Diet of hedgehogs (*Erinaceus europaeus*) in the upper Waitaki Basin, New Zealand: Implications for conservation

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Abstract: European hedgehogs (*Erinaceus europaeus*) have recently been identified as a conservation threat in New Zealand. Hedgehogs were kill-trapped at 14 wetland and braided riverbed sites in the upper Waitaki Basin between late October 1997 and early February 1998 and their gut contents described. The most commonly eaten prey were Coleoptera (present in 81% of 192 guts), Lepidoptera (52%; n = 192), Dermaptera (49%; n = 192), Hymenoptera (42%; n = 192) and Orthoptera (31%; n = 319). Large numbers of single invertebrate prey types were frequently eaten by individual animals, likely indicating hedgehogs' ability to take advantage of rich patches of food. Weta remains occurred in 22% of guts, with the gut of one adult male containing 283 *Hemiandrus* legs. No remains of the endangered robust grasshopper were found. Eggshell was recorded in 4% of 615 guts. Native lizard remains were found in 6% of 615 guts and three times as many adult female hedgehog guts contained lizards compared with adult males. This difference may be linked to females' high energetic demands during the breeding season. The dependence of hedgehogs on invertebrate prey is likely to have significant implications for the conservation of threatened endemic invertebrates, which often show restricted ranges. While birds' eggs and native lizards appear to be of lesser importance, small, localised populations of these fauna may still be threatened by hedgehog predation.

Keywords: diet; *Erinaceus europaeus*; hedgehog; invertebrate; lizard; predation; threatened species; weta.

Introduction

Information on a species' diet is fundamental to understanding its ecological relationships and life history. Where the species is considered a pest, this also allows an assessment of potential impacts on other components of affected ecosystems (Litvaitis *et al.*, 1996). This information can be helpful when designing management strategies that aim to reduce impacts such as predation pressure on vulnerable native prey species. This is the situation in New Zealand where native fauna have suffered from the effects of a suite of introduced mammalian predators, most of which have arrived in the two centuries since the first arrival of Europeans (Towns *et al.*, 1997; Atkinson, 2001).

European hedgehogs (*Erinaceus europaeus* L.) were deliberately introduced into New Zealand in the late 19th Century and have since become widespread in all but the most inhospitable habitats (Brockie, 1990). While not previously considered a significant threat to native fauna in New Zealand (Brockie, 1990), evidence from their native Europe and, increasingly, from New Zealand studies suggests otherwise (Kruuk, 1964; Green *et al.*, 1987; Uttley *et al.*, 1989; Jackson and Green, 2000; Sanders and Brown, 2001; Sanders and Maloney, 2002). Much of the information on the diet of hedgehogs in New Zealand is based on two published studies: Brockie (1959) examined a small sample of stomach contents and droppings, mainly from the lower North Island; and Campbell (1973) studied diet of hedgehogs on Canterbury pasture land. Given the wide diversity of habitat types within New Zealand, generalisations about the feeding behaviour of hedgehogs based on these studies alone may distort the risk posed by this species in other, more vulnerable systems.

This paper describes the diet of hedgehogs in the upper Waitaki Basin, South Island, New Zealand. A range of habitats of high conservation value are found within the basin including tarns, wetlands and up to 14% of New Zealand's open braided river habitat (Keedwell and Brown, 2001; G.H. Wilson, Landcare Research, Hamilton, N.Z. *unpubl. data*). The braided riverbeds support populations of rare bird species, including black-fronted terns (*Sterna albostriata*), wrybill (*Anarhynchus frontalis*) and the critically endangered black stilt (*Himantopus novaezelandiae*). Also present are endemic skink and gecko species and invertebrates including weta (*Hemiandrus* spp.), the threatened robust grasshopper (*Brachaspis robustus*) and a locally restricted Carabid beetle [*Metaglymma aberrans* (*tersatum*)].

Methods

Hedgehogs were kill-trapped as part of an intensive predator control programme undertaken by the Department of Conservation at 14 sites containing braided riverbed and wetland habitats of high conservation value in the upper Waitaki Basin between late October 1997 and early February 1998. Details of trapping protocols are described in Keedwell and Brown (2001). For each hedgehog killed, the date of capture, trap location, and gender were noted. Animals were classified as adult or juvenile, based on visual assessment of size and of appearance of genitalia, by trappers at time of collection. Not all available carcasses were examined.

