Weasel (*Mustela nivalis*) dynamics in South Island beech forests of the Maruia Valley

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Abstract

The Maruia Valley in the South Island of New Zealand experienced a major beech mast event in autumn 2014, which resulted in a rodent irruption and subsequent increases in mustelid populations. Interestingly, this included weasels (*Mustela nivalis*), which were caught at an unprecedented rate. Therefore, this study investigated the dynamics of this weasel population and its interactions with other key predator species in this valley. The first weasel was caught almost 2 months after the mouse abundance increased, reflecting the slower reproductive cycle of predators. There was some evidence of niche differentiation between weasels and stoats (*M. erminea*) in grassland habitats in the valley. However, twin catches indicated that these species also coexisted in similar ecosystems, with a likely crossover in home range, defying the previous belief that weasels avoid stoat-scented areas. These findings indicate that both weasels and stoats thrived and seemingly were able to coexist for small periods of time due to the high rodent abundance providing a large and valuable food resource. Testing of the trigger weights of DOC200 traps showed that a percentage of weasels, particularly females, would avoid capture even if they encountered and entered a trap. Therefore, it is imperative that increased monitoring and trapping of weasels is undertaken in beech forests to help protect valuable native species

Keywords: Weasel, *Mustela nivalis*, weasel ecology, monitoring, rodent tracking, beech forest mast, Te Maruia Waka Huia, predator trapping

1. Introduction

New Zealand's flora and fauna evolved in the absence of mammalian predators. However, three mustelid species (the ferret *Mustela furo*, stoat *M. erminea* and weasel *M. nivalis*)[1] were introduced in the 1880s in efforts to suppress populations of European rabbits (*Oryctolagus cuniculus*) (Peden 2015), which were brought here by early settlers and quickly reached plague proportions. Like their target prey, these predators also rapidly spread and can now be found in almost every ecosystem in New Zealand where they impact on a wide range of native animals.

The stoat is the most common predator in New Zealand forests (Murphy & Bradfield 1992) and so much is already understood about its population dynamics and biology. By contrast, little information is currently available on weasels because they are usually far less common than stoats making them difficult to study, and are considered less of a threat than other predator species that occur in forests – although Miskelly (1997) implicated the weasel as a key factor in the losses sustained by the now Critically Endangered Whittaker's skink (*Oligosoma whitakeri*), and this predator should be considered a major threat to other threatened species when present at high abundances.

1.1 Interspecific competition between weasels and stoats

When resources are limited, interspecific competition can manifest itself as the dominant consumption of a resource and antagonistic behaviours such as aggression, which can sometimes be lethal (intraguild predation) (Bridgman 2012). Such intraguild interactions are usually asymmetric, with a single dominant species. In the case of weasels and stoats, it is the stoat that is dominant due to its physical size and social behaviours (Sheffield & King 1994). However, the weasel is better suited to exploit populations of small rodents due to its foraging and breeding strategies, and ability to enter smaller tunnels (Erlinge & Sandell 1988).

In the presence of high rodent abundances, weasels and stoats have been known to coexist even at a local level, suggesting that they may utilise different habitats and prey species (Sheffield & King 1994). This use of differing habitats may indicate niche differentiation, allowing for a level of avoidance and thus minimising competition between the two species. Coexistence between the two species is both temporary and unstable, being reliant on appropriate environmental factors for sustaining rodent populations.

1.2 Beech mast events as a driver of prey populations

Seed production by New Zealand beech species is of little direct significance to the life cycle of the carnivorous weasel. However, this seed production, particularly in periods of heightened yields (or mast years), drives increased abundances of rodents, upon which weasel prey. Therefore, beech seed could be considered to play a keystone role in the behaviours of r-selected species inhabiting New Zealand beech forests.

Beech trees do not seed annually and so there are erratic production levels ranging from zero to thousands of seeds per square metre (King 1983), which are classified as poor mast (<500 seeds/m²), partial mast (500–4000 seeds/m²) and major mast (>4000 seeds/m²) (Wardle 1984). There is also variation in the energy content of the seeds between species, with red beech (*Fuscospora*

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[1] *Mustela erminea* and *M. nivalis* are technically both weasels and often referred to as short-tailed weasel and common weasel, respectively. However, these are known as the weasel and stoat in New Zealand (King & Powell 2007) and so these names are used in this report.

fusca) seeds containing three times as much energy as the seeds of other beech species (180 kJ per seed v. 60 kJ per seed for silver beech (*Lophozonia menziesii*)), making red beech particularly important in driving rodent numbers (Beggs 1999).

Seeds that fall in autumn do not germinate until the following spring and rodents are able to cache the seeds, prolonging their usefulness as a food resource. When there is an abundance of food resources, ship rats (*Rattus rattus*) have the capability of breeding through the winter months (McQueen & Lawrence 2008). Consequently, during major beech mast events, ship rat populations can experience exponential increases calculated at approximately 1.2% per day (G. Elliott, Department of Conservation (DOC), pers. comm., May 2016).

Mast events can also lead to rapid but short-term increases in mouse (*Mus musculus*) populations, which can experience a ten-fold increase in density over a single quarter (Choquenot & Ruscoe 2000). Mice have the capacity to produce 5–10 litters per year with an average litter size of 5–6 young (GISD 2016). The strong correlation between timing of increased mouse abundance with increased seed fall is supported by Murphy (1992).

These irruptions in ship rat and mouse populations lead to subsequent increases in stoat and weasel populations.

1.3   Objective

The Maruia Valley in the South Island of New Zealand experienced a beech mast event in the autumn of 2014, driven primarily by red beech, that led to an unprecedented catch rate of weasels in 2015. Therefore, the aim of this study was to investigate the dynamics of this weasel population and its interactions with other key predator species in this valley. In addition, the trigger weights of traps were tested to determine their effectiveness in controlling weasels.

2. Weasel biology and ecology

2.1 Morphology

The weasel is the smallest of the mustelids and the smallest member of the order Carnivora (Sheffield & King 1994). The subspecies that is found in New Zealand (*M. n. vulgaris*) originated from western and central Europe (GISD 2008).

Considerably smaller than the stoat, the weasel has an elongated body that is perfectly engineered for hunting in tight, confined tunnels and underground spaces. It resembles the stoat in body colouration, with chocolate brown dorsal fur adjoining white ventral fur along an irregular boundary. The weasel ventral pelage may include brown spots and they lack the black tip on the tail.

Sexual dimorphism is pronounced in this species, with females weighing 35–90 g and males weighing 72–185 g (Corbet & Harris 1991).[2] Females also have a smaller overall body length than males with averages of 182 mm and 217 mm respectively (NPCA 2014), giving females a greater hunting efficiency, which is critical when rearing young (Sheffield & King 1994). Sheffield & King (1994) suggest that this variance in body size could be a consequence of the differing energy budgets of the sexes.

2.2 Breeding

The weasel is a typical *r*-strategist, exhibiting reproduction at a young age, a short gestation period, the production of numerous offspring, a short parental care period and the ability to increase its population size exponentially in periods of high food availability (King & Moors 1979). These rapid increases in population abundance impact on *k*-selected species that are slow breeders and have populations that are usually maintained close to their carrying capacity. However, this reliance on food abundance to sustain populations also means that *r*-strategists are susceptible to having short life spans because of reductions in their prey (Rafferty n.d). Consequently, localised weasel populations can fluctuate depending on the distribution and abundance of food, with the potential for local extinctions (King et al. 2001).

Male weasels are typically dominant through most of the year but may be warded off by females if unwanted as a partner. The release of ova requires the stimulus of mating and so the male will grab the female by the neck and hold her with his teeth, often dragging her around. This process may be repeated over 2–3 days, which is the timeframe for females to begin ovulation. There is no pair bonding in this species and so the female may accept many males, with those who catch her later in her short heat period being more likely to father the offspring. Following mating, the male takes no part in rearing the young (King & Powell 2007).

Weasels usually make their dens in the burrows or nests of displaced prey (King & Powell 2007) and have a gestation period of 34–37 days. New Zealand weasels typically produce an average of 4.5 kittens per litter and can produce two litters in the same year, but only when food availability is high. Weaning begins at around 32 days and is completed by 42–56 days (GISD 2008). The young are eating meat at around 18 days and exhibit behaviours that lead to killing at 32–38 days. By day 40, the young have full locomotive capacity and by day 49 they are highly adept at killing mice. By days 49–56, the young have standard adult body dimensions and by day 60 the skull has finished growing in both sexes. Female offspring reach sexual maturity at 3 months old (GISD 2008).

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2   There is marked variation in the male weight range internationally, from 60–100 g in North America to 125–250 g in Africa (Sheffield & King 1994).

Following weaning, the adult female will return to oestrus (Sheffield & King 1994). However, mortality in the second litter can be high depending on the availability of food sources. With weasels having an expected lifespan of 1 year once independence has been reached in the wild, the chances of a female breeding for a second successive year are extremely low (King & Moors 1979).

