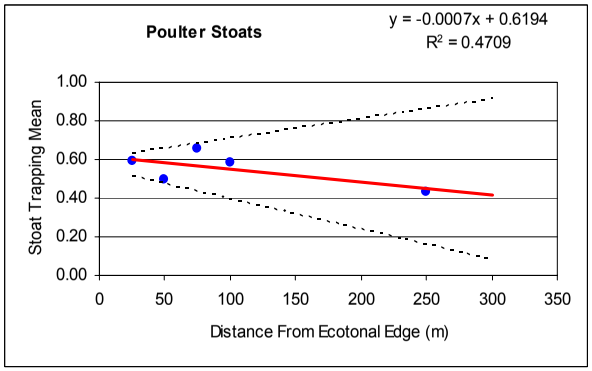
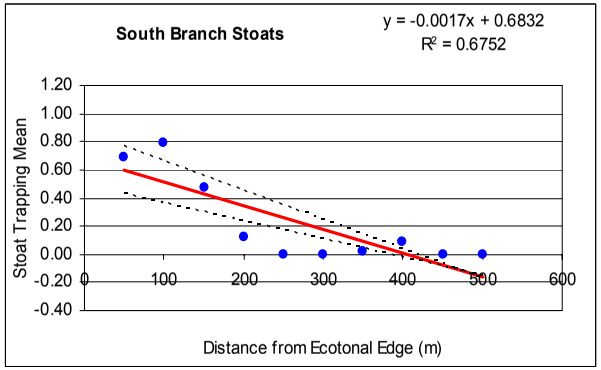
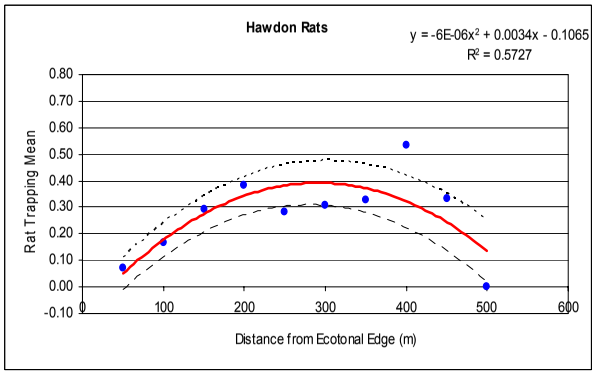
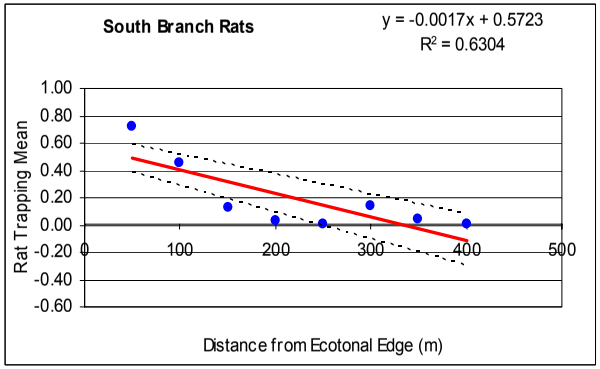
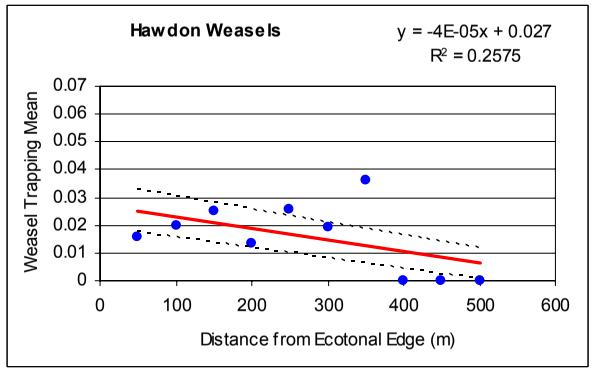
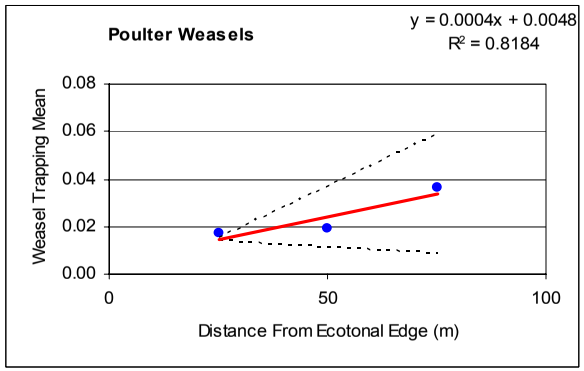
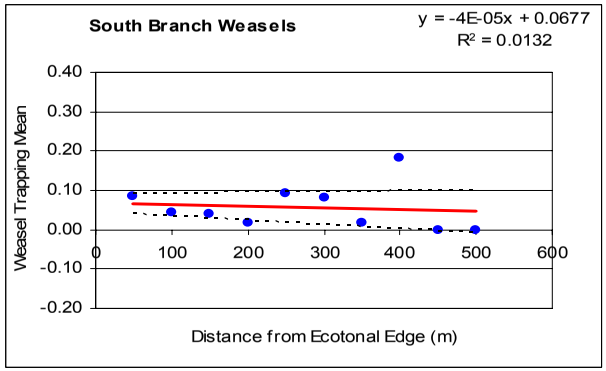
Ship rat captures were recorded to a distance of 500m away from the ecotonal edge in the Hawdon valley and 300 m in the South Branch. In the Hawdon valley, high Ship rat captures were recorded at a distance of 300 m away from the ecotonal edge, compared to the South Branch, which recorded high Ship rat captures in close proximity to the ecotonal edge. Both trapping rates are similar to those recorded in relation to elevation, suggesting Ship rats are more likely to be controlled by elevation than distance from the ecotonal edge.

Weasel captures were recorded to a distance between 500-600 m from the ecotonal edge in the Hawdon and South Branch valleys and 75 m in the Poulter valley. A small increase in the mean trapping rate of Weasels was recorded to a distance of between 200-300 m away from the ecotonal edge in the Hawdon and South Branch valleys before dropping in trapping rate. Due to the narrow range of traps in the Poulter valley, a small increase in the mean trapping rate was recorded to a distance of 75 metres away from the ecotonal edge, indicating a similarity in trapping rate with the Hawdon and South Branch valleys.

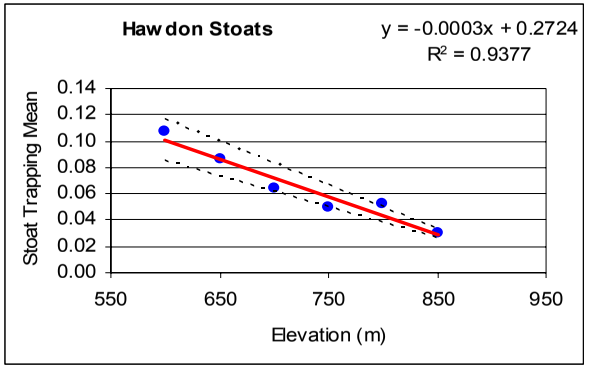
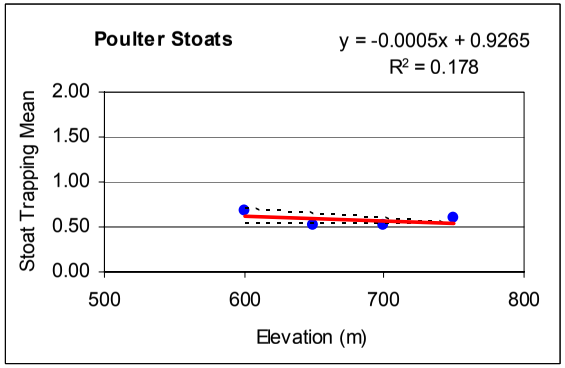
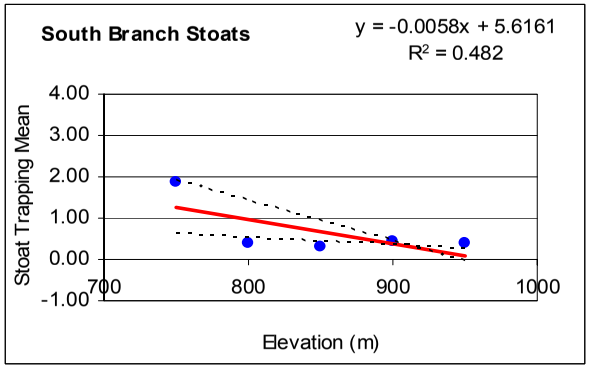
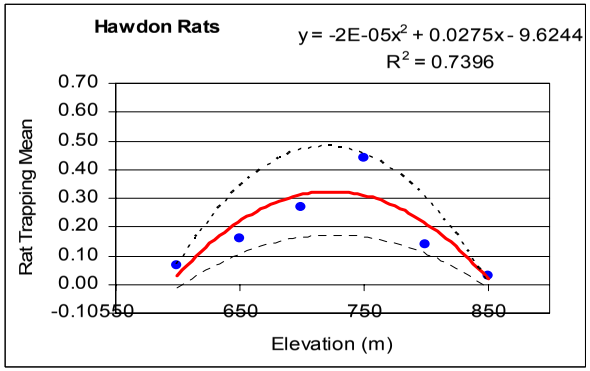
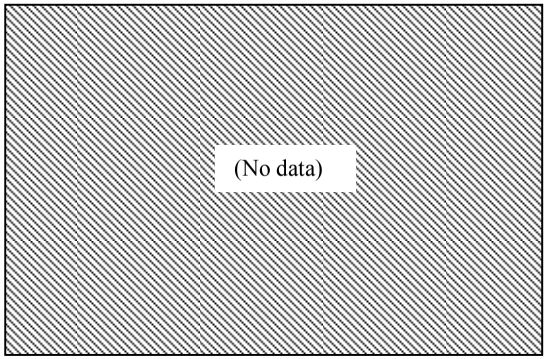
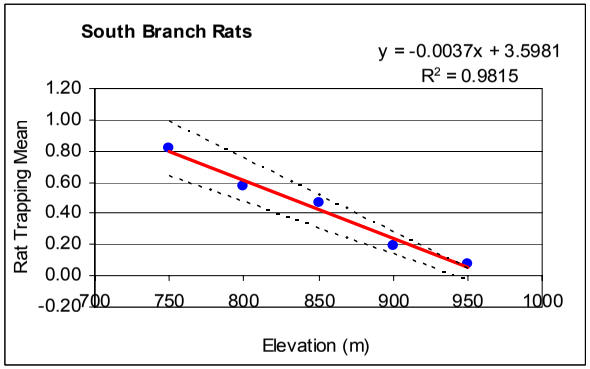
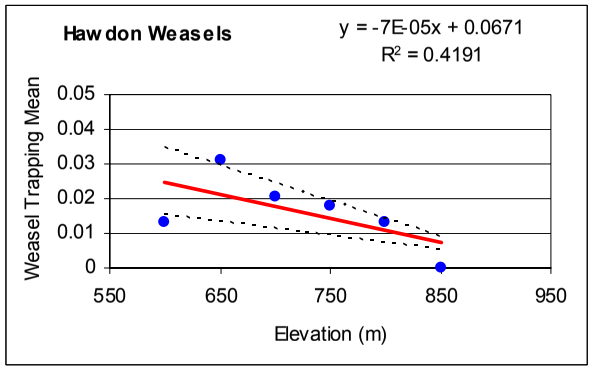
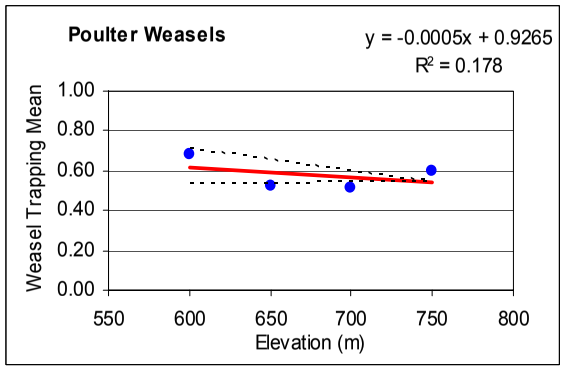
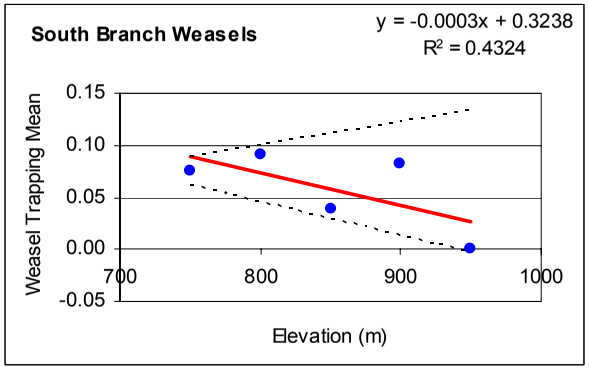
Elevation (Template 2)

Stoats, Ship rats and Weasels were prevalent in the Hawdon valley (between 600-850 m), Poulter Valley (between 600-750m) and South Branch (between 750-900 m). All 1436 traps in the Hawdon valley, 356 traps in the Poulter valley, and 982 traps in the South Branch were used to calculate the mean trapping rate for each species.

TEMPLATE 1: DISTANCE FROM ECOTONAL EDGE

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS		(No data)	
WEASELS			

TEMPLATE 2: ELEVATION

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS			
WEASELS			

Similar trapping rates were recorded for Stoats relative to elevation in the Hawdon and South Branch valleys. Stoats declined with elevation to 850 m in the Hawdon valley and 950 m in the South Branch. A similar decline in trapping rate was recorded between 600-700 m in the Poulter valley, though not to the same extent as shown in the other trapping valleys.

A high trapping rate of Ship rats was recorded in both the Hawdon and South Branch at an elevation between 700-750 m. At lower elevations (recorded in the Hawdon valley), the mean trapping rate of Ship rats increases from between 550-600 m to an elevation of 700 m and remains constant to 750 m. At higher elevations, the mean trapping rate of Ship rats declines in both valleys reaching a zero mean trapping rate between 850 -950 m.

The mean trapping rate of Weasels was recorded to decline in the Hawdon and South Branch valleys, reaching a zero mean trapping rate between 850-950 m. A small negative trend was also recorded in the Poulter valley trapping data between 600-700 m, though not to the same extent as the Hawdon and South Branch valleys.

Slope (Template 3)

Stoats, Ship rats and Weasels were recorded on slopes between 0-80° in the Hawdon and Poulter valleys, and between 0-50° in the South Branch. In total, 1171 out of 1436 (81%) of traps in the Hawdon valley, 330 out of 356 traps (93%) in the Poulter valley, and 959 out of 982 (98%) traps in the South Branch were used to calculate the mean trapping rate of each species. Trap points located on the margin between two or more pixels representing different slope angles, were responsible for a number of traps in each valley being unaccounted for.

High mean trapping rates of Stoats were recorded on low slope angles (0-20°) in the Hawdon, Poulter and South Branch valleys. In the Hawdon valley, the mean trapping rate was recorded to decline to a slope angle of 40 ° and then remain constant on higher slopes.

High Ship rat captures were recorded on both ends on the slope scale in the Hawdon and South Branch valleys. The mean trapping rate of Ship rats in the Hawdon was recorded to rise relative to an increase in slope. In the South Branch, the mean trapping rate was recorded to decrease relative to slope, indicating that an unknown factor was controlling trapping rates in each valley.

Similar mean trapping rates recorded for Ship rats were also recorded for Weasels in the Hawdon, Poulter and South Branch valleys. Trapping data from the Poulter and South Branch valleys recorded a decrease in mean trapping rate relative to slope, compared to an increase in trapping rate in the Hawdon valley.

