Skink and invertebrate abundance in relation to vegetation, rabbits and predators in a New Zealand dryland ecosystem

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Abstract: We explored the relationships between ground vegetation, ground fauna (native skinks and invertebrates), rabbits, and predators in a modified New Zealand dryland ecosystem. We hypothesised that vegetation cover would provide habitat for ground fauna. We also hypothesised that rabbits (*Oryctolagus cuniculus*) would reduce the abundance of these fauna by reducing vegetation, and by providing prey for mammalian predators (cats *Felis catus* and ferrets *Mustela putorius*) that consume ground fauna as secondary prey. We measured these variables at 30 sites across three pastoral properties in the South Island in 1996 and 2002. There were mostly positive relationships between vegetation ground cover and fauna captures in pitfall traps. Relatively few beetles and caterpillars were caught where cover was less than 80%, no millipedes were caught where cover was less than 70%, and few spiders and mostly no skinks, crickets, flies or slugs were caught where vegetation cover was less than 50%. Most grasshoppers were caught where cover ranged from 30 to 80%. Faunal species richness was also positively related to cover. This supports our hypothesis that ground vegetation provides habitat for skinks and invertebrates in this ecosystem. The introduction of rabbit haemorrhagic disease in 1997 provided a natural experiment to test the hypothesised indirect effects of rabbits on ground fauna. Declines in rabbits varied between properties, and vegetation cover and predator abundance changed according to the magnitude of these declines. However, skink and invertebrate abundance did not track these changes as expected, but instead varied more or less consistently between properties. Some fauna increased (skink captures quadrupled and cricket captures nearly doubled), others declined (flies, caterpillars and spiders), and some did not change (beetles, millipedes, slugs and grasshoppers, and faunal species richness and diversity). Therefore, rabbits, predators and vegetation did not affect changes in skinks and invertebrates in consistent ways. The dynamics of ground fauna are likely to be more influenced by factors other than those we measured.

Keywords: *Felis catus*; ground fauna; *Mustela putorius*; *Oryctolagus cuniculus*; plant cover; rabbit haemorrhagic disease; secondary prey

Introduction

There have been profound changes in vegetation in New Zealand's dry grassland ecosystems as native herbaceous and grass species have been replaced by introduced species. Some of these introduced species are known to have had major effects on the diversity and abundance of some native fauna (e.g. moths over the last 80 years; White 1991). However, the current relationships between plant and animal abundance and diversity in these modified dryland environments are largely unknown. The introduction of mammalian herbivores (e.g. livestock, rabbits *Oryctolagus cuniculus*) and predators (e.g. cats *Felis catus*, ferrets *Mustela putorius*) has also impacted on native fauna (Rebergen et al. 1998; Norbury 2001; Reardon 2006; Wilson et al. 2007; Norbury & Heyward 2008). Maintaining the diversity and abundance of remaining grassland fauna requires an understanding of the interactions between native fauna, vegetation, herbivores and predators.

We hypothesised that ground vegetation cover, irrespective of native or introduced species, would provide habitat for ground fauna such as skinks and invertebrates. We also hypothesised that rabbits would directly compete with these fauna by reducing vegetation cover (Norbury & Norbury 1996), and by providing prey for mammalian predators that consume ground fauna as secondary prey (Clapperton & Byrom 2005; Gillies & Fitzgerald 2005). The latter effect is known as hyperpredation (i.e. more rabbits result in greater predation of secondary prey; Courchamp et al. 2000) or apparent competition (more rabbits result in fewer secondary prey because there are more predators in the system; Holt 1977).

We measured the spatial relationships between the abundance, species diversity and species richness of ground vegetation and native skinks and invertebrates in a dry grassland ecosystem in 1996 and 2002 that had been modified by pastoralism. The introduction of rabbit haemorrhagic disease in 1997 provided a natural experiment to test the hypothesised indirect effects of rabbits on ground fauna.

Methods

Study sites

We collected data on sites at three study areas: Grays Hills Station (6000 ha; 44°17' S, 170°23' E), 20 km from Twizel township in the Mackenzie Basin; Bendigo Station (2500 ha; 45°2' S, 169°18' E), 10 km from Cromwell township in Central Otago; and Earnscleugh Station (1000 ha; 45° 10' S, 169°17' E), 5 km from Clyde township in Central Otago. Sheep were largely absent from Earnscleugh but grazed at unknown densities on Grays Hills and Bendigo. Rabbit haemorrhagic disease (RHD) was confirmed on all properties in late 1997 (Parkes et al. 2002).