Guts (stomach and intestines) were removed from carcasses soon after death and preserved in 70% alcohol. Contents were analysed and food items classified into taxonomic categories. Not all guts were examined to the same level of resolution because of limited time and financial restraints. Also, because the primary aim of this work was to investigate the impact of hedgehogs on a selection of native species deemed by conservation managers to be of high conservation value, a hierarchical system was used to record the presence or absence of different key prey types in each gut. Thus, 615 guts were examined for bird, eggshell and lizard remains; of these, a random sample of 354 were also searched for evidence of *Brachaspis robustus*; 319 for Orthoptera in general; and, in 192 guts, invertebrate remains were classified at least to order. Results are presented as percentage occurrence (100 × number of guts containing a food type / total number of guts examined for that food type) with 95% binomial confidence intervals following Zar (1999, pp. 527–528) Where sufficient data were available, frequencies of occurrence of each prey type were compared between demographic classes of hedgehog and between months of capture using standard chi-square tests. Sample sizes for demographic groups and months are given in Table 1.

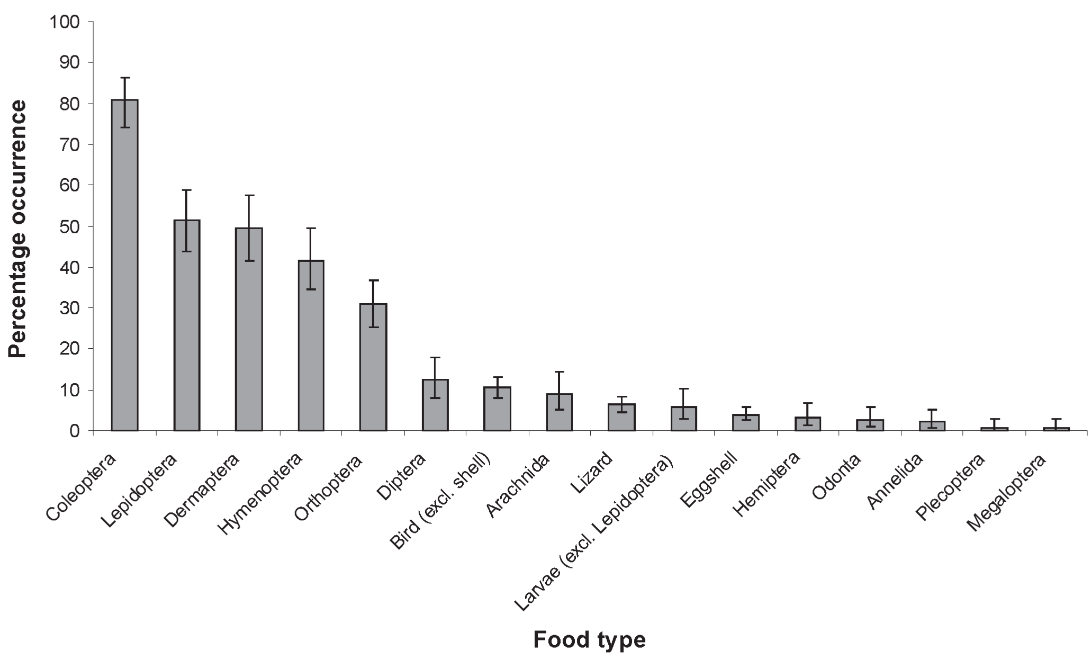

Figure 1. Percentage occurrence of food types identified from hedgehog guts obtained from the Upper Waitaki Basin, South Island, New Zealand, between October 1997 and February 1998. Error bars are 95% binomial confidence intervals. Sample sizes were: avian, shell and lizard remains, *n* = 615; Orthoptera, *n* = 319; all prey recorded, *n* = 192.

Table 1. Sample sizes, by demographic class, of 615 hedgehog guts used in analyses of dietary trends. Hedgehogs were trapped in the upper Waitaki Basin, South Island, New Zealand in November (n = 197) and December (n = 218) 1997 and January (n = 198) and February (n = 2) 1998.

