Impacts of mice and hedgehogs on native forest invertebrates: a pilot study

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ABSTRACT

At Boundary Stream Mainland Island (BSMI), Hawkes Bay, New Zealand, both mice (*Mus musculus*) and hedgehogs (*Erinaceus europaeus*) are found at unknown densities and are subject to limited control. Research elsewhere suggests that both species may have a significant impact as predators of native invertebrates. This report proposes an experimental study design for assessing their impacts. Three experimental treatments are recommended: both mice and hedgehogs excluded from study plots; mice present, but hedgehogs excluded; and both pest species with full access. The response variables should be the abundances of invertebrates commonly eaten by mice and hedgehogs: lepidopteran larvae, carabid beetles, spiders, millipedes and weta. As there is high spatial and temporal variation in the abundances of invertebrate groups, a large number of experimental replicates would be required. Therefore, the experiment should be limited to one habitat type at BSMI, although there is potential for including a variety of habitat types by involving other mainland reserves in the experiment. Similar exclosures should be constructed across all treatments to standardise localised environmental effects. A brief trial of a suggested exclosure design showed that reinvasion of mice, probably from overhanging vegetation, can occur following their removal. Regular trapping within exclosures should, therefore, be maintained. We suggest appropriate methods for monitoring abundances of a range of invertebrate taxa. If this combined approach is constrained by costs, only pitfall traps or refugia should be used. Given the likelihood of widespread conservation management benefits, there is a clear and urgent need for this research. Maximising replication should be a priority, even at the cost of forgoing one treatment level.

Keywords: experimental design, invertebrate, mouse, *Mus musculus*, hedgehog, *Erinaceus europaeus*, forest

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1. Introduction

Boundary Stream Mainland Island (BSMI) is an intensively managed area of native forest and bush in eastern Hawkes Bay, New Zealand, covering 802 ha of the south-eastern flanks of the Maungaharuru Range. It is made up of 702 ha of the Boundary Stream Scenic Reserve and 100 ha of private land, and extends from c. 300 m to 1000 m above sea level. This altitudinal range, combined with the complex topography of the area, supports a matrix of at least 12 types of vegetation dominated by broadleaf (*Griselinea littoralis*)/tawa (*Beilschmiedia tawa*)/podocarp forest, kamahi (*Weinmannia racemosa*)/rewarewa (*Knightia excelsa*)/kanuka (*Kunzea ericoides*) forest, and mixed beech (*Nothofagus* spp.) forest.

Ecological restoration at BSMI is based on the control of multiple introduced mammalian pest species. It began with an aerial application of 1080 poison in 1995, which was primarily aimed at brushtail possums (*Trichosurus vulpecula*). Residual trap catch rates of possums have been maintained below the target 5% ever since (DOC 2004a). Rodent control began in 1996, using brodifacoum bait applied in bait stations that were set in a grid of 150 × 150 m, with a perimeter ring of stations at 100-m spacing. This spacing was designed to be effective against possums and rats (both *Rattus rattus* and *R. norvegicus* are present; the former are more commonly trapped). The control regime appears to be effective against rats, as rates of detection in tracking tunnels have been consistently low (< 5%) in treatment areas. These low rates were maintained following the replacement of brodifacoum with Pindone in December 2000. In monitored non-treatment areas outside the reserve, rat index measures are generally an order of magnitude higher than at BSMI (DOC 2004a).

Mustelids are controlled at BSMI by kill-trapping with Fenn traps. Trap lines run through the reserve, and there is intensive perimeter trapping as well as a 1–2-km-wide buffer zone outside the reserve in which traps are also deployed. Mustelid activity is monitored in the reserve using tracking tunnels. Over the past 8 years of monitoring, some general trends have emerged: most ferrets (*Mustela furo*), stoats (*M. erminea*) and weasels (*M. nivalis*) are trapped at the perimeter of the reserve, and there has been a marked decrease in the numbers of both stoats and weasels trapped within the reserve. Thus, whilst some captures (mainly of stoats) continue to be made within the reserve interior, tracking indices suggest a general reduction in mustelid activity within the reserve subsequent to intensive management (DOC 2004a).

Other introduced small mammals, such as hedgehogs (*Erinaceus europaeus*) and mice (*Mus musculus*), are typically considered of secondary importance in many critical conservation management situations where possums, rats, mustelids and

feral cats (*Felis catus*) are involved. This is generally for one of four reasons: because management resources are limited; the species listed in the latter group are more likely to have greater direct impacts on endangered vertebrate fauna, and their control is, therefore, given priority; potential threats have been poorly understood (in the case of hedgehogs); or control on a large scale is logistically very difficult (mice).

At BSMI, hedgehogs are not currently targeted, although records are kept of the large numbers trapped as by-catch in the mustelid control programme, and their habitat use and diet within the reserve has been studied (Berry 1999a). Mice are also not specifically targeted; however, the poisoning programme aimed at rats and possums is likely to have an impact on mouse populations. Mouse abundance/activity is monitored using tracking tunnel indices. These indices are generally an order of magnitude greater than those of rats in rodent control areas of BSMI, and are at similar levels to areas outside the treatment area, which suggests that only limited control of mice has been achieved within the reserve. A possible explanation for this is that bait station spacing is inappropriate for effective mouse control: tracking rates for mice increased with distance of tunnels from bait stations, whereas there was no difference in rat tracking rates (DOC 2003); a similar relationship was found at Rotoiti by Hamilton et al. (2003). Index measures may also be affected by inverse relationships between mouse and rat activity (Innes et al. 1995; Brown et al. 1996; Murphy et al. 1999). It is, therefore, impossible to determine whether the recorded mouse tracking indices within the reserve are due to numerical or behavioural effects. However, a high level of mouse activity or density is cause for concern in the management of a conservation reserve.

Hedgehogs are primarily insectivorous and invertebrates also constitute a large proportion of mouse diets (Jones & Sanders 2005; Ruscoe & Murphy 2005). Consequently, concerns about the impacts of these two species on native invertebrates within forest ecosystems have been expressed in project reports from BSMI and other 'flagship' projects, such as the Rotoiti Nature Recovery Project (Watts 2001). A Department of Conservation (DOC)-led workshop in June 2003 concluded that the question of whether to control mice to protect invertebrates in intensively managed areas was a 'most urgent research need' (C. Gillies, DOC, unpubl. minutes).

Consequently, a pilot/feasibility study was carried out to address the primary question 'In the near absence of rats, possums and mustelids in forest ecosystems, what is the nature and magnitude of response of a range of ecologically significant invertebrates to the control of mice and/or hedgehogs to low levels?'. This report describes this study and suggests an experimental design for investigating the impacts of mice and hedgehogs on native forest invertebrates.

2. Objectives

This report has three main objectives:

- To identify a suitable range of invertebrate taxa for inclusion in any monitoring exercise or experimental manipulation to investigate the effects of hedgehog and/or mouse control.
- To propose a robust experimental design that has sufficient statistical power to adequately examine the ecological relationships between the focal invertebrate taxa and hedgehogs and/or mice. This includes an assessment of issues of stratification within and between habitat types within BSMI and of the potential for using other suitably managed sites.
- To propose practical methods for achieving the proposed experimental treatments and for monitoring responses of invertebrate taxa.

Each of these is dealt with in turn in the following sections.

