Potential interactions of hedgehogs with North Island brown kiwi at Boundary Stream Mainland Island

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1. Introduction

The European hedgehog (*Erinaceus europaeus* L.) was introduced to New Zealand in 1870 and has now spread over the three main islands as well as to several offshore islands (Brockie, 1990). New Zealand hedgehogs have maintained a similar habitat to European specimens, i.e. pasture, sand-dunes and urban areas (Brockie 1975) but have expanded their habitat range to include alpine tussock grasslands (Wodzicki & Wright 1984) and some forest types including the vegetation found at Boundary Stream Mainland Island (BSMI), Hawkes Bay.

The ecology of the North Island brown kiwi (*Apteryx australis mantelli*) is not well understood. Its nocturnal and secretive behaviour has in the past made this bird difficult to observe (McLennan et al 1987). Kiwi were once present at Boundary Stream, but declined and disappeared in the last few years (McRitchie 1998). It is generally accepted that the key threat to the kiwi is predation from mustelids, cats and dogs (McLennan *et al* 1990), but it is possible that hedgehogs also pose a threat. No previous research on the kiwi has incorporated interactions between hedgehogs and kiwi. These studies have either focused on other aspects of the ecology of the kiwi or have occurred in areas where hedgehogs were absent. As a result the interactions, whether positive or negative, between the hedgehog and the kiwi are essentially unknown.

1.1 OBJECTIVES

This report was commissioned by the Department of Conservation, East Coast/Hawkes Bay Conservancy, to assess the likely effect of the hedgehog on kiwi at Boundary Stream Mainland Island (BSMI), if kiwi were to be re-introduced to the reserve. The report has five objectives:

1. To describe the ecological interactions that can be expected between hedgehogs and kiwi within BSMI.

2. To provide an estimate of the current densities of hedgehogs within BSMI and its associated non-treatment area.

3. Based on inferred pre-treatment and current hedgehog population densities and the likely future population dynamics (under the current pest control regime), to assess the likely magnitude of any adverse impacts of the hedgehogs on a (re-introduced) kiwi population over the next 3-5 years.

4. If possible, to nominate a maximum hedgehog density, on a seasonal basis, that is compatible with a flourishing kiwi population.

5. To discuss the positive and negative aspects of any techniques for hedgehog control in a BSMI or similar context.

Information presented in this report was chiefly obtained for a Master of Conservation Science thesis completed through Victoria University of Wellington by the author. The study focused on documenting the ecology of the hedgehog within the reserve and assessing their significance to the conservation goals of the reserve (Berry 1999). Dietary and telemetry studies were carried out between November 1997 and April 1998. Further fieldwork required for this report was performed in early May 1999.

2. Study area

Boundary Stream Mainland Island is situated on the eastern flanks of the Maungaharuru Range approximately 60 kilometres northwest of Napier, on the eastern coast of the North Island, New Zealand. Boundary Stream consists of c 800 hectares of private and Crown land. The reserve covers an altitudinal range from 300 m a.s.l. to 1000 m a.s.l and constitutes most of the catchment for the upper Boundary Stream. The reserve, made up of 12 vegetation types, is the largest intact forest tract within the Maungaharuru Ecological District, and includes over 230 plant species (Anon 1995). The majority of fieldwork occurred within an area of approximately 100 hectares towards the western end of the reserve centred around an elevation of 800 m. The vegetation present ranged from 'improved' pasture to broadleaf forest with podocarps and red beech forest. A full summary of the vegetation is provided in Berry (1999).

3. Methods

3.1 DIETARY ANALYSIS OF HEDGEHOGS

Dietary analysis was performed using scats and a small sample of stomachs. Previous researchers have found no significant differences between these two types of samples (Brockie 1959; Campbell 1973). Scats were collected throughout a variety of vegetation types and the stomachs were obtained from animals killed in Fenn traps or animals used for telemetry studies.

Three methods of analysis were used in this study, providing a realistic estimate of the diet. The three methods chosen were; occurrence in the sample, relative volume, and minimum number of each prey item. All of these methods allow comparisons between both previous hedgehog studies (e.g. Brockie 1959; Campbell 1973) and those of kiwi (e.g. Reid et al 1993). Full descriptions of the methods can be found in Berry (1999).

3.2 POPULATION ESTIMATES FOR HEDGEHOGS

The population index of 'minimum number of animals' known to be alive (MNA, Krebs 1966) was chosen for this study. Hilborn et al (1976) used this method and found it was reliable but gave underestimates of approximately 10-20%. Reeve also chose this method for his study on hedgehogs in 1982. Individual hedgehogs were either radio-tagged (for home range and habitat utilisation analysis) or marked by clipping spines. Population estimates were obtained by searching the study area over several nights. This was repeated infrequently throughout the main field period. Full description of the methodology is given in Berry (1999).

4. Results

4.1 DIETARY

One hundred and forty one scats were collected during the 1997/1998 period of fieldwork, and 18 (six empty) stomachs were obtained as a control to the scat analysis. A total of 43 separate food types were identified in the scats and the stomachs (Appendix 1). These included five types of plant material (monocot, dicot, moss, seed, and fungi). Thirty-four types of invertebrate items were identified, while four classes of vertebrate food were distinguished. This report groups the food items identified into 15 categories.

4.1.1 Plant material

Plant material was common in both scats (68.09%) and stomachs (83.33%) but only occurred in small amounts - 12.13% and 14.29% respectively (Table 1), implying that plant material was not generally eaten intentionally but was a by-product of eating food found among litter and ground layer plant species. The majority of plant material consumed was leaf blades of grass species but small complete leaves of dicot plant species, several intact seeds and flower heads were also present.