Long-term average rainfall ranges from 385 to 456 mm per annum, and the mean monthly minimum and maximum temperatures range from 3°C in July to 17°C in January. Climatic conditions were not identical between samplings. Twice as much rain fell during the 6-month growing season before the 1996 sampling (i.e. September to February; 465 mm measured at Cromwell township) compared with the same period before the 2002 sampling (225 mm), and it was slightly cooler then (mean temperatures, 13.4°C and 14.4°C, respectively).

All three study areas are hill country with numerous rock outcrops. Vegetation consisted of scattered clumps of briar (*Rosa rubiginosa*), matagouri (*Discaria toumatou*), fescue tussock (*Festuca novaezelandiae*), and a sward of introduced grasses and herbaceous species including browntop (*Agrostis capillaris*), sweet vernal (*Anthoxanthum odoratum*), hare's-foot trefoil (*Trifolium arvense*), mouse-ear hawkweed (*Hieracium pilosella*), purging flax (*Linum catharticum*), and St Johns wort (*Hypericum perforatum*).

Sampling procedures

In March 1996, we randomly selected 10 sites at each study area. Sites were located at 300–800 m above sea level, and on even- to convex-shaped slopes of 5–15 degrees. At each site we captured skinks and invertebrates over 14 continuous days in 10 pitfall traps (plastic cups, 11 cm wide and 10 cm deep) spaced 10 m apart along a 100-m-long line transect. Traps were partly filled with the preservative ethylene glycol. Trapping was therefore lethal. Traps were operated simultaneously on Earnscleugh and Bendigo, and opened 10 days later on Grays Hills. Invertebrates were identified mostly to genus level, and to species where possible. Apart from the millipedes and one of the two caterpillar species, the fauna were native to New Zealand.

We also measured vegetation cover along each transect in March 1996 using the wheel-point apparatus of Tidmarsh and Havenga (1955). We measured cover rather than biomass because cover is easier to measure and is less affected by short-term seasonal conditions. The method involves rolling a wheel with long protruding spikes or points along the ground and recording what each point strikes. Gibson and Bosch (1996) calculated that 200 points account adequately for within-site variation in a New Zealand grassland ecosystem. Points were distributed at 1.5-m intervals along three transects at each site: one along the 100-m pitfall-trap transect, and two along parallel transects positioned 5 m either side of the pitfall-trap transect. Percentage cover of vegetation was calculated as the number of strikes on vegetation at ground level, divided by the total number of strikes, which also included leaf litter, rock, and bare ground. We recorded plant species composition at each site. Every site was resurveyed for vegetation and ground-dwelling fauna in April 2002.

We measured rabbit and predator abundance on each property from 1994 to 2003 as part of a related study on predator ecology. Rabbits, ferrets and cats were counted every 3–4 months on a transect that passed each of the 10 fauna sampling sites mentioned above. Transects lengths were 14.3 km (Earnscleugh), 13.1 km (Bendigo) and 19 km (Grays Hills). Counting on Grays Hills was not continued beyond July 1996. On each occasion, animals were counted on 2–3 consecutive nights under spotlight from the back of a slow-moving vehicle (10–15 km per hour). Counting began about 1 h after sunset by the same observer. The terrain allowed counting within a strip approximately 100 m wide. The average number of animals seen per kilometre was used as an index of animal abundance. The rabbit populations were subject to two major perturbations during the period of counting: the Bendigo and Grays Hills populations were poisoned with 1080 applied to aerially sown carrot baits in September 1994; and all populations were infected with RHD from September 1997 onwards.

Statistical analyses

We counted the number of plant and animal species (= species richness) and weighted these numbers by their relative abundance (= species diversity using the Simpson and Shannon indices; Krebs 1989). We used non-parametric tests because most of the data were not normally distributed. A Kruskal–Wallis test was used to determine differences between study areas. For most of the data, there were no significant differences between areas for a given year and so data were pooled across each of the three study areas. A Spearman's rank correlation was used to determine spatial relationships between vegetation