Aspect (Template 4)

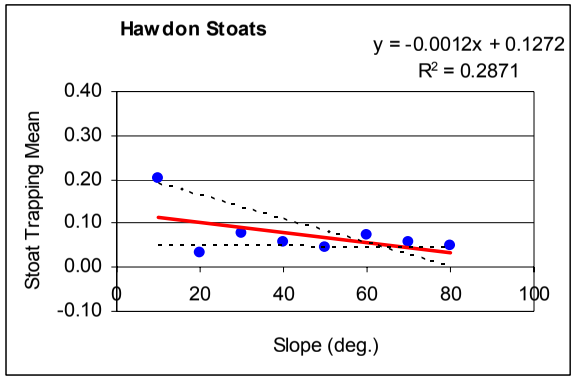
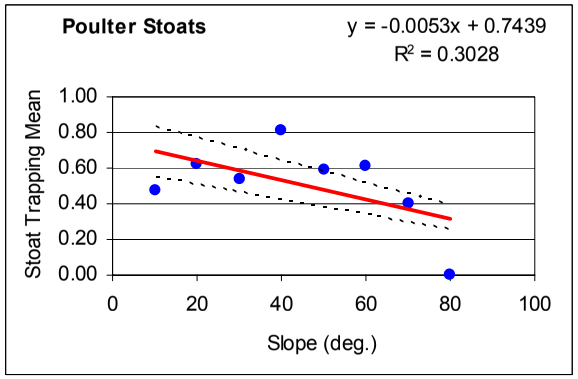
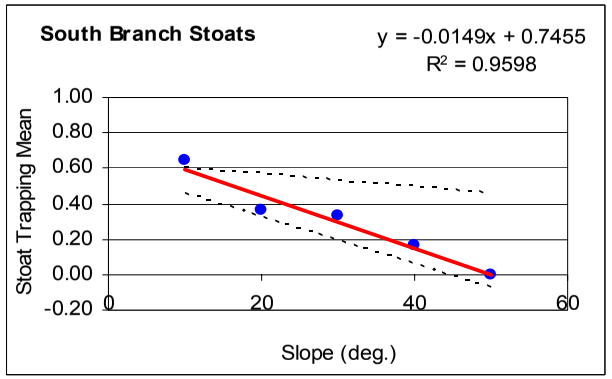
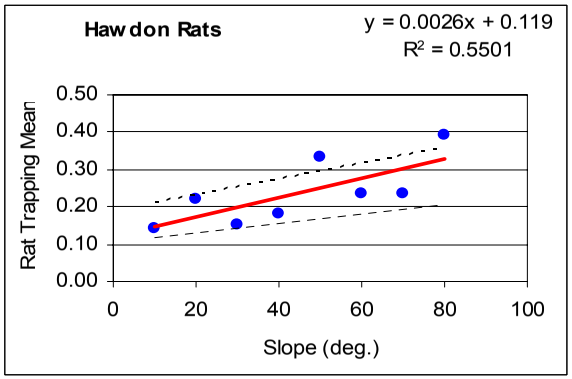
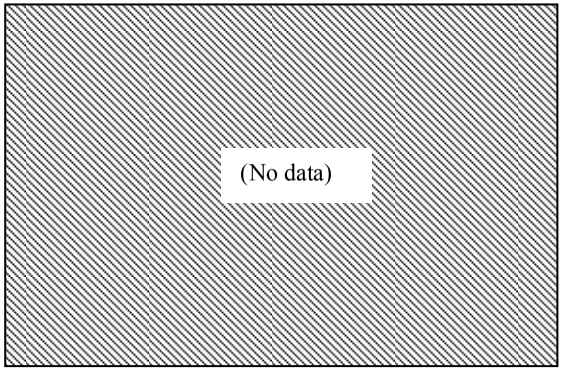
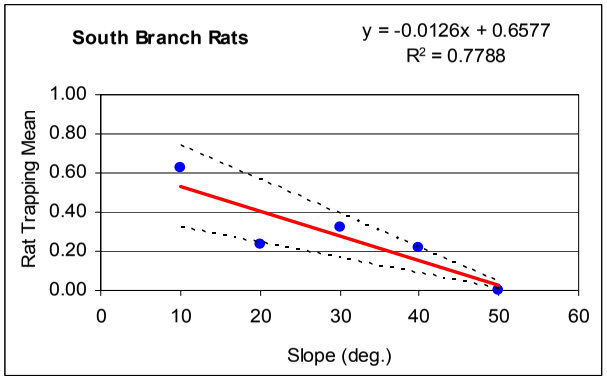
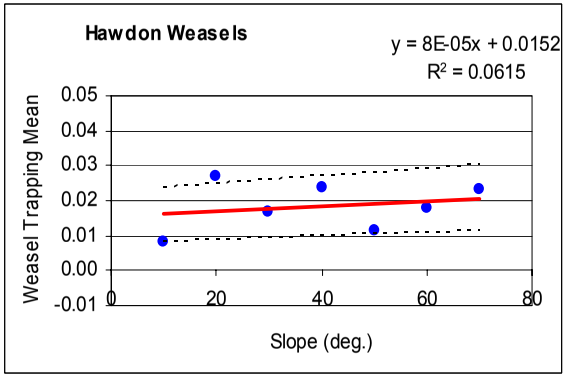
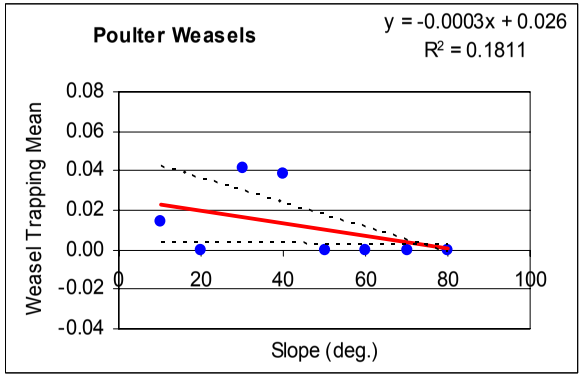
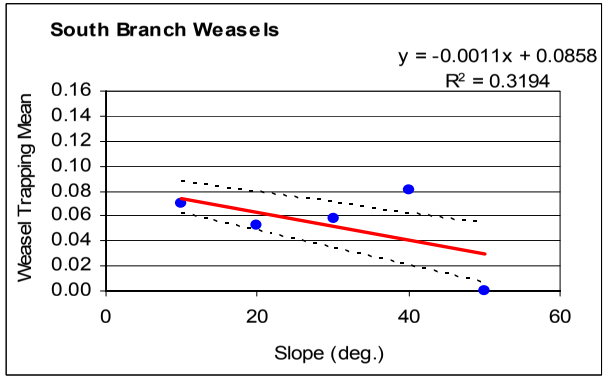
The mean trapping rate of Stoats, Ship rats and Weasels were analysed according to the orientation of the terrain in each of the trapping valleys. In total, 1370 out of 1436 (95%) of traps in the Hawdon valley; 315 out of 356 traps (88%) in the Poulter valley and 852 out of 982 (86%) traps in the South Branch were used to calculate the mean trapping rate of each species. Trap points located on the margin between two or more pixels representing different aspects, were responsible for a number of traps in each valley being unaccounted.

In relation to aspect, high levels of Stoat numbers were predominately caught on eastern and western slopes depending on the orientation of each valley. The Hawdon valley, with a north to south orientation recorded high stoat capture rates on slopes with a south eastern (112.5-157.5°), southern (157.5-202.5°) and south western aspects (202.5-247.5°). The Poulter valley, with a slight northwest to southeast orientation recorded high stoat captures on slopes with eastern (67.5-172.5°) and western aspect (247.5-292.5°). The South Branch with a southwest to northeast orientation recorded high stoat captures on slopes with south-western and north-eastern aspect (22.5-67.5°).

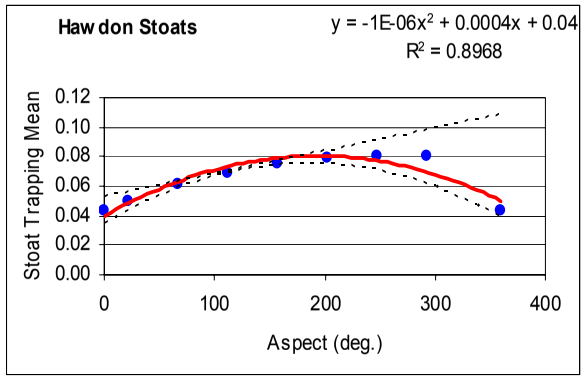
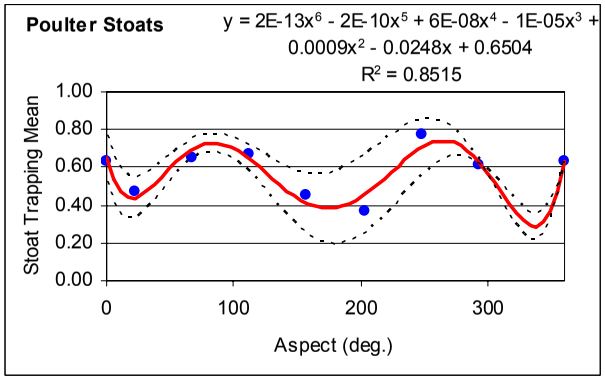
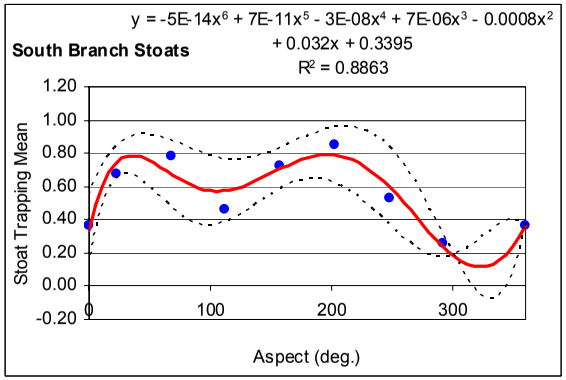
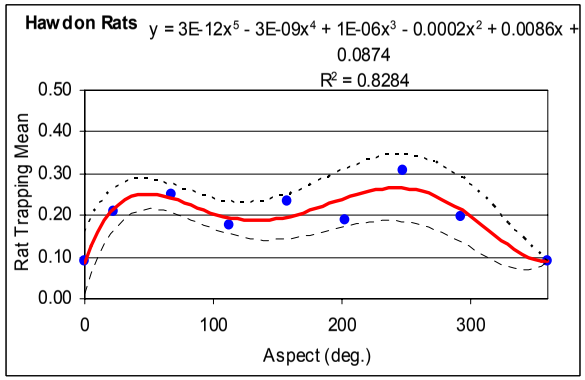
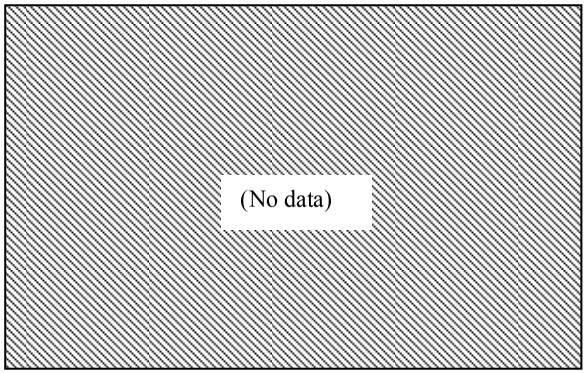
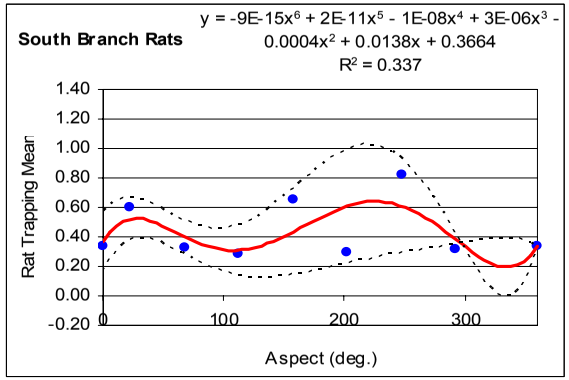
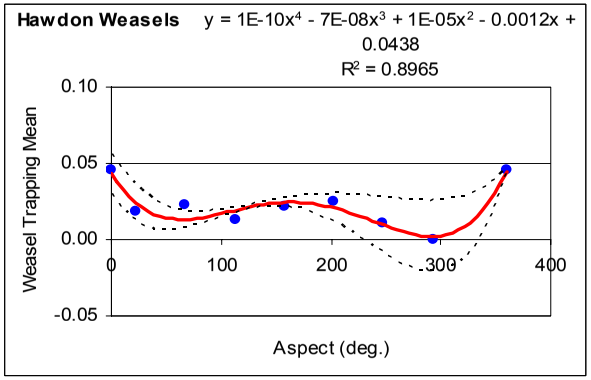
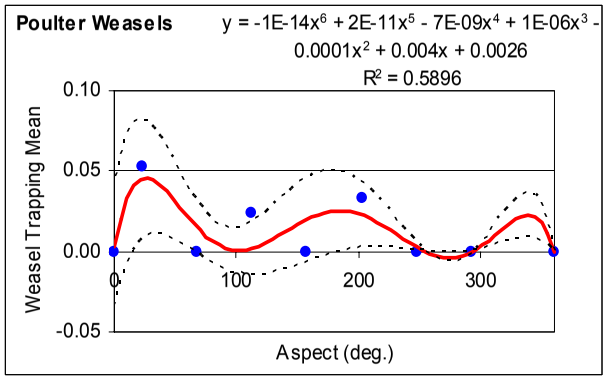
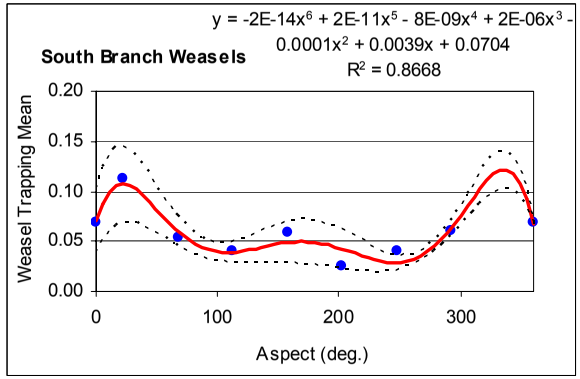
High ship rat catches were also recorded on eastern and western aspects in the Hawdon and South Branch valleys. Both valleys recorded high mean trapping rates on north-eastern and south-western slopes, which correlate to similar patterns recorded for Stoats with each corresponding valley. A similar low trapping rate was also recorded for Ship rats on eastern and western slopes in both trapping valleys.

High levels of Weasels were predominately caught on northern and southern slopes depending on the orientation of each valley. In the Hawdon and Poulter valleys, an increase in mean trapping rate was recorded on north-western (292.5-337.5°), northern (337.5-360° and 0-22.5°), north-eastern and southern aspects (157.5-202.5°). Similar trapping rates were

TEMPLATE 3: SLOPE

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS			
WEASELS			

TEMPLATE 4: ASPECT

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS			
WEASELS			

recorded in the South Branch, although the rise on in trapping rate terrain with a southern aspect was less obvious.

*Distance from River (*Template 5)

Stoat, Ship rats and Weasels were recorded to a distance of 300 m from the Hawdon River (Hawdon valley), 400m from the Poulter River (Poulter valley) and 500 m from the Hurunui River (South Branch valley). In total, 765 out of 1436 (53%) of traps in the Hawdon valley, 291 out of 356 traps (82%) in the Poulter valley, and 870 out of 982 (88%) traps in the South Branch were used to calculate the mean trapping rate of each species.

A decline in the mean trapping rate with distance from river was recorded for Stoats in each of the trapping valleys. Both the Hawdon and South Branch valleys indicate a drop in mean trapping rate, reaching a zero trapping mean threshold at a distance of between 300-400 m in each valley. A similar decrease in mean trapping rate of Stoats was also recorded in the Poulter, though not to the same extent as the Hawdon and South Branch trapping rates.