2.3 Diet

The weasel is considered a specialist predator of small mammals, having a reliance on only a few prey species (Brandt & Lambin 2007). In New Zealand, the primary food sources for weasels include mice, invertebrates, lizards and birds (King 2005). A study conducted in Mapara and Kaharoa in the North Island of New Zealand showed that mice made up the largest proportion of the diet both in terms of frequency and occurrence (72%) and by weight (64%)(Murphy et al. 1998), while another study in the Pureora Forest Park in the central North Island found that weasels relied on mice and invertebrates as a key component of their diet, while stoats preferred larger prey but still had a high occurrence of invertebrates in their diet (King et al. 1996a).

Weasels have an opportunistic foraging strategy that is reliant on both auditory and visual cues, whereby the movement of prey stimulates an immediate attack, while a stationary prey item is likely to be missed, even if it is close to the weasel (Sheffield & King 1994). This strategy is less efficient at capturing mice than voles (*Microtus* spp.), which are more commonly taken by its European counterparts.

The elongate body and short legs result in weasels having high locomotive energy costs (Chappell et al. 2012) but may represent a 'compromise between energy conservation and predation efficiency' (Sheffield & King 1994). Consequently, weasels need to find five to ten small meals each day to meet their energy requirements, storing any excess nutrition as muscle rather than fat because the latter would compromise their ability to quickly enter and move through tunnels. Studies on captive weasels have shown that non-breeding females consume a higher percentage of their body weight in food than males (King & Powell 2007).

Any increase in rodent abundance will often exceed the predatory capacity of weasels (King et al. 2001) which, combined with the fact that predator reproductive cycles are longer than those of their prey, results in time delays in the numerical response to increased prey abundances (Brandt & Lambin 2007). By contrast, when prey availability is low, weasels are forced to expand their home ranges (King et al. 2001), resulting in expended energy comprising a large portion of the daily energy budget (Chappell et al. 2012). It is generally considered that predators in New Zealand, particularly mustelids, will prey switch when there is a shortage of their preferred prey, placing native species at risk (Murphy et al. 1998). However, Brandt & Lambin (2007) argued that prey switching does not usually occur in specialist predators. Therefore, further research is required to fully understand the impact of rodent control operations on mustelid populations.

2.4 Behavioural patterns

There is much debate in the literature about the activity patterns of weasels, with some stating that they are diurnal and others that they are nocturnal (Brandt & Lambin 2005). King & Powell (2007) suggested that because of their high food requirements, weasels will hunt when hungry, be it day or night.

In one English study weasels spent 86% of their active time in clear areas without venturing into adjacent forests (Brandt & Lambin 2007) and hunting was undertaken over less than half of their home range area. As this was a study conducted in England, further study in New Zealand conditions would be required to ascertain if the same behaviours are exhibited here. Furthermore, both weasels and stoats have a readiness and willingness to climb to great heights to seek food (King & Powell 2007).

Hunting efficiencies have generally been shown to benefit animals with high locomotive energy costs when there is a high density of prey. However, Brandt & Lambin (2005) observed the reverse in weasels, with daily activity patterns increasing in response to increasing field vole (*Microtus agrestis*) densities. This may be due to the inability of weasels to store excess energy as fat deposits (Chappell et al. 2012), but could also be translated as increased intra-specific activity such as seeking out a mate or defending their territory (Brandt & Lambin 2005).

King & Powell (2007) note that weasels prefer to remain inside their dens on cold or wet days, relying instead on the consumption of cached prey, despite their preference for fresh meat, but will also readily scavenge dead rodents. In addition, the relatively short pelage and long, thin shape of weasels gives them a high basal metabolic rate and increased levels of heat loss, increasing their thermoregulation costs (Sheffield & King 1994).

Laboratory tests have shown that weasels have a limited propensity to run, averaging <2 km per day and only running for a maximum of 10 minutes followed by periods of inactivity (Chappell et al. 2012). Increased periods of activity are observed during breeding, however, with increased movements by males seeking partners and increased hunting by females to feed the young (King & Powell 2007). These increased movements can be recorded as an increase in trap catch, particularly among males who are more active across a larger home range.

2.5 Distribution, habitat and home range

The population dynamics of weasels have proven difficult to study due to their size, secrecy and low population densities compared with their prey, which are often seen in abundance. Consequently, information on population abundances relies on data gleaned from control and monitoring operations (King & Powell 2007).

Weasels have a patchy distribution across both the North and South Islands of New Zealand and are absent from offshore islands and Stewart Island/Rakiura (NPCA 2014).

However, where they do occur, they are found in an array of ecosystems from urban gardens to agricultural land, scrub, cut-over native and exotic forests, and around the fringes of open countryside (GISD 2008). Indeed, the author detected weasel registration on tracking cards in the lower alpine tussock areas in the Lewis Pass during rodent monitoring.

In the Pureora Forest Park, 16 weasels from 24 272 trap nights were caught along road edges of logged native forest and in exotic forests but were not found in tawa (*Beilschmiedia tawa*)-dominant podocarp-hardwood forests (King et al. 1996b). This distribution was correlated with sites that had higher catch rates of mice and a low canopy height, such as dense vascular ground cover that was predominantly composed of weeds.

This was mirrored around Lake Waikaremoana in 1994–96, with 11 weasels being caught in areas of thick, abundant grass along the shoreline of the lake and where secondary succession was occurring on old, exposed lake beds (King et al. 2001). These findings highlight the habitat preferences and scarcity of weasels in New Zealand ecosystems.

This rarity of weasels may be related to several factors, including potential interspecific competition by stoats for available resources (Bridgman 2012). Modelling of weasel trap catches over 10 years in the Poulter and Hawdon Valleys and the South Branch of the Hurunui River in Canterbury using a Geographic Information System (GIS) showed that weasels were caught more on northern- and southern-facing slopes in the South Branch and were reduced to a mean catch of zero at 300–400 m from the rivers. It was also found that the weasel catch decreased with increasing altitude, with higher catch rates in the valley floors and close to the forest edges out to 200–300 m from the ecotonal edge (Lough 2006). Lough (2006) suggests that this avoidance of areas close to the ecotonal edges may have resulted from stoat dominance.

It is known that in times of reduced food resources home ranges will increase as previously stated, and this is reflected in a study in Poland where home ranges of two radio tracked males expanded from 24.2 ± 11.9 ha to 117 ha and 216 ha because of crashes in vole populations, with crossover in home ranges also detected (Jedrzejewska et.al. 1995). In New Zealand, Murphy & Robins (unpublished) found three male weasels had home ranges of 66 ha, 117 ha and 150 ha respectively, and a female had a range of 59 ha in a situation of lowered mouse abundance. It is noteworthy that Jedrzejewska et.al. (1995) also discovered that of the maximum area used by weasels, on average 24 ± 8.2% was intensively used. A radio telemetry tracking study in Bialowieza Forest in northeast Poland found that individuals travelled a mean linear distance of 1.32 ± 0.83 km per day through habitat comprising fields and meadows, riparian margins, sedge meadows, hardwood forests and reed beds (Chappell et al. 2012).

2.6 Control options

Because weasels are not considered a great threat to wildlife in New Zealand and are typically present at a low abundance, their control has not received the level of attention afforded to stoats and other pest animal species. Consequently, weasels are currently caught in kill traps such as the DOC150 or the DOC200 set in wooden tunnels (Fig. 1), which have been designed to target rats (*Rattus* spp.), stoats and hedgehogs (*Erinaceus europaeus*) (Predator Traps n.d).

Figure 1. DOC200 kill trap set in the Maruia Valley and lured using solid state fish lures (Connovation®). A captured male stoat (*Mustela erminea*) is shown alongside the trap.

The factory trigger weight for both of these traps is reported as 80 g (Predator Traps n.d.), meaning that female weasels at the bottom end of the size range would not trigger them. This, alongside the fact that males may have a larger home range, increasing the likelihood that they will encounter traps (King et al. 2001), likely explains why 75% of weasels that are caught in kill traps are male (King & Powell 2007).

A trapping network will only be successful at a localised scale and is very labour-intensive (King & Moors 1979), with the necessary level of labour depending on the infrastructure layout that is chosen, i.e. landscape or grid depending on the scale of the programme and the species being protected. The landscape option allows for the more expansive use of available traps, which are set 100 m apart for mustelids and target normal habitats within the landscape, following spatial features such as roads, stream edges and bush–pasture boundaries (Predator Traps 2005). By contrast, the grid option employs a predetermined pattern, which is usually 100-m grids for stoats. Both options are classified as intensive and localised, with an understanding that complete eradication is not practicable in a mainland setting (Lough 2006).