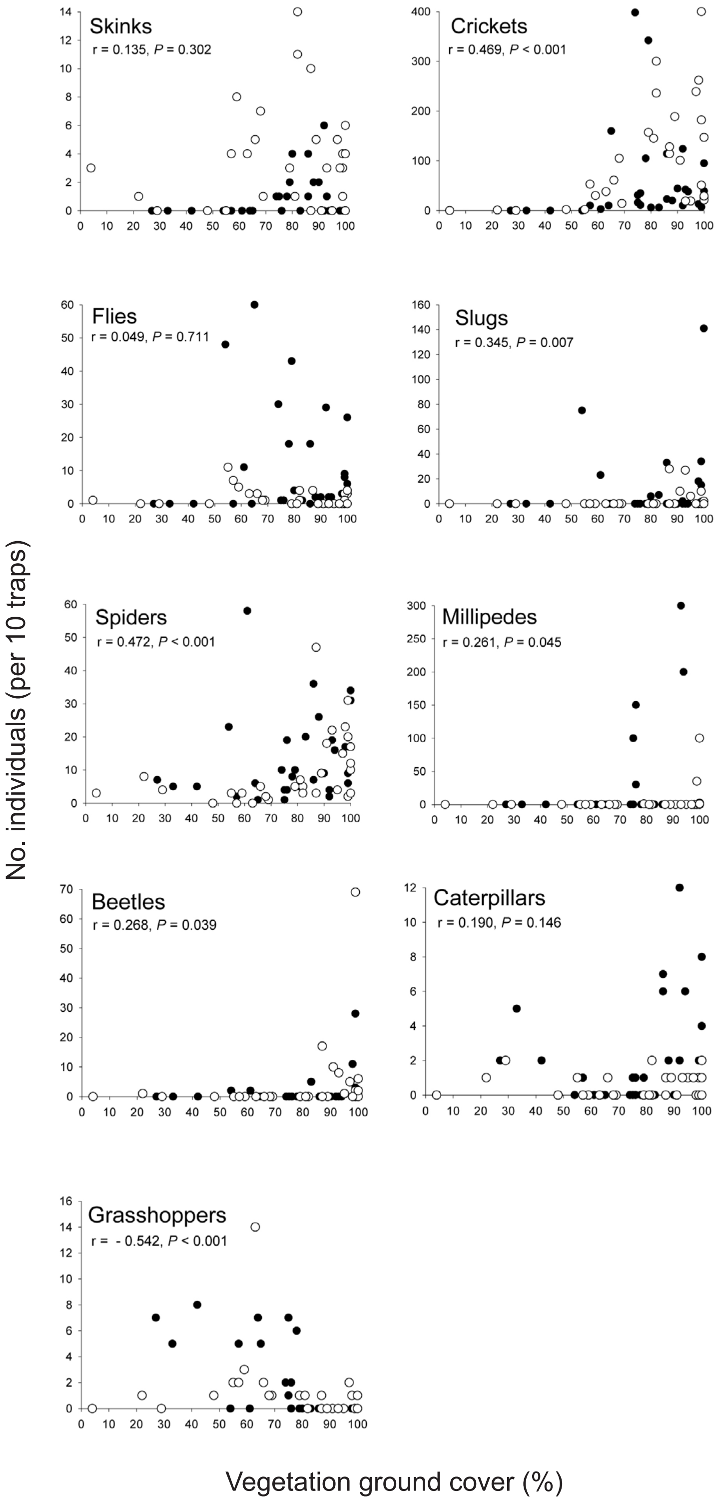

Figure 1. Vegetation ground cover and numbers of skinks and invertebrates caught in a line of 10 pitfall traps at a given site. Ten sites from each of the three study areas are shown for the 1996 (●, $N = 30$) and 2002 samples (○, $N = 30$). r = correlation coefficient.

and fauna, and a Wilcoxon signed rank test was used to determine differences between sampling occasions.

Results

Vegetation cover and ground fauna

There were mostly positive relationships between vegetation ground cover and faunal captures. The combined 1996 and 2002 data suggested thresholds in ground cover below which few or no animals were caught (Fig. 1). Relatively few beetles (Carabidae) and caterpillars (Noctuidae) were caught where cover was less than 80%, no millipedes (*Ophyiulus* sp.) were caught where cover was less than 70%, and few (<1 per trap) spiders (*Aparua* sp., *Clubiona* sp., *Anoteropsis* sp.) and mostly no skinks (*Oligosoma maccanni* and *O. polychroma nigriplantare*), crickets (*Bobilla* sp.), flies (Diptera) or slugs (Systellommatophora) were caught where vegetation cover was less than 50%. Few grasshoppers (*Phaulacridium* sp. and *Brachaspis* sp.) were caught where cover was less than 30% or where it was greater than 80%. Significantly positive relationships between vegetation cover and faunal captures were found for crickets, slugs, spiders, millipedes, and beetles. A significantly negative relationship was found for grasshoppers. The positive relationships were driven mostly by the scarcity of animals at very low ground cover.