3. Potential offtake of invertebrates by hedgehogs and mice

In this section, we review previous research to identify the potential effects of mice and hedgehogs on invertebrates at BSMI. Because the total offtake by a pest population is a product of the local density of the pest species and individuals' diets, we also review information about each species' density, distribution and diet, primarily at BSMI, but also at other comparable sites.

3.1 MICE

3.1.1 Diet

Introduction

There is no information available about mouse diet at BSMI. Consequently, we analysed the gut contents of a sample of kill-trapped animals to determine the invertebrate component of mouse diet. Information on pest species' diets will facilitate the identification of invertebrate taxa to be monitored in an experimental test of their impacts.

Methods

Mice were kill-trapped for 10 nights on three 0.5-ha blocks of mixed beech/tawa/podocarp habitat near to the Tumanako Loop Track. Each block contained 49 trap stations arranged in a 7 × 7 grid at 10-m spacing. Stations consisted of two mouse snap-traps enclosed in a tracking tunnel that was pinned down to prevent

interference. Traps were baited with peanut butter and checked daily between 21 February and 3 March 2005. A total of 66 mice were trapped.

Carcasses were frozen whole for up to 1 month before processing. On thawing, guts were removed and stored in alcohol prior to their contents being examined. Four carcasses were unsuitable for examination. Food items were identified using a reference collection of locally trapped invertebrates and the photographic guidelines in Watts (2001). These were then classified into broad taxonomic groups and summarised by the frequency of food types in the total number of guts examined (frequency of occurrence method).

Results and discussion

Two-thirds of the mouse guts examined contained lepidopteran larvae, and spider remains were found in just under half of the samples (Table 1). Remains of the larvae of the tortricid moth *Cryptaspasma querula*, a species commonly associated with tawa seed (Beveridge 1964), were recorded in 31% of guts sampled. Plant material (mostly unidentifiable matrix) occurred in 37% of guts, and beetle, snail and weta remains were also commonly detected (Table 1).

The main findings of a range of other studies of mouse diet are summarised in Table 2. In spite of variation in the classification and degree of resolution of food types, a number of common themes emerge, which support our findings outlined above. There is often marked temporal variation in diet, reflecting seasonal patterns in the availability of preferred foods. Plant matter, especially seeds, is commonly eaten, and a large proportion of mouse diet is made up of invertebrate foods, especially during summer. Lepidopteran larvae are eaten in large numbers in most habitats. A suite of studies based in the Orongorongo Valley examined the relationship between beech mast events, invertebrate abundances and mouse abundance. Both litter-feeding and arboreal larvae (which pupate on the ground) were eaten (Dugdale 1996), with the former predominating in hard beech forest after beech seeding and the latter in podocarp/hardwood forest (Alley et al. 2001). Fitzgerald et al. (1996) found a strong correlation between mouse numbers and numbers of the larvae of a species of moth emerging in the previous summer. Male beech flowers provide both shelter and food for larvae in abundant years, which leads to the question of whether beech seed

TABLE 1. PERCENTAGE OCCURRENCE OF FOOD GROUPS IDENTIFIED IN 62 MOUSE (*Mus musculus*) GUTS OBTAINED FROM ANIMALS TRAPPED IN BOUNDARY STREAM MAINLAND ISLAND IN FEBRUARY–MARCH 2005.

FOOD TYPE	PERCENTAGE OCCURRENCE	95% CONFIDENCE INTERVAL
Lepidopteran larvae	66	53–78
Aranae (spider)	47	33–60
Plant	37	25–51
Coleoptera	27	16–41
Mollusca (snails)	23	13–35
Weta	16	8–28
Coleopteran larvae	8	3–18
Diptera	6	2–16
Gut empty	13	6–24

or the availability of invertebrate foods is the main driver of mouse population eruptions following heavy beech flowering. A recent reanalysis of data by Ruscoe et al. (2005) suggests that seed availability drives these population changes.

Spiders, beetles and, occasionally, weta make up significant proportions of mouse diets in New Zealand (Miller & Miller 1995; Fitzgerald et al. 1996; Wilson et al. 2005). Some spiders commonly eaten by mice were more abundant after beech masting in the Orongorongo Valley (Alley et al. 2001). Miller & Webb (2001) noted that female mice consumed more spiders when reproductively active. Wilson et al. (2005) described an inverse relationship between captures of ground weta (*Hemiandrus* spp.) and mice, and suggested that predation by mice may limit the local abundance of weta.

Mice may select invertebrate prey on the basis of size. Dugdale (1996) noted that caterpillar remains identified in mouse stomachs were all of species of body length > 10 mm, and Craddock (1997) found that more invertebrates in the size range 3–12 mm were eaten by mice than those outside these limits. Preferential predation by mice on larger individuals may have led to a reduction in mean body size of two weevil species on subantarctic Marion Island (Chown & Smith 1993).

High-density mouse populations may have large direct impacts on ecosystem function. Smith et al. (2002) estimated that mice consumed 13% of available adult weevil biomass daily on Marion Island, and van Aarde et al. (2004) noted that estimates of total daily offtake of invetebrates ranged from 0.7% to 2.9% of the standing crop. Evidence presented by Marris (2000) suggests that mice have had a major impact on the abundance and diversity of invertebrates, particularly beetles, on Antipodes Island, when compared with nearby, mouse-free Bollons Island. Such impacts may equate to direct competition with native insectivores

TABLE 2. DETAILS OF OTHER STUDIES OF MOUSE (*Mus musculus*) DIET IN NEW ZEALAND.

HABITAT TYPE	FREQUENCY OF OCCURRENCE									SOURCE
	ARTHROPODS		LEPIDOPTERA		BEETLE			SPIDER	WETA	
	ALL	ADULT	LARVAE	PUPAE	ALL	ADULT	LARVAE			
Grassland	62	–	82	–	–	–	–	9	7	Pickard 1984
Mature pine forest	–	83	79	15	–	–	–	–	–	Badan 1986
Young pine forest	–	80	91	24	–	–	–	–	–	Badan 1986
Kauri forest	–	90	27	0	–	–	–	–	–	Badan 1986
Hard beech/podocarp	94	–	50	–	–	12	15	45	17	Fitzgerald et al. 1996
Taraire/tawa forest	12–16*	–	7–9*	–	0.1*	–	–	4*	0.1*	Craddock 1997
Coastal dunes	90	–	67	–	65†	–	–	59	12	Miller & Webb 2001
Beech forest	90	–	73	–	–	67	–	67	13	Watts 2001
Rewarewa + pine/totara forest	93	–	43	–	–	12	2.5	40	8	Unpubl. data‡
Alpine tussock + beech forest	97	–	22	–	–	–	–	34	36	Wilson et al. 2005

* % gut volume.

† Mostly larvae.

‡ C. Ochoa, R. Schnitzler & T. Markwell, Victoria University of Wellington.

or may affect nutrient recycling given the ecological niche occupied by some invertebrate groups. Impacts may also be inferred following recovery of native species after pest eradication. On Mana Island, captures of Cook Strait giant weta (*Deinacrida rugosa*) increased after mice were removed (Newman 1994). As well as direct predation effects, an abundant mouse population may support higher numbers of predators, such as stoats, which also consume invertebrates in considerable numbers.

There have been few studies designed a priori to investigate the impacts of mice on invertebrate communities. van Aarde et al. (2004) compared changes in invertebrate biomass and abundance in five mouse-proof exclosures with those in open plots over 5 years on Marion Island. Temporal variation was similarly large in all plots and generally dwarfed any treatment differences, although the positive effects of exclosures on the biomass of lepidopteran larvae were only marginally non-significant. The authors' conclusion that their experiment had low power should be noted.