4.1.2 Vertebrate component

Only six food items were identified as being of vertebrate origin. Three were fragments of unidentified eggs, one passerine bird (adult/hatchling), hair of a mouse, and one unidentified sample of mammalian hair. Vertebrates occurred in a small number of the scat samples (7), and only contributed 0.25 % of the total volume of the sample (Table 1). Hedgehog hair was recorded in small amounts within four scats. These hairs are considered to have been accidentally ingested when self-grooming.

4.1.3 Invertebrate component

Invertebrates formed the major part of the diet of the hedgehogs. Thirty-four categories of food items were identified as of invertebrate origin (Appendix

1). For this report these categories have been summarised in eleven groups (Table 1). Pill millipedes were the dominant food type while carabid beetles (*Mecodema* spp. and *Holocapsis* spp.), 'other beetle families' and Araneae (spiders) were the next major groups of food items. The significance of these four food items differed depending on the method (Table 1).

Orthoptera (weta), 'other millipedes' and `other invertebrates' had a large occurrence rate within the scats, making up 31.21%, 22.7%, and 25.5% respectively. However, these food items were not important with respect to their relative volume or the number of each item eaten (range 3.64% to 6.8%).

Soft body items (e.g. earthworms and molluscs) within the stomach sample ranked sixth in occurrence (41.7%) and had a combined relative volume of 14%. Within the scat sample these soft body items had a combined occurrence of 17%, suggesting that less of these food items could be identified within the pellets. Likewise the relative volume within the scats also dropped. The combined volume of the soft-bodied items was 2%.

4.2 POPULATION ESTIMATES

The population study resulted in 37 hedgehogs within 11 hectares of the forested study area being marked and observed on a regular basis. Taking into account the non-sampled proportion of the population, a population estimate of 44 hedgehogs (or 4 per hectare) seems reasonable. Based on the following assumptions, a minimum number of hedgehogs within the reserve can be estimated:

> Assumption 1 :The population estimate for the study area was obtained from approximately 800 m above sea level. Brockie (1975) suggests that within New Zealand there is a negative relationship between altitude and hedgehog density. Brockie considers 800 m to be the cut-off height that hedgehogs are 'common'. Above this, the temperature and weather conditions play an important factor in controlling hedgehog population sizes. Below this, the numbers can build up to 12 animals per hectare (Brockie 1975). It is assumed that if the habitat is not limited in other ways and has similar vegetation to the study area, but at a lower altitude, it would theoretically support a slightly higher population of animals.
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> Assumption 2: The vegetation types range from kamahi forest with limited undergrowth, which would support very low numbers of hedgehogs, to dense podocarp/broad leaf forest with an abundant ground cover, which would support large numbers of hedgehogs. The vegetation, water sources, nesting locations and food supplies all relate to the possible density that hedgehogs could reach in an area.
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> Assumption 3: The area of the reserve used to obtain the population density estimate in April 1998 could have been influenced by the nearby pasture (i.e. edge effects). It is assumed, however, that the hedgehog density is evenly distributed throughout the reserve with respect to

the proximity to the pasture. This assumption is supported by evidence from telemetry data (Berry 1999) and personal observations on hedgehogs within the middle of the reserve.

Taking into account the above assumptions and the population size within the study area, an estimate for the population size of the European hedgehog within BSMI is 4400 or approximately 5.5 per hectare as of April 1998. This total is a conservative estimate of the minimum population within Boundary Stream Mainland Island. A re-assessment of the population density within the reserve and non-treatment areas in May 1999 failed as it was found most hedgehogs had already entered hibernation (some weeks earlier than 1998), so this part of the study brief could not be answered directly.

5. Hedgehog - kiwi interactions

There are potentially several areas of interaction between the hedgehog and the kiwi. These can be grouped into four categories: competition for food, competition for other resources, direct predation, and indirect predation.

5.1 COMPETITION FOR FOOD

Previous dietary analysis of hedgehogs both in New Zealand and overseas have found similar results to the present study. Hedgehogs ate any large species of invertebrate if located within the litter or low vegetation. Millipedes, earthworms, spiders, beetles (adults and larvae), Lepidoptera larvae, and weta are all key elements of the hedgehog diet (Brockie 1959; Campbell 1973; Yalden 1976; Dimelow 1963b; Wroot 1985). Brockie (1990) stated that hedgehogs do not feed indiscriminately but select food items. This study lends more support to this conclusion. Both pill millipedes and weta appeared to be eaten in greater proportions than they were representatively sampled within the reserve, suggesting that the hedgehogs positively selected these food items.

This study found that earthworms formed only a small proportion of the hedgehog diet. Earthworms are only vulnerable to predation from hedgehogs when they are on the surface. MacDonald (1983) demonstrated that the number of earthworms on the surface decreases in proportion to the time since it has rained and the rise in air temperature. As the majority of the fieldwork occurred during a drought and rain was infrequent, the importance of earthworms in an average year might have been severely underestimated. A higher focus on earthworms would accord with northern Europe evidence noted by Brockie (1990).

Many introduced mammals to New Zealand feed heavily on invertebrates periodically, but none have invertebrates consistently forming the major part of their diet. The diet of the hedgehog is unique among the introduced fauna of New Zealand.

Little is known about the exact diet of kiwi and the amount of each food item consumed. Dietary analysis has focused on individuals found deceased (e.g. Bull 1951; Watt 1971; Reid *et al* 1992) or on a small sample of faeces (e.g. Miles 1995). While kiwi probe into the soil for a proportion of their food, the majority of the kiwi's diet appears to be collected either on the surface or in the litter layer (Miles 1995). Earthworms, cicada nymphs, and beetle adults (Carabidae and Scarabaeidae) are consistently mentioned in the literature as the main food of kiwi. A few seeds, leaves and a wide variety of other invertebrates (Bull 1951; Watt 1971; Reid et al 1992; Miles 1995) supplement these 'key' foods. The importance of these 'other invertebrates' (spiders, Lepidoptera larvae, and weta) may depend on the region of New Zealand.