A contradicting trend in trapping rates of Ship rats was recorded in the Hawdon and South Branch valleys. In the Hawdon valley, an increase in mean trapping rate was recorded to a distance of 200 m before levelling out, as opposed to a decrease in trapping rate in the South Branch. It is suggested that these results are a reflection of similar recorded results in relation to elevation and distance from ecotonal edge.

A decrease in mean trapping rates was recorded for Weasels in each trapping valley. Trapping rates were recorded to fall in the Hawdon, Poulter and South Branch valleys, reaching a zero mean trapping rate threshold between 300-400 m away from each river. This result is similar to trapping rates recorded for Stoats in each trapping valley.

Distance from River Tributaries (Template 6)

The mean trapping rates of Stoat, Ship rats and Weasels were recorded to a distance of 400 m away from each river tributary in the Hawdon, Poulter and South Branch valleys. In total, 1171 out of 1436 (81%) of traps in the Hawdon valley; 310 out of 356 traps (87%) in the

Poulter valley and 973 out of 982 (99%) traps in the South Branch were used to calculate the mean trapping rate of each species.

Similar mean trapping rates were recorded for Stoats in the Poulter and South Branch valleys. A decrease in trapping rate was recorded in both trapping valleys at a distance between 200-300 m, followed by an increase in trapping rate to a distance of 400 m. In the Hawdon valley, the mean trapping rate was recorded to increase slightly to a distance between 200-300 m and fall again over the next 100 m.

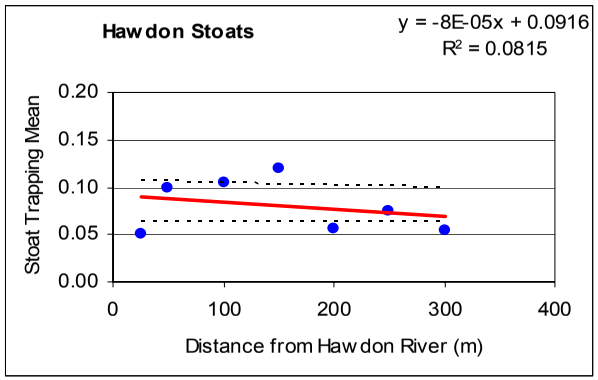
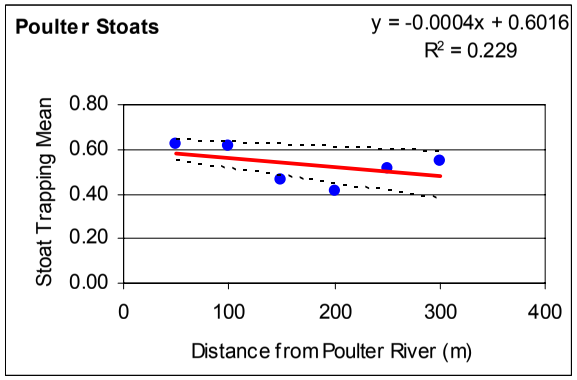
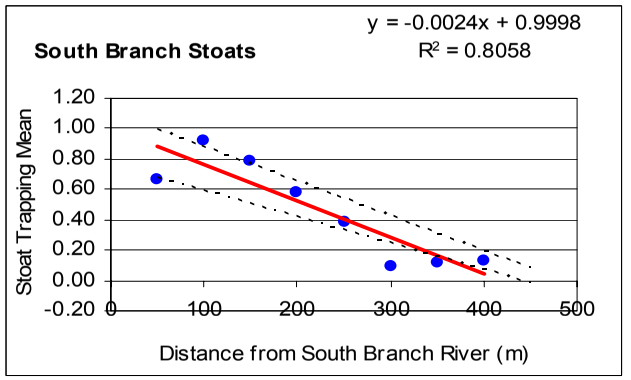
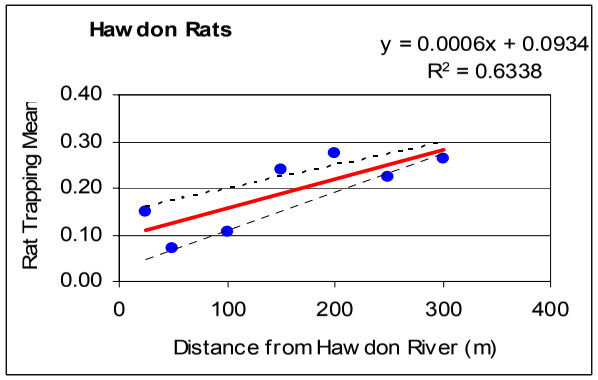
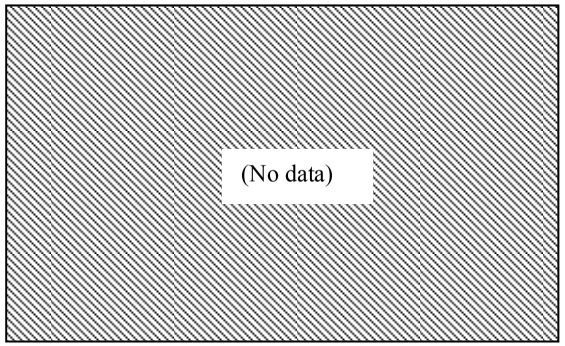
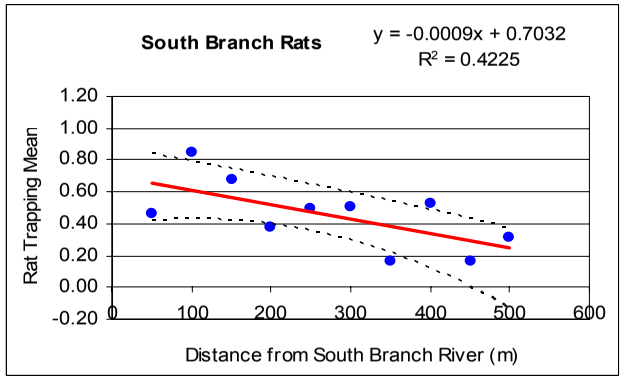
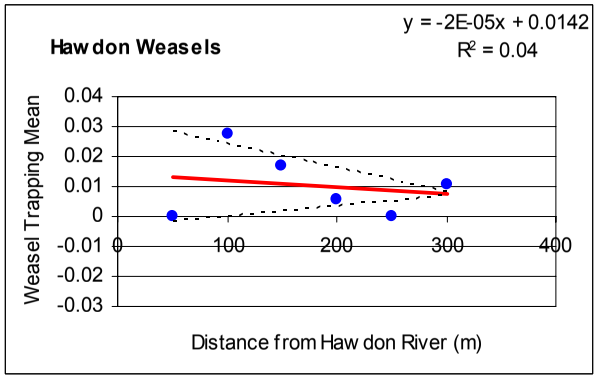
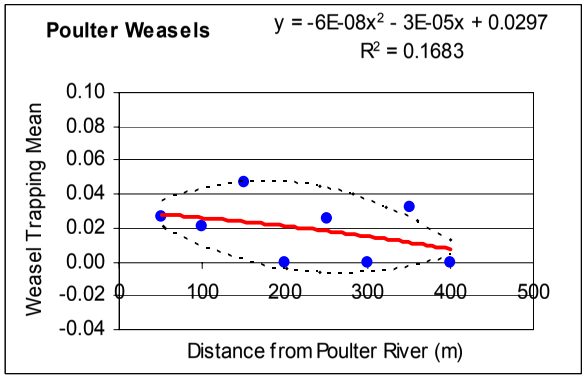
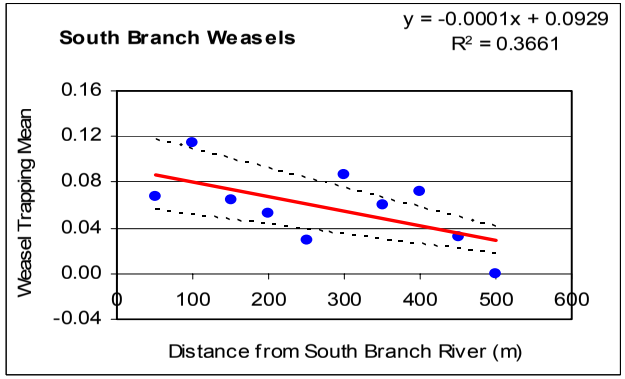
Different trapping rates were recorded for Ship rats in the Hawdon and South Branch valleys. An increase in mean trapping rate was recorded to a distance of between 200-300 m in the Hawdon valley, before levelling out between 300-400 m. In the South Branch, the mean trapping rate was recorded to decline over an increase in distance. Both these results suggest that the trapping rate of Ship rats is not affected by the location of each river tributary in both valleys.

Similar mean trapping rates were recorded for Weasels in each trapping valley. A decline in mean trapping rates was recorded to a distance of 200-300 m in the Hawdon and South Branch 150-250nm in the Poulter valley. Despite the slight difference in the mean trapping rate of Weasels in the Poulter valley, it is suggested that both the Stoat and Weasel trapping rates are comparable to each other relative to distance from each river tributary.

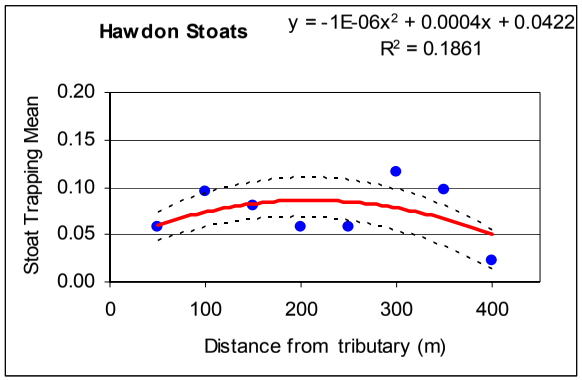
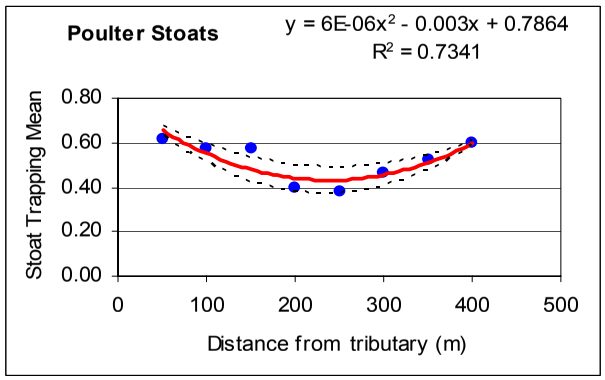
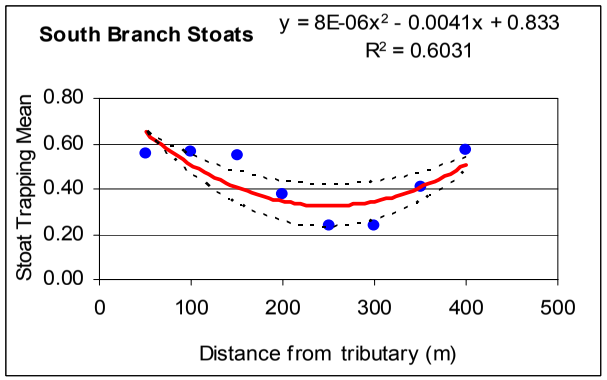
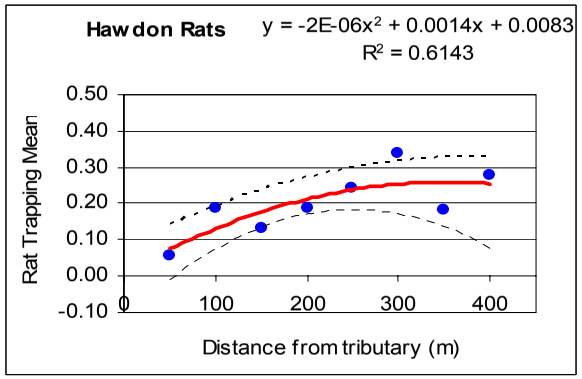
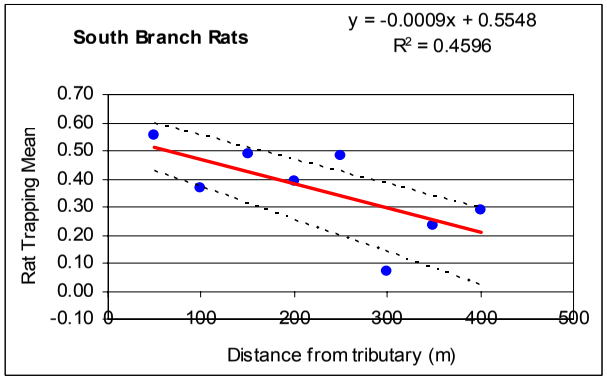
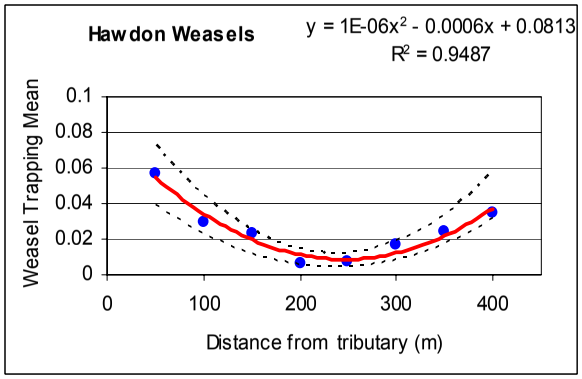
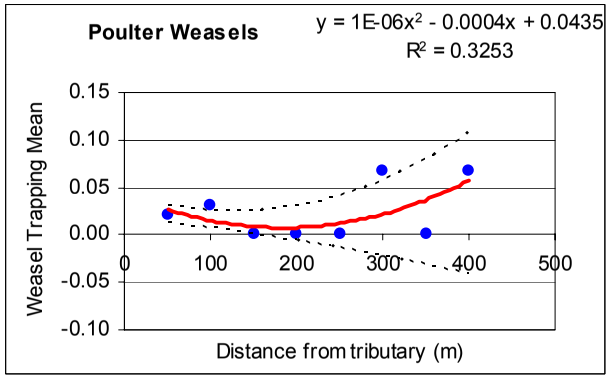
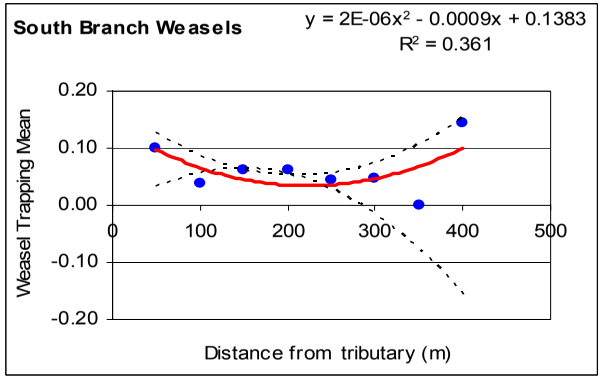
Temperature (Mean maximum and minimum temperature) (Templates 7, 8, 9)

The mean trapping rate of Stoats, Ship rats and Weasels relative to mean maximum and minimum temperature (in brackets) was recorded between 13.5-15°C (0-2°C) in the Hawdon and Poulter valleys, and 11-13°C (0-2°C) in the South Branch valley. In total, all 1436 traps in the Hawdon valley, 356 traps in the Poulter valley, and 982 traps in the South Branch were used to calculate the mean trapping rate for each species. Lower mean maximum temperatures in the South Branch are correlated with an increase in the overall elevation of the valley.

TEMPLATE 5: DISTANCE FROM RIVER

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS			
WEASELS			

TEMPLATE 6: DISTANCE FROM RIVER TRIBUTARY

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS		(No data)	
WEASELS			

Different mean trapping rates were recorded for Stoats in the Hawdon and South Branch valleys. The mean trapping rate in the Hawdon valley remained relatively constant between mean maximum and minimum temperatures of 0-2°C, compared to an increase in trapping rate recorded in the South Branch between mean maximum and minimum temperatures of 0-2°C. Due to an insignificant range of data points in the Poulter valley, an accurate mean trapping rate could not be calculated.