3.1.2 Density and distribution

Introduction

There has been no attempt to estimate the absolute density of any rodent species at BSMI since rodent control was instigated in 1996. Instead, the effectiveness of the rodent control measures has been inferred from relative differences in the rates of visits to tracking tunnels by rodent species in treatment and non-treatment areas, and in different habitat types within these areas.

Although indices such as rates of visits to tracking tunnels may be appropriate for indicating very large differences in rodent activity or density (e.g. mouse tracking tunnel rates are generally an order of magnitude greater than those of rats in rodent control areas of BSMI), it is of concern that inferences with regard to absolute 'numbers' or 'densities' of rodents are being made based on tunnel tracking rates. Since tracking rates reflect an interaction between activity and density, changes in the index cannot be used to infer changes in either of these independently (Sarrazin & Bider 1973). In a comparison between estimates of absolute density (based on robust mark-recapture methods) and a range of commonly used indices, Ruscoe et al. (2001) found no relationship between tunnel tracking rate and mouse density. It is of further concern that relatively small differences in tracking rates between areas are reported as real differences in activity or density without appropriate statistical tests being performed or even confidence intervals estimated on these rates.

Results and discussion

Trapping rates have been shown to be linearly related to the absolute density of mice (Ruscoe et al. 2001). In our diet study (section 3.1.1), we recorded a mean ± SEM capture rate of 2.38 ± 0.20 captures per 100 corrected trap-nights (C/100 CTN) (Nelson & Clark 1973). This capture rate is within the range reported by Wilson et al. (2005) (0.0–3.4; mean = 1.55 C/100 CTN) for mice in beech forest at the same time of year. Capture rates in a range of North Island forest types were generally below 5 C/100 CTN in February (King et al. 1996). Values in this range are considered to represent relatively low population densities, given that

capture rates can reach over 70 C/100 CTN (reviewed by Murphy & Pickard 1990; Ruscoe & Murphy 2005).

This emphasis on capture rates as indices of density reflects the fact that absolute density is rarely estimated. The few published estimates of mouse population density in New Zealand habitats vary greatly. In mixed beech and broadleaf habitat in the Orongorongo Valley, Fitzgerald et al. (1981) recorded densities ranging from 3.3 mice/ha in August to 0.55 mice/ha in February. In dune habitat near Dunedin, densities ranged from 12–14 mice/ha in summer to 22–24 mice/ha in autumn–winter (Miller 1999), whereas densities of over 50 mice/ha have been recorded following heavy seedfall in beech and rimu (*Dacrydium cupressinum*) forest habitat (Ruscoe et al. 2001, 2004).

Both trap-rate indices and estimates of density follow fairly predictable patterns in non-masting habitat types, with peaks recorded in late-summer–autumn and declining through winter to spring–summer minima. Following mast events, mouse densities can increase rapidly over a short period during autumn and winter.

3.2 HEDGEHOGS

3.2.1 Diet

Berry (1999a,b) examined the contents of 12 hedgehog stomachs and 141 droppings obtained from BSMI during an undefined period. The most frequently occurring food types were pill millipedes *Procyliosoma tuberculata* (75% of scats; 80% of guts), carabid beetles (45%; 67%), spiders (57%; 75%), other beetles (50%; 50%), and weta (22%; 25%).

Although there have been no other published studies of hedgehog diet in comparable forest habitat in either New Zealand or Europe, some general dietary trends for this species are apparent. These indicate a predominantly insectivorous habit, but with opportunistic use of other food types where available (Reeve 1994; Jones & Sanders 2005). Whilst there is likely to be marked spatial and temporal variation in diet due to variations in the availabilities of different foods, hedgehogs generally feed on a range of invertebrate taxa, with a relatively small number of these making up the majority of the diet (Wroot 1984). Other vertebrate sources, such as lizards, birds' eggs and chicks, and carrion are also eaten where available (Reeve 1994; Jones & Sanders 2005).

Quantitative studies of hedgehog diet report coleopterans to be the most frequently eaten food type (e.g. Yalden 1976; Grosshans 1983; Wroot 1984; Jones et al. 2005) and the dietary component that provides the majority of energy intake (Reeve 1994). Carabid and scarabaeid beetles are generally most commonly eaten (Yalden 1976; Grosshans 1983). Brockie (1959) found beetle remains in 37% of samples from a range of New Zealand habitat types. Campbell (1973) noted the importance of grass grubs and 'unknown coleopterans' in the diet of hedgehogs in pasture habitat in Canterbury, New Zealand. Both Brockie (1959) and Campbell (1973) recorded large numbers of Lepidoptera, especially the larvae, in hedgehog diets in New Zealand: Campbell (1973) recorded larvae in 65% of stomachs and 46% of droppings. Similar frequencies of occurrence have been noted in Europe (Yalden 1976; Grosshans 1983; Wroot 1984). The

importance of soft-bodied prey, such as larvae and earthworms, is likely to be underestimated in many studies due to the difficulties inherent in identification of often very masticated remains in the gut or faecal matrix. The occurrence of very large numbers of a particular prey in some guts suggests that hedgehogs are able to target, or at least exploit, rich aggregations of a prey (Parkes 1975; Wroot 1984; Jones et al. 2005), which may accentuate their potential impact on seasonally or spatially limited prey. For example, in the Mackenzie Basin, Jones et al. (2005) recorded weta *Hemiandrus furovarius* remains in 22% of guts and often in large numbers per gut (compared with the 5% found by Brockie (1959)), a pattern ascribed by the paper's authors to the highly clumped distribution of this species.

3.2.2 Density and distribution

The only available estimate of hedgehog density at BSIM was made by Berry (1999a,b), who suggested a 'theoretical estimate' of 5.5/ha at Boundary Stream. However, this estimate cannot be considered reliable, as it was based on a minimum-number-alive (MNA) index, which appears to cover a period of either 2.5 or 4.5 months; both periods are too long for a robust estimate of a resident or 'closed' population to be made. Furthermore, the methods by which hedgehogs were counted are not explicitly described, other than that they were searched for and marked 'infrequently over the study period'. Consequently, the resulting MNA estimate is subject to a series of highly questionable assumptions in the derivation of a final density 'estimate'.

A potentially valuable method by which hedgehog abundance could be estimated is to examine existing trapping records from a short (5–6 day) period soon after the animals emerge from hibernation in the spring, and to apply a Zippen removal analysis (Zippen 1956, 1958). This gives an abundance estimate based on the asymptote of cumulative catch data. Unfortunately, traps in BSMI are checked approximately weekly, and a number of weeks' data would be required to obtain sufficient data points (trapping occasions) for such an analysis, invalidating the assumption of population 'closure' necessary for a robust population estimate.

Indices based on trap-catch rates are often used as an approximate guide to abundance. At BSMI, mean trap rate of hedgehogs was 0.07/100 CTN in 2003 (range: 0 (July) – 0.13 (February)) and 0.11/100 CTN in 2004 (December excluded; range: 0 (July) – 0.26 (February)) (DOC, unpubl. data). As a comparison, hedgehogs were the most frequently trapped species along river and lake margins in the Mackenzie Basin, caught at rates of up to 2.04/100 CTN (Keedwell & Brown 2001). Mean capture rates in different forest types at Pureora Forest Park ranged from 0.10 (logged podocarp) and 1.51 (unlogged podocarp) to 2.02 (older exotics) hedgehogs/100 CTN (King et al. 1996). At Trounson Kauri Park, Fenn traps set in mixed kauri and broadleaf forest caught up to 1.3 hedgehogs/100 CTN (Hendra 1999). These statistics suggest that hedgehogs do not occur at high density within the reserve at BSMI.