All the invertebrates eaten by the kiwi are also food items of the hedgehogs at BSMI. Many of these invertebrates are eaten in large quantities by the hedgehog, and there appears to be a substantial (70-80%) overlap in the diets of kiwi and hedgehogs.

5.1.1 Consumption rates

The amount that hedgehogs consume each night is an important element in establishing their potential effect on kiwi. On average, stoats have a daily requirement of 75 g (Day 1968), while ship rats and Norway rats eat approximately 10-15% of their body weight per day (i.e. 15-30 g). The average daily requirement for hedgehogs is estimated to be approximately 150 g (Herter 1965; Wroot 1985), while during autumn, prior to hibernation, they can eat up to 250 g of biomass each night. This is equal to estimates of the daily requirements of feral cats (i.e. 170g, Fitzgerald & Karl 1979). The mammal with the closest diet to that of a hedgehog is a mouse. A mouse has a daily requirement of only 3-4 g of food, but mice waste 'a bit more', as generally they eat only a proportion of the food (Murphy & Pickard 1990). Therefore hypothetically one hedgehog may consume the equivalent amount to that of up to 10 ship rats or 75 mice per night. If each hedgehog ate on average 150 g, a total of 660 kg of biomass is being removed each night from within the reserve. It is suggested this amount of biomass, while not accurately quantified, will be detrimental to the kiwi and the ecosystem as a whole. I could not locate an estimate of the kiwi consumption rate for comparison.

5.2 COMPETITION FOR OTHER RESOURCES

Hedgehogs may compete with kiwi for other resources. Habitat utilisation of hedgehogs was linked to food resources and vegetation cover. Telemetry showed that hedgehogs nested under logs, in dense vegetation and in burrows (Berry 1999). Each hedgehog uses several nests throughout its home range and actively investigates new 'better' nests. Miles (1995) and McLennan *et al.* (1987) demonstrated that kiwi utilise similar types of vegetation to the hedgehog for nest/den sites. It has been suggested that the home ranges of kiwi are closely related to the resources found within the available habitat (e.g. Potter 1990; Taborsky & Taborsky 1995). Therefore conflict will occur between kiwi and hedgehog over foraging habitats and nesting locations. A reduction in the carrying capacity of the reserve for kiwi may occur, as suitable nest sites and other resources will be harder to locate. The hedgehog's behaviour of searching for new nest locations may also lead it to disturb incubating kiwi and cause nest abandonment, even though the hedgehog's motivation was not predation

5.3 DIRECT PREDATION OF KIWI

Kiwi are possibly at risk from direct predation from Hedgehogs. Occurrences of vertebrate food items in the hedgehog diet were rare within this study. It cannot be determined whether these food items were a result of active predation or opportunistic feeding on carrion. Throughout the literature, evidence exists on the importance of vertebrates in the diet of hedgehogs. Kruuk (1964) witnessed attacks on black-headed gulls eggs and chicks. Yalden (1976) found 12% of stomachs contained mammalian remains while Shilova-Krassova (1952 in Reeve 1994) found several mice, a lizard and a snake. Moss (pers. comm.) suggested that 26% of the diet of hedgehogs in braided rivers of the Mackenzie Basin was vertebrate remains (feathers 12%, eggshells 4% and lizard 10%). Reports of predation exist for bantam chicks (W. Evans, pers. comm.) and skylarks (S. Thomsen, pers. comm.).

Direct predation of adult or large juvenile kiwi seems unlikely, as a large bird is likely to be able to fight off or evade a hedgehog, but eggs or young chicks may be at risk. Past investigations into nest predation of kiwi have been located in areas where hedgehogs are absent or are at low densities (e.g. Lake Waikaremoana, McLennan 1997). The North Island brown kiwi has the behavioural trait of leaving the nest camouflaged but unattended for up to ten hours (McLennan et al. 1996). Hedgehogs may discover nests hidden by the kiwi either as they forage for food or as they investigate new nest locations. The camouflaged entrance may not be an effective defence, as hedgehogs forage using smell and sound rather than sight. Once discovered, the size and weight of the egg is also theoretically not a defence towards a hedgehog. It has been shown that hedgehog predation of eggs is not related to the animal's ability to open its jaw (Cott 1951).

Young kiwi chicks are also at risk from occasional predation by Hedgehogs. Predation can occur within the first couple of weeks in the nest when the adult bird is away or once the chick has left the nest. Overseas studies (e.g. Herter 1965; Reeve 1994) have shown that, while foraging, hedgehogs will attack most small vertebrates that they meet. Kiwi chicks are. left on their own at 1-3 weeks of age (Heather & Robertson, 1996) and may also be at risk of predation until they reach a minimum weight and are able to defend themselves successfully.

5.4 INDIRECT PREDATION OF KIWI

Competition for food and other resources may not directly affect the survivorship of kiwi within BSMI but this competition may lead to a reduced fitness of the overall population of kiwi and thus make them more susceptible to other forms of predation. Stoat predation of small juvenile kiwi has been highlighted as a severe problem (McLennan *et al* 1996), but kiwi are considered safe from this form of predation once they reach a certain minimal weight. Direct competition with hedgehogs may reduce the duality and quantity of food within the habitat and hence increase the time required for juvenile kiwi to reach this 'minimum safe weight'.