Table 1. Vegetation ground cover, species richness and species diversity in 1996 and 2002 at the three study areas. Values are means of 10 sites. One standard deviation in parentheses. ns = no significant difference between years at the 5% probability level.

	Earnscleugh		Bendigo		Grays Hills		Mean of study areas		
	1996	2002	1996	2002	1996	2002	1996	2002	Statistical difference
% vegetation ground cover	77.9 (12.7)	92.4 (7.5)	65.4 (24.7)	55.3 (29.2)	88.2 (13.1)	82.0 (18.6)	77.2 (11.4)	76.6 (19.1)	W = −19 *P* = 0.829, ns
Plant species richness	13.5 (4.2)	16.3 (6.1)	12.3 (4.5)	10.1 (4.9)	13.3 (4.8)	9.8 (4.0)	13.0 (0.6)	12.1 (3.7)	W = −139 *P* = 0.134, ns
Plant species diversity:									
Simpson Index	0.78 (0.06)	0.68 (0.22)	0.77 (0.06)	0.65 (0.25)	0.68 (0.17)	0.61 (0.24)	0.74 (0.06)	0.65 (0.04)	W = −209 *P* = 0.032
Shannon Index	1.87 (0.27)	1.74 (0.66)	1.78 (0.30)	1.48 (0.64)	1.63 (0.57)	1.41 (0.68)	1.76 (0.12)	1.54 (0.17)	W = −205 *P* = 0.036

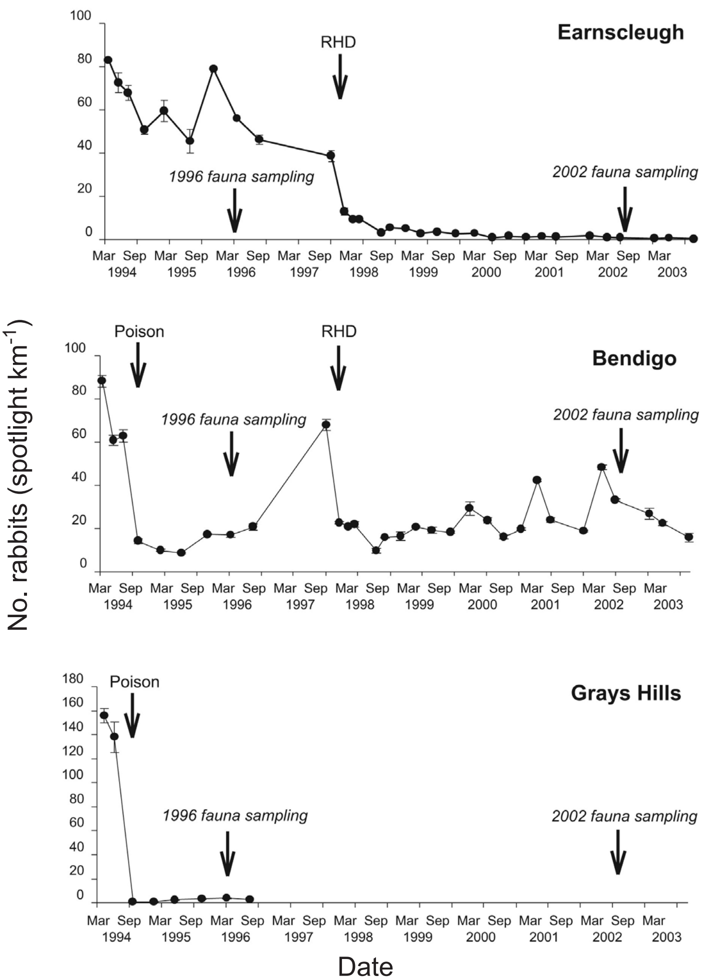

Figure 2. Numbers of rabbits seen by spotlight at night per kilometre of transect. Rabbits were poisoned on Bendigo and Grays Hills before we measured skinks and invertebrates in March 1996. Spotlighting was not continued on Grays Hills but sites nearby showed that rabbit haemorrhagic disease was very effective (Parkes et al. 2002) and therefore likely to have kept rabbit abundance low on this property. Error terms are ± one standard error among 2–3 consecutive night counts.