In terms of toxins, both anticoagulants and 1080 are just as likely to kill weasels as by-kill, with surviving weasels responding quicker afterward than stoats through their ability to breed before stoats (E. Murphy, pers. comm., DOC, June 2018). The use of anticoagulants however is heavily restricted on public conservation land and new toxins such as para-aminopropiophenone (PAPP) are not yet recognised or registered as a control option for weasels, only stoats and feral cats (*Felis catus*) (Envirolink n.d). Therefore, the use of trapping networks is currently the best option for controlling weasels in public conservation lands.

3. Methods

3.1 Study site

This study was conducted in a 21000-ha area in the Maruia Valley that is being managed by DOC under the Te Maruia Waka Huia integrated species protection programme (Fig. 2). The core area is located in the Spenser Ecological Region and lies predominantly in the Lewis Pass National Reserve and partially within the Victoria Forest Park. It is split by the Maruia River, Pell Stream and Alfred River, with Lake Daniell at the head of the valley (Fig. A1.1, Appendix 1), and has significant ecological value due to its high levels of biodiversity.

The vegetation in the study area mainly comprises rich, fertile, red beech terraces, mixed in places with silver beech and occasional mountain beech (*Fuscospora cliffortioides*), and with a profusion of *Coprosma* species in the understorey where light availability is higher.
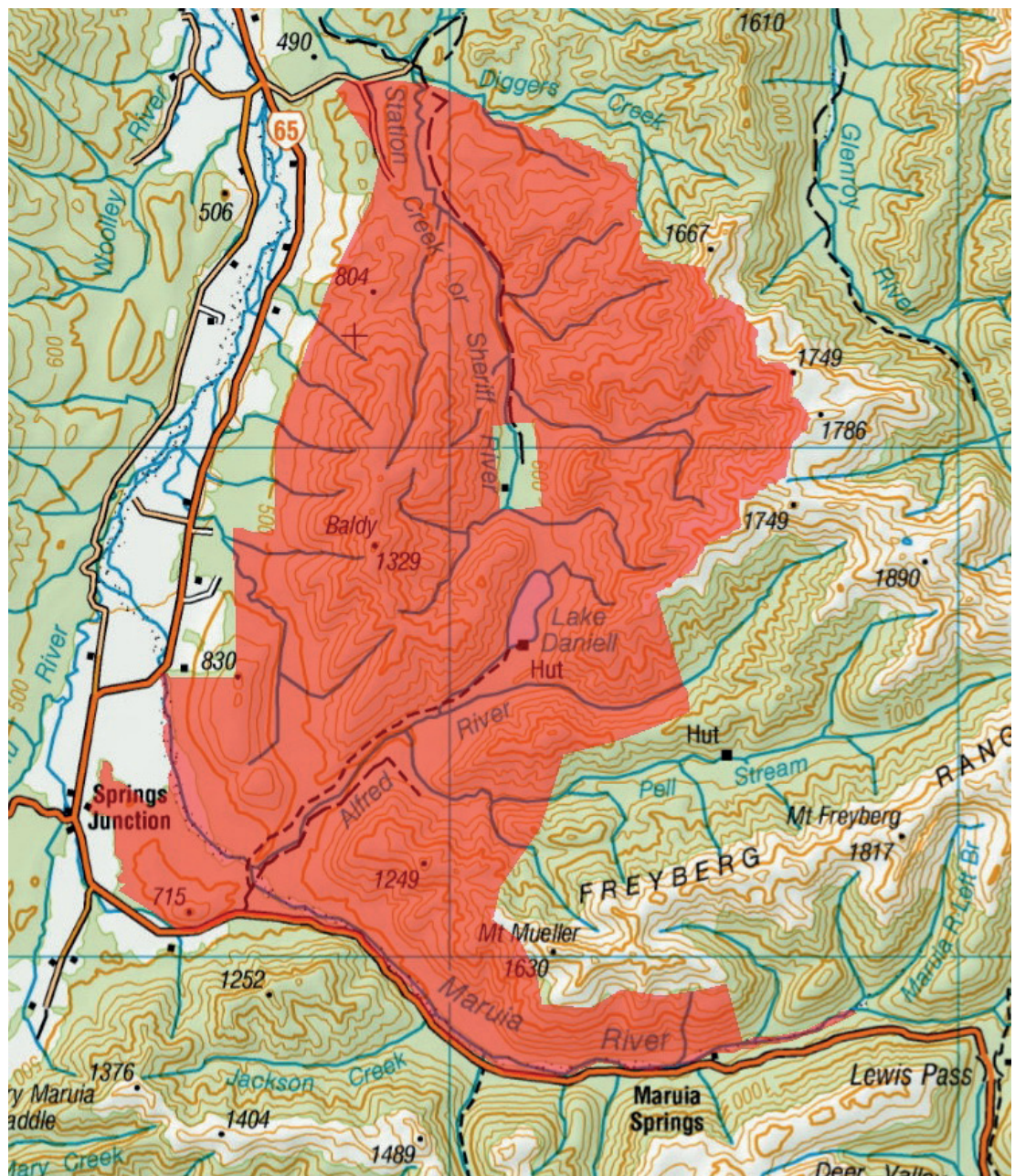

Figure 2.   Map showing the Te Maruia Waka Huia study site.

The ancient frost flats along the edge of the Maruia River are predominantly grassland interspersed with threatened *Cosproma wallii* and *Melicytus flexuosus*, small stands of kānuka (*Kunzea ericoides*), and regenerating beech which occurs in small stands close to the ecotonal edges.

Lake Daniell is surrounded by fertile terraces to the east, which are home to recovering populations of native bird species as a result of ongoing animal pest control programmes.[3] These rich terraces run south along the Alfred River and Pell Stream, where they are a haven for native species, particularly passerine birds such as the South Island robin (*Petroica australis*), but also kākā (*Nestor meridionalis*) and kākāriki (*Cyanoramphus* spp.), and the long-tailed bat (*Chalinolobus tuberculata*). Many of the bird populations in this area are closely connected to the supply of beech seed – for instance, kākāriki breeding increases in response to increased seed production (O'Donnell & Hoare 2012).

The Maruia Valley is protected from coastal influences by the Victoria Range and the Spenser Mountains, giving it an inland climate, with temperatures ranging from 30°C and above in the summer to as low as –10°C during the cold winters, and with an average rainfall of 2439 mm. Winter snows are common below the bush line and can remain on the valley floor for short periods of time. Stoats are quite at home underneath the snow, and weasels will burrow through the snow if the need arises (King & Powell 2007).

Populations of weasels, stoats, ship rats and mice occur in the Maruia Valley, and possums (*Trichosurus vulpecula*), ferrets and feral cats (*Felis catus*) are also found here. However, possums and ferrets are present at very low abundances,[4] and the prevalence of predation by feral cats on weasels is currently unknown in this area and so any comment on their effects on weasel populations would be purely speculative. Therefore, these species are not discussed.

State Highway 7 splits the frost flat ecotones between the Maruia River and the beech forests to the south, forming a key pathway for mustelid movement and providing an ideal spatial location for kill traps, which intercept animal pests as they move within their home range or pass through during juvenile dispersal whilst seeking to establish a home range.

A major mast seed event occurred in the Maruia Valley in autumn 2014, resulting in the production of 4800 red beech seeds/m², 460 silver beech seeds/m² and 13500 mountain beech seeds/m².[5] This led to a rodent irruption that not only placed native species at risk, but also resulted in increases in stoats and weasels, with the latter being caught for the first time since trapping began in the valley in 2011 and in unprecedented numbers for New Zealand.

The management response to the threat of increased predator numbers was an aerial application of the acute toxin 1080 in cereal pellet form at a toxicity of 0.15% (weight/weight), which was sown at 1 kg/ha over nearly 80000 ha of the Maruia Valley and surrounding region. The aim was to substantially reduce rodent abundances with an associated by-kill on stoats. However, for various reasons this was not as successful as planned, with large populations of rats and mice remaining following the treatment.

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[3] Native bird species are monitored annually in this area, including on the Lake Daniell terraces, by DOC through 5-minute bird counts. There is also a control area to the north of Lake Rappahannock that is used to measure non-treatment populations.

[4] The abundance of possums was determined to be extremely low in 2015, with a residual trap catch index of 0%, and only three ferrets have been caught to date, the identification of which was based on the jawbone due to the high level of decay.

[5] Beech seed data were collected from January through to June 2014 by the author and counted by researchers at the University of Canterbury, Christchurch.