	Numbers of guts				
Examined for	Adult male	Adult female	Juvenile male	Juvenile female	Total
Bird, eggshell, lizard	305	236	35	39	615
Robust grasshopper	173	137	21	23	354
All Orthoptera	157	131	17	14	319
All prey	94	78	8	12	192

Results

Beetles (Coleoptera) were the most frequently observed food item, and occurred in 81% (95% binomial confidence interval: 74–86%, n = 192) of guts examined (Fig. 1); these were mainly grass grubs (*Costelytra zealandica*, *C. odontrea*). Also common were ragwort (*Chrysomela* spp.), darkling (*Tenebrionidae*), click (*Elateridae*) and Carabid beetle species. The rare, locally restricted endemic *Metaglymma aberrans* was found in three guts.

Butterflies and moths (Lepidoptera) were found in 52% (44–59%, n = 192) of guts, the vast majority being larvae. These occasionally occurred in large numbers in a single gut: one animal had eaten 52 and three others over 30. Dermaptera (earwigs) had also been eaten by about half of the animals examined, with adult females eating these insects about one and a half times as frequently as adult males (χ^2 = 5.31; d.f. = 1; P = 0.002).

Bees, wasps and ants (Hymenoptera) occurred in 42% (34–49%, n = 192) of guts, frequently in large numbers: one gut contained 40 bumblebee (*Bombus* spp.) legs while 52 spider wasp (Pompilidae) wings were found in another. Hymenopteran remains were found more frequently in adult than juvenile guts although this difference did not reach formal significance (χ^2 = 3.37; d.f. = 1; P = 0.07).

No robust grasshopper remains were found in the 345 guts examined. Grasshoppers were found in 9% (6–13%) of 319 guts, but all identifiable remains were *Phaulacridium marginale*. Weta remains occurred in 22% (17–27%) of the samples; most were ground weta (*Hemiandrus* spp.), but a few mountain rock weta (*Hemideina maori*) were also identified. As with Lepidopteran larvae and Hymenoptera, some hedgehogs had eaten large numbers of weta, with the gut of one adult male hedgehog containing 283 *Hemiandrus* legs, indicating the consumption of at least 47 weta in a single night's foraging. Another gut contained 85 *Hemiandrus* legs. Counts of Diptera remains revealed a similar pattern, with the guts of two individuals containing 487 and 306 larvae.

Avian remains were found in 10% (8–13%, n = 615) of guts and mostly consisted of feathers, although one gut contained an entire foot. Eggshell fragments occurred in 4% (2–6%) of guts.

Lizards were identified by small pieces of skin or by feet and were found in 6% (4–8%, n = 615) of guts. Most were skink remains; the majority were McCann's skink (*Oligosoma maccanni*), with the remainder being common skinks (*O. nigriplantare polychroma*). The few geckos eaten were *Hoplodactylus* species, probably the common gecko *H. maculatus*. Lizard remains were found in three times as many adult female guts as in those of adult males (χ^2 = 11.47; d.f. = 1; P < 0.001).

Other material found in hedgehog guts included vegetation: largely grass, but also flower petals, leaves, grass and seeds including sweet briar (*Rosa rubiginosa*). Occasional bone fragments, unidentified hairs and small numbers of hedgehog spines were also recorded. The frequency of occurrence of any prey type did not vary significantly between the months for which sufficient data were available (November–January).

Discussion

The feeding patterns of hedgehogs in the upper Waitaki Basin generally match those reported for *Erinaceus europaeus* in other studies from both New Zealand and Europe. These indicate a predominantly insectivorous habit, but with opportunistic use of other food types where available. Hedgehogs feed on a range of invertebrate taxa, with a relatively small number of these making up the majority of the diet (Wroot, 1994). In this study, the most commonly eaten groups were Coleoptera, Lepidoptera (especially as larval forms), Dermaptera, Hymenoptera and Orthoptera.