Different mean trapping rats were also recorded for Ship rats in the Hawdon and South Branch valleys. A slight increase in the mean trapping rate of Ship rats was recorded between mean maximum and minimum temperatures in the Hawdon valley. In the South Branch, an increase in mean trapping rate is more evident relative to both mean maximum and minimum temperatures, with a greater change in trapping rate between temperature intervals.

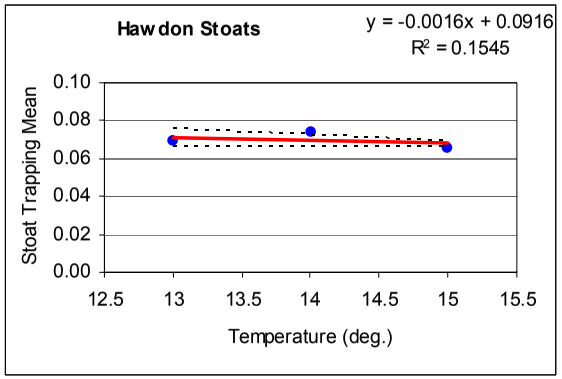
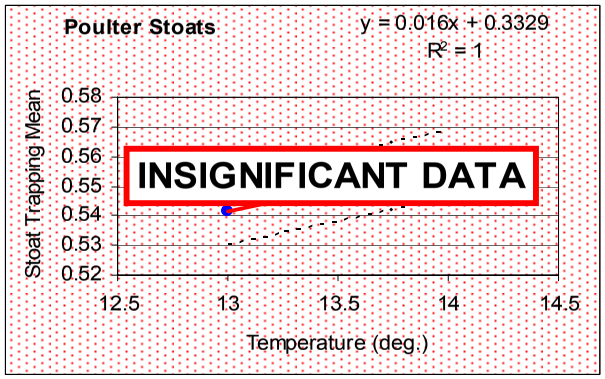
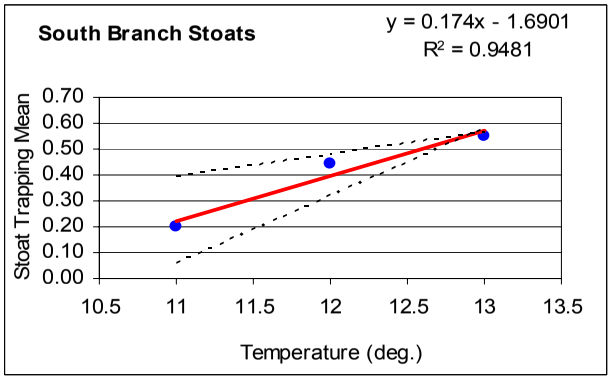
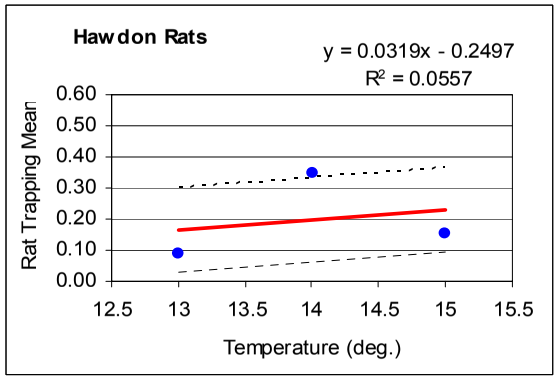
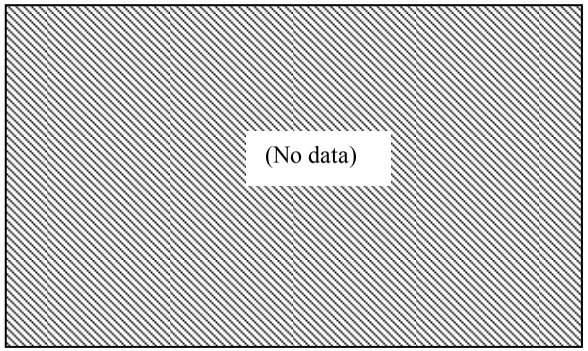
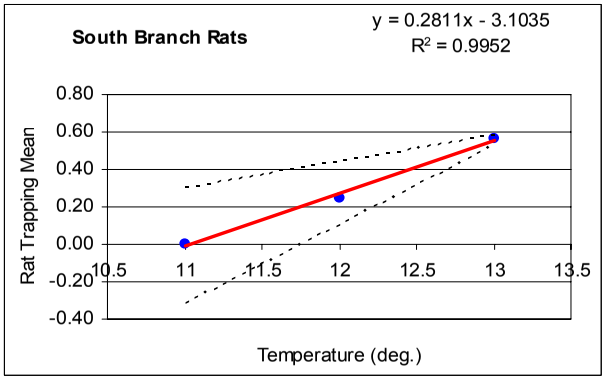
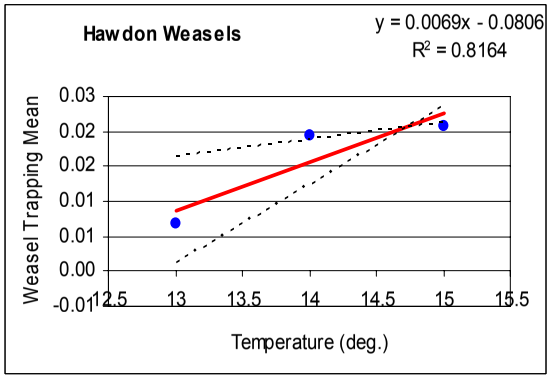
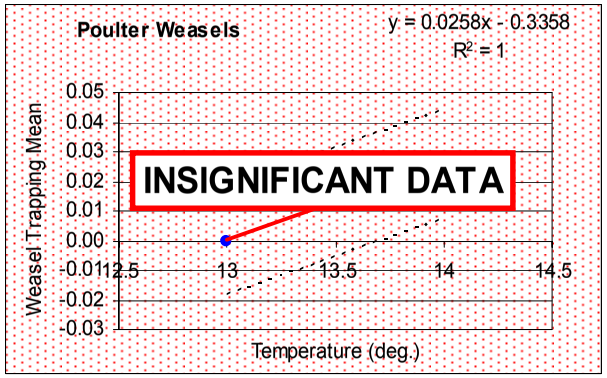
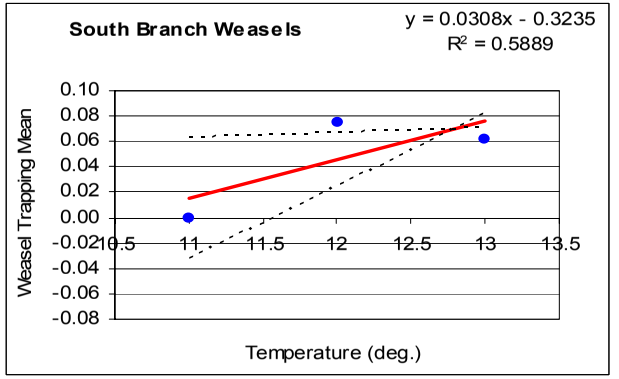
Similar mean trapping rates were recorded for Weasels in the Hawdon and South Branch valleys. A small increase in trapping rate was recorded in relation to an increase in mean and maximum temperatures in both valleys. This result indicates that a consistent rate of change in both mean and maximum temperatures at varying temperature intervals, with Weasel captures relatively higher in areas receiving a generally warmer mean minimum and maximum temperature than others. No mean trapping rate was recorded in the Poulter valley, due to an insignificant range of data points between changes in temperature.

Precipitation

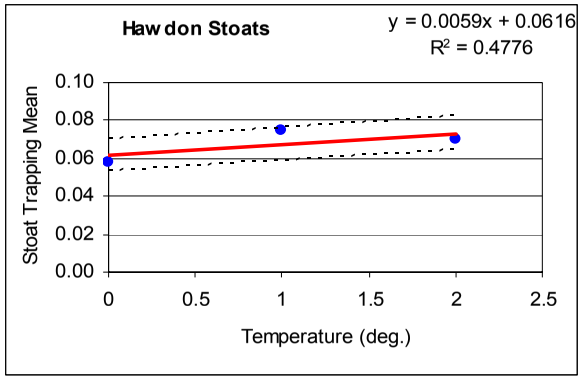
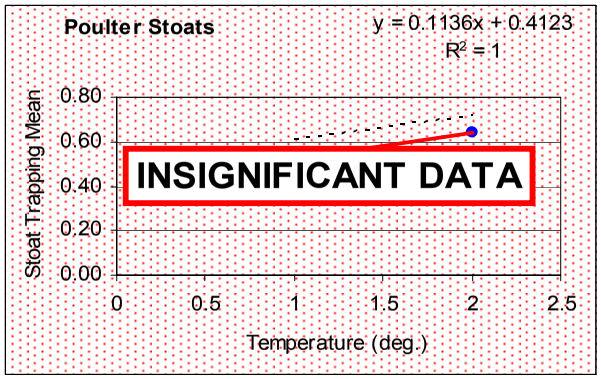
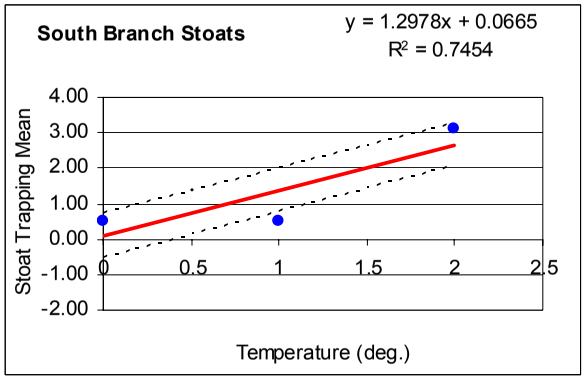
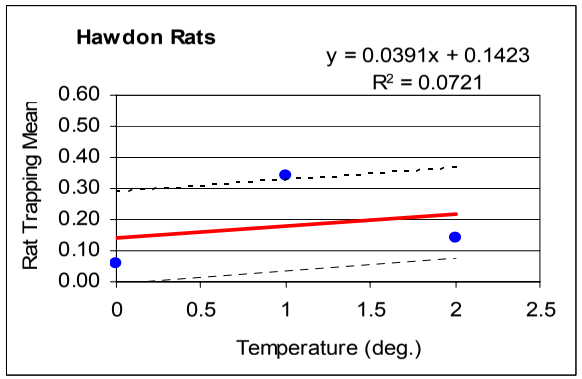
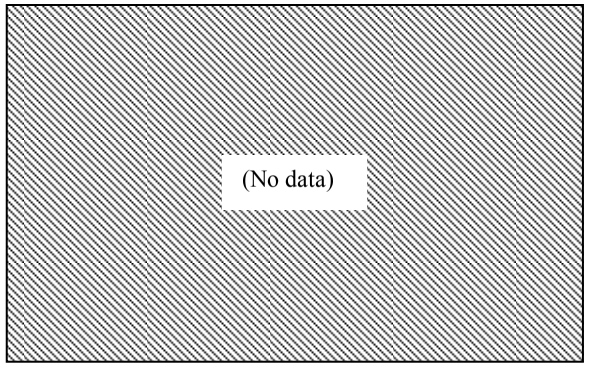
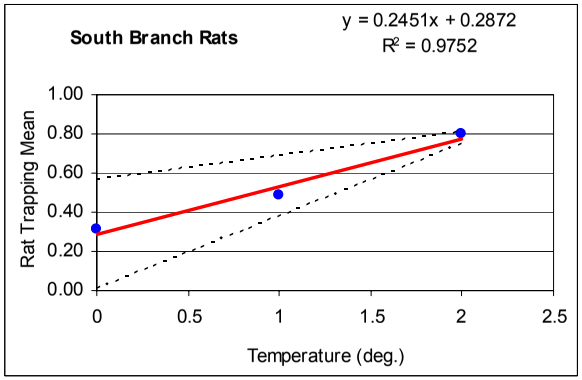
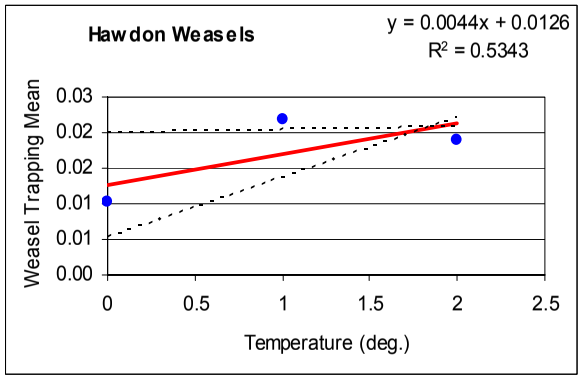
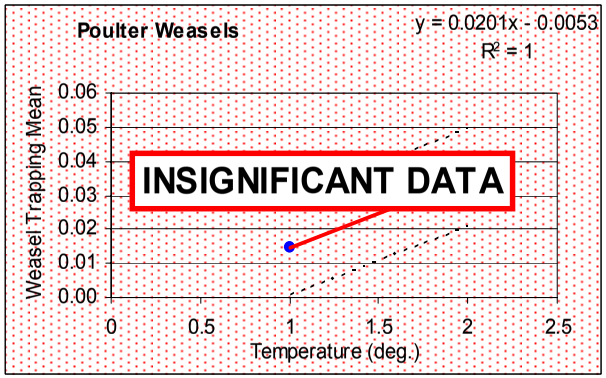
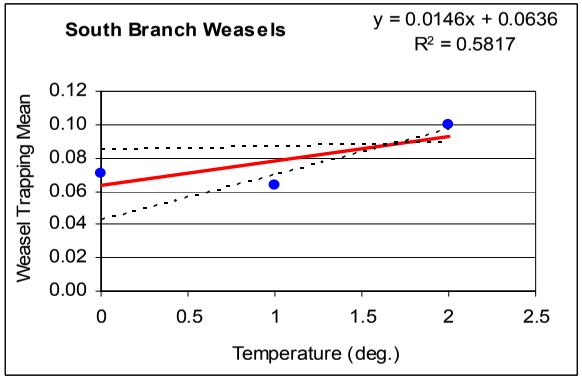
The mean trapping rate of Stoats, Ship rats and Weasels relative to precipitation was recorded between 125-250 mm in the Hawdon valley, 125-275 mm in the Poulter valley, and 200-325 mm in the South Branch valley. In total, all 1436 traps in the Hawdon valley; 356 traps in the Poulter valley and 982 traps in the South Branch were used to calculate the mean trapping rate for each species. Lower precipitation in the South Branch is correlated with an increase in the overall elevation of the valley.

A decrease in the mean trapping rate with increasing precipitation was recorded for Stoats, Ship rats and Weasels in the Hawdon, Poulter and South Branch valleys. Stoat, Ship rat and Weasel captures were relatively higher in areas receiving a generally lower proportion of rainfall than others.