There are few data available on hedgehog distribution with regard to habitat type within the reserve. Berry (1999a,b) followed seven male hedgehogs using radio-telemetry. These hedgehogs visited all available habitat types, but five of the seven preferred broadleaf forest and four used low shrubs or grassland more than would be expected. There appeared to be a general avoidance of pasture and

low montane forest. The fact that relatively higher numbers of hedgehogs were captured in the reserve buffer zone compared with the interior may indicate that hedgehog activity and/or density is concentrated at the reserve margins. Hedgehogs have been shown to vary their foraging behaviour based on temporal and spatial shifts in the availability of preferred prey, and evidence from Berry (1999a,b) and additional observations (CJ and G. Norbury, Landcare Research, Alexandra, unpubl. data) suggests that there is variation between individuals in habitat use. However, the trapping data on which the margin habitat preference suggestion is based are confounded by variation in trap sets. Initially, Fenn traps were covered using Philproof covers designed for mustelid trapping. When traps were later used in the buffer zone around the reserve, and when hedgehog trap rates increased, a different cover type ('DOC 200' trap boxes) was used. These covers make it much easier for hedgehogs to gain access to the traps than the Philproof design (T. Ward-Smith, DOC, BSMI, pers. comm.). A further confounding factor is that simply by increasing the perimeter of the trapped area, more animals (both residents and immigrants) become available for trapping.

There are few reliable estimates of hedgehog density for other New Zealand habitats. Parkes (1975) estimated densities of up to 1.1–2.5/ha on 16 ha of dairy farm in the Manawatu over 17 months, and Brockie (1974) estimated up to 1.75/ha on a Lower Hutt golf course. Gorton (1997) estimated a hedgehog density of 0.88/ha in mixed pasture and native bush. Estimates from British studies give values of 0.23–0.25/ha in mixed rural habitats, and 0.83/ha on a golf course and adjacent woodland (Reeve 1981; Doncaster 1992).

3.3 SUMMARY

- There are few robust data on the density and distribution of mice and hedgehogs within BSMI. The densities of both these species in the study area should be estimated by robust methods at least annually during the study. This will allow the degree of any estimated impact to be calibrated against pest density.
- Hedgehogs are insectivorous and mice are omnivorous, with invertebrates constituting a large proportion of both species' diets.
- Studies elsewhere have shown that mice can have very large impacts on local invertebrate abundances and biomass. Hedgehog impacts in New Zealand may be similar, but this has never been formally investigated.
- Invertebrates commonly eaten by mice and hedgehogs, and therefore appropriate for monitoring, are lepidopteran larvae, carabid beetles, spiders, millipedes and weta.

4. Measuring the impacts of mice and hedgehogs

In this section, we outline an experimental design that would enable investigation into the impacts of mice and hedgehogs on native forest invertebrates in BSMI.

4.1 EXPERIMENTAL DESIGN

4.1.1 Treatments

Ideally, there should be three treatments: two levels of experimental treatment, and a control for comparison. The suggested treatments would be:

1. Both mice and hedgehogs excluded
2. Mice present, but hedgehogs excluded
3. Both pest species with full access to plots (control)

This design assumes that the effects of hedgehogs and mice on invertebrates is additive, so that any difference in response between Treatments 2 and 3 would be due to the effects of hedgehog predation. This is an essential assumption, as it is the only realistic method of isolating the effects of hedgehogs. In theory, it would be possible to add hedgehogs to otherwise predator-free exclosures; however, this is not practical given the scale of the proposed study. Mouse predation effects alone would be assessed by comparing Treatment 1 with Treatment 2. This design has the benefit of flexibility; if, for economic or logistic reasons, it is decided to focus on, for example, the effects of mice alone, then only Treatments 1 and 2 would be required.

4.1.2 Power analysis

Introduction

In an experiment such as that proposed, experimental plots will exhibit some intrinsic degree of variation. This is especially true of experimental units in field settings, where the experimenter has limited control over environmental variables. In addition, the response variable in this study (invertebrate relative abundance) is likely to show marked spatial and temporal variation. It is, therefore, important that treatments are replicated, so that treatment effects can be separated from sample-unit variation (McArdle 1996). Defining the number of replicates is important for both statistical and economic reasons: too few and the study will be unable to detect a result of scientific importance; too many and resources will be wasted. To this end, we examined how the ability of the study to detect a real change in the response variable, i.e. the 'statistical power', would vary with the number of replicates. There is a common convention for setting a threshold for statistical power at 0.80, i.e. an 80% chance of detecting a real difference. We have followed this convention in the subsequent analyses.

Methods

An essential component of an a priori assessment of power is an estimate of the variance in the response parameter of interest. We estimated this using data from the invertebrate monitoring programme at BSMI for the period 1997/98 to 2003/04. Data from 2002/03 were incomplete so were not used. Relative abundances of invertebrates at BSMI are monitored using pitfall traps set in five lines, with each line made up of five groups of four traps. Each trap-line runs through a different habitat type. Traps are set for 1 month in December–January each summer. Data from one line were excluded because this line included rank grass habitat: this habitat can be expected to have an entirely different invertebrate community structure from the adjacent forest, and pitfall traps within rank grass will have a different catch-efficiency compared with those in forest litter (Luff 1975). We considered a group of four traps to be a sampling unit, as within-group spacing (< 1 m) meant that individual traps were unlikely to be independent. Groups of traps were > 10 m apart and were considered independent.

Statistical power was estimated by simulation. The original data sets were used to estimate means and variances of counts for monitored invertebrate groups within each habitat type. These statistics were then used to simulate large data sets with the same parameters as the original data. An 'experiment' was set up in the statistical software package GenStat with two 'treatments'. The difference between the means of these treatments was increased incrementally and 5000 ANOVAs were carried out over a range of sample sizes at each incremental change. The duration of the experiment was set at 6 years, as in the preliminary data set. For each combination of effect size (difference between means) and sample size, the number of times a significant treatment effect occurred was recorded. The resulting distributions describe the probability of detecting a range of real differences between treatments for a range of sample sizes (experimental replicates). Figure 1 illustrates the relationship between experimental power and the level of replication for carabid beetles. The analyses were used to predict the number of experimental replicates ('plots') required. Data from invertebrate monitoring in tall tawa/podocarp forest were used, as this is the most common forest type within the reserve. We describe the results for two representative invertebrate groups: carabid beetles and spiders.

To show the effect of not restricting experimental plots to one habitat type, we also present a similar analysis for carabid beetles where data from four habitat types are included.