Most quantitative studies of hedgehog diet report Coleopterans to be the most frequently eaten food type (e.g. Yalden, 1976; Grosshans, 1983; Wroot, 1984) and as the dietary component that provides the majority of energy intake (Reeve, 1994). Carabid and Scarabaeid beetles are generally the 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. This heavy reliance on beetles by hedgehogs is likely to have implications for the conservation of rare endemic beetles in New Zealand, such as the chafer (*Prodontia matagouriae)* that was recently discovered within the area covered by this study (Emerson and Barratt, 1997) and the Carabid, *Metaglymma aberrans*, identified in gut contents in this study.

Both Brockie (1959) and Campbell (1973) noted the importance 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). These studies also found earwig remains to be common in hedgehog guts and droppings. Although consistently consumed in relatively large numbers, the low body mass and low calorific value of earwigs means that they contribute a relatively small proportion of overall dietary energy (Yalden, 1976; Wroot, 1984). The reason for the higher frequency of occurrence of earwigs in female guts compared with those of males in this study is unclear.

Hymenoptera were also commonly eaten, occasionally in large numbers, which may reflect nest raiding by hedgehogs. This behaviour has been reported in European studies, where it has been suggested that dead or torpid insects are the most readily consumed (Yalden, 1976; Obrtel and Holišová, 1981; Grosshans, 1983). The tendency for the greater frequency of occurrence of Hymenoptera in adult guts may represent an age-related dietary shift as older hedgehogs become more successful at exploiting preferred prey types (Dimelow, 1963; Yalden, 1976; Dickman, 1988).

The occurrence of very large numbers of a particular prey in some guts suggests that hedgehogs are able to target, or at least to exploit, rich aggregations of a prey. This ability to focus foraging on a locally abundant food source has been described by Parkes (1975) in a study of hedgehogs in Manawatu, New Zealand, and by Wroot (1984) in the United Kingdom. Hedgehogs may also learn the location of rich sources of food and change their foraging behaviour accordingly (Cassini and Krebs, 1994).

The overall frequency of weta remains recorded in this study (22%) is higher than the 5% found by Brockie (1959). This probably reflects greater availability of weta in the habitats studied here. Most weta identified here were *Hemiandrus furovarius*, a ground dwelling nocturnal species that builds burrows in the stony soil of river basins. It may be highly localised in suitable habitat (Johns, 2001). These factors all predispose *Hemiandrus furovarius* to predation by nocturnally foraging hedgehogs and may facilitate the consumption of large numbers by a single animal in one feeding bout. Although this species is not considered endangered (Johns, 2001), it is restricted to the study area and continued predation pressure may be cause for concern.

The robust grasshopper is a threatened species of the highest conservation priority (McGuinness, 2001) and its absence from any of the 354 guts examined is likely to reflect this extreme rarity. The probability of a hedgehog encountering *Brachaspis robustus* is likely to be further diminished by the fact that the preferred habitat of the grasshopper is stony substrate with little vegetation cover (White, 1994). Although some hedgehogs forage in this habitat type, most are more likely to forage in more heavily vegetated areas where their preferred prey are found in greater numbers (Reeve, 1994; C. Jones *unpubl. data*). While not a commonly recorded prey type, hedgehogs appear to readily eat grasshoppers and other Orthopteran species when encountered (Grosshans, 1983; this study). Given that *Brachaspis robustus* relies on remaining motionless to avoid detection by predators, this is unlikely to be an effective defence against an olfactory-searching predator like the hedgehog.

Studies of gut contents cannot determine what proportion of the bird remains is derived from scavenging as opposed to direct predation. Hedgehogs take chicks of ground-nesting and domestic birds (Kruuk, 1964; P. Fisher, Landcare Research, Lincoln, N.Z., *pers. comm.*), and there are occasional reports of attacks on adult birds (Stocker, 1987). Sanders and Maloney (2002) found hedgehogs to be responsible for 20% of recorded predation events on nests of three native species (black stilts, black-fronted terns and banded dotterels, *Charadrius bicinctus*) nesting on braided riverbeds in the study area between 1994 and 1999. The small proportion of hedgehog guts that contained eggshell is likely to be an underestimate of the true level of nest predation, because it is the contents of the egg and not the shell that are the main source of nutrients for a predator, and these are not easily detected in gut or faecal analyses. Hedgehogs typically focus their feeding on egg contents and avoid consuming shell (M. Sanders and C. Jones, personal observations).