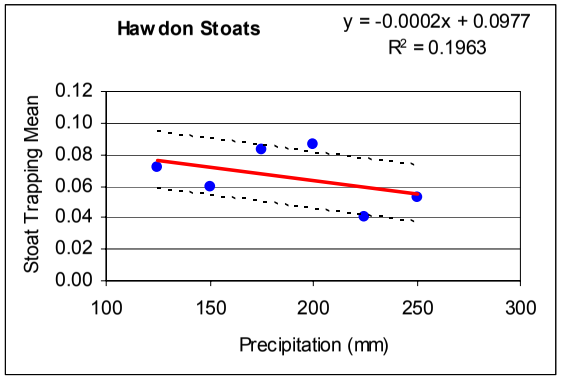
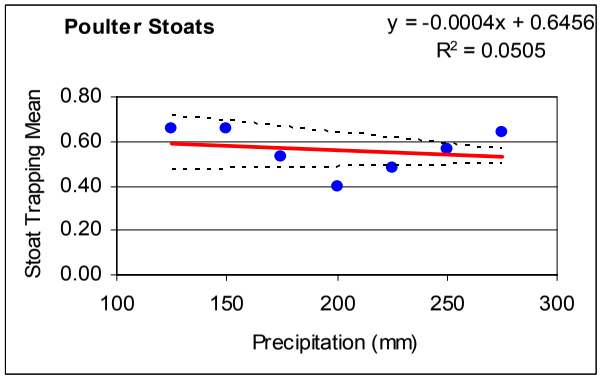
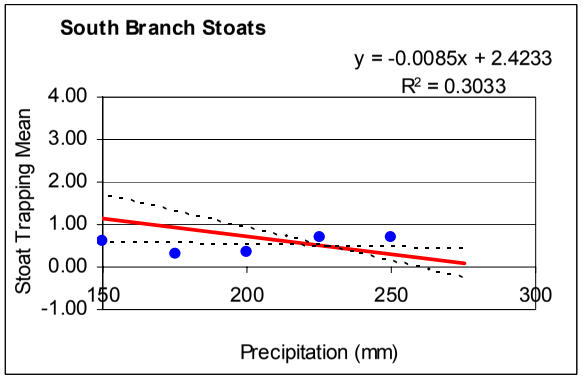
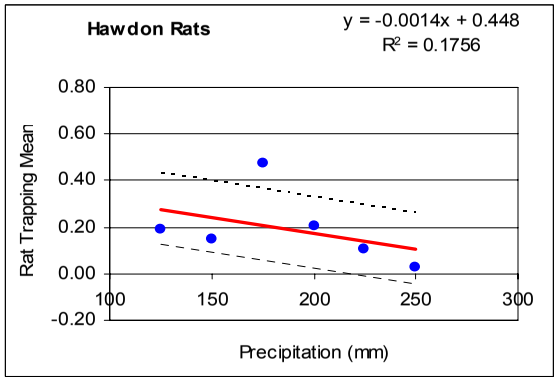
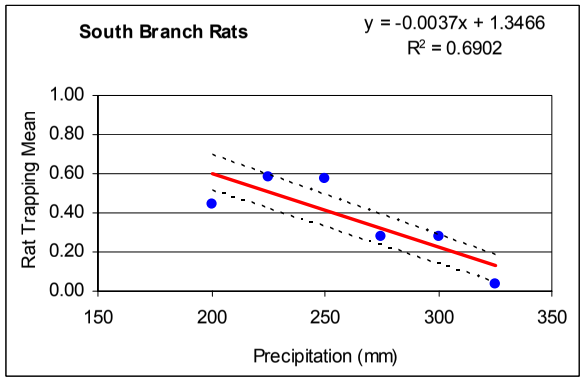
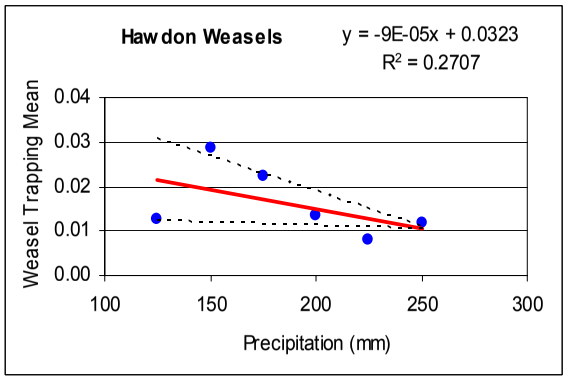
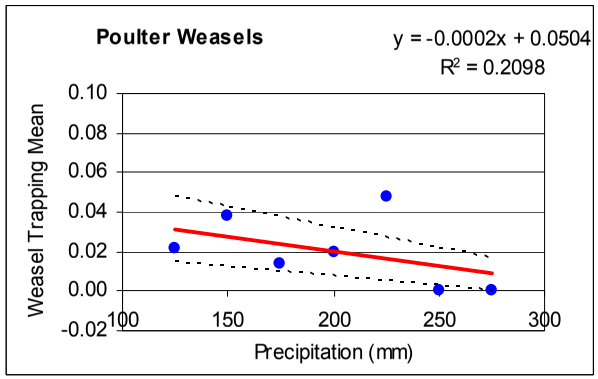
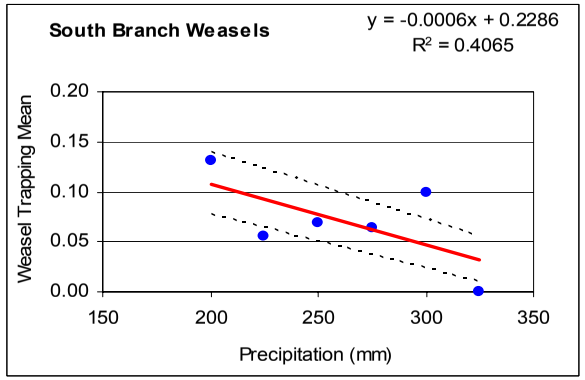
TEMPLATE 7: MEAN MAXIMUM TEMPERATURE

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS			
WEASELS			

TEMPLATE 8: MEAN MINIMUM TEMPERATURE

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS			
WEASELS			

TEMPLATE 9: MEAN PRECIPITATION

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS		(No data)	
WEASELS			

*Distance from Trapping Edge (*Template 10)

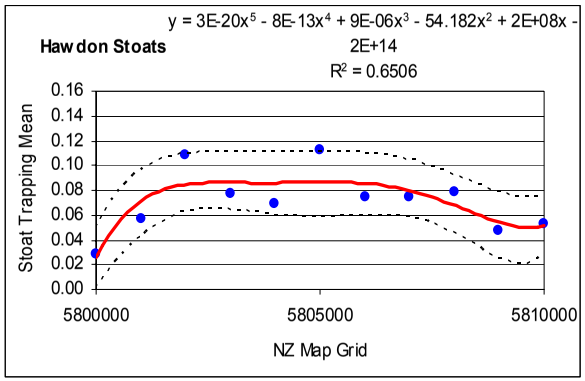
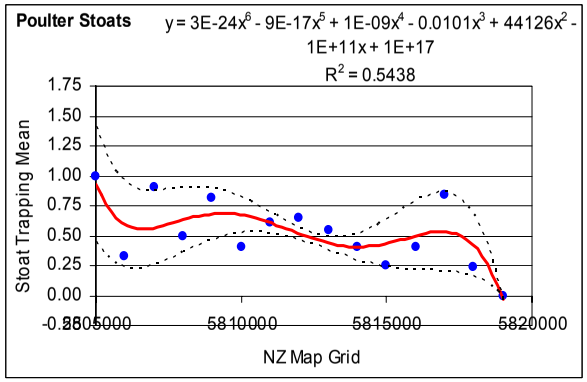
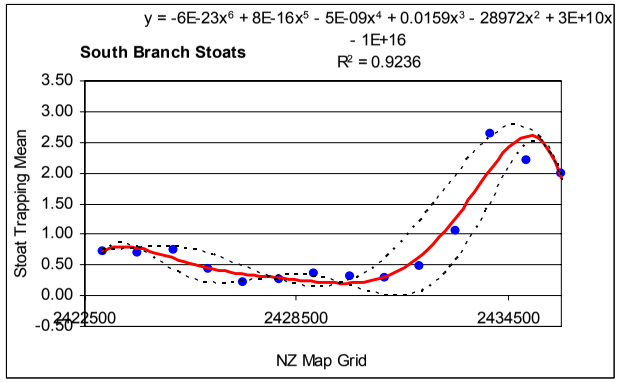
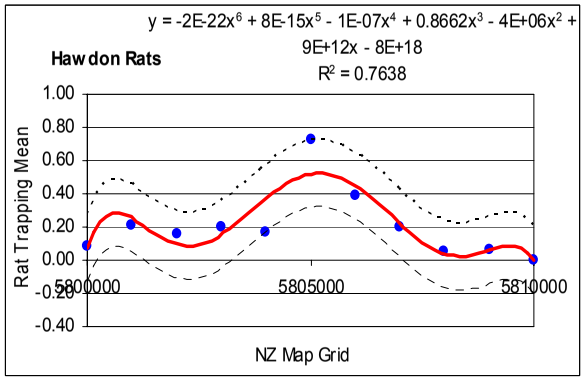
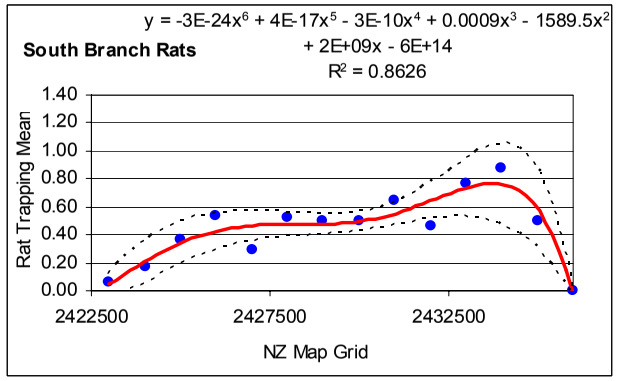
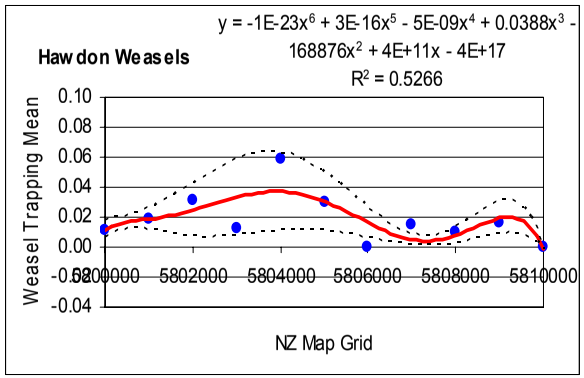
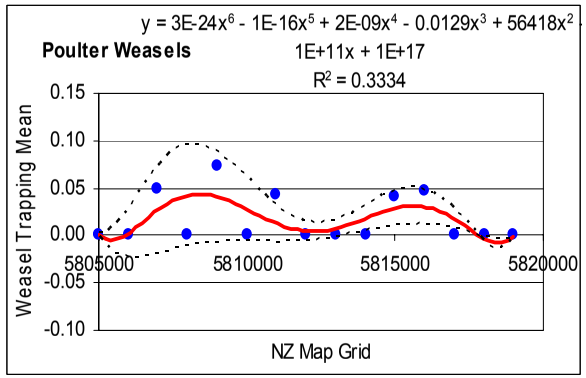
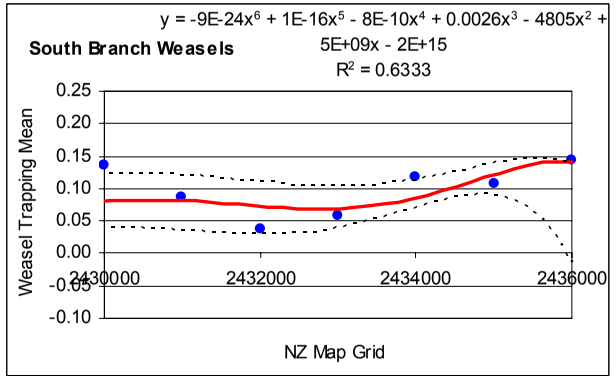
The mean trapping rate of Stoats, Ship rats and Weasels in relation to distance from trapping edge was derived from New Zealand Map Grid co-ordinates 580000N-5801000N in the Hawdon valley, 5805000N-5819000N in the Poulter valley and 2423000E-2436000E in the South Branch. In total, all 1436 traps in the Hawdon valley; 356 traps in the Poulter valley and 982 traps in the South Branch were used to calculate the mean trapping rate for each species.

Different mean trapping rates of Stoats were recorded in the Hawdon, Poulter and South Branch valleys. In the Hawdon valley, the mean trapping of Stoats remained at a fairly constant rate between 0.08-0.09 within the current trapping grid (5802000N-5809000N). Near the southern edge of the trapping grid (5800000N-5802000N), the trapping rate falls to a mean rate of 0.03. The trapping rate also falls near the northern edge of the trapping grid located near the head of the Hawdon valley (5807000N-5809000N), and remains at a steady rate varying between 0.04-0.06 (5809000N-5810000N). In the Poulter valley, the mean trapping rate of Stoats fluctuates between means of 0.40-0.75 within the established trapping grid (5806500N-5817500N), only to increase near southern end the trapping grid (5805000N-5806500N) and fall near the northern edge of the trapping grid near the headwaters of the Poulter River and Thompson Stream (5817500N-5819000N). In the South Branch, the trapping mean rate remains at a steady rate within the established trapping grid (2426000E-2432000E), with a significant increase in stoat trapping rate recorded at the eastern end of the South Branch trapping grid (2432000E-2435000E). A smaller secondary increase is also recorded near the western end of the trapping grid (2423000E-2426000E).

Different mean trapping rates of Ship rats in relation to distance from trapping edge were recorded in the Hawdon and South Branch valleys. In the Hawdon valley, an increase in mean trapping rate from 0.20-0.52 was recorded within the trapping grid (5802000N-5808000N), with a smaller increase in trapping rate (0.10-0.28) identified at the southern end of the trapping grid (5800000N-5802000N). The trapping mean rate remains constant between 0.00-0.10) near the northern end of the trapping grid (5808000- 5810000) with the rate declining to the zero threshold close to the trapping edge. In the South Branch, the mean trapping rate slowly increases from a low 0.05 near the western trapping edge (2423000E) to a high rate of 0.78 recorded near the eastern trapping edge (2425750E). The trapping rate subsequently falls from this point reaching zero close to the eastern trapping grid boundary (2425750E-2426000E).

Similar mean trapping rates were recorded for Weasels relative to distance from trapping edge in the Hawdon and Poulter valleys. The mean trapping rate of Weasels in the Hawdon valley increases close to the southern end of the trapping grid (5800000N) to a rate of 0.38 near the centre of the trapping grid (5804000N). A decline in trapping rates was recorded towards the northern end with a smaller incline (0.01-0.02) recorded near the northern extent of the trapping grid (5808000N-5810000N). A similar fluctuating trend in mean trapping rates was recorded in the Poulter valley with an increase the mean trapping rate recorded between 0.00-0.045 near the southern trapping boundary (5806000N-5812000N). The second increase was recorded near the northern trapping boundary (5812000N-5818000N). In the Poulter valley where no increase or subsequent decrease in mean trapping rates occur, the mean trapping rate is absent or remains at a low rate (<0.01). In the South Branch, the mean trapping rate of Weasels is comparable to the mean trapping rate of Stoats, with a large increase recorded at the eastern end of the South Branch trapping grid (2433000E-2436000E). The mean trapping rate remains constant throughout the rest of the South Branch trapping grid though a small increase is recorded within these margins near the western trapping boundary (2433000E-2432500E).

TEMPLATE 10: TRAPPING GRID CROSS SECTION (VALLEY END TO END)

	HAWDON	POULTER	SOUTH BRANCH
STOATS			
SHIP RATS		(No data)	
WEASELS			

4.1.2 Comparing Spatial Distributions between each pest species

Stoats vs. Ship rats

Stoats generally prey on Ship rats (King 1990a; King 1996a;) as part of their diets, so naturally with the predator-prey relationship that exists between each species areas of high stoat populations are in turn associated with areas of low ship rat populations. This study found a similar trend with Stoat and Ship rat trapping rates in the Hawdon valley; a different mean trapping pattern between Stoats and Ship rats recorded in the South Branch, however, provides an insight into how each species coexists. Stoat mean trapping rates in the Hawdon peaked in close proximity to the ecotonal edge, while Ship rat trapping rates peaked at an elevation of 750-800 m a.s.l or about 300 m away from the ecotonal edge. In the South Branch, high ship rat trapping rates were recorded with corresponding by high trapping rates of Stoats near the ecotonal edge of the beech forest. However, high trapping rates on slopes with similar aspects in the Hawdon and South Branch were recorded for both species, indicating a similarity between the valleys.