Population dynamics of the hedgehog at BSMI

At Boundary Stream Mainland Island, pest control has been pursued intensively since 1996. Populations of the key pests (i.e. feral goats, brushtail possum, and ship rat) are kept to a minimum and the populations of mustelids are heavily reduced (S. Cranwell, pers. comm.). Mice populations are currently targeted but the effectiveness of the management regime is in question (C. Ward, pers. comm.). This study suggests that in April 1998 the reserve contained approximately 4400 hedgehogs, which is larger than the populations of other introduced mammals within the reserve, with possibly the exception of mice. However, the biomass removal and ecological impact of the hedgehog makes it the most important introduced mammal currently within the reserve. The future dynamics of the population of hedgehogs within the reserve are difficult to assess.

Telemetry studies showed that hedgehogs do not defend territories and it was concluded that they use a non-territorial despotic distribution to prevent conflicts within the population (Berry 1999). As a result the densities that a population of hedgehogs can reach are higher than species that defend territories. The fecundity of the hedgehog within the reserve is currently unknown, but general knowledge on the biology of the hedgehog may indicate the future dynamics. Hedgehogs have a great reproductive turnover, and can bear up to 10 young but on average have only 4.5 young per litter (Reeve 1994). Hedgehogs do not become sexually mature until about 9 months of age (Reeve 1994). In New Zealand, hedgehogs generally have two litters per year compared to one litter in the Northern Hemisphere (R. Brockie, pers. comm.). This high fecundity means that the population may quickly increase if other factors are not limiting.

The population of hedgehogs within the reserve is closely related to the effectiveness of the control measures employed by the Department of Conservation. Within this study, very little evidence was obtained to suggest that the current control regimes have much effect in determining the population of hedgehogs within the reserve, other than possibly making the reserve better for them by controlling other introduced mammals. Between October 1997 and April 1998, 78 hedgehogs were killed in Fenn traps, compared with 18 rodents and 8 stoats, so Fenn traps do not appear to be controlling the hedgehog population. In the past, feral cats and mustelids in the reserve may have predated on hedgehogs. However, this type of predation is rarely observed (Roser & Lavers 1976; Fitzgerald & Karl 1979). This low-level predation is likely to have been even further reduced as both mustelids and feral cats are successfully controlled at BSMI.

Hedgehogs in the past would have competed with rodents for suitable food items. This competition would have been heavily reduced since 1996 as ship rat populations have been substantially reduced throughout the reserve. Despite the removal of rats, only a slow increase in larger invertebrates has been observed since 1996 (B. Christensen, pers. comm.). It is suggested that this could be considered evidence of a compensatory increase in the hedgehog population.

As the habitat continues to improve and with the reduction in both competition for food and predation pressure, the population of hedgehogs is expected to increase. Prior to the initiation of the management regime hedgehogs were present within the reserve and were an influence on the ecosystem. It is estimated that the hedgehog population would have increased a moderate degree (40-50%) since the beginning of the management regime and this is likely to continue.

The changes to the reserve that allowed the increase in the hedgehog population are also the same reasons why the re-introduction of kiwi has been proposed. There needs to be further investigation into the long-term population dynamics of hedgehogs within BSMI and the non-treatment reserves (e.g.Thomas Bush).

7. Effects of hedgehogs on kiwi at BMSI

Hedgehogs must be considered a serious competitor of kiwi for food and to a lesser extent other habitat requirements (e.g. nest locations). Kiwi are also at minor risk from direct and indirect predation due to the presence of hedgehogs. The level of competition for resources and risk of predation depends largely on the future population dynamics of the hedgehog. The population of hedgehogs within the reserve is likely to increase from the ongoing improvement to the habitat, so whatever the adverse effects on kiwi by the population of hedgehogs at the current levels, the future effects are likely to be greater

The effect of hedgehog populations on kiwi within the BSMI depends on the time of the year. Competition for resources would be greatest during autumn when hedgehogs are feeding heavily to build up weight for hibernation. This could be important, as it coincides with the immediate pre-breeding period for kiwi which may be a sensitive time for them. However, this increase in competition is compensated by a reduction in winter as hedgehogs hibernate throughout the colder months (May to September) at BSMI (Berry 1999). As a result, competition for food and other resources between kiwi and hedgehogs will not occur during winter. This also means that the risks of predation of nests of kiwi are reduced, as kiwi lay their eggs between June to September (McLennan 1987). However, kiwi have a long incubation period (75-80 days) and overlap does exist between the egg/chick stage of the kiwi life cycle and the active period of hedgehogs at BSMI.

The hedgehog density has probably increased to a moderate degree in response to the "mainland island" pest control, but not dramatically so. Hedgehogs would have been a major influence on the forest ecosystem previously. Kiwi were present in the reserve until the last few years (McRitchie 1998) and it may be inferred that the recent local extinction was caused primarily by the predation rate due to mustelids (McLennan *et al*. 1996) and that hedgehogs did not contribute substantially to the decline. If the more serious kiwi predators are controlled to low levels, a kiwi population could be re-established successfully in the presence of the current hedgehog densities. However, it can not be simply concluded that since kiwi previously co-existed with hedgehogs within the reserve they can do so again. The importance of the hedgehog to the decline of the kiwi is unknown.

At BSMI, J. McLennan has estimated that the reserve should be able to hold up to approximately 300 adult kiwi or 0.38 per ha (McRitchie 1998). However McLennan may not have allowed for the likely detrimental impact of hedgehogs on kiwi carrying capacity in predicting a likely kiwi population of good BSMI habitat when fully restored. The effect of the current (and future) hedgehog density would be to limit the kiwi density that could be reached, mainly through food competition. Even at the current estimated hedgehog population density and the maximal kiwi density, each kiwi would be competing with 14 hedgehogs for food. With 70-80% dietary overlap and assuming hedgehog densities are essentially food-limited, it could be suggested hedgehogs eat about two-thirds of the potential kiwi food. All else being equal then (i.e. no other competition between hedgehogs and kiwi and neither kiwi nor hedgehogs being limited by predators), the carrying capacity for the kiwi might be about one-third of its potential without hedgehogs.