The impacts of hedgehog predation are likely to be significant for small populations of braided riverbed birds. Although banded dotterels are common, black stilts are classified as critically endangered and black-fronted terns as endangered (IUCN criteria: Birdlife International, 2000). Overseas, removal of hedgehogs has had a significant positive effect on nesting success of ground-nesting wader species (*Charadrii* spp.) on the Western Isles of Scotland, where hedgehogs have also been introduced (Jackson, 2001).

Hedgehogs in this study also ate native lizards, although the overall frequency of occurrence of lizard remains was relatively low (6%). Even at this level of predation, the presence of large numbers of hedgehogs in an area may still have a high impact on local native herpetofauna. There are few reliable estimates of hedgehog densities for habitats of conservation importance in New Zealand, but hedgehogs were the most frequently trapped species in the predator control programme from which these data were obtained (Keedwell and Brown, 2001). High trap rates have also been recorded in a range of other habitat types in New Zealand (King *et al.*, 1996; Hendra, 1999).

One in nine female hedgehog guts examined in this study contained lizard remains, three times the frequency for males. This pattern was also found in a smaller study carried out at Macraes Flat in north Otago (A. van der Sluijs, J. Spitzen and M. Tocher, Department of Conservation, Dunedin, *unpubl. data*). This inter-sexual difference may be related to breeding biology. Each lizard may represent a significant source of lipid and protein to pregnant or lactating females during the spring–summer breeding season. Cassini and Föger (1995) found that heavier female hedgehogs foraged more often in the most food-rich sites of a study area in England and subsequently had the highest intake rates of their preferred food, earthworms (*Lumbricus terrestris*).

The absence of more rare, locally occurring skink species such as *Oligosoma waimatense* and *O. lineoocellatum* from this sample of hedgehog guts may be a function of the relative availability of these species. The low frequency of occurrence of gecko (*Hoplodactylus* spp.) remains may reflect the tendency of these lizards to utilise rocky refugia. McCann's skinks (*Oligosoma maccanni*), on the other hand, are most abundant in the vegetated areas where hedgehogs forage most often (Patterson, 1992).

Hedgehog predation on native lizards has relevance to other ecosystems within New Zealand. Hedgehogs are widespread in the majority of low- and mid-level habitats (Brockie, 1990). They are therefore likely to co-exist with, and accordingly represent a significant threat to, other threatened lizard species. One such example is the Whitaker's skink (*Cyclodina whitakeri*), which is found in only one mainland site. Hedgehogs are also present at this site (Towns, 1999).

Analyses of gut contents are affected by the differential digestibility of prey items, with some softer-bodied prey likely to be under-represented (Dickman and Huang, 1988). In spite of this limitation, the large sample size used in this study does allow us to draw some robust conclusions. Hedgehogs depend mainly on invertebrate prey. This may have significant implications for the conservation of threatened endemic invertebrates, which often show restricted ranges. While birds' eggs and native lizards appear to be of lesser importance than invertebrates, small, localised bird and lizard populations may still be threatened by hedgehog predation. Both theoretical and empirical studies suggest that predation on such "secondary" prey is likely to be inversely density dependent with respect to prey density (Pech *et al.*, 1995; Sinclair and Pech, 1996; Norbury, 2001; Jones, 2003). This means that an abundant predator population (e.g. hedgehogs), sustained by abundant primary prey (e.g. invertebrates), can drive a small population of its secondary prey (e.g. native birds or lizards) to extinction through "incidental predation" (Vickery *et al.*, 1992) without affecting its own density. This scenario is likely to occur in areas such as that used in this study where hedgehogs are sympatric with locally threatened populations of native prey.

Further research should therefore be directed at estimating densities of hedgehogs in habitats of high conservation value and at establishing the impacts of hedgehog predation on the vital demographic parameters of populations of threatened native species. Conservation managers should be aware of the potential impacts of hedgehogs on native wildlife and should modify pest control strategies accordingly, where this species is present.

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