Results and discussion

The results, which are summarised in Table 3, illustrate a number of key points. The inherent variability in local abundances of focal invertebrate taxa means that a large number of replicates would be required to detect a change in abundance in response to experimental treatments. For example, with 20 plots per treatment, an approximate increase of 30%–35% in invertebrate abundance could be reliably detected. This leads to the question of how big an effect is biologically relevant. Unfortunately, there are few published guidelines on which to base an estimate. van Aarde et al. (2004) recorded a difference of 43% in lepidopteran larval biomass between their mouse exclusion plots and open, control plots; however, their small sample size ($n = 5$) meant that this difference failed to reach statistical

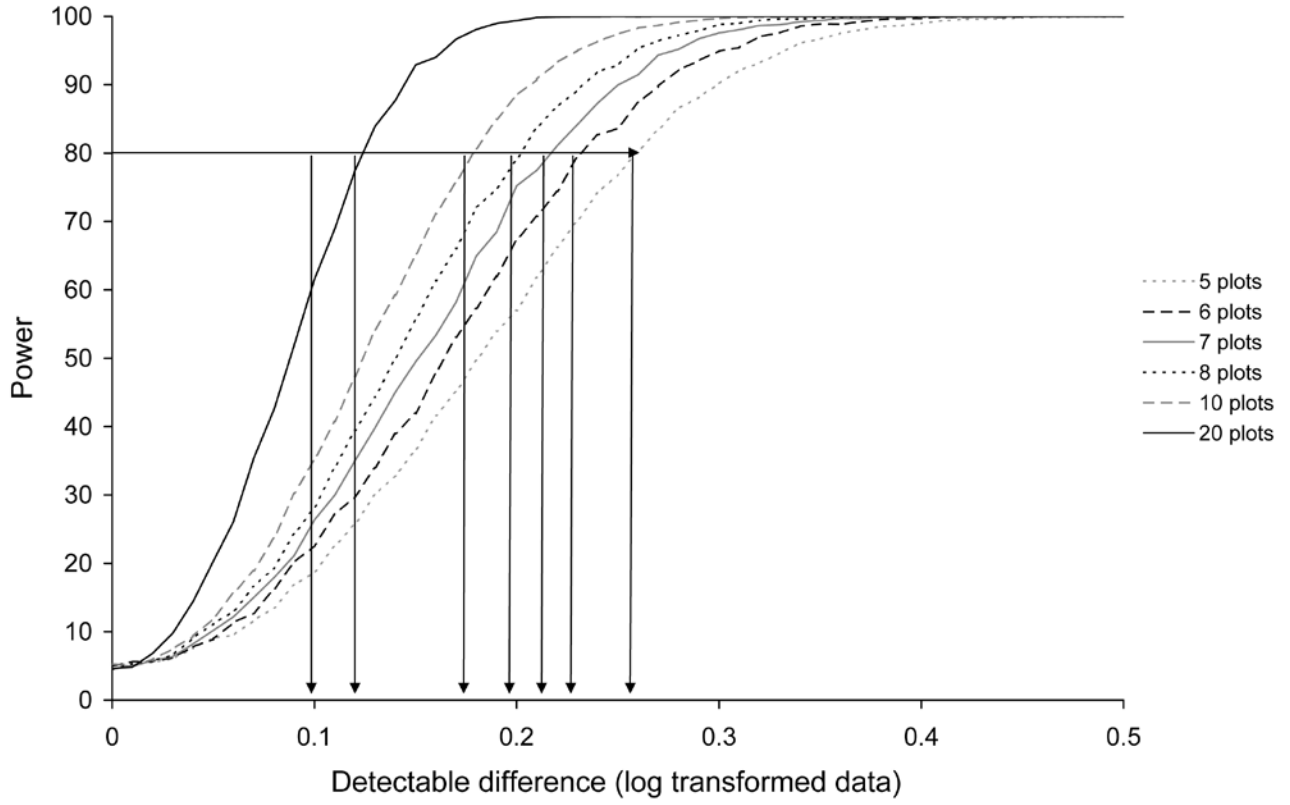

Figure 1. Power curves for carabid beetles. Data were transformed onto a log-scale. Therefore, the detectable difference reported is multiplicative: for example, a difference of 0.17 would correspond to a $10^{0.17} = 1.48\times$ difference in beetle counts, i.e. nearly a 50% increase or decrease.

TABLE 3. DETECTABLE DIFFERENCE (%) IN ABUNDANCE OF REPRESENTATIVE INVERTEBRATE GROUPS OVER 6 YEARS WITH POWER OF 0.80.

Only a sample of possible scenarios was investigated in the across-habitat comparison, to illustrate the relative impact of introducing this source of variation on the experimental design.

NUMBER OF PLOTS	WITHIN ONE HABITAT TYPE		ACROSS HABITAT TYPES
PER TREATMENT	CARABIDS	SPIDERS	CARABIDS
5	82	86	346
6	70	78	280
7	66	70	247
8	58	62	216
10	51	55	175
20	32	35	104
30	26	27	78

significance. On Mana Island, captures of Cook Strait giant weta increased from an average of 1.85/1000 trap nights before mouse eradication to 20/1000 trap nights 3 years after mice were removed (Newman 1994); a response of this scale would clearly be detectable with fewer than 20 plots.

The degree of replication required to reliably detect anything other than a very large proportional change becomes unmanageable if treatment plots are spread across a range of habitats (Table 3). We therefore suggest that any manipulation be restricted to a single habitat type, probably one of the most abundant within the reserve: broadleaf/tawa/podocarp forest or kamahi/kanuka/rewarewa forest. The number of plots in any final design will largely be determined by cost, but we strongly suggest that maximising replication is a priority, even at the cost of forgoing one treatment level. All suitable locations for study plots should first be randomly chosen; logistically unsuitable sites should then be 'culled' from the group, and treatments randomly assigned to the available plots.

4.1.3 Data analysis

As the data collected will be in the form of counts of individuals of each invertebrate taxon from the same plots at regular time intervals, the most appropriate statistical method for comparing the effects of treatments is a repeated measures ANOVA. This allows for the fact that successive measurements made on the same experimental units (plots) are likely to be temporally correlated, and facilitates comparisons of mean effects between treatment(s) and control plots.

4.2 POTENTIAL FOR STRATIFICATION AMONG SITES

The level of replication required to adequately address these research questions means that any study is likely to be expensive and to require significant input in terms of staff time and logistical support, particularly during the initial set-up phase. Whilst an understanding of the relative impacts of mice and/or hedgehogs in a range of habitat types (i.e. stratification by habitat type) is desirable, it is probably not feasible for a study of this intensity if conducted at one site. The scope of the study could be increased to include more habitat types by replicating the design at other sites, such as the Rotoiti Nature Recovery Project (beech forest) and Trounson Kauri Park (kauri/podocarp forest). Both sites are intensively managed and face similar pest-control issues: rats, possums and mustelids are maintained at low levels, mouse control is sporadic and of limited efficacy, and the effects of hedgehogs are unknown (DOC 2004b; Gillies et al. 2003). At Rotoiti, the effects of mouse predation during heavy beech seedfall events could be incorporated into the analysis.

Spreading a large-scale study across sites would not only allow pest effects to be investigated in a range of habitat types whilst maintaining continuity of design and analyses, but would also spread financial and labour costs amongst DOC conservancies. The results of the study would be relevant to a range of conservation areas across New Zealand and, therefore, of greater general utility than results from one specific site and/or habitat type.

4.3 PHYSICAL DESIGN

There are a number of published accounts of the construction of barriers or enclosures/exclosures designed to inhibit the movements of mice or other small rodents. These designs vary in complexity, according to the aims of the particular study, and therefore vary in construction and maintenance costs. We reviewed the published designs and, in some cases, sought advice directly from researchers who had used them. We use this information to suggest an appropriate design for trial. The final design must be relatively simple and inexpensive, as significant replication of plots will be required for any subsequent experimental manipulation. Materials need to be low-maintenance, robust to weather effects, and easily replaced if damaged.