It is not possible with the current data to nominate a maximum hedgehog density compatible with a "flourishing" kiwi population in BSMI. It is likely that at current hedgehog densities kiwi numbers would be limited to levels well below the 300 suggested by J. McLennan, somewhere in the low-middle of the density range. It is possible the long-term viability of such an isolated population might not be assured. However, it is unlikely that hedgehogs at the current or immediately foreseeable densities would limit kiwi densities over the 3-5 years thought by Department of Conservation to be of particular concern.

8. Management of hedgehogs

Regardless of the degree of potential impact on kiwi, the hedgehog is now the most significant introduced animal in BSMI in terms of its effect on the indigenous ecosystem. Its presence in such densities is inconsistent with the ambitious ecosystem restoration goals set for the 'mainland island'. The reserve is heavily trapped and has permanent bait stations delivering poison throughout the year. While populations of other mammalian species are kept low, hedgehogs appear not to be affected by this management regime.

The management of hedgehogs involves two areas: 1) the monitoring of populations within the conservation area, and 2) the effective control of these populations.

8.1 MONITORING OF HEDGEHOGS

Trapping and tracking tunnels are being used in BSMI to indicate the abun-(lance of rodents, mustelids, and the brushtail possum. Many of these techniques have been standardised throughout New Zealand since the early 1970s, but no method exists for hedgehogs. Tracking tunnels could be adapted to allow access to hedgehogs, but making the tunnel entrance bigger may result in brushtail possums disturbing the tunnels and the tracking paper within them (C. Gillies, pers. comm.). This may not be a problem in BSMI, given the extremely low possum densities of less than 1 possum per l00-trap nights (C. Ward, per comm.)

Information on the distances travelled each night showed that the activity of an individual differs between animals and between nights. It was found that hedgehogs during summer travel on average approximately 900 metres each night. The furthest distance recorded was 2.3 km within one night (Berry 1999). Little information exists on the overall trends in behaviour of a hedgehog over a year. One possibility is that hedgehogs forage more just after coming out of hibernation (spring) and if tracking tunnels were used only during this period a false index of density would be made and the population size overestimated. Long-term research would be required, involving intensive live-trapping/monitoring, to check that tracking tunnel rates work sufficiently well to guide hedgehog management.

Another possible method is the use of scats as an indicator of overall density of hedgehogs. This method works well with both deer species (*Cervus* spp.) and rabbits (*Oryctolagus* spp.). However, hedgehogs have been shown to generally defecate near their nest and rarely at night (Dimelow 1963a; Berry 1999), but a relationship between the number of scats found per kilometre to the relative density of hedgehogs may still be developed. Further research is required before the method could be successfully used as a measure of density.

8.2 CONTROL OF HEDGEHOGS

At Boundary Stream Mainland Island, many control programmes exist, each designed to target either individual pest species or a suite of species. For hedgehogs, the ideal control method would be a small modification of an existing programme to allow effective control of them for the least amount of cost. Exactly how this can be achieved requires further research, but three areas exist: 1) trapping, 2) poisoning, or 3) other possible methods.

8.2.1 Trapping

This study was initiated because of the high bycatch of hedgehogs within the mustelid Fenn traps at Boundary Stream, which are similar to designs used throughout New Zealand. The traps consist of a long plastic tunnel (Philproof®) covering two mark IV Fenn traps either side of bait (usually either cracked fresh egg or plastic egg). The study area had an established line of Fenn traps running through it. Ideally if the bycatch method was effec tive at controlling the overall population within the reserve a high proportion of the marked hedgehogs from the present study living by the Fenn transect should have been caught, but of the 24 individuals living in the region of the transect that were marked or radio tagged, only two were ever caught by the Fenn traps.

Radio tagging made it possible for observations to be made on animal behaviour around Fenn traps without disturbing the animal. Hedgehogs were witnessed on several occasions foraging within two metres of a Fenn trap. Also one hedgehog nested approximately 10 metres away of one Fenn trap for eight days. But hedgehogs appeared not to be aware of the trap even when nearby, and hedgehogs were never observed being caught.

The catch rate in Fenn traps may give the impression that this is an effective control method but further research is need. However, it is suggested that the Fenn traps over a 12-month period are killing only approximately 15% of the hedgehog population within Boundary Stream. This is based on the animals that were marked for this study, and the fact that for 4-5 months the traps are operation, hedgehogs are in hibernation and not trappable. The catch rate might be increased with the use of different bait (e.g. fish or rabbit), better trap placement, changes in the trap density within the reserve or a combination of these factors. However, it is worth remembering that the main focus of Fenn traps is mustelids so if the traps are to be used more effectively for hedgehogs, adjustment to set-up will be required.

8.2 POISONING

At the time of fieldwork, 1080 (monofluoroacetate) was used once for the initial control at BSMI in 1996 and Brodifacoum has been used continuously since in 'Philproof®' poison bait stations. As these poisons are so widely used to control pest species, it is very important to understand their short and long-term effects on non-target species.

Brodifacoum is a rodenticide developed in the mid 1970s. It has been used successfully on offshore islands for removal of rodents but is also used to control rabbits, wallabies and brushtail possums (Eason & Spurr 1995). It works by interfering with the normal synthesis of vitamin K-dependent clotting factors in the liver of vertebrates (Hadler & Shadbolt 1975). There is no published LD_{50} figure for hedgehogs in respect of 1080 or brodifacoum.