3.2 Rodent tracking

Rodent abundance is reported as a rodent tracking index (RTI), which is expressed as a percentage of interference in tracking tunnels. This is an established, standardised and recognised method for obtaining a coarse index of relative abundance that was first described in 1977 (Gilles & Williams 2013). It can provide a baseline measure of abundance prior to the implementation of pest control, a comparative post-measure to gauge the success of an operation and, unlike trapping, has the advantage of being non-destructive to target and non-target species. The method is simplistic but labour intensive, involving the placement of inked cards in specially designed tunnels over a fine night and their removal for reading the following day. The reading of the cards requires a knowledge of small animal footprint registrations (see Fig. 3), but guides are available.
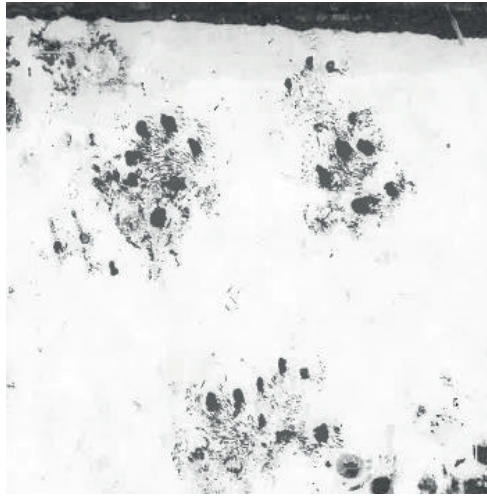

Figure 3.   Registration from a tracking tunnel ink card placed in the Lewis Pass in early 2015. This registration is likely to be a stoat (*Mustela erminea*).

Each line consists of ten tunnels baited with peanut butter at the ends (Fig. 4) that are spaced 50 m apart along randomly located transects which are 200 m from other lines. The selected lines traverse representative environments within the area of interest, with the number of lines required being dependent on the scale of the study (Gilles & Williams 2013).

In this study, ten tracking tunnel lines were used, and were considered representative of the area around the trapping infrastructure where the weasels were caught. Data were collected from November 2013 to November 2015 to obtain a picture of variations in rodent population abundances from pre-mast to post-mast. Tracking tunnels were run in the months February, May, August and November on a single fine night.

3.3 Trap catch

Raw trap catch data were collected every month from January to December 2015, with the exception of September, from the trapping network shown in Fig. A1.1 (Appendix 1).[6] The pest species caught, line name and trap number per check period were recorded. These data were then used to determine whether multiple species were caught in the same traps, any crossover in typical habitat use and home ranges of competitive species over time, and the relationship between each of these and prey abundances. Mapped data were analysed using ArcGIS 10.3.

Figure 4.   Tracking tunnel containing a pre-inked card.

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6   Note: The Pell Stream and Reid's Stream lines were operational until 2012, when they were shut down and replaced with Goodnature® A24 self-setting traps. Only the Lake Daniell Track and Alfred River lines were operational until January 2015, when the network was expanded to counter the rat irruption and the subsequent stoat increases. Although trapping began in 2011, only data from 2015 are used in this study because weasels had not been caught until then.

3.4 Spatial overlap of stoats and weasels

The spatial interactions between stoats and weasels were analysed by using GIS to map the individual catches of each species in the study area and considering these in terms of their home range, niche differentiation and habitat crossover.

By mapping catch data monthly to the respective trap and species caught, focused on weasel and stoat only, any pattern of distribution between each species could be easily identified. This mapping also allowed for identification of high catch areas, which provided information to implement strategic changes to the trapping network to better protect native species. To avoid clutter and allow ease of analysis, each month's catch is a separate shapefile. In order to portray overall catch on one map, where there is multiple catch on any given trap, the catch is recorded above or below the previous record to maintain clarity.

The spatial distribution of stoats and weasels was examined in greater detail along the Pell Stream line[7]. The line is situated on an open beech forest terrace with little understorey above grassed and open riparian terraces (Fig 5).

3.5 Trigger weight analysis

The mean trigger weight of a computer-generated random sample of 100 traps (see Fig. A2.1, Appendix 2) was calculated to test the functionality of DOC200 traps for catching weasels and the range of catchable weights. Trigger weights were determined by gradually adding weights to the plate to simulate an animal crossing them until they were tripped. The trap was reset and tested again to ensure a consistent trigger weight.

Figure 5.   Typical habitat at the southern end of the Pell Stream trap line showing the sparse vegetation cover and flat topography.

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[7]   There is no specific reason this line was selected. Any of the lines with multiple catch could be used for the same analysis.

It is currently unknown whether the weight range of weasels during mouse irruptions would be normally distributed or skewed towards the upper range of weights due to the abundance of resources. Furthermore, even if a normal distribution is assumed, the standard deviation cannot be determined without actual data on the captured weight range, making it impossible to test the percentage of trap catch within the trigger weight ranges. Therefore, a computer-generated random sampling model was used to determine the mean weight and its standard deviation based on the presumed trapped population dynamics for females. In this computer sampling, all potential weights within the known range were randomly sampled, with each weight having 10 chances of being selected over 100 computer-generated random samples and the top 10 then being used in each test. Computer modelling was then performed to determine the mean and standard deviation. The proportion of females that would not be captured by the most sensitive traps was then calculated by the Norm.Dist function in Excel, using the mean and standard deviation of the computer-modelled samples.

4. Results

4.1 Rodent tracking indices

RTIs for rats and mice over the period November 2013 to November 2015 are shown in Fig. 6. The tracking abundance of rats increased between February and August 2014, whereas mice remained scarce during this period, not exhibiting an increase until August 2014 and peaking in February 2015.
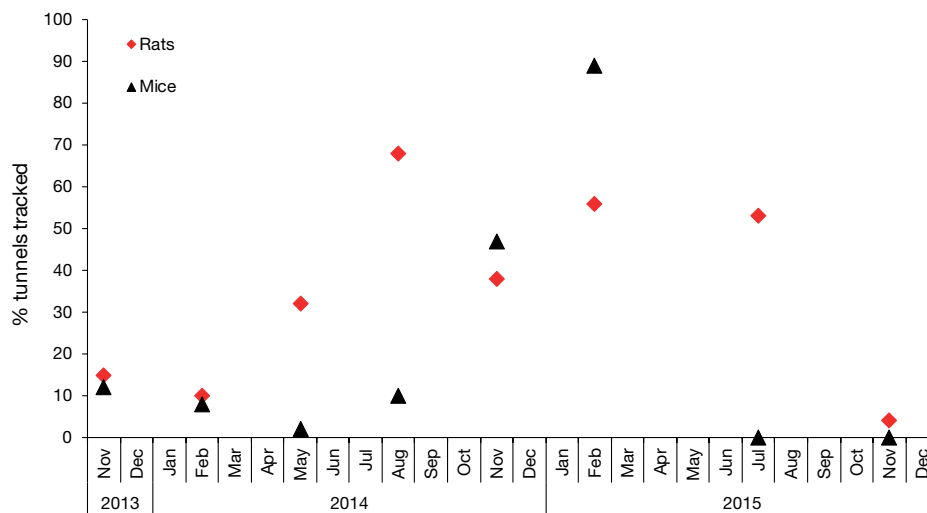

Figure 6.   Rodent tracking indices for rats (*Rattus rattus*) and mice (*Mus musculus*) in the Maruia Valley study area, November 2013 to December 2015.

4.2 Trap catch data

Trap catch data for weasels and stoats in the study area between late 2013 and 2015 are provided in Fig. 7, and maps of the distributions of weasel and stoat catches across the entire trap network in 2015 are provided in Fig A1.2 (Appendix 1).

No weasels were captured in the study area until early February 2015, which was almost 2 months after the mouse abundance reached high levels. Furthermore, comparison of the tracking index for mice and the trap catch of weasels (Fig. 8) shows that while mouse tracking rates increased in February, weasel numbers increased in April. A second peak in weasel abundance was also observed in July, at which time the mouse tracking rate had decreased to zero but rats were still tracking at a high abundance (see Fig. 6).