Wire-mesh fences could be used to exclude mice and hedgehogs. To maintain mouse-free exclosures, van Aarde et al. (2004) used a 1-m-high electrified wire-mesh fence in association with repeated trapping. The mesh size was not specified in this study, but at Karori Wildlife Sanctuary it has been found that fencing with a mesh diameter of 7.5 mm is permeable to small mice (K. Calder, Karori Wildlife Sanctuary, pers. comm.). Exclosures that are designed to exclude hedgehogs but allow access to mice (Treatment 2) could be constructed from wire-mesh 'rabbit-proof' fencing materials. Although hedgehogs are not truly fossorial in habit, they are still able to dig under obstacles, so fences should be dug into the ground to a depth of approximately 10 cm. There should also be an outward-overhanging lip at the top of the fence to prevent access by climbing. Mice would be able to gain access to plots through the mesh of the fence.

In other studies of small rodents, more solid fencing materials have been used. Drickamer et al. (1999) constructed a fence of 1-m-wide 'hardware cloth' buried to a depth of 30 cm and topped with a 30-cm-wide strip of aluminium flashing; the aluminium sheets were also applied to the fence post tops. A similar design was used by Mahady & Wolff (2002) in Tennessee, USA, with PVC pipe set along the fence top to create an overhang (L. Drickamer, Northern Arizona University, and J. Wolff, University of Memphis, pers. comm.). In Australia, both Barker et al. (1991) and Arthur et al. (2004) used partially buried, galvanised steel sheets to construct exclosures, and in Oregon, USA, Manning et al. (1995) used overlapping corrugated metal sheeting to construct rodent-proof exclosures. This last design has been recommended as being effective as well as simple to construct and maintain (L. Drickamer, pers. comm; J. Wolff, pers. comm. to D. Wilson, Landcare Research, Dunedin). Costs may be reduced by using corrugated fibreglass or plastic sheets instead of metal. As an indication of relative costs, the closed corrugated plastic wall design is estimated to cost around NZ$14/m (GST included) compared with NZ$24/m for small mesh fences with sheet metal flashing (R. Burns, DOC, and R. Heyward, Landcare Research, pers. comm.).

Although closed-wall mouse-proof exclosures are likely to be the most simple and cost-effective design for excluding mice, there are two potential disadvantages associated with this design. Firstly, the walls may alter the environmental conditions inside the exclosure. This could affect the suitability of the local microhabitat for some invertebrate groups; for example, blocking air movements can affect the degree of desiccation of ground litter, which can, in turn, affect the composition of the invertebrate litter fauna (Didham et al. 1996). This is likely to be more pronounced close to the fence. Such changes may confound the effects

of any experimental treatments if only applied to one treatment level, i.e. it would be difficult to determine whether any changes in the abundance of monitored invertebrate groups were due to the release from predation pressure, changes in microclimate, or some interaction of the two. Secondly, exclosures may also affect population dynamics of some terrestrial invertebrate groups (e.g. carabid beetles) by inhibiting dispersal although effects are likely to vary with species (Davies & Margules 1998). One possible solution to these problems would be to increase exclosure size until edge/climate effects are minimal. However, given the level of replication required, this is unlikely to be a practical solution, and the level of replication should not be compromised, as this would lead to reduced confidence in obtaining robust scientific outcomes. An alternative option would be to construct identical treatment and non-treatment plots, so that environmental effects are consistent across all treatments, and to allow access to mice and/or hedgehogs by cutting holes of an appropriate size at ground level.

Maintaining consistency of design across treatments is imperative. Invertebrate sampling should be concentrated in the central areas of the plots, preferably no closer than 2 m from the fence, or, if this is insufficient space for sampling, at a distance from the fence equal to the height of the fence.

The spacing and size of plots will be determined by the need for independence of sampling units and the requirements of robust invertebrate sampling protocols. The area of available habitat and construction costs must also be considered. Plots must be spaced so that each can be assumed to be independent of its nearest neighbours. Hutcheson & Jones (1999) used trap sites at 80-m spacing to compare beetle communities in homogenous habitat; other studies (reviewed in Hutcheson et al. 1997) suggest that independent samples may be obtained with sites spaced at 20–50 m, depending on habitat. We therefore suggest that ideally plots should be spaced 100 m apart, but that some compromise, possibly to a minimum of 60 m, is acceptable. A plot of 10 × 10 m is probably the minimum size that would permit adequate sampling of monitored invertebrates without significantly compromising population and community dynamics of these taxa (RT, unpubl. data).

4.4 TRIAL OF MOUSE-PROOF EXCLOSURE

We briefly tested a closed-wall exclosure to assess the effectiveness of the design in preventing entry of mice. The exclosure was built of sections of corrugated plastic sheeting (690 mm wide; 1200 mm high) arranged so that the corrugations were vertical. Overlapping sections were bolted together and were wrapped around and bolted to the outsides of wooden corner posts to create an enclosed area of 9 × 9 m (Fig. 2). The plastic sheets were buried to a depth of at least 400 mm, giving walls of height 600–800 mm: variation in height was caused by the undulating topography of the site and the presence of large tree roots.

Five tracking tunnels were used to detect the presence of mice. On detection of prints, nine sets of two snap-traps, which were enclosed in tunnels, were set. The results of this monitoring and removal exercise are shown in Table 4. The results show that even if an exclosure can be reasonably considered to be mouse-free, as in the period 1–8 June, reinvasion still occurs. The most probable route

Figure 2. Trial mouse (*Mus musculus*)-proof exclosure in podocarp forest near the Tumanako loop track, Boundary Stream Mainland Island, May 2005. *Photo: R. Burns, DOC.*

for this is via overhanging tree limbs. This risk could be significantly reduced by either removing suitable branches or by covering exclosures with a 'roof' of small-diameter netting. However, neither course of action is appropriate for three reasons: the amount of leaf litter entering the exclosures would be significantly reduced; invasion by some important invertebrate taxa (e.g. adult Lepidoptera) could be affected; and the removal of a potentially large number of tree limbs would greatly increase the labour required to construct and maintain exclosures to a level that is likely to be economically unjustifiable. Therefore, regular monitoring and removal by trapping of invading mice is likely to be the best method to maintain the integrity of experimental treatments.

TABLE 4. RESULTS OF MONITORING MOUSE (*Mus musculus*) ACTIVITY WITHIN TRIAL EXCLOSURE, BOUNDARY STREAM MAINLAND ISLAND, MAY–JUNE 2005.