As with mustelids (Moller *et al.* 1996), direct poisoning of hedgehogs with cereal baits is unlikely to occur. The common lures used in New Zealand include cinnamon, orange, lemon and aniseed (Cowan 1987; Eason & Spurr 1995). These are unlikely to attract hedgehogs and the probability of a hedgehog eating cereal bait appears to be small. However, reports of hedgehogs consuming 1080 jam (Moller *et al.* 1996) and eating cereal baits (S. Cranwell, pers. comm.) do exist.

While direct poisoning is unlikely, secondary (indirect) poisoning may be a viable cost-effective method of control. Brodifacoum is persistent and slow acting, so hedgehogs can accumulate a lethal dose indirectly by scavenging on poisoned carcasses, or by feeding on live prey that are about to die or have not yet gathered a lethal dose (Godfrey 1985). Most of the food of hedgehogs is invertebrates, so if secondary poisoning is to be effective, toxin transfer via invertebrates is required. There are many reports of invertebrates been seen on baits, but knowledge of the amount of poison retained by invertebrates is limited and not complete. Ogilvie *el al.* (1997) found no brodifacoum in tree weta or cockroaches or in beetles (found on bait), but 4.3 mg g^{-1} of brodifacoum was detected in cave weta found on bait.

More research has been done on invertebrates and 1080. Notman (1989) found tree weta contained 46 mg g^{-1} of 1080, while cave weta contained 4 mg g^{-1} and centipedes contained 2 mg g^{-1} of 1080. Eason *et al.* (1993) also found residues of 1080 in tree and cave weta and cockroaches but not in beetles and millipedes, spiders or earthworms. M^c^Queen & Lloyd (1998) tested fifteen species of invertebrates (all possible food items of hedgehogs). They found the mean 1080 concentration of 58 mg g^{-1} (range 22-130 mg g^{-1}).

However, these concentrations are misleading. The invertebrates sampled for these studies were collected on or near to poison baits. The majority of invertebrates do not come into contact with poison and thus the average 1080 or brodifacoum concentration within an invertebrate population would be significantly lower. It is this average level which more relevant to determining the likelihood of secondary poisoning of hedgehogs.

Other pathways for secondary poisoning include the eating of carcasses of poisoned rodents or brushtail possums, birds or lizards. Previous studies (e.g. Brockie 1959; Yalden 1976) have shown that vertebrate food items are relatively common in the diet of hedgehogs. Eason & Spurr (1995) provide a summary of bird species affected by poison programmes. Lizards have been reported of dying from consuming bait on Mauritius, but no evidence of lizard poisoning is known from New Zealand (Eason & Spurr 1995). The use of bait stations at BSMI should reduce the possibility of non-target poisoning (Brown *et al.* 1997) and thus the chances of secondary poisoning of hedgehogs.

Regardless of whether hedgehogs are poisoned directly or indirectly, the amount of poison required to kill an animal will show if poisoning is a viable method of control. Data on susceptibility of many introduced species including hedgehogs is scant. The sensitivity of many animals to poisons relates to the metabolic rate of the animal (McIlroy 1994). The lower the metabolic rate of the animal the less sensitive it is the poison. Hedgehogs have a reputation for immunity to toxins but are also considered to have a high metabolism (Reeve 1994). Ognev (1928 in Reeve 1994) suggested that hedgehogs were 35-40 times more resistant to viper venom than white mice or guinea pigs. The present study supports previous research (e.g. Brockie 1959; Wroot 1985) that hedgehogs prey on millipedes and carabid beetles, which use distasteful and/or noxious substances in defence. Herter (1965) found that hedgehogs ate meloid beetles, which are generally avoided by other predators. These beetles contain cantharidin, claimed to be 3000 times more toxic to humans than to hedgehogs (Burton 1969 in Reeve 1994). Ognev (1928 in Reeve 1994) claimed that arsenic, mercuric chloride, and opium have 'no effect whatsoever' on hedgehogs, but this seems improbable.

While anecdotal evidence of fatal poisoning of hedgehogs exists in New Zealand (e.g. Alterio 1996), historical reports have led to the belief that hedgehogs are relatively untroubled by many toxic substances. There is very limited formal evidence that hedgehogs die from consumption of poison baits or by secondary poisoning.

This study at BSMI was not designed to test the effectiveness of the current poisoning regime. However, six livers were taken from study animals and sent to the Ministry of Agriculture and Forestry for brodifacoum assay to assess the likelihood of poisoning. Four of these livers contained brodifacoum residues (Table 2).

None of the seven radio-tracked hedgehogs and 30 other marked hedgehogs died during 4 + months of intensive monitoring in the presence of brodifacoum in bait stations, although as previously noted two were killed in Fenn traps. This does not encourage optimism in a secondary poisoning approach, using brodifacoum. It is suggested that poisoning of hedgehogs may require a lot of poison to be added to the ecosystem and thus may not develop into a cost-effective method of control. However, before a decision on whether poisoning will be an effective control measure, considerable research is required.

8.3 OTHER CONTROL METHODS

There are several other viable methods for the control of hedgehogs at Boundary Stream. Possible methods range from long-term measures (e.g. biocontrol) to large pitfall traps. Biocontrol and sterilisation drugs are the 'friendly, clean' control methods. There are many diseases and parasites of the hedgehog, which were not introduced to New Zealand when the original migrants arrived in the 19th century. Parasites (e.g. hedgehog flea, *Archaeopsylla erineci*) would effectively lower the survival probability over winter. The sharing of nests and promiscuous mating system (Reeve 1986) means that the parasites would easily spread through the population. This, however, is a long-term control measure requiring serious research and high financial costs.