The stoat catch was correlated with rat abundance, increasing from November 2013 and then declining in February 2015.
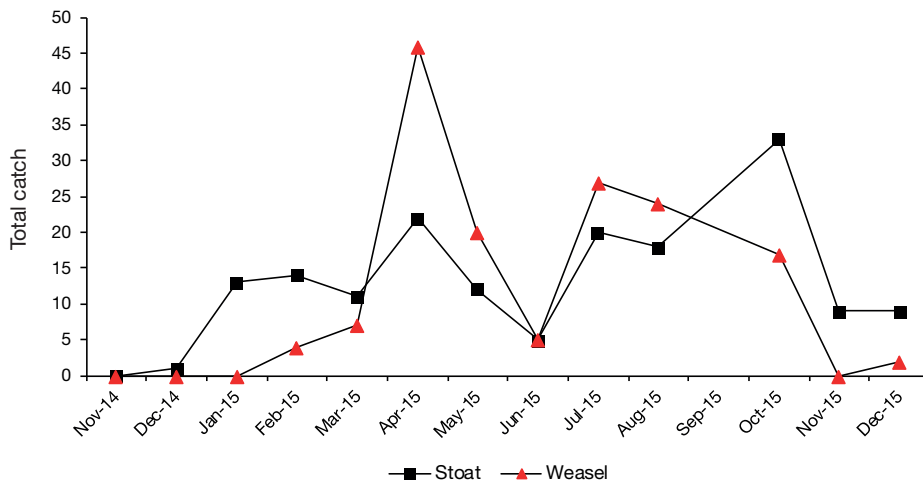

Figure 7. DOC200 trap catch data for weasels (*Mustela nivalis*) and stoats (*M. erminea*) in the Maruia Valley from November 2014 to May 2016. Note: No trap checks for weasels or stoats were undertaken in September, requiring the catch data to be apportioned over 2 months and potentially smoothing out the graph for October.
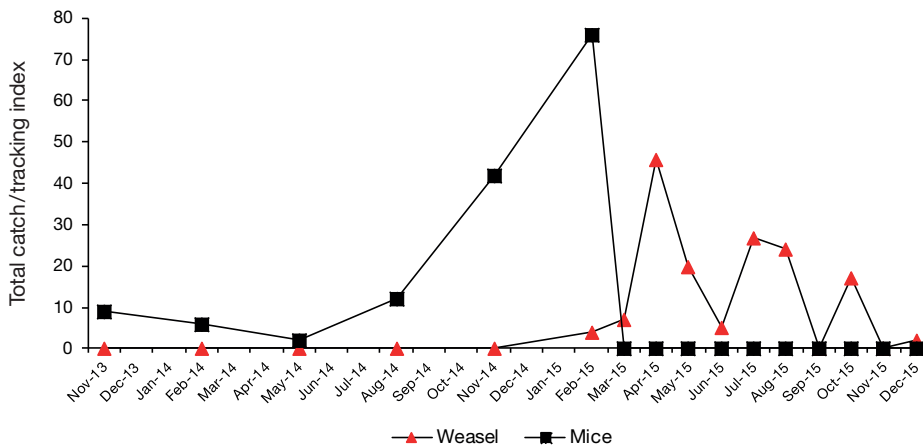

Figure 8. Combined trap catch of weasels (*Mustela nivalis*) and tracking indices of mice (*Mus musculus*), showing the timing of increased abundances of predators and prey in the Maruia Valley study area.

4.3 Spatial overlap of stoats and weasels

Weasels and stoats were caught in close proximity to each other, with 7.8% of the traps (n = 500) recording both species. There was no clear pattern in the order of capture, with stoats being caught after weasels and weasels being caught after stoats in almost equal proportions. Furthermore, the time interval between a stoat capture and a subsequent weasel capture was relatively evenly distributed around the mean catch time (Fig. 9).

The map provided in Fig. A1.2 (Appendix 1) shows that high stoat catches were punctuated by a few weasel catches in many areas, such as at the Sluice Box close to the bridge. By separating the catch data and mapping it for each monthly period, a pattern emerged of close proximity catch of both species, mirroring the pattern of overall catch where April, July and August recorded catch where both species were within the same area (Fig. 10).

Using the Pell Stream data for April 2015, the pattern of catch indicates home ranges crossing over in more than one occurrence. Figure 11 reviews a stoat capture on the Pell Stream line and
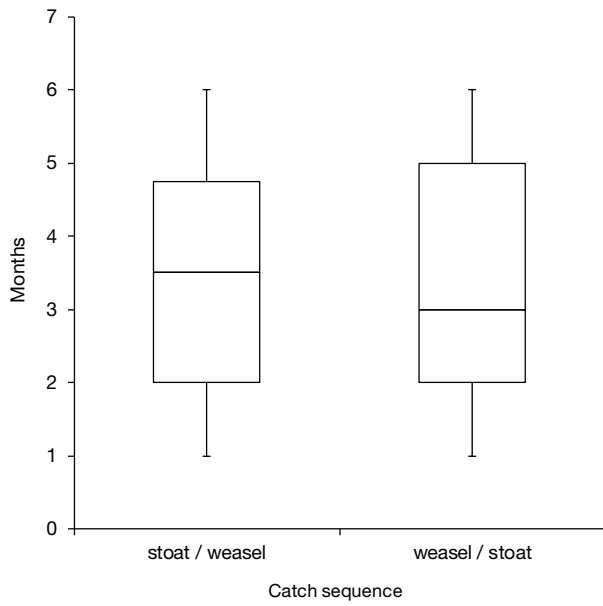
Figure 9. Comparison of the sequence of catches (stoat-weasel v. weasel-stoat) in DOC200 traps in the Maruia Valley, 2015.
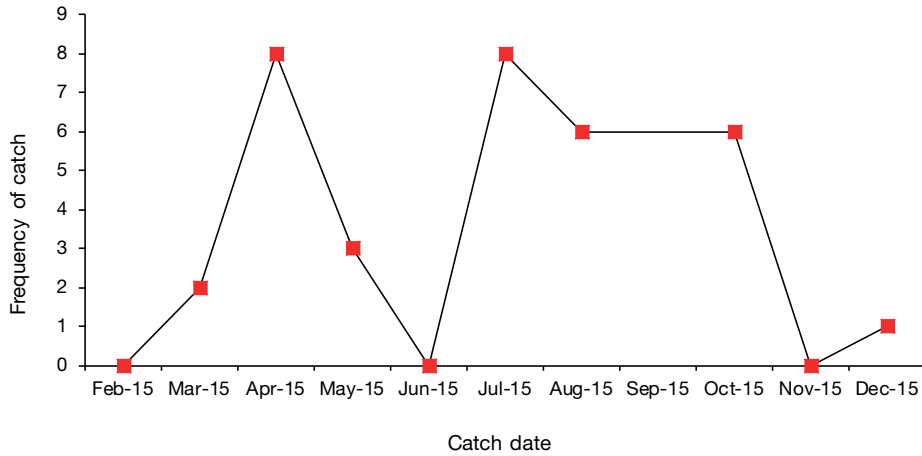

Figure 10. Number of occurrences of weasels (*Mustela nivalis*) and stoats (*M. erminea*) being captured in close proximity in the Maruia Valley during 2015.
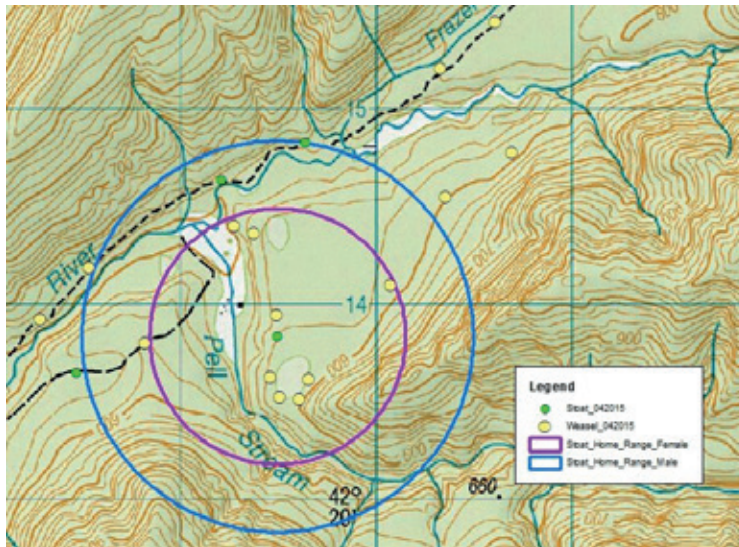

Figure 11. Mapped catches of weasels (*Mustela nivalis*) within the maximum home range of a male or female stoat (*M. erminea*) in the Pell Stream area, April 2015.

assumes this as the centre of the home range for both sexes at the upper limit of known ranges. Even if the edge of the circle was placed on the trap point and rotated, in any position weasels are still caught within the home range of a stoat.

Fewer weasels were caught in the northern parts of the Pell Stream line network, which had steeper topography and thicker vegetation than in the southern parts of the line, which were more open. Furthermore, no weasels were caught at the northernmost end of the terrace where the trap line descends back into alluvial and open terraces along the Alfred River, with some grassland habitats along the riparian edges.