DATE	TUNNELS TRACKED	MICE TRAPPED	ACTION
26 May			Exclosure completed, tunnels set
27 May	4 of 5		Traps set
30 May	0	2	
1 June	0	1	
3 June	0	0	
7 June	0	0	
9 June	3 of 5	1	
10 June	0	0	
13 June	3 of 5	1	
15 June	0	0	

4.5 SUMMARY

- We propose that any experiment should include three treatments: both mice and hedgehogs excluded; mice present, but hedgehogs excluded; and both pest species with full access to plots.
- The high level of spatial and temporal variability shown by many invertebrate groups means that a large number of replicates would be required to detect a treatment effect with a reasonable level of certainty. In the absence of data showing what constitutes a biologically meaningful change, we suggest that there should be at least 20 plots for a within-site experiment. This figure is based on the experiment running for 6 years.
- To make across-habitat comparisons at one site, the number of replicates required would increase greatly. Therefore, the experiment should be limited to one habitat type at BSMI. Should it be considered desirable to test the experimental hypotheses in a variety of habitat types, there is the potential for including other intensively managed mainland reserves in the experiment; this would also have the advantage of spreading the costs and workload amongst DOC conservancies.
- Repeated measures ANOVA should be used as the primary statistical method for analysing the results.
- Exclosures should be 10 × 10 m and spaced at 60–100 m to maintain independence.
- Barriers to exclude pest species should be identical across treatments. This will standardise any environmental effects of the exclosures across treatments.
- A closed-wall design is probably the most cost-effective method for constructing exclosures. To impose the appropriate treatment levels, appropriately sized apertures could be cut at ground level to allow access to plots by mice and hedgehogs.
- A brief trial of the suggested exclosure design showed that reinvasion of mice can occur following their removal. Therefore, regular trapping within exclosures should be continued throughout the experiment.
- Invertebrate sampling should be concentrated in the central areas of the plots, preferably no closer than 2 m from the fence, or, if this is insufficient space for sampling, at a distance from the fence equal to the height of the fence.

5. Monitoring the responses of invertebrates

Invertebrates are small, often very cryptic, can occur in large numbers, and for many groups are difficult to identify with certainty in the field. Consequently, most invertebrate monitoring exercises require a significant degree of kill-trapping. Populations of invertebrates can also show high degrees of variance over space and time, which means that large numbers of samples and replicates of treatments are necessary to obtain meaningful results. When monitoring invertebrate populations within relatively small and partially enclosed plots, such as those proposed here, we have to find a balance between sampling regimes that are effective for the taxa of interest, but that do not have a significant negative impact on populations of interest. Unfortunately, there are no real guidelines available, and calculating this for each situation and taxon would require a significant study in itself. As this is neither practical nor affordable, we will use previous experience, best estimates and common sense to determine the most suitable protocols. Sampling regimes should be reassessed as the study progresses to determine whether changes are required. We will focus on an optimum sampling regime, but will suggest a compromise should funding and/or other resources not permit this.

Most of the commonly employed sampling and trapping methods for invertebrates (e.g. pitfall traps, sticky traps and Malaise traps) provide *relative* estimates of abundance, rather than *absolute* measures of population density. The advantages of relative sampling techniques are that they are usually cheap and efficient to set up, and tend to provide larger data sets than absolute sampling methods (Southwood 1978). However, since results are interpreted in terms of the difference in catch between plots and over time, they rely on the assumption that trap efficiency is constant spatially and temporally. This is often not the case, especially when comparing different habitat types or when the treatments being tested involve significant modification of the habitat in some plots and not others. Thus, comparisons with catches from other studies or across habitats, or the assumption that results reflect the actual population density of the organisms under study, are often invalid.

The taxa that we particularly wish to monitor in this study are those that are likely to be important components of mouse and hedgehog diets: ground-dwelling caterpillars (Lepidoptera), ground beetles (Carabidae), spiders (Araneae), ground weta (Anostostomatidae), and cave weta (Rhaphidophoridae). Pill millipedes (Sphaerotheridae) have also been indicated as an important component of the diet of hedgehogs (Berry 1999a,b); however, the pitfall data from BSMI does not currently separate these from other types of millipedes, so it is unclear how prevalent they may be in the area. Since a number of the other common forest millipedes exude a toxic chemical when disturbed specifically to make them unpalatable to predators, we cannot infer results for all millipedes onto pill millipedes.

Several invertebrate sampling techniques could potentially be used in this study. We discuss the relative merits of these below.

5.1 PITFALL TRAPS

Pitfall trapping is one of the most commonly used methods for sampling ground-dwelling invertebrates, and is the main method of invertebrate monitoring currently used at BSMI; the power analyses presented in section 4.1.2 are based on the results of this programme. Pitfall traps provide information on the relative abundance of invertebrates in different plots, based on the assumption that trap efficiency is the same between plots. This is a reasonable assumption when using the same trap design within plots in the same habitat. However, it is very difficult to compare results from studies that have used different pitfall trap designs (Luff 1975; Abensperg-Traun & Steven 1995) or results from different habitats (Melbourne 1999).

The benefits of using pitfall traps for this study would be that they are cheap, have been proven to catch some of the groups that we are most interested in (particularly spiders, ground beetles and weta), and DOC staff are familiar with their use. However, since they are lethal traps, their excessive use may potentially affect study populations in enclosed plots. This is particularly true for the large, flightless species, such as ground beetles, spiders and weta.

For 10 × 10-m plots, we recommend using four pitfall traps arranged in a 3 × 3-m square around the centre of the plot. These should be run for a 4-week period in December–January each year to be consistent with previous pitfall data collected in the area. Traps should be serviced weekly. For the rest of the year, it is critical that these traps remain closed (with sticks angled like ladders inside the trap to provide a route of escape for any animals that fall in).

5.2 WOODEN-DISC REFUGIA

In an effort to minimise the impact of kill-trapping within the plots, the use of pine-disc refugia to monitor changes in the abundance of ground-dwelling invertebrates (following the design of Bowie & Frampton (2004)) is being trialled at BSMI as part of this pilot study. Five groups (20 m apart) of four pine discs (1.5–2.0 m apart) were set out in a line in early February 2004. In mid-April, the discs were lifted and the number of visible invertebrates was counted. They will be checked again in winter (July), spring (October) and summer (January). Disturbance of the discs must be minimised so that their suitability as refugia is not compromised. This trial should indicate whether the discs would be a useful alternative to kill-trapping using pitfall traps. The fact that the results from artificial refugia may be influenced by the density of natural refugia in the surrounding area means that this method must be considered a relative sampling technique only.

The most abundant colonisers in April 2005 under the discs at BSMI were millipedes (but not pill millipedes), which occurred beneath 65% of the discs and in all groups. Four groups (seven discs) had at least one earthworm, and three groups (four discs) had centipedes. One caterpillar was found. The only beetles recorded were three rove beetles (Staphylinidae), and spiders had yet to colonise any of the discs. For the wooden discs to be a useful technique for the proposed study, it is critical that they be colonised by ground beetles and spiders.

Bowie & Frampton (2004) found that wooden discs are very useful for monitoring ground beetles (Carabidae), spiders and earthworms. The numbers of invertebrates under their discs continued to increase for at least the first year after placement, with ground beetles taking about 8 months to colonise. Therefore, the results reported here, from the first 2 months of the study, should be viewed as highly preliminary.

5.3 TULLGREN FUNNEL LITTER EXTRACTIONS

Litter-inhabiting lepidopteran larvae are a key group of invertebrate prey in both mouse and hedgehog diets (see section 3). Although these larvae are found in pitfall trap samples, their litter-dwelling habit and less wide-ranging movements than other taxa, e.g. beetles, mean that the sampling regime for pitfall traps is unlikely to result in robust estimates of lepidopteran larval abundance. To obtain absolute estimates of litter fauna, Tullgren or Berlese extraction funnels can be used (e.g. Moeed & Meads 1986). In this method, representative sample-squares (20 × 20 cm) of litter are collected into bags and placed on a grill within a Tullgren funnel. The lid of the funnel has a lightbulb that slowly heats and dries the litter, forcing the animals within to migrate downwards, whereupon they fall through the grill arrangement and land in a collecting container of alcohol at the bottom of the funnel. It can take a week or more to ensure that the litter is fully dried and all the animals have been collected. Using this technique, not only can an absolute population measure for a square area of litter be made, but it is also possible to estimate the volume and dry mass of the litter to account for variation in litter depth and density.