Use of pitfall traps to catch hedgehogs has been suggested as a possible method of control (e.g. Karori Wildlife Sanctuary; R. Empson, pers. comm.). However, this method does not seem feasible. Firstly the pitfall would need to be at least 40 cm in diameter and 80 cm deep with smooth sides. Construction of pitfall traps would be very costly in both manpower and time. Secondly, there is the problem of limiting bycatch especially kiwi. Finally, there is the lack of effective bait to attract the hedgehog to the pitfall trap. If you can develop bait to attract hedgehogs to a pitfall trap, then it would be more cost-effective to use Fenn or cage traps to catch the animals instead.

Other methods that are more site-specific include the use of dogs and manually killing hedgehogs. While this may be very expensive in both time and manpower, one person could, feasibly, in a short control period of two evenings a week over a month in early spring, control the numbers within area a size of this study (i.e. 100 hectares).

As an alternative to hedgehog control, small areas of importance could be fenced to prevent hedgehog access. While this is not actually a control method but more of a means of protecting a "conservation asset" at risk from hedgehogs, it has been used successfully to protect ground-nesting birds in Britain. The fence would only need to be approximately 40 cm high with the supports on the inside to prevent hedgehogs from climbing it. The use of hedgehog exclosures could be used on a replicated experimental basis, to assess the response of invertebrate populations to the absence of hedgehogs. This may help to determine the relative value of hedgehog control.

8.4 TIMING OF CONTROL

The timing of any method of control is critical for optimising effectiveness, to allow the least amount of work to produce the greatest result. Generally, in New Zealand poison operations occur during winter when target species are not breeding and food is scarce, but this will not kill hedgehogs, as they are hibernating and not active.

Each pest species has individual characteristics that can be used to allow effective control to occur. Hedgehogs are relatively short-lived animals. The bulk of deaths occur during winter while in hibernation (Morris 1973). Approximately one-third of hedgehogs do not survive their first winter in New Zealand (Brockie 1990). However, if individuals do survive, they have a mean life expectancy of 3.5 years in New Zealand (Parkes 1975). Intensive control of hedgehogs could be done within the first couple of months once the survivors emerge from hibernation and before the first litter of offspring. This would heavily reduce the population. It would be difficult to remove the entire population of hedgehogs from Boundary Stream, as some individuals will avoid the control methods and there is the likelihood of re-invasion from surrounding areas.

9. Conclusions

The interactions between hedgehogs and kiwi are largely unknown. If the reintroduction of North Island brown kiwi to BSMI occurred, there would exist several areas of interaction between the kiwi and the already established population of hedgehogs. Hedgehogs must be considered a serious competitor for food and to a lesser extent other habitat requirements (i.e. nest locations). Kiwi are also at minor risk from direct and indirect predation due to the presence of hedgehogs. The level of competition for resources and risk of predation depends largely on the future population dynamics of the hedgehog, and the population of hedgehogs within the reserve is likely to increase from the ongoing improvement to the habitat.

This study suggests that in April 1998 the reserve contained approximately 4400 hedgehogs. This total population is considerably larger than the populations of other introduced mammals within the reserve, with possibly the exception of mice. However, the biomass removal and ecological impact of the hedgehog makes it the most significant introduced mammal currently within the reserve. The hedgehog presence in such densities is inconsistent with the ambitious ecosystem restoration goals set for the mainland island.

It is not possible with the current data to nominate a maximum hedgehog density compatible with a "flourishing" kiwi population in BSMI. It is quite likely that at current hedgehog densities kiwi numbers would be limited to levels well below the 300 suggested by T. McLennan, and it is possible the long-term viability of such an isolated population might not be assured. However, it is unlikely that hedgehogs at the current or immediately foreseeable densities would limit kiwi in the near future.

None of the current control programmes established at BSMI appear to be effective in reducing the hedgehog population. Modification of current methods or development of new methods may need to occur. More research or trials are required before a cost-effective management regime can be prescribed.

Hedgehog exclosures could be used on a replicated experimental basis, to assess the response of invertebrate populations to the absence of hedgehogs. This may help to determine the relative value of hedgehog control. Monitoring of kiwi throughout the reintroduction and following years will provide an excellent opportunity to investigate the interactions of kiwi and hedgehogs.

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Table 1: Summary table of the analysis of food items
Analysis is based on 12 stomachs and 141 scats.

FOOD ITEM	STOMACH Percentage of Occurrence	STOMACH Percentage of Relative Volume	STOMACH Percentage of Minimum Food Items	SCAT Percentage of Occurrence	SCAT Percentage of Relative Volume	SCAT Percentage of Minimum Food Items
Beetle -Carabidae	66.67	12.50	14.06	45.39	10.07	19.78
Beetle - Other Families	50.00	9.82	9.38	49.65	12.95	19.46
Orthoptera (weta)	25.00	8.04	4.69	22.70	5.12	3.64
Hemiptera	8.33	0.89	1.56	12.77	2.48	2.53
Araneae (spider)	75.00	11.61	18.75	56.74	8.58	11.39
Chilopoda (centipede)	8.33	0.89	1.56	7.80	1.16	1.27
Diplopoda- (other millipede)	25.00	3.57	4.69	31.21	5.45	5.54
Diplopoda-(pill millipede)	75.00	18.75	20.31	80.85	31.93	24.53
Earthworms	41.67	8.04	7.81	6.38	0.83	1.42
Mollusc (snail, slugs)	41.67	5.36	7.81	10.64	1.24	2.69
Other Invertebrates (4 orders)	33.33	6.25	9.38	25.53	3.96	6.80
Vertebrate	-	-	-	4.96	0.25	0.95
Monocot	50.00	8.04	-	39.01	8.25	-
Dicot	33.33	6.25	-	29.08	3.88	-
Dirt	-	-	-	15.60	2.23	-