Stoats vs. Weasels

Weasels avoid contact with Stoats due to their relatively small size, and the aggressive competitive nature of Stoats over food resources (King 1989b; 1990). Results from this study have proven that Weasel populations avoid areas in close proximity to the ecotonal edge of the beech forest in each trapping valley, a preferred habitat for stoat's. Instead trapping data from the Hawdon and South Branch valleys show the mean trapping rate of Weasels remains constant to a distance between 200-300 m metres away from the ecotonal edge, before dropping in rate at greater distances away from the forest edge. These trends were recorded with the spatial attributes; elevation, slope and distance from river. The aspect of terrain presents another dimension to the spatial distribution of Weasels with high trapping rates recorded on slopes against low mean trapping rates of Stoats. This finding is consistent inall three trapping valleys.

Weasels vs. Ship rats

Weasels generally have a similar feeding pattern to that of Stoats, except that they are closely adapted to the exploration of small rodents such as mice and less capable of taking larger prey (King 1990). As discussed previously, Ship rats are part of the general diet of Stoats and therefore attract these animals into an area where Ship rats are numerous. This study has found that the spatial distribution of Weasels overall have a very little or no impact on the spatial distribution of Ship rats in any of the three trapping valleys; However the predator-prey relationship that exists between Stoats and Ship rats may result in Weasels being restricted to areas of low populations of Ship rats. Spatial attributes; aspect and distance from trapping edge later proved this suggestion with weasel trapping rates rising relative to drops in trapping rates of Stoats and Ship rats in each trapping valley.

4.1.3 Investigation into why ship rat populations differ in the Hawdon and South Branch valleys

Results from this study have indicated that similar spatial distributions of Stoats and Weasels exist in the Hawdon, Poulter and South Branch valleys. However, the spatial distribution of Ship rats recorded in the Hawdon and South Branch valleys differs between valleys, implying that other environmental or social factors are controlling the spatial distribution of Ship rats in each valley. Like Stoats, the spatial distribution of Ship rats fluctuates depending on the availability of food. It is suggested from the results of this study that the spatial location of different beech species might be controlling the distribution of Ship rats in both valleys.

Both the Hawdon and South Branch valleys are predominately composed of mountain beech (*N. solandri* var. *cliffortodes*). Extensive red beech (*Nothofagus fusca*) mixed with silver beech (N. *menziesii*) is common on river terraces and old alluvial fans in the South Branch, whilst strands of red beech are present at the toe of steep slopes rising to mid slopes at an elevation of 750m a.s.l in the Hawdon Valley. Stands of silver beech are also present in the Hawdon, though restricted to the headwaters of the valley. Mountain beech forests are restricted to montaine and sub alpine areas of central and eastern regions of both islands of New Zealand, where they form an extensive natural monoculture in the drier sub alpine eastern regions (Wardle 1984). Mountain Beech trees produced seed crops more frequently

between every 3-7 years compared to 3-10 years for red beech and 6-10 years for silver beech (Wardle 1984, Ogden et al. 1996).

Mountain beech trees produce the greatest seed crops compared to other beech species; Wardle (1984) recorded a mean annual production of 7,431 seeds / m^2 for mountain beech trees in the Craigieburn region, compared to 6342 seeds/m^2 for red beech (Rahu Saddle) and 5729 seeds/m^2 for silver beech (Rowallan). 53.5-68.3% of seeds in the Wardle study were sound and capable of germination. The largest and best quality crops of beech seed comes from the upper-mid slopes, with the quality decreasing both at the highest altitudes and towards the lower altitudes (Wardle 1965; Manson 1974; Wardle 1984).The interval between 'full' mast years also tends to increase at higher altitudes (Wardle 1984, Allen and Platt 1990).

The highest mean trapping rate of Ship rats in the Hawdon was recorded at an elevation between 700-750 m a.s.l at a distance of about 300 m away from the ecotonal edge. In the South Branch, the highest trapping rate was also recorded at a similar elevation though in close proximity to the ecotonal edge. These results correlate firstly, with each other in relation to elevation, though more importantly they relate to upper-mid slopes designated from research by Wardle (1984) as areas producing the largest and best quality crops, signifying a strong link between ship rat populations and species of beech.

4.2 Identifying Key Spatial Attributes

The third objective of this thesis was to investigate which combination of spatial attributes accounted for a large percentage of variability in the distribution of Stoats, Ship rats and Weasels within the Hawdon, Poulter and South Branch valleys. This was achieved by analysing and comparing the significance of each Pearson Coefficient correlation result (r^2) in relation to Stoats, Ship rats and Weasels in each trapping valley. This section discusses the uncertainty and significance associated each mean trapping rate.

4.2.1 Uncertainty factor between mean trapping rates

The problem with calculating a mean trapping rate of Stoats, Ship rats or Weasels is that the number of traps between each interval (i.e., distance from ecotonal edge, elevation and slope)

constantly fluctuates between a higher and low numbers of traps. High and low trap intervals are associated with the location of trapping grids in the Hawdon, Poulter and South Branch valleys with high trap intervals located near the forest edge on the valley floor and low trapping intervals located at a higher elevation or distance from the valley floor.

Increases and decreases in uncertainty are associated with the relative position of each data point used to calculate each mean trapping rate. An increase in the uncertainty is also related to a change in mean trapping rate, especially noticeable for low and high polynomial trend lines. Understanding the uncertainty of each trapping mean rate can help establish whether the rate measured is significant or not.

4.2.2 Significance of Results

Figures 4.1-4.2 show recorded Pearson Correlation coefficients for Stoats, Ship rats and Weasels in the Hawdon, Poulter and South Branch valleys. The spatial attributes of aspect and distance from trapping edge, which both used a high order polynomial trend line to record each mean trapping rate, were analysed and compared separately.

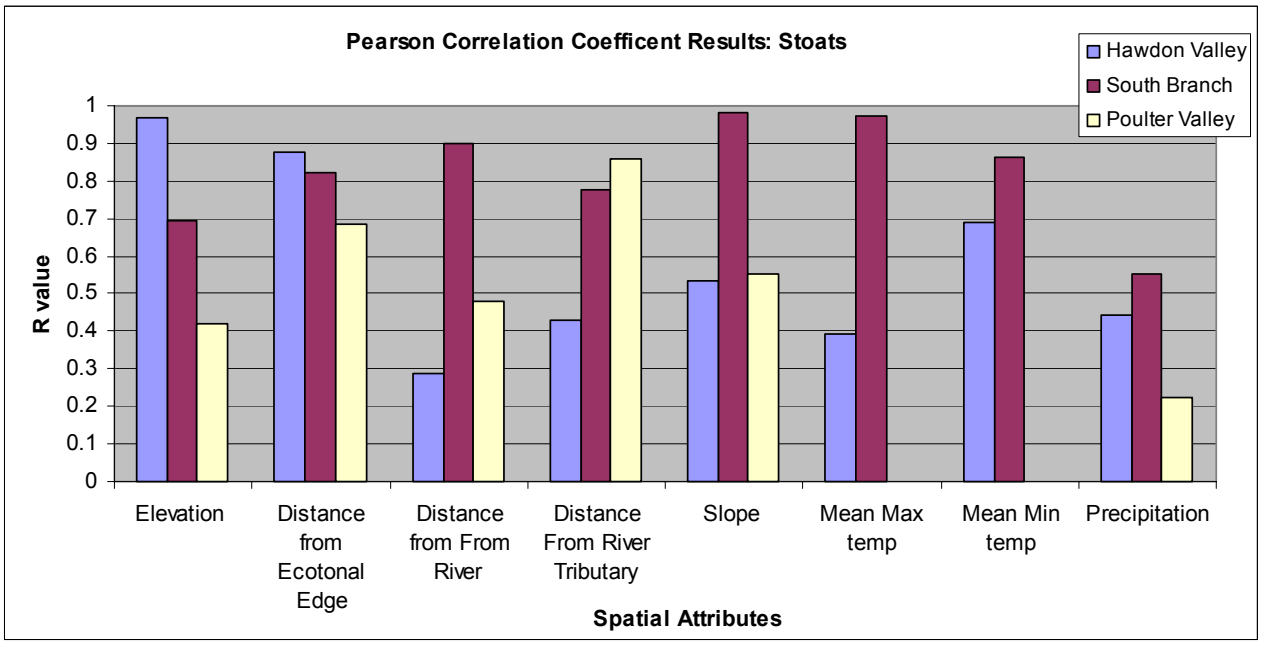


Figure 4.1: Pearson Correlation Coefficient results for Stoats caught in the Hawdon, Poulter and South Branch valleys

Figure 4.1 shows high correlation coefficients (>0.80) recorded for Stoats in relation to elevation, distance from ecotonal edge, slope, distance from river, distance from river

tributary and mean maximum temperature. The South Branch, in particular, recorded a high correlation coefficient result for each spatial attribute compared to the Hawdon and South Branch valleys.

The significance of these results were then tested at 0.01 and 0.05 levels of significance; Mean trapping rates that recorded a 0.01 level of significance were distance from ecotonal edge, and elevation in the Hawdon and South Branch valleys, This means that these attributes have a 1% or less chance that a given relationship is just due to chance. A similar level of significance was also recorded for slope and mean maximum temperature in the South Branch. These results indicate that the relationship between trapping rate and both distance from ecotonal edge and elevation were significant in two out of three valleys.

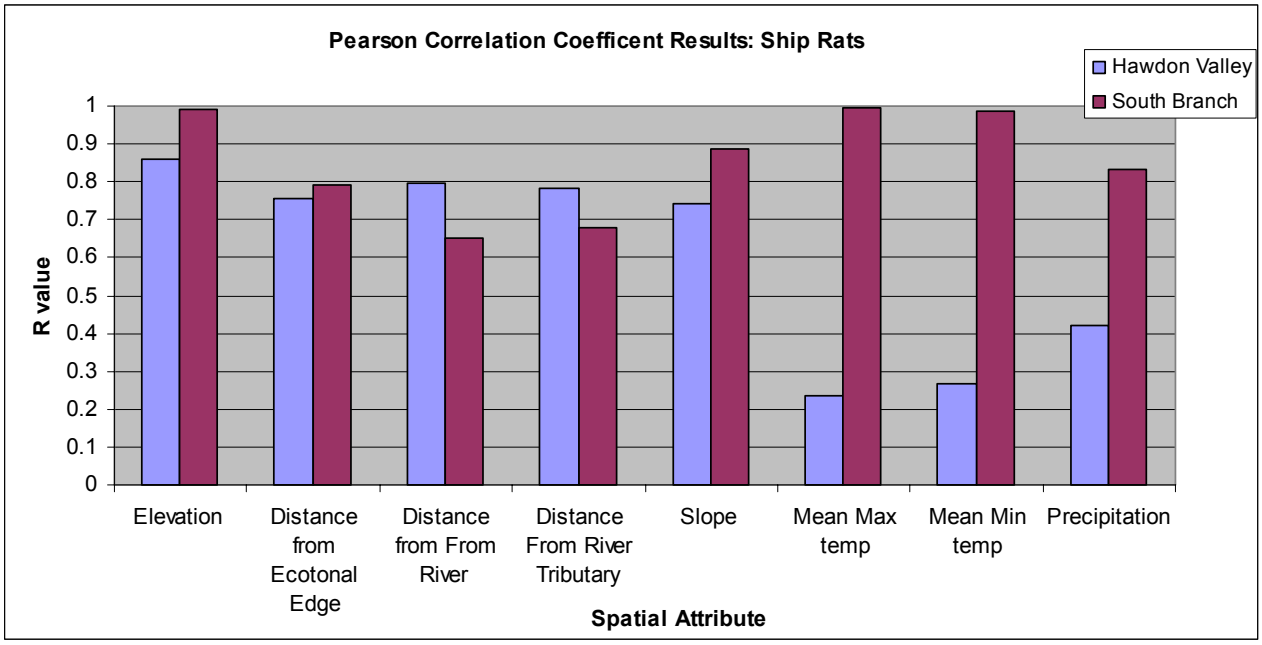


Figure 4.2: Pearson Correlation Coefficient results for Ship rats caught in the Hawdon and South Branch valleys

Figure 4.2 shows high correlation coefficients were recorded for Ship rats in relation to elevation, slope, mean maximum temperature and mean minimum temperature. Similar correlation coefficient results were recorded for the following spatial attributes; elevation, distance from ecotonal edge, distance from river, distance from river tributary and slope Elevation and distance from ecotonal edge in the Hawdon valley, and elevation, distance from ecotonal edge, slope, mean maximum temperature and mean minimum temperature in the South Branch were all found to be significant at the 0.01 level. Distance from river was recorded a 0.05 level of significance in the Hawdon and South Branch. These results indicate

that the relationship between mean trapping rate and distance from ecotonal edge and elevation were highly significant in each valley. However, elevation recorded a higher correlation coefficient in both trapping valleys and therefore is considered a more appropriate spatial predictor of Ship rats.

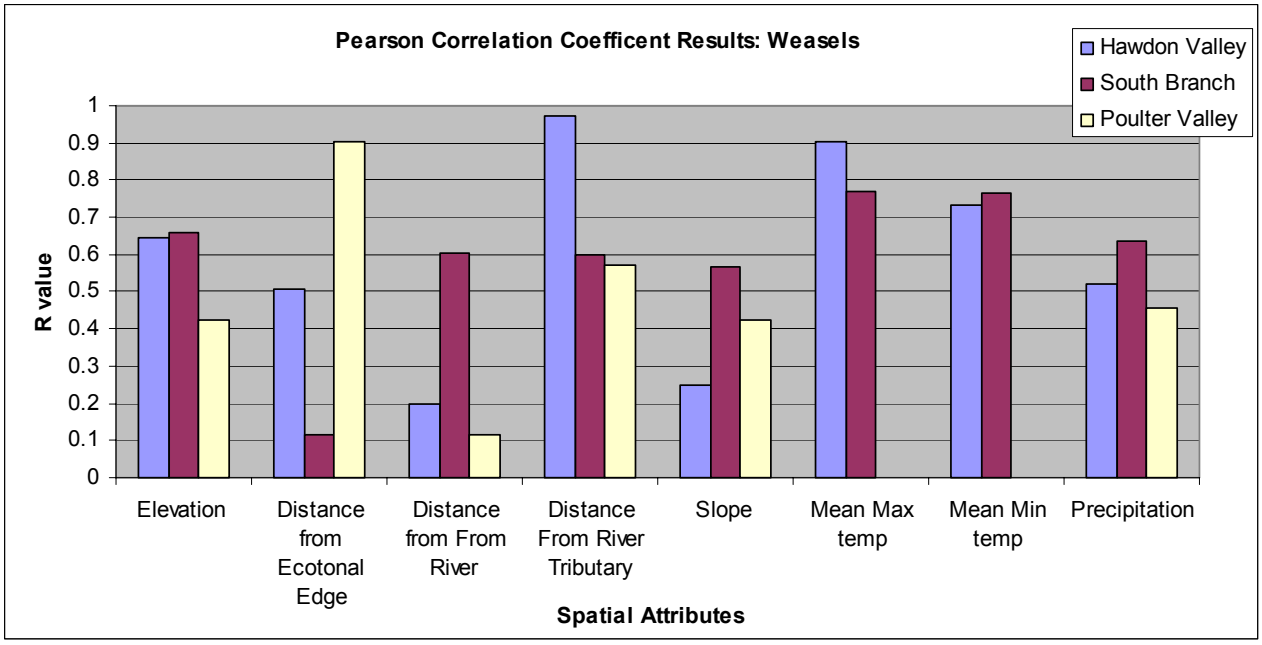


Figure 4.3: Pearson Correlation Coefficient results for Weasels caught in the Hawdon and South Branch valleys

Figure 4.3 shows high correlation coefficients were recorded for Weasels in relation to distance from ecotonal edge, distance to river tributary and mean maximum temperature. The South Branch, in particular recorded a consistent mid to high correlation result for each spatial attribute compared with the Hawdon and Poulter valleys. No mean trapping rates were found to be significant at the 0.01 level; however distance from river was recorded at the 0.05 level of significance in the South Branch. From these results, the spatial attribute 'elevation' was chosen to be a potential spatial predictor of weasel populations, based on a consistent correlation coefficient results between each trapping valley. It is suggested that a low capture rate of Weasels in each trapping valley compared to numbers of Stoats and Ship rats caught, is responsible firstly, for the variability in results and absence of significance between many of the spatial attributes.