To obtain a reasonable estimate of caterpillar populations in leaf litter, three or four samples per plot should be taken in each of spring, summer and autumn. The disadvantages of this technique are the need for a significant quantity of relatively expensive Tullgren funnels and the fact that it is a destructive method in which both litter and animals are removed from the plots. A long-term Tullgren funnel study on a small plot will result in the removal of quite large amounts of litter, so that it may become difficult to find representative areas where the litter has not previously been affected. Consequently, we do not recommend Tullgren funnel extractions as a preferred sampling technique in the proposed study.

5.4 EMERGENCE TRAPS

Emergence traps provide an estimate of the absolute density of adult insects emerging from an area of ground (Chaddha et al. 1993). Ground-based emergence traps usually consist of a cone or pyramid of gauze on a wire or wooden frame, with some sort of collecting bottle apparatus at the top (e.g. Moeed & Meads 1987; Chaddha et al. 1993; Green 1996). The base of the emergence trap is of a set dimension and fastened to the ground beneath the litter layer. Emergence traps are useful for collecting a wide range of invertebrates that emerge from the forest floor, but are particularly good for flying insects (especially flies, parasitic wasps and moths), which can be missed in pitfall traps. Beetles, ground weta and spiders can also be caught in emergence traps; therefore, the use of these

traps could add extra data for the groups sampled by pitfall traps and/or pine-disc refugia. In New Zealand, data from emergence traps have already been used to assess the relationship between the abundance of moths in litter and mouse numbers (Fitzgerald et al. 1996).

Some emergence traps are difficult to set up and to extract the insects from, are easily damaged and may require checking as often as every 2 days. In an effort to provide a more efficient solution, one of the authors has recently designed and trialled a new emergence trap that overcomes many of these problems (RT, unpubl. data). This design has a tough plastic custom-moulded frame, with large panels of a synthetic mesh (for climate consistency) and easy-to-use collection units of the type often found on Malaise traps (Fig. 3). The collection pottles can be used with a preservative (Gaults fluid, ethanol or glycol), as in pitfall traps, which means that they can be left out for up to 2 weeks without servicing. These units cover an area of 48 × 48 cm, are light and stackable for transportation, quick to deploy in the field, and easy to collect the specimens from.

When sampling litter fauna, it is not advisable to leave an emergence trap fixed in place continuously, as this prevents new litter from settling and new insects from colonising the sampled area. A better approach would be to sample representative areas of litter using four emergence traps per plot operated for a 4-week period in October, again in December–January, and for a third time in April. This would catch a representative sample of insects emerging in the spring, summer and autumn peaks (some species may be caught in all months, others may only turn up in one). To reduce the effect of the traps on the litter community itself, we recommend that any one area of ground should not be sampled twice in the same year.

Figure 3. The Toft emergence trap. *Photo: RT.*

5.5 SUMMARY

- We recommend the use of emergence traps in spring, summer and autumn as a technique for assessing changes in the abundance of insects, particularly Lepidoptera, emerging from the litter.
- Other ground-dwelling invertebrates (spiders, ground beetles and weta) should be sampled using pitfall traps or pine-disc refugia. Pitfalls are a reliable means of obtaining data on weta, spider and ground beetle abundance, as well as extra data on lepidopteran larvae. However, refugia have the advantage of being non-destructive.
- We do not recommend the use of Tullgren funnel extractions, as they will be too destructive to the habitat within the plots over the long term.
- The decision on whether to use pine-disc refugia in the plots should not be made until at least January 2006, when the discs under trial have been on the ground for a year. That decision should be based on whether reasonable numbers of spiders and ground beetles will use them in that habitat.
- Should pitfall traps be used, we recommend that they should not be used for more than 1 month in each year within the plots.
- If financial or other constraints preclude the use of the combined monitoring approach outlined above, it would be better to reduce the number of invertebrate taxa monitored whilst maintaining the quality of data rather than to compromise the latter in favour of attempting to measure everything less effectively. Accordingly, we would suggest using pitfall traps or pine-disc refugia only, as these methods would still allow a number of invertebrate groups to be monitored effectively.

6. Conclusions

When considering the potential effects of predatory pest species on an ecosystem, three important questions must be asked:

- Does the pest species have an impact?
- How big is the impact?
- What does this impact mean for the prey species' population dynamics and related ecological processes?

The research outlined in this report addresses the first two questions. The third question can only be answered by studying the ecology and population dynamics of the species suffering the impacts. Where the urgent conservation management of complex systems is involved, the first two questions will have more immediate and widespread application. Investigations of the impacts of mice and hedgehogs on native invertebrates have been recommended as priority areas for research at both regional and national levels within DOC. The proposed research, whilst logistically demanding, will have direct and widespread relevance to forest reserve management.

Decisions about whether or not to attempt to control mice and hedgehogs to low levels will have to be made by conservation managers. As mouse populations can respond rapidly to any reduction in control, management will have to take the form of either a sustained 'press' on the species or intensive monitoring combined with control when mouse densities rise above a predetermined threshold. The most likely method of control will involve the use of poison stations at much greater density than those currently used to target rats and possums (Hamilton et al. 2003). This will be expensive and such expenditure must be justified in terms of conservation benefits. Without research such as that proposed here, these benefits cannot be estimated with any confidence.

The success of the proposed study will depend on the ability of current management practices to maintain rat and mustelid populations at low levels. The assumption that there are minimal effects on local invertebrate guilds due to these pests is critical in the design and interpretation of this proposed experiment. Significant predation on focal invertebrates by other predators will confound any treatment effects. To test the validity of this assumption, it is strongly recommended that all experimental plots are regularly monitored to detect the presence of other potential predators using tracking tunnels. Consistent evidence of other predators within plots could signal a need to set traps in the immediate area to maintain the integrity of the experiment.

One potential problem with our design is that logistical and/or financial constraints may preclude the construction of a sufficient number of control (non-treatment) plots and sufficient replication of the two experimental treatment levels. If this is the case, we suggest that the effects of mice are a higher research priority, as hedgehogs are already subject to some level of control as a result of the mustelid trapping programme, which is probably reducing the impacts of this species to some extent and, accordingly, the urgency of the research need. However, should this course of action be chosen, it would be advisable to test the assumption that hedgehog impact is reduced through by-catch by combining a capture-recapture estimate of local hedgehog density with an assessment of the effects of the mustelid trapping programme on the survival of marked individual hedgehogs.

7. Recommendations

We make the following recommendations:

- This research should be conducted, as it has the potential for widespread conservation management benefits.
- A robust experimental design, involving randomisation of treatment allocation and plot locations, should be adhered to, as large natural variations in invertebrate populations could confound treatment effects.
- Maximising replication is a priority, even at the cost of forgoing one treatment level and/or adopting a less complex monitoring programme. If there are constraints, priority should be given to focusing on the impacts of mice, and pitfall traps/refugia are the single most useful monitoring method.

- Although the experiment should be limited to one habitat type at BSMI (probably broadleaf/tawa/podocarp forest or kamahi/kanuka/rewarewa forest), the option of including other intensively managed mainland reserves in the experiment, and thereby spreading the costs and workload amongst DOC conservancies whilst testing the experimental hypotheses in a variety of habitat types, should be investigated further.
- Absolute densities of mice and hedgehogs at the study sites should be estimated during the experiment as a calibration of any impacts due to these species.

8. Acknowledgements

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