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INVERTEBRATES FEEDING ON BAITS USED FOR VERTEBRATE PEST CONTROL IN NEW ZEALAND

Summary: This study was initiated in response to concerns that vertebrate pest control operations in New Zealand may be having deleterious impacts on invertebrate populations and, secondarily, on insectivorous non-target vertebrate populations. Invertebrates feeding on non-toxic baits of the types used for vertebrate pest control were collected and identified. The bait types were diced carrots and three types of cereal-based baits (No.7, RS5, and AgTech). The study was conducted in two rata/kamahi dominated forests (Bell Hill Scenic Reserve and Kopara Forest, West Coast), in July and September 1996. The most common species found on baits was the ant *Huberia brouni* (Hymenoptera: Formicidae). Other common taxa were Orthoptera (at least eight species of weta including *Zealandosandrus* aff. *gracilis*, *Gymnoplectron* sp., and *Pleioplectron* sp.), Coleoptera (at least nine species of beetles including *Saphobius nitidulus*, *Nestrius* sp., and *Phrynixus* sp.), Dermaptera (at least one species of the earwig *Parisolabis* sp.), Opiliones (at least three species of harvestmen), and Acarina (at least three species of mites). The ants and weta were found predominately on cereal-based baits, and the beetles, earwigs, harvestmen, and mites predominantly on carrot baits. More invertebrates were found on carrot and RS5 cereal-based baits than on the other two bait types, and more on baits at night than during the day. Fewer invertebrates were found on cinnamon-flavoured baits (used for 1080-poisoning of possums) than on plain baits (used for brodifacoum-poisoning of rodents). The number of species and number of individual invertebrates found on baits were a small proportion of the number likely to be present in the forest litter. We predict that vertebrate pest control operations are unlikely to have any long-term deleterious impacts on invertebrate populations. This prediction should be tested by monitoring populations of invertebrate species, found to eat baits, during vertebrate pest control operations.

Keywords: Invertebrates; baits; vertebrate pest control; 1080; sodium monofluoroacetate; brodifacoum; non-target species.

Introduction

Large-scale vertebrate pest control operations in New Zealand use baits containing sodium monofluoroacetate (compound 1080) against brushtail possums (*Trichosurus vulpecula* Kerr) and brodifacoum against rats (*Rattus* spp.) and mice (*Mus musculus* L.). Several species of invertebrates also eat these baits (Notman, 1989; Pierce and Montgomery, 1992; Lloyd and Hackwell, 1993; Spurr, 1994a; Eason and Spurr, 1995; Morgan *et al.,* 1996; Ogilvie *et al.,* 1997). Compound 1080 is toxic to invertebrates, and its use for possum control poses a risk to invertebrate populations. It also poses a risk of secondary poisoning to insectivorous birds, bats, lizards, and frogs because residues of 1080 have been found in live invertebrates (Eason *et al.,* 1993). Brodifacoum is not considered toxic to invertebrates (Eason and Spurr, 1995), but because residues of brodifacoum have also been found in live invertebrates (Morgan *et al.,* 1996; Ogilvie *et al.,* 1997), there is a risk of secondary poisoning to insectivorous non-target species.

The impacts of aerial 1080-poisoning for possum control and aerial application of Talon® 20P (containing brodifacoum) for rodent control on ground-dwelling invertebrate populations have previously been assessed by counting invertebrates caught in pitfall traps before and after the control operations (Spurr, 1994a, 1996). No deleterious impacts were detected at the order or family level, but impacts at the species level have not yet been assessed. The objective of the present study was to determine the species identity and relative abundance of invertebrates eating baits used for vertebrate pest control. This would enable us to select the invertebrate species to monitor during vertebrate pest control operations and to predict the likely impacts of vertebrate pest control on their populations. The present study is complementary to two other studies, one by Wakelin, Sherley and McCartney (in press) in podocarp/hardwood forest and one by S. McQueen, B. Lloyd and R. Williams (*pers. comm.*) in beech forest, both in the central North Island.