The vast majority of weasels were also trapped either on or within close proximity to ecotonal edges (Fig. A1.2, Appendix 1), with weasels being caught in far superior numbers to stoats along ecotonal edges in two areas.
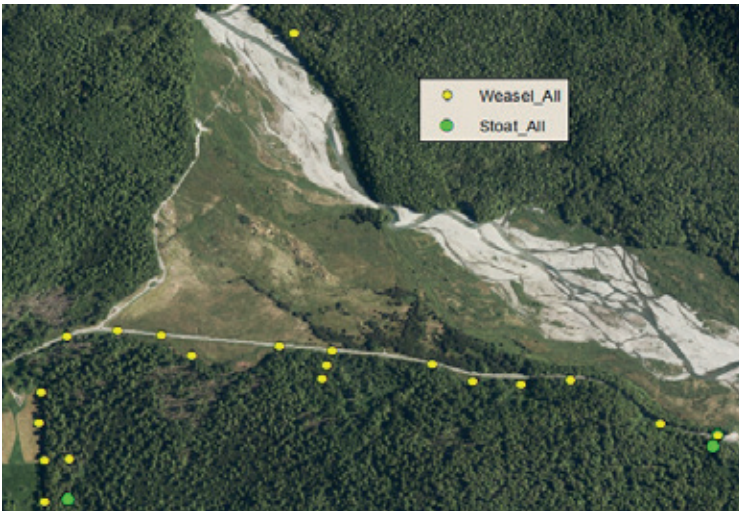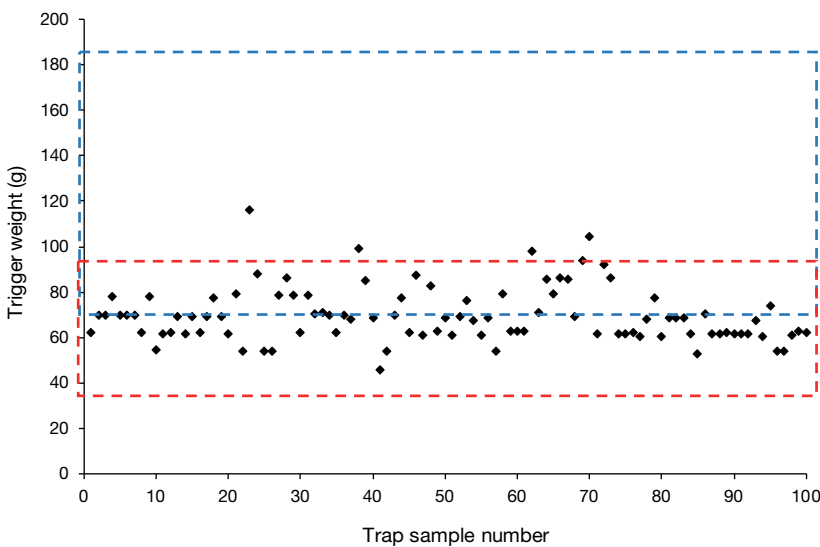

One of these areas was the Calf Paddock, where no stoats were detected across a wide section of the Lewis Pass line, which is interesting given the trap catch along this line averaged 3.2 rats/trap during 2015, with only 3 out of 86 traps not catching any rats. By overlaying the catches of weasels and stoats on an aerial photograph of the Calf Paddock (Fig. 12), it is clear that weasels were primarily caught in the expanse of grassland that occurs here. Similarly, weasels predominated the catch along the farmed edge of the Lockington line at the Calf Paddock (Fig. 12, lower left of image).

Figure 12. Mapped weasel (*Mustela nivalis*) and stoat (*M. erminea*) catches from around the Calf Paddock in 2015 overlaid onto an aerial photograph.

4.4 Trigger weight analysis

The mean trigger weight for a random sample of 100 traps was 70 g (range = 45.7–116 g) (see Table A2.1, Appendix 2). To determine the potential for catching weasels of both sexes, the trigger weights were graphed alongside the weight range of each sex (Fig. 13). This showed that only 2% of the tested traps would catch females ranging between 35 g and 54 g, and a further 6% of tested traps would not catch any females due to their heavier (>90 g) trigger weights.

Figure 13. Tested trigger weights for DOC200 traps in the Maruia Valley overlaid with the weight ranges for female (red) and male (blue) weasels (*Mustela nivalis*).

5. Discussion

5.1 Predator and prey abundances in response to mast seeding

Alongside the red beech masting, the observed heavy seeding of snow grass (*Chionochloa* spp.) combined with the high production of mountain beech seed in the Maruia Valley in autumn 2014 would have significantly increased the volume of food resources available to both mice and rats. It has been calculated that laboratory mice have a metabolisable energy (ME) requirement of 75 kJ ME/day (Subcommittee on Laboratory Animal Nutrition 1995). However, it would be safe to assume that this would be higher in a natural environment where they need to combat the weather, travel over larger distances for foraging and potentially evade predators. Beggs (1999) calculated that red beech seed provides up to 864 000 kJ/m² and silver beech seed provides up to 27 600 kJ/m².

Beech seed rain in the Maruia Valley started in January 2014 and continued until June 2014, and rat populations immediately responded to this, increasing in abundance between February and August 2014.[8] However, mice showed a later increase that more or less followed their longer breeding season during mast years (King 1983; Murphy 1992), exhibiting peak abundance in February 2015.

Bridgman (2012) suggested that rats dominate the landscape and potentially display intraguild dominance. However, 18.5% of the tunnels were visited by both species in a single night in November 2014, and this increased to 46.9% in February 2015. Therefore, it is possible that an abundance of food resources allowed mice and rats to coexist during this period.

It is apparent that the aerial 1080 application in October had no impact on mice, supporting the assertions of Fisher & Airey (2009) that mice can detect 1080 even when masked. As a result, mice increased to atypical abundances in the forest, as discussed by Choquenot & Ruscoe (2000) and Murphy (1992), providing the driver for a weasel incursion. Although the trap network expansion in early 2015 increased the likelihood that weasels would encounter traps, they were also caught in established trapping areas where they had not previously been recorded.

The first weasel was caught in early February 2015 and weasel numbers increased in April, which was almost 2 months after the mouse abundance reached high levels. While it is possible that weasels were present before 2015 but had been misidentified, a number of experienced staff checked the traps over the years, and they would have correctly identified any incident of a weasel being captured during this time. It is also possible that weasels entered the study area from surrounding country, being attracted to the readily available food source that was present. However, this is unlikely given the scale of the population increase. Therefore, it is most likely that this mismatch in timing was due to the slower reproductive cycle of predators (Brandt & Lambin 2007) and reflects the age at which young weasels are able to actively kill on their own (GISD 2008).

The second peak in weasel abundance that was observed in July is interesting given that the tracking of mice had decreased to zero at this time, whereas rats were still tracking at a high abundance (Fig. 5). Weasels are considered scavengers as well as hunters (King et al. 1996a) and so food resources in the form of trapped rats appear to have been sufficient for another litter to be produced – indeed, those servicing the traps reported the presence of scavenged carcasses of weasels and rats.

There was a period of time between February and October when the weasel trap catch was likely significantly higher than is usually experienced anywhere in New Zealand based on the studies of King et al. (1996b, 2001) and the general scarcity of weasels in New Zealand ecosystems (Bridgman 2012).

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[8] Note: A decline in rat abundance was observed in February 2015 in both the treatment and non-treatment areas and could not be explained by DOC ecologists; therefore, this is considered an anomaly.

The beech mast of 2014 occurred across the South Island of New Zealand, and many other areas also experienced abnormal weasel catches following aerial 1080 operations. For example, the Hawdon Valley experienced a radical increase in weasel catches over the 2015 season, which was potentially correlated with a mouse plague from December 2014. Similarly, the Cobb, Wangapeka and Fyfe Valleys (L. Marshall, pers. comm., DOC, March 2016), the Oparara Valley (G. Coleman, pers. comm., DOC, March 2016), and the Waitutu Forest (C. Bishop, pers. comm., DOC, March 2016) experienced increases in weasels following the application of 1080.

The stoat catch was correlated with rat abundance, increasing from November 2013 and then declining in February 2015. It should also be noted, however, that almost 300 DOC200 traps were installed in January and February 2015, and that twice as many trap checks were undertaken through February, which will have skewed the data.

5.2 Interactions between weasels and stoats

5.2.1 Overlap in distribution

Weasels and stoats were caught in close proximity to each other, indicating that interspecific competition for available resources was negligible or absent under conditions where there were significantly increased rodent population abundances. One good example of this could be seen along the Pell Stream line.

The weasel catch was lower in sections of the Pell Stream line network that lay further north, indicating that the change in topography and cover may have increased the energy requirements of weasels compared with flatter, more open country. However, no weasels were caught at the northernmost end of the terrace where the trap line descends back into alluvial and open terraces along the Alfred River, with some grassland habitats along the riparian edges.

The Pell Stream catch data showed that weasels, if not present beforehand, had established home ranges or at least ventured into areas where stoats have always been trapped previously. This indicates that these species were potentially coexisting in this area and also lends some support to the argument by Erlinge & Sandell (1988) that weasels are better at exploiting small rodents than stoats, negating the stoat's superiority in competitive interference.

The spatial pattern of catches along the Pell Stream line indicated that the home ranges of weasels and stoats overlapped on more than one occasion. The pattern of weasel catches also differed from that observed in the Hawdon Valley, Poulter Valley and South Branch of the Hurunui Valley by Lough (2006), as at least two weasels were captured outside the suggested 200–300 m from the river edge and the vast majority of trapped weasels were either on or within close proximity to ecotonal edges.