Although there were greater captures overall where vegetation cover was high, high cover did not always mean high captures. In areas of high cover, captures always ranged from zero to maximum levels. Inspection of the data showed that sites with high vegetation cover but with relatively low faunal captures were often dominated by exotic grasses, especially *Agrostis capillaris*. This tended not to be the case for sites with high vegetation cover and abundant fauna.

Faunal species richness was positively correlated with vegetation cover ($r = 0.278$, $P = 0.032$). There were no significant relationships between faunal diversity and vegetation cover (Simpson Index, $r = -0.204$, $P = 0.117$; Shannon Index, $r = -0.105$, $P = 0.422$), or between faunal captures, richness or diversity and plant species richness or diversity (P values ranged from 0.085 to 0.720).

Temporal changes in rabbits, predators and vegetation

Declines in rabbits varied between properties (Fig. 2), and predator abundance (Fig. 3) and vegetation cover (Table 1) changed according to the magnitude of these declines. On Earnscleugh, rabbit and predator numbers were reduced from high levels when RHD arrived. Sheep were mostly absent. There were small increases in vegetation cover on all 10 sites from an average of 78% to 92%. This was due largely to the expansion of *Agrostis capillaris* by 2002. On Bendigo, rabbit numbers actually increased from moderately low levels following a poisoning operation that occurred before we began the study. Rabbits recovered by the time RHD arrived, which reduced them again to similarly low levels but they gradually increased thereafter. Predator numbers varied over this period but did not appear

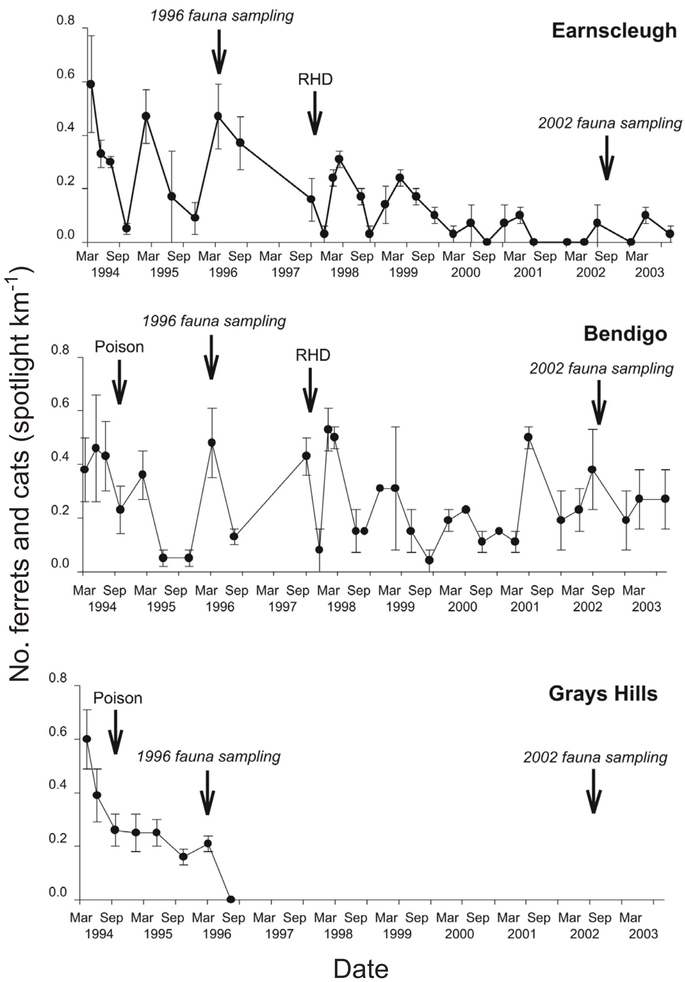

Figure 3. Numbers of ferrets and cats seen by spotlight at night per kilometre of transect. Spotlighting was not continued on Grays Hills but sites nearby showed that rabbit haemorrhagic disease was very effective (Parkes et al. 2002) and therefore likely to have kept rabbit, and therefore predator, abundance low on this property. Error terms are ± one standard error among 2–3 consecutive night counts.