4.2.3 Significance of mean trapping rates which used higher order polynomial trendlines

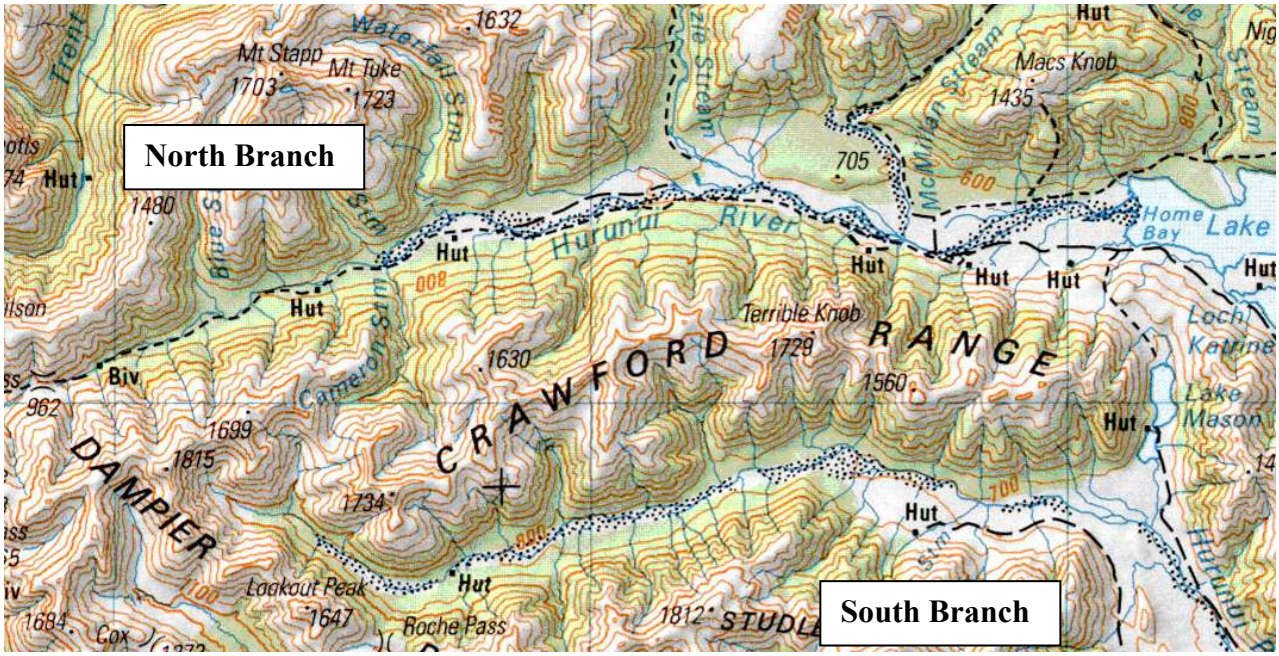
Both aspect and distance from trapping edge used between fourth to sixth order polynomial trendline to analyse mean trapping rate of Stoats, Ship rats and Weasels in each trapping valley. High order polynomial trend lines were used to graph a number of fluctuating mean trapping data points, that could not be analysed with a simple linear or curved (2^{nd} order polynomial) trendline. The significance of high order polynomial trend lines cannot be compared with other types of trendline as they can manipulate each recorded Pearson correlation coefficient result (r2). They, however, can be compared with each other. Aspect recorded an overall a higher Pearson correlation result for Stoats, Ship rats and Weasels than distance from trapping edge. The mean trapping rate used was also consistent between each trapping valley, suggesting that aspect is a potential spatial predictor of each species.

4.2.4 Key Spatial Attributes

The results from the thesis have identified that elevation and ecotonal edge are both significant spatial predictors for Stoats and Ship rats. However, a constant level of significance for each spatial attribute between trapping valleys was not present for Weasels. By analysing and comparing the significance of each spatial attribute, it was decided that a combination of elevation, ecotonal edge and aspect were potential spatial predictors for predicting the spatial distribution of Stoats. For Ship rats and Weasels, a combination of elevation and aspect were used as potential spatial predictors for both species. The level of uncertainty of each recorded mean trapping rate remains a consistent problem with a large fluctuation of between data points.

4.3 Creating Spatial Distribution Maps

The fourth objective of the thesis correlates the results from this thesis and uses the data to make a spatial prediction map for Stoats, Ship rats and Weasels for the North Branch of the Huuruni River (Hurunui Mainland Island) (Map 4.1). Compared to the South Branch, the North Branch of the Hurunui is not intensively laiden with traps though provides the Department of Conservation with information about the native habitat before poisoning while the South Branch shows the native habitat during and after poisoning. Both valleys are relatively similar in topography, geology and vegetation; however a large part of the North Branch has been modified by forest burning for farming in the late 19th and early 20th Century. This section details the process involved in predicting a spatial pattern map for each species, using and comments on the results from each spatial map.



Map 4.1 Map showing the Locations of the North and South Branch of the Hurunui (Map Scale 1:250,000 [NZMap 262+ Series])

4.3.1 Creation of a Prediction model

From the results of this thesis, a combination of distance from ecotonal edge, elevation and aspect were chosen to predict the spatial distribution of Stoats. Figure 4.4 shows the model created to spatially predict the distribution of Stoats, Ship Rats and Weasels in the North Branch.

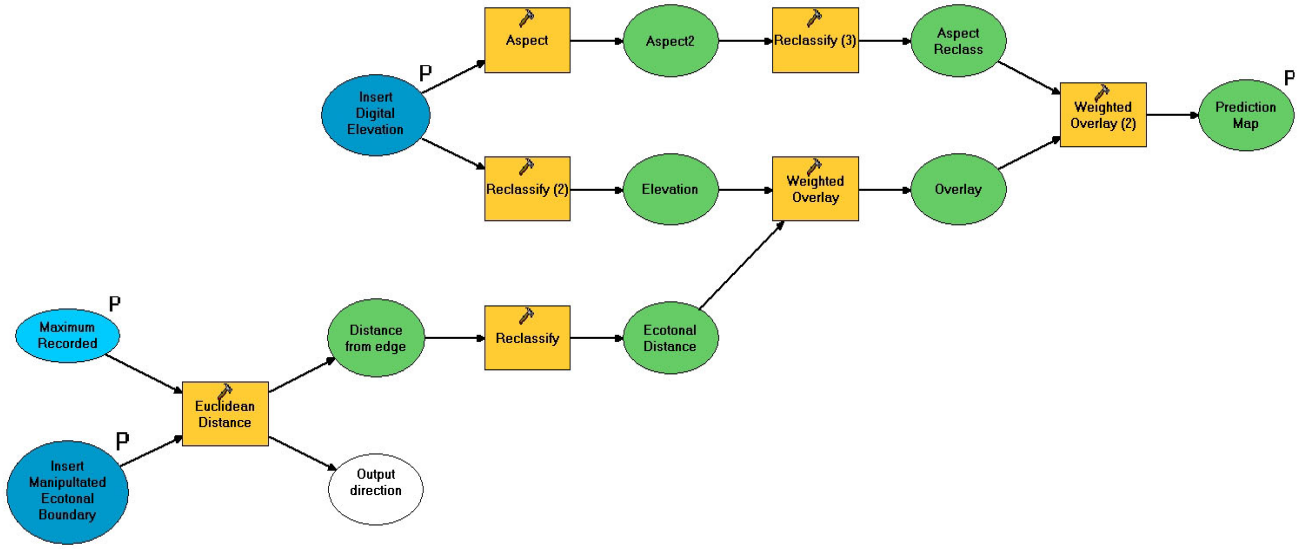


Figure 4.4 Model created to predict the spatial pattern of Stoats, Ship Rats and Weasels in the North Branch of the Hurunui River using ESRI's Model builder

Aspect and Elevation data were derived from a 15 m Digital Elevation Model created for the North Branch based on a similar process described in section 3.1.3. Distance from ecotonal edge was calculated to a distance of 400 m, using the same method explained in section 3.2.1. Each spatial attribute was then reclassed into their respective interval groups using a numerical scale. It was decided to combine both the elevation and distance from ecotonal edge data separately from the aspect data, as both attributes were recorded high levels of significance. Elevation intervals which were not analysed in the Hawdon, Poulter and South Branch valleys were restricted from this analysis. Both spatial attributes were ranked according to areas which recorded a high mean trapping rate and weighted equally (50:50) with each other. The result of this weighted output is then combined with aspect data. Aspect data are ranked based on results recorded in the South Branch due the similarity in localities between each valley. The weighted output from the elevation and ecotonal distance data is weighted again in its favour (60:40) with the aspect data. The final spatial prediction map for Stoats is based on this weighted output.

A combination of elevation and aspect were chosen to be spatial predictors of Ship rats and Weasels. In this situation, the same model that predicted the spatial distribution of Stoats (Figure 4.4) can be used to predict the spatial pattern of Ship Rat and Weasels. The main difference to this model is that only aspect and elevation are combined and weight

appropriately (i.e., elevation (60%), aspect (40%)). Both elevation and aspect are ranked according to high mean trap rates.

4.3.2 Spatial Distribution of Stoats (Map 4.2)

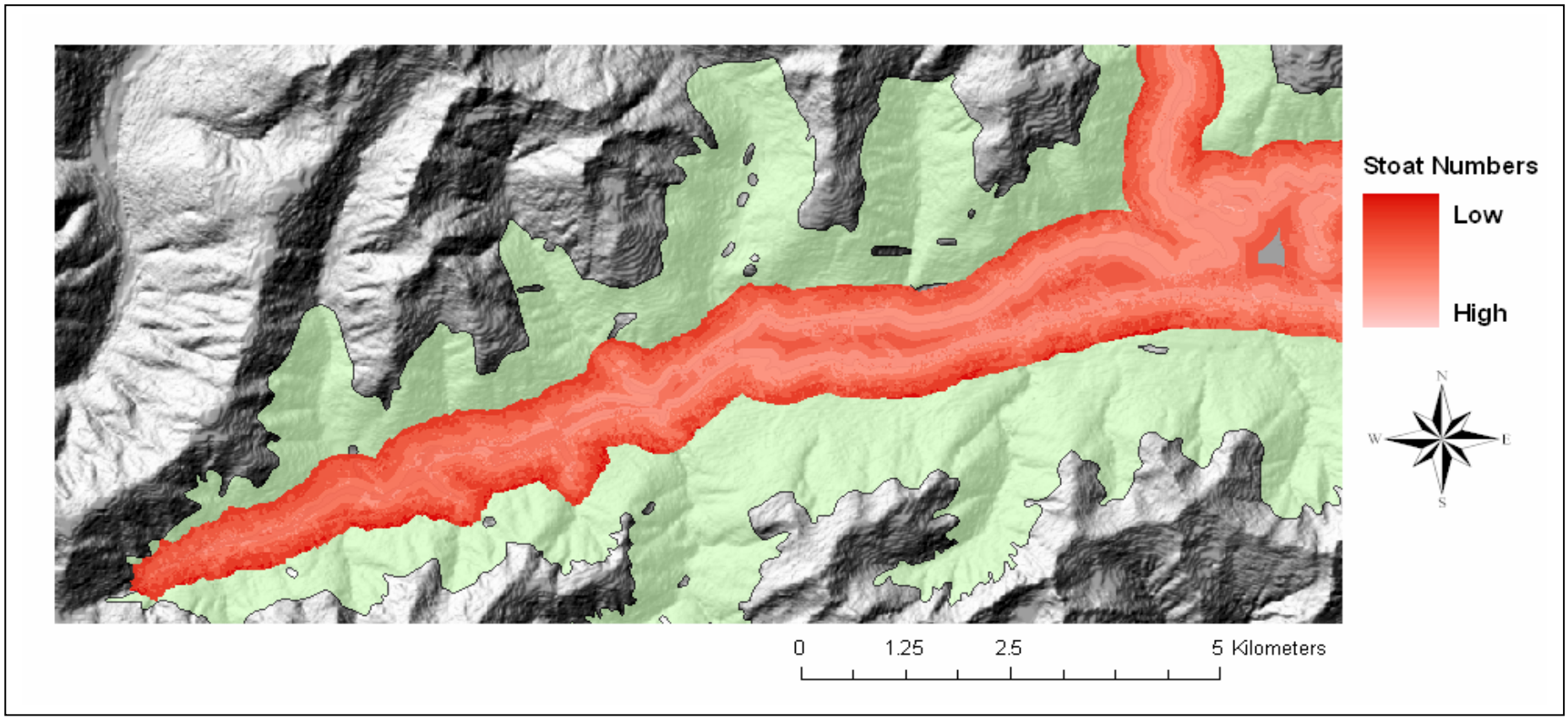
Map 4.2 shows the predicted spatial distribution of Stoats near the headwaters of the North Branch of the Hurunui River. The map predicts stoat populations remaining high close to the ecotonal edge with a gradual decrease with distance away from this edge. Secondly, stoat numbers decrease relative to an increase in elevation; this is recorded near the headwaters of the North Branch (south-western end of the valley) where stoat levels near the ecotonal edge are relatively lower compared to north-eastern end of the valley. Stoat populations are predicted to remain low above an elevation of 950 m. The spatial distribution map also predicts that stoat numbers are higher on north eastern and south western orientated slopes.