In the Calf Paddock, no stoats were detected across a wide section of the Lewis Pass line, despite this line averaging 3.2 rats/trap and only 3 out of 86 traps not catching any rats in 2015. Observation of the catches of weasels and stoats overlaid on an aerial photograph of the Calf Paddock showed that the expanse of grassland here favoured the hunting habits of weasels over stoats, which typically avoid open areas (Murphy & Dowding 1994). This also suggests that there may be niche differentiation between the two species, whereby weasels dominate open grasslands of prime mouse habitat that are likely devoid of high rat numbers due to their largely arboreal preference.

Similarly, weasels predominated the catch along the farmed edge of the Lockington line at the Calf Paddock. Although niche differentiation may also have occurred in this area, the two species were caught side by side in areas of grassland along the Lewis Pass line and in bush–pasture margins on local farmland. The grasslands along the highway vary in size but the Calf Paddock is by far the largest in area, providing scope for large mouse populations, which could allow weasels to have smaller home ranges and therefore lower energy expenditures. Radio tracking of both mustelid species in these areas would help determine their spatial movements and potential overlaps in their home ranges.

5.2.2 Scent marking

Examination of the entire catch data also allows the theory of scent marking to be theoretically tested. Scent marking provides environmentally persistent cues to other individuals and is a necessary component of the dynamics among predators in any ecosystem, particularly where visual or auditory cues prove difficult to detect (e.g. at night or underground) (Davies 2009) – although it has been suggested that naïve animals may not be receptive to scent cues (Shapira et al. 2012). Mustelids are able to expel musk from their anal sacs at will, and although this is usually only in small quantities, individuals that are severely frightened may expel the full contents, which is up to 100 mL for an adult male (King & Powell 2007). These secretions are considered to linger for several weeks as a territorial marker (Davies 2009).

Mustelids also have smaller glands on the skin of the body around the flanks, belly and on the cheeks that are used for body rubbing, which provides a threat signal in the face of an aggressive encounter (King & Powell 2007). In addition, Davies (2009) suggested that ventral glands are located in the ventral fur of stoats and weasels for scent marking objects using different secretions from those produced by the anal glands.

If mustelids can expel their full anal sac when frightened (King & Powell 2007) and this then lingers for several weeks (Davies 2009) then, in theory, weasels would avoid traps where stoats had previously been caught as a result of scent from both the anal and ventral glands, which would supposedly be left on the grill as the stoat pushed through the trap entrance. Supporting this, Erlinge & Sandell (1988) found that in cage trials, weasels were typically reluctant to enter traps that had been scented with stoat odours, either backing out or avoiding them completely. However, in the natural environment, there has been no evidence of captured stoats scent marking traps by secreting their full anal gland, and even when there has been a likelihood that some scent was present following a capture, weasels have been caught after stoats (E. Murphy, pers. comm., August 2016).

In the present study, 7.8% of the traps (n = 500) recorded both species, with many areas experiencing high stoat catches punctuated by a few weasel catches and one trap situated on the Pell Stream line catching a sequence of stoat-weasel-stoat-stoat in the middle of the line (see Fig. A1.2, Appendix 1). Furthermore, these captures followed a similar pattern to that observed for the overall catch. Therefore, there was no evidence that weasels exhibited avoidance behaviours when stoats had been previously trapped.

In July 2015, rat abundance was still high, offering a potential food source for both species combined with potentially cached winter food reserves. By contrast, in August, no catches were made along the highway, with the predominant volume of twin catches occurring in the forest away from grassland habitats. Both species were again caught along the highway at the easternmost end of the trap line in October, however.

So do these twin catches indicate coexistence, increased weasel ranges as a result of reduced food resources or juveniles seeking their own home territories during dispersal? Knowledge of the sex and approximate age of the individuals caught may have helped answer this question given the larger home range of males compared with females (King et al. 2001). However, it can be assumed that 114 of the 152 weasels that were caught in 2015 were likely to have been males based on the 75% trap catch quota mentioned by King & Powell (2007). Again, many of these unanswered questions require further study to increase knowledge of the dynamics between the two species.

5.3 Trigger weight of traps

It was found that at the factory setting of 80 g, only the very upper weight range of female weasels would have been caught by the DOC200 traps.

The computer-generated random sampling model arrived at a mean weight of 60 ± 16 g for a normally distributed population of females, which is only 1 g above the average of 59 g noted by Corbet & Harris (1991). Since there is no way of determining the population size of weasels throughout the research period, the percentage of the population that was caught is unknown. However, trigger weight analysis determined that 18% of female weasels would not be captured if they encounter traps and only 35% of females would be caught by the 2% of traps that could capture animals weighing up to 54 g, allowing the remaining females and those which only encounter the top 6% of tested traps within their home range to remain within the breeding population and breed at least once and potentially twice.

This untouched breeding population is concerning in a land that is incapable of dealing with pest incursions. However, weasels ceased to be caught anywhere in the network from February 2016 (data not shown), indicating that they had either become locally extinct or population abundance had returned to very low levels.

6. Conclusions

In autumn 2014, a major beech seed mast event in the Maruia Valley provided a rich food source for rodent populations, increasing their numbers and, in turn, stoat numbers. Furthermore, 4 years following the inception of a trapping programme, weasels were caught for the first time and in numbers that were atypical for New Zealand.

The addition of another carnivore in the rich and diverse beech forests of the Maruia Valley would increase the impacts on native species. The finding that stoats and weasels seemingly coexisted for short periods of time as a result of the abundance of food resources defies conventional intraguild dynamics and previously known behaviours.

Although this research provided evidence that helps to answer some questions, it leaves many more unanswered. Therefore, to close these knowledge gaps and give pest management practitioners further insight into weasel dynamics, additional research efforts are required in several areas, as outlined below. A better understanding of pest dynamics in beech forests is critical to slowing the loss of native species and improving our tenuous grip on the continued existence of at risk species.

7. Recommendations

This research had several limitations, leaving several questions unanswered. In particular, the abnormally high weasel population abundance was recognised too late in the study to allow sufficient information to be gathered to improve our knowledge of weasel population dynamics in New Zealand.

In the event that another weasel population increase occurs that is identified sufficiently early, I recommend that the following research is considered to help close the gaps identified above:

- Investigate the potential for live capture and placing transmitters on individual weasels and stoats. For example, Sirtrack® offers a wide variety of transmitters that are capable of tracking the entire movements of animals. This will allow cross-species ranges and behaviours, such as niche differentiation, to be examined more closely.

- Shorten the trap check frequencies to allow the catches to be sexed and weighed prior to decay or scavenging. This will facilitate GIS analysis and provide carcasses for gut content analysis (although this can be performed regardless of the state of decomposition).
- Establish tracking tunnel lines in grassland habitats as well as forest and forest margins during beech mast events to ascertain variations in mouse abundances across a range of habitats and to detect rats in these habitats.
- Alter the frequency of tracking tunnel measurement to correspond with trap checks to better gauge fluctuations in rodent abundances. This will require increased people resources.

8. Acknowledgements

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Appendix 1

Weasel (*Mustela nivalis*) and stoat (*M. erminea*) catches in the Maruia Valley
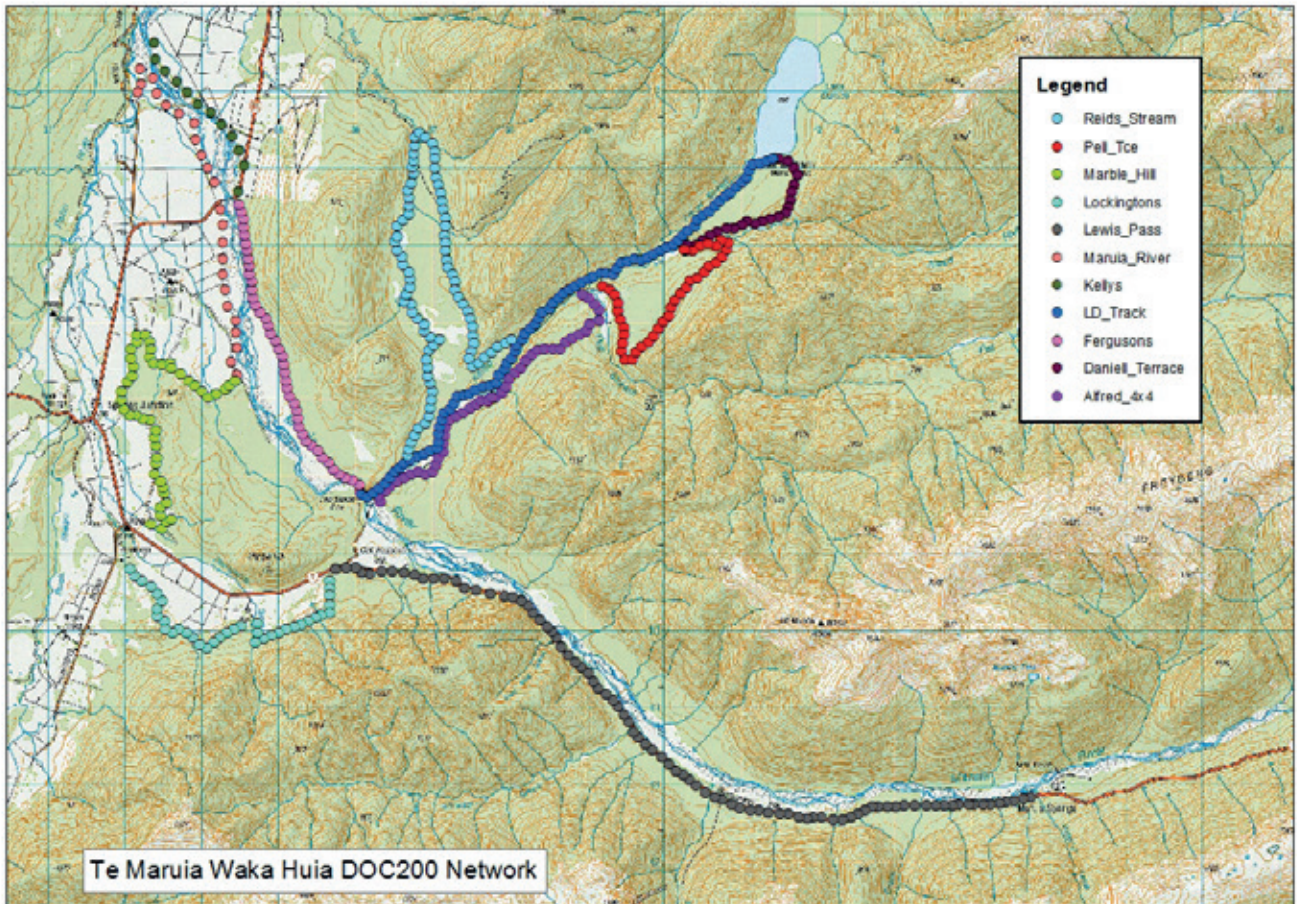