Table 2. Numbers, species richness and species diversity of skinks and invertebrates captured in a line of 10 pitfall traps located at each site in 1996 and 2002 at the three study areas. Values are means of 10 sites. One standard deviation in parentheses. ns = no significant difference between years at the 5% probability level. Note: for crickets and spiders, probabilities were only slightly above 0.05.

	Earnscleugh		Bendigo		Grays Hills		Mean of study areas		
	1996	2002	1996	2002	1996	2002	1996	2002	Statistical difference
No. skinks	0.7 (1.3)	3.7 (4.1)	1.5 (2.1)	3.8 (4.2)	0.4 (0.7)	3.5 (2.4)	0.9 (0.6)	3.7 (0.2)	W = 259 $P < 0.001$
No. crickets	27.1 (34.2)	133.4 (127.1)	14.8 (14.7)	67.7 (90.2)	129.0 (138.2)	106.0 (92.9)	57.0 (62.7)	102.4 (33.0)	W = 164 $P = 0.063$
No. beetles	0.9 (1.7)	3.8 (5.9)	0 (0)	0.1 (0.3)	4.5 (8.9)	8.2 (21.5)	1.8 (2.4)	4.0 (4.1)	W = 40 $P = 0.393$, ns
No. millipedes	78.0 (106.7)	13.8 (32.2)	0 (0)	0 (0)	0 (0)	0.1 (0.3)	26.0 (45.0)	4.6 (7.9)	W = −22 $P = 0.148$, ns
No. flies	8.9 (14.9)	1.1 (1.6)	0.5 (0.8)	2.2 (3.5)	23.2 (18.3)	2.3 (2.5)	10.9 (11.5)	1.9 (0.7)	W = −217 $P = 0.004$
No. slugs	14.4 (24.2)	8.2 (10.9)	0 (0)	0 (0)	21.0 (43.7)	0.2 (0.6)	11.8 (10.7)	2.8 (4.7)	W = −42 $P = 0.146$, ns
No. caterpillars	1.6 (2.6)	0.7 (0.7)	3.0 (3.8)	0.5 (0.7)	1.7 (2.6)	0.4 (0.7)	2.1 (0.8)	0.5 (0.2)	W = −115 $P = 0.018$
No. grasshoppers	0.9 (2.2)	0.1 (0.3)	3.3 (3.4)	0.7 (0.7)	1.3 (2.3)	2.6 (4.1)	1.8 (1.3)	1.1 (1.3)	W = −40 $P = 0.441$, ns
No. spiders	20.4 (16.5)	13.6 (13.9)	7.2 (7.0)	3.6 (2.8)	12.8 (11.3)	11.3 (10.3)	13.5 (6.6)	9.5 (5.2)	W = −190 $P = 0.052$
Animal species richness	8.3 (1.7)	8.6 (1.6)	5.9 (1.6)	6.4 (2.4)	8.7 (1.3)	9.4 (1.2)	7.6 (1.5)	8.1 (1.6)	W = 87 $P = 0.270$, ns
Animal species diversity:									
Simpson Index	0.58 (0.18)	0.48 (0.25)	0.66 (0.19)	0.52 (0.30)	0.58 (0.20)	0.52 (0.23)	0.61 (0.05)	0.51 (0.02)	W = −163 $P = 0.096$, ns
Shannon Index	1.23 (0.43)	1.04 (0.50)	1.29 (0.35)	1.03 (0.53)	1.23 (0.40)	1.18 (0.50)	1.25 (0.03)	1.08 (0.08)	W = −151 $P = 0.123$, ns

to decline like those on Earnscleugh. The Bendigo sites were grazed by sheep. There were small declines in vegetation cover on nine sites, and average cover dropped from 65% to 55%, with little change in plant species composition. On Grays Hills, rabbits (and therefore predators) had already been reduced from high levels by poisoning before 1996. Rabbit and predator monitoring were not continued here but sites nearby showed that RHD was very effective in the region (Parkes et al. 2002). We therefore assumed that rabbits and predators remained low on Grays Hills. Sheep grazed these sites. There were small declines in vegetation cover on four sites, and cover dropped slightly from an average of 88% to 82%. There was little change in plant species composition. For the pooled data, no significant changes in plant species richness were observed, but plant species diversity declined (Table 1).