4.3.3 Spatial Distribution of Ship rats (Map 4.3)

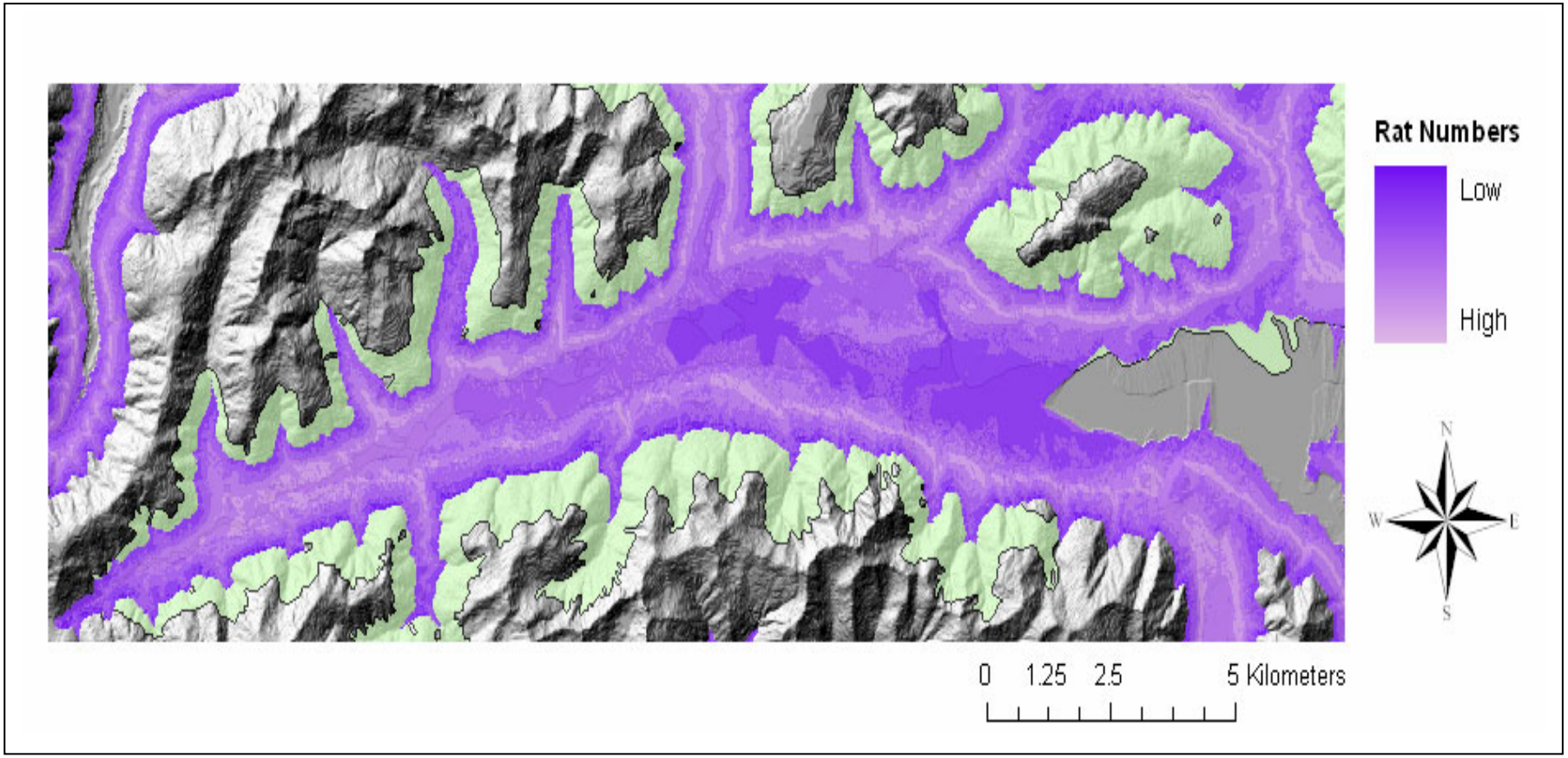
Map 4.3 shows the predicted spatial distribution of Ship rats in the North Branch of the Hurunui River. This map predicts high populations of Ship rats at an elevation between 700-750m. Ship rat populations are predicted to be low or even absent on most of the valley floor, especially near the forest edge where stoat numbers are predicted to be high. The distance between the forest edge and high Ship rat population number decreases with an increase elevation to the point where both meet. This is observed near the headwaters (south-western end) of the North Branch. At higher elevations, populations of Ship rats are predicted to decrease and become exceedingly rare beyond the tree line. The spatial distribution map also predicts ship rat numbers to be higher on north eastern and south western orientated slopes.

4.3.4 Spatial Distribution of Weasels (Map 4.3)

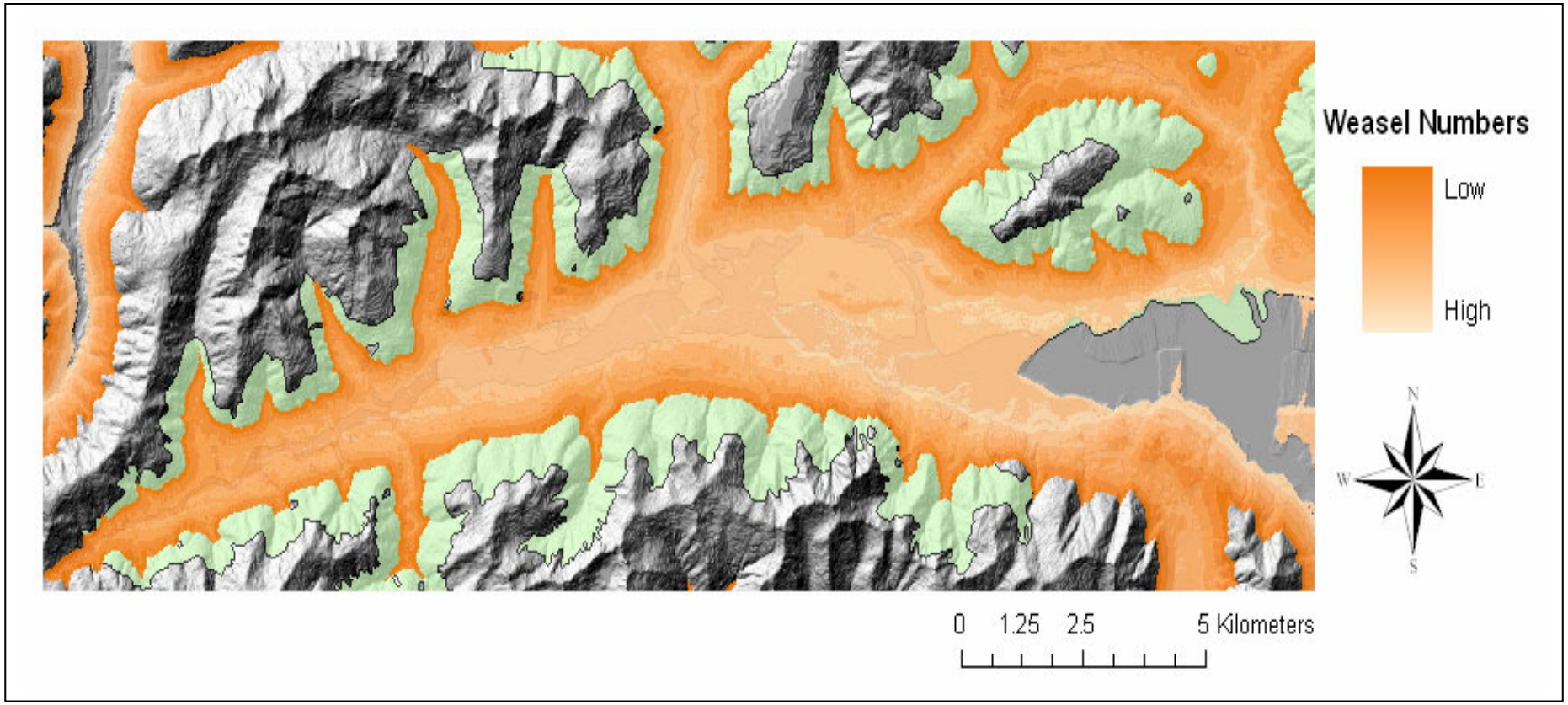
Figure 4.4 displays the spatial distribution map of Weasels in the North Branch of the Hurunui River. This map predicts high numbers of Weasels associated with the valley floor and forest edge. Weasel numbers are predicted decrease relative to an increase in elevation to between 900-950m. At this point weasel numbers are predicted to be extremely rare. The spatial distribution map also predicts ship rat numbers to be higher on northern and south



Map 4.2 Predicted spatial distribution of Stoats near the of the North Branch of the Hurunui River
(Areas of shaded light green indicate the altitudinal extent of the beech forest in the valley)



Map 4.3 Predicted spatial distribution of Ship Rats in the North Branch of the Hurunui River
(Areas of shaded light green indicate the altitudinal extent of the beech forest in the valley)



Map 4.4 Predicted spatial distribution of Weasels in the North Branch of the Hurunui River
(Areas of shaded light green indicate the altitudinal extent of the beech forest in the valley)

orientated slopes; therefore Weasel numbers are gradually higher in the North Branch, compared to a number of smaller valley tributaries.

4.4 Conclusion

The results from this thesis have indicated that an increase in elevation and distance from the ecotonal edge between the forest edges were significant in limiting Stoat numbers in a beech forest environment. Elevation was also an important factor in controlling Ship rat and Weasel populations. Aspect was also considered in this thesis as a potential predictor of each pest species, and was incorporated into each spatial distribution model. The other seven spatial attributes that were studied in this thesis, unfortunately, produced insignificant results in the Hawdon, Poulter and South Branch valleys.

The significance of each result played an important role in choosing potential spatial predictors for Stoats, Ship rats and Weasels. By calculating the Pearson correlation coefficient result to each mean trapping rate and comparing the result to either a 0.01 or 0.05 level of significance, the probability of each mean trapping rate being by chance is greatly diminished if the correlation coefficient result is greater or equal to that a 0.01 or 0.05 level of significance. Uncertainty associated with each mean trapping rate was also considered when choosing potential spatial predictors.

The spatial distribution maps created for Stoats, Ship rats and Weasels in the North Branch using ESRI's Model Builder predicted high numbers Stoats and Weasels on the valley floor in close proximity to the beech forest edge. High Ship rat numbers were predicted at an elevation between 700-750m. A decline in the number of each species is predicted at higher elevations with numbers becoming exceedingly rare above the tree line of the North Branch.

CHAPTER FIVE: RECOMMENDATIONS AND CONCLUSIONS

The final chapter of the thesis discusses the benefits and limitations of using an associative model in a GIS to spatially predict the distribution of Stoats, Ship rats and Weasels in a beech forest catchment and provides a list of recommendations for the Department of Conservation, describing better ways to control Stoats, Ship Rats and Weasels in the Hawdon, Poulter and South Branch valleys.

5.1 Ecological Modelling and GIS

Models are simplications of reality and widely used to help understand complex systems (Gough and Ruston 2000). Constructing a model forces us to state explicitly what we know about the way in which landscapes influence the distribution of a species and thereby, formalising our understanding and identifying gaps in our knowledge (Starfield 1997). Models can test our ideas and generate new hypothese about the mechanisms underlying observed space use patterns by performing 'experiments' that would not be normally possible in the field (Turner et al. 1995).

Modelling approaches combined with Geographic Information Systems (GIS) are widely advocated as powerful tools for investigating wildlife distributions (Johnson, 1990; Gardner and Turner, 1991; Norton and Possingham, 1993, Elllis and Seal 1995; Edwards et al. 1996; Naesset, 1997; Macdonald et al. 1998). GIS are useful for analysing the distributions of organisms in relation to the landscapes in which they are found (Gough and Rushton 2000). GIS can also be used to produce models to predict species distributions in unsurveyed areas.

Many interacting biotic and abiotic factors influence the distribution of a species, most of which can not be incorporated into a GIS because some are unknown and others are difficult to measure (Gough and Rushton 2000). Some factors will only have a limited influence on the distribution of a species and therefore do not warrant the effort required to quantify them. It is therefore, necessary to create a simplified representation, (i.e., a model) of the species niche by identifying those factors that are considered to have the greatest influence on the distribution of the species. Associative modelling techniques have the greatest potential for modelling species with highly specialised habitat requirements which are easily related to

landscape characteristics that are easily perceived and mapped by humans. (Gough and Ruston 2000)

5.2 Benefits of using Associative modelling techniques for this application

Associative models are considered as a 'top down', 'black box' approach, as they attempt to determine relationships between the distribution of a species and measured landscape characteristics (Gough and Ruston 2000). The benefits of using an associative modelling technique to predict the spatial distribution of Stoats, Ship rats and Weasels populations in a Beech forest environment include a large variety of associative models and the ability to study spatial patterns of each pest species over large areas without the constraints associated with money and time.

A wide range of associative approaches can be employed to investigate animal distributions within landscapes. Associative models range from simple rule based associative models to more formal mathematical linkages between the distribution of a species and environmental data. These approaches include discriminant analysis (Williams 1983), regression techniques (Mc Cullugh and Nelder 1983; Tabachnick and Fidell 1996) and Bayesian modelling (Lee 1989).

Although these methods differ in complexity, all are based on linking information regarding the incidence of the species to measured environmental variables, land use or vegetation characteristics considered to be important in influencing the distribution of the organism, such as estimates in prey abundance. Once a link has been identified between species occurrence and landscape attributes, the link can potentially be used to predict the distribution of the species in other areas of the landscape

The large investment in time and equipment required to study species such as Stoats, Ship rats and Weasels in the field, means that most studies, (including this study) have been conducted with few individuals at small and local spatial scales over relatively short time periods. One way to overcoming this problem is to bring information about each pest species and the landscape into a computer and investigate the effects of landscape on the species with modelling (Gough and Ruston 2000).

In this thesis, the spatial distribution of Stoats, Ship rats and Weasels was derived on a simple rule associative model, based on the significance of ten environmental variables chosen as potential spatial predictors for each pest species. The use of this type of model allowed the user of the model to visualise the spatial distribution of each species in the Hawdon, Poulter and South Branch valleys. The model could also be applied to areas such as the North Branch of the Hurunui River with no former or current trapping grids.
The use of a GIS model instead of a mathematical model allows individuals with no previous experience of statistical regression modelling the opportunity to model a species spatial distribution to a limited degree of freedom and accuracy.

5.3 Limitations of using Associative modelling techniques for this application

Limitations of using an Associative model to predict the spatial distribution of Stoats, Ship rats and Weasels populations in a Beech forest environment, are derived from the information used to predict the model and the age of the data. Like all other models, associative models are unable to predict a perfect solution.

Associative models are based on survey data that effectively represent a snapshot of a species distribution at a given point in time. The link established between distribution data and explanatory variables may adequately describe the relationship for the area surveyed at the time the data were collected. This formal association may however, be inappropriate for describing the relationship between species incidence and landscape characteristics in another area, as static models may also become obsolete in the area in which they were developed if the relationship between a species distribution and landscape change with time (Gough and Rushton 2000). Associative models can therefore be considered as useful for explaining present or past observed patterns in species occurrence and distribution, pertinent only to time and space where the original data were gathered (Morrison et al. 1992).

Associative approaches using landscape attributes as explanatory / predictor variables can only be used effectively if these variables are the main factors determining the distribution of the species. Other factors, including interspecific interactions such as competition, predation and disease can have a significant effect on the distribution on Stoats, Ship rats and Weasels. Consequently, their distributions may change even though their characteristics of the landscape represented in the GIS are unchanged.

Models have the potential to allow extrapolation in both space and time with minimal resources requirements (Starfield and Bleoch 1986). There is, however no perfect solution with spatial modelling; all models, irrespective of type require reappraisal and improvements to be made in the light of increased understanding and the availability of more data from field - studies (Jorgensen 1986; Starfield 1997).

The spatial distribution model created for Stoats, Ship rats and Weasels in this study was derived from three trapping valleys, each predominately covered in Beech (*Nothofagus* sp.) forest. This eliminates, to some extent, some uncertainty when applying the same spatial distribution model to an area where no trapping grid exists. Each spatial distribution map, however, was derived from trapping data collected by the Department of Conservation between 1994-2005, which does not account for longer term population dynamics between Stoats, Ship rats and Weasels. The associative model used does not take into consideration observed patterns of social interaction between each pest species including social interactions with other animals especially; Feral cats (*Felius Catus*) which are known predators of Stoats, Ship rats and Weasels, and interactions with the beech mast cycle.

Associative models are also limited to the spatial extent on which data are collected. In this thesis, analysis of the spatial distribution of Stoats, Ship Rats and Weasels was limited to an elevation below 950m. Further consideration is needed when spatially mapping stoats, in particular, at higher elevations where a second ecotonal edge exists between beech forest and alpine areas (i.e. Treeline).

GIS are able to predict the spatial distribution of a pest species to a similar (or better) level compared to more formal associative model. The potential of GIS is however, restrained by the same limitations related to these models. By using a larger trapping data set range and identifying a number of social interactions between Stoats, Ship Rats and Weasels one can improve the accuracy of spatially modelling each species within a Beech forest environment and therefore, improve our understanding how landscapes influence the distribution of each pest species.

5.4 Conclusions and Recommendations

Based on our models and this thesis, the author recommends the following:

- Ecological modelling and GIS are important tools in the management of rodents in conservational estates

- Ecological Modelling using GIS allows modern technology to better target control measures and contain mustelid and rodent populations that allow conservation estates to improve.

- Ecological modelling using GIS provides solutions to predict mustelid and rodent populations with greater accuracy in uncontrolled areas

- DOC should also consider developing the technology at existing sites with particular emphasis on measuring its accuracy and reliability

- DOC should consider deploying this technology in a number of uncontrolled sites to determine the scientific merit, long term cost effectiveness and economic application.

ACKNOWLEDGEMENTS

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