Figure A1.1.   Map of the DOC200 kill trap infrastructure in the core Te Maruia Waka Huia 1.1 ecosystem management unit (EMU) site with associated line names.
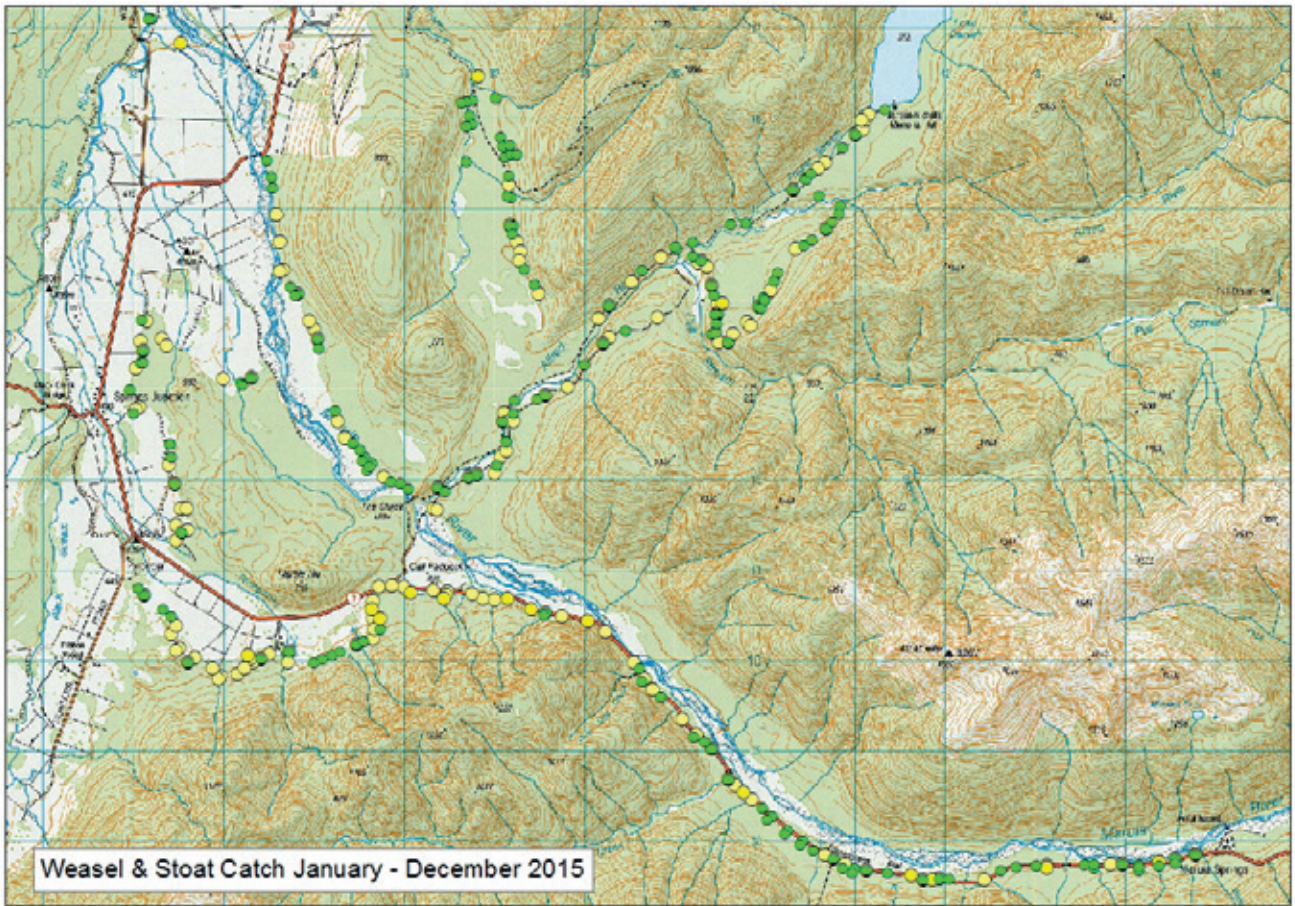
Figure A1.2.   Map of the combined catches of weasels (yellow) and stoats (green), providing a visual overview of potential sites of coexistence as well as high catch 'clusters'.

Appendix 2

Trigger weight analysis

Table A2.1. Trigger weights of the random sample of traps shown in Fig. A2.1.

Trigger Weight Analysis							

Trap ID	Weight	Trap ID	Weight	Trap ID	Weight	Summary statistics	
R-1	62.1	P-4	62.5	SH70	54	Mean	70.46875
R-8	70	P-5	68.4	SH73	60.8	Standard Error	1.810431
R-9	70	P-9	60.8	SH84	62.6	Mode	70
R-13	78	P-12	69.1				
R-19	70	P-13	76			Minimum	45.7
R-24	70	P-15	67.4			Q1	61.975
R-31	70	P-16	61.2			Median (Q2)	69.8
R-34	61.9	P-18	68.7			Q3	78
R-35	78	P-19	54.2			Maximum	116
R-37	54.4	P-27	79.3			Range = Max - Min	70.3
R-40	61.7	P-31	62.5				
R-55	61.9	P-35	62.8			IQR = Q3 - Q1	16.025
R-68	69	T-5	62.7			1.5 x IQR	24.0375
R-70	61.5	T-6	98			Q1 - 1.5 x IQR	37.9375
R-71	69.2	T-7	71.2			Q3 + 1.5 x IQR	102.0375
R-73	62.1	T-10	85.9				
R-74	69.2	T-24	79.1			Standard Deviation	12.54303
R-76	77.6	F-9	86.3			Sample Variance	157.3277
R-82	69.2	F-10	85.8			Kurtosis	2.775876
LD-4	61.5	F-14	69.5			Skewness	1.097254
LD-17	79.4	F-18	93.7				
LD-18	54	F-19	104.3				
LD-25	116	F-21	61.6				
LD-28	88.1	F-26	92				
LD-29	54	F-35	86.1				
LD-30	54.2	F-36	61.4				
LD-67	78.6	F-38	61.6				
LD-70	86.3	E-3	62.3				
LD-71	78.5	E-5	60.2				
LD-74	62	E-18	68.2				
LD-81	78.4	E-28	77.2				
M-12	70.3	E-30	60.3				
M-16	70.8	E-33	68.6				
M-21	70	E-36	68.7				
M-23	62.3	E-37	68.6				
M-35	70	SH3	61.3				
M-36	68.3	SH4	52.8				
M-39	99.2	SH5	70.2				
M-42	85.1	SH6	61.5				
M-44	68.6	SH33	61.8				
A-37	45.7	SH40	61.9				
A-44	54.1	SH41	61.5				
A-48	69.6	SH48	61.7				
A-49	77.6	SH49	61.7				
A-51	62.4	SH52	67.5				
A-52	87.7	SH60	60.5				
A-53	61.1	SH62	73.9				
A-69	82.9	SH68	54				