Table 2: Brodifacoum residues for hedgehogs' livers at BSMI

Sex	**Weight** (gm)	**Amount of Brodifacoum** (mg/kg)
Female	775	Not Detected
Female	700	Not Detected
Female	600	0.27
Female	775	0.72
Male	--	0.76
Male	750	0.04

APPENDIX 1: DIETARY ANALYSIS DATA

FOOD ITEM		SCAT SAMPLE Min number of Prey	% Total Prey	Number of Occurrences	% Occurrence	Relative Volume	% Relative Volume
Insects							
Beetles:	Total	232	36.83	102	72.34	200	14.16
	Carabidae	125	19.84	64	45.39	122	8.64
	Scarabaeidae	32	5.08	21	14.89	30	2.12
	-grass grub	24	3.81	20	14.18	22	1.56
	Longhorn	23	3.65	21	14.89	39	2.76
	Weevils	3	0.48	3	2.13	10	0.71
	Rove	2	0.32	2	1.42	1	0.07
	Stag	2	0.32	2	1.42	2	0.14
	Unknown	19	3.02	28	19.86	35	2.48
B. Larvae	Unknown	4	0.63	5	3.55	7	0.50
	Grass grub	12	1.90	8	5.67	11	0.78
Orthoptera	Tree	16	2.54	24	17.02	51	3.61
	Ground	3	0.48	4	2.84	7	0.50
	Cricket	4	0.63	4	2.84	4	0.28
Hemiptera	Homoptera	0	0.00	1	0.71	1	0.07
	- circada	13	2.06	13	9.22	26	1.84
	Heteroptera	3	0.48	4	2.84	3	0.21
Hymenoptera	Wasp	12	1.90	13	9.22	16	1.13
	Ant	2	0.32	2	1.42	2	0.14
Lepidptera	Adult	3	0.48	4	2.84	4	0.28
	Larvae/pupae	10	1.59	8	5.67	9	0.64
Diptera		10	1.59	9	6.38	10	0.71
Other Invertebrates							
Arachinda	Spider	61	9.68	73	51.77	96	6.80
	Harvestman	3	0.48	4	2.84	5	0.35
	Ticks	7	1.11	2	1.42	2	0.14
	Pseudoscorpion	1	0.16	1	0.71	1	0.07
Crustacean	Woodlice	3	0.48	3	2.13	4	0.28
	Sandhoppers	3	0.48	3	2.13	3	0.21
Myriapods	Centipede	8	1.27	11	7.80	14	0.99
	Millipede	35	5.56	44	31.21	66	4.67
	Pill Millipede	155	24.60	114	80.85	387	27.41
Earthworm		9	1.43	9	6.38	10	0.71
Mollusc	Snails	1	0.16	1	0.71	1	0.07
	Semi	8	1.27	6	4.26	6	0.42
	Slug	8	1.27	8	5.67	8	0.57
Vertebrates							
Bird	Passerine	1	0.16	2	1.42	4	0.28
	Egg	3	0.48	3	2.13	3	0.21
Mammal	Mouse	1	0.16	5	3.55	1	0.07
	Unknown	1	0.16	1	0.71	1	0.07
Plant Material							
Monocot				55	39.01	100	7.08
Dicot				41	29.08	47	3.33
Moss				7	4.96	9	0.64
Seeds				3	2.13	3	0.21
Fungi				1	0.71	1	0.07
Dirt/girt				22	15.60	27	1.91

FOOD ITEM			STOMACH SAMPLE Min number of Prey	% Total Prey	Number of Occurrences	% Occurrence	Relative Volume	% Relative Volume
Insects								
	Beetles:	Total	15	18.99	11	91.67	22	18.86
		Carabidae	9	11.39	8	66.67	14	12.50
		Scarabaeidae	1	1.27	1	8.33	1	0.89
		-grass grub						
		Longhorn	1	1.27	1	8.33	2	1.79
		Weevils						
		Rove	1	1.27	1	8.33	1	0.89
		Stag						
		Unknown	1	3.80	3	25.00	3	2.12
	B. Larvae	Unknown						
		Grass grub						
	Orthoptera	Tree	3	3.80	3	25.00	9	8.04
		Ground						
		Cricket						
	Hemiptera	Homoptera						
		- circada	1	1.27	1	8.33	1	0.89
		Heteroptera						
	Hymenoptera	Wasp	5	6.33	3	25.00	4	3.57
		Ant						
	Lepidptera	Adult						
		Larvae/pupae	1	1.27	1	8.33	2	1.79
	Diptera							
Other Invertebrates								
	Arachinda	Spider	12	15.19	9	75.00	13	11.61
		Harvestman						
		Ticks						
		Pseudoscorpion						
	Crustacean	Woodlice						
		Sandhoppers						
	Myriapods	Centipede	1	1.27	1	8.33	1	0.89
		Millipede	3	3.80	3	25.00	4	3.57
		Pill Millipede	13	16.46	9	75.00	21	18.75
	Earthworm		5	6.33	5	41.67	9	7.81
	Mollusc	Snails						
		Semi	2	2.53	2	16.67	2	1.79
		Slug	3	3.80	3	25.00	4	3.57
Vertebrates								
	Bird	Passerine						
		Egg						
	Mammal	Mouse						
		Unknown						
Plant Material								
	Monocot				6	50.00	9	8.04
	Dicot				4	33.33	7	6.25
	Moss				1	8.33	1	0.89
	Seeds							
	Fungi							
Dirt/girt								