Temporal changes in skinks and invertebrates

Skink and invertebrate abundance did not track the above changes in rabbits, predators and vegetation as we expected, but instead varied more or less consistently between properties (Table 2). On average, skink numbers quadrupled between 1996 and 2002, and cricket numbers nearly doubled. There were significant declines in the number of flies (83% decline), caterpillars (76% decline), and spiders (30% decline). The number of beetles, millipedes, slugs, and grasshoppers captured did not change significantly. There were no significant changes in faunal species richness or diversity.

Discussion

Vegetation cover and ground fauna

Our hypothesis that ground vegetation provides habitat for skinks and invertebrates in this ecosystem was supported. Our data suggest that for the highly modified grassland ecosystem studied here, ground cover generally needs to be at least 50% to support populations of skinks and invertebrates captured in pitfall traps. Where ground cover is less than 50%, ground-dwelling fauna will be relatively scarce. This is not to say that vegetation-depleted areas are not important for certain invertebrate taxa that prefer open habitat (Patrick 1994; Peat & Patrick 1999), but less than 50% ground cover does indicate significant impoverishment of ground fauna overall. This threshold might provide a simple minimum target to maintain basic ground faunal assemblages in these modified ecosystems.

The few studies that have measured the relationships between ground cover of herbaceous vegetation and its associated fauna in New Zealand's grasslands also show declines in animal abundance where vegetation composition, stature and complexity are reduced. Patterson (1985) measured very high skink densities in intact tall-tussock grassland, but found fewer skinks where tussocks were replaced by short exotic pastures, or where burning had reduced tussock cover (Patterson 1984). White (1991) reported major declines in abundance and species richness of native moth species (e.g. Crambidae and Noctuidae) over a period of 50–70 years as the introduced grass *Agrostis capillaris* replaced native herbs on which many moths relied. There was also evidence from this study of an impoverished ground fauna where *Agrostis capillaris* dominated the sward. Jellinek et al. (2004) also found positive relationships between ground vegetation cover and lizard abundance and species richness in bushland areas near Hobart, Tasmania.

Notwithstanding these trends, we are conscious of potentially erroneous conclusions that can be drawn from pitfall trap data. It is widely recognised that pitfall trap catches depend on both population abundance and an organism's activity. However, for invertebrates at least, activity appears to be inversely related to vegetation cover due to the physical obstruction of plant material (Greenslade 1964; Crist et al. 1992; Thomas et al. 2006). If this were true of our study, it would tend to emphasise the conclusions of the work because it would have the effect of underestimating the relative abundance of invertebrates with increasing vegetation cover. Schlesinger (2007) concluded that pitfall trapping provided an unbiased method for comparing lizard abundances over a range of vegetation covers. We are also conscious of interpreting ecological thresholds too simplistically (e.g. Huggett 2005; Lindenmayer & Luck 2005). For example, the fact that we found relatively abundant fauna above 50% vegetation cover does not necessarily imply those faunal populations are viable, especially given that we also observed apparently low faunal abundance and species richness where cover was high – in other words, populations that may have already declined.

We emphasise that the ecosystems we studied were highly modified by pastoralism and are therefore unlikely to represent an intact community of indigenous ground fauna. The data are, however, indicative of the ground fauna that might be lost further from these modified ecosystems if plant cover is reduced to low levels.

Temporal changes in rabbits, predators, vegetation and ground fauna

Our hypothesis that rabbits reduce the abundance of ground fauna by reducing vegetation, and by providing prey for mammalian predators (cats and ferrets) that consume ground fauna as secondary prey, was not supported. Therefore, the dynamics of ground fauna are likely to be more influenced by factors other than those we measured. Climatic conditions can play an important role in invertebrate population dynamics (e.g. White & Sedcole 1991; Curry 1994; Samways 2005), and different faunal groups can respond in different ways (Wolda 1988). Climatic conditions were not identical between the years of this study (see Methods). If we were to repeat the trial, we would sample the fauna more frequently in order to separate short-term temporal dynamics from potentially longer term treatment effects.

This was a preliminary study. Comprehensive surveys are required to provide robust predictors of faunal assemblages in this ecosystem and to assess other factors, such as burning and grazing by livestock, which are likely to affect native fauna. This will require investigating fauna of all types (not just those caught in pitfall traps) along gradients of other vegetation parameters (not just herbaceous ground cover), habitat patch size, connectivity with other patches, edge effects, spatial context in the landscape, and less modified vegetation than examined here. These are topics for further study.

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