Methods

The study was done in two rata (*Metrosideros umbellata* Cav.)/kamahi (*Weinmannia racemosa* Linn. f.) forests (Bell Hill Scenic Reserve and Kopara Forest), on the West Coast, South Island (42°33' S, 171°35' E and 42°35' S, 171°34' E), in winter 1996. Most vertebrate pest control operations take place in winter. Possums were moderately abundant at the time of the study. Rats, mice, and the weka (*Gallirallus australis* Sparrman), a native rail known to eat baits (Spurr, 1994b; Eason and Spurr, 1995), were also present.

Four types of baits used for the control of possums and rodents were compared: diced carrots and three types of cereal-based baits — No.7, RS5, and AgTech (manufactured by Animal Control Products Ltd, Wanganui). Carrots, No.7, and RS5 are used for aerial 1080-poisoning operations against brushtail possums, while AgTech and No.7 are used for aerial brodifacoum-poisoning operations against rats and mice. The cereal-based baits are also used in bait stations to control possums and rodents. All baits tested were non-toxic.

In July 1996, each bait type was distributed in five plots in each forest (i.e., 40 plots in total with a single bait type per plot). The plots were at least 50 m apart, and bait types were assigned to plots in blocked random order. Within each plot, 16 baits were placed on the forest floor on a 2 m x 2 m grid, so the average bait density (for 6-g baits) was 15 kg ha^{-1}. This is about the standard density for carrot baits but three times the density for cereal-based baits used in possum control operations. The forest floor was predominantly deep litter, with some ferns and mosses. Individual bait locations were marked with reflective tape so they could be found at night. The baits were laid out during the day, then checked on the subsequent 3 nights (1800-2200) and days (1000-1600). The weather was fine at Kopara but rainy at Bell Hill. Observations at night were made using a broad beam 6 v white light. Invertebrates in contact with baits were collected if possible or identified to family or order by sight before they escaped. We could not assume that all invertebrates in contact with baits were eating them. However, all invertebrates in contact with baits were recorded because contact with baits may be sufficient for invertebrates to be poisoned by 1080 (David, 1950). Invertebrates were sent to Landcare Research, Mt Albert, for identification.

The number of baits available for sampling invertebrates, even early in the night (1800-2200), was less than the number put out because possums, rats, mice, and weka ate some baits before they could be checked (Fig. 1). Up to 61% of the baits had been eaten by these vertebrates after 24 hours. Significantly more cereal-based baits than carrot baits were eaten ($F_{3,32} = 8.960$, $P = 0.004$). Eaten baits were replaced at each check.

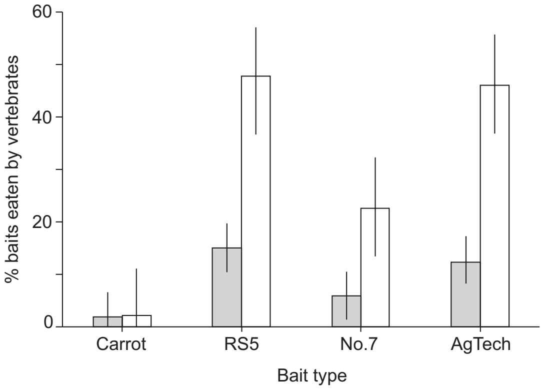

Figure 1: *Percentage of baits (mean ± S.E.) eaten by possums, rodents, or weka at night, before 2200 (black bars) and after 2200 (white bars), July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast.*

In September 1996, baits were laid out only in the 20 plots in Bell Hill Scenic Reserve (i.e., five of each bait type in blocked random order). Within each plot of 16 baits, four baits contained 0.1% cinnamon oil and 0.1% green dye (as in 1080-poisoning operations for possum control), four had only cinnamon oil, four had only green dye (as in brodifacoum-poisoning operations for rodent control), and four had neither. The baits were observed only at night for 3 nights. The weather was fine each night. Invertebrate collection and identification procedure was the same as in July 1996. Baits eaten by possums, rodents, or weka were replaced at each check.

Analysis of variance and adjusted Bonferroni pairwise comparisons (Wilkinson, 1990) were used to compare the number of each bait type or bait treatment with invertebrates on them and also the total number of invertebrates on baits of each type or treatment. Differences were considered significant at $P < 0.05$.

Results

There was no difference between the two forests in the percentage of baits with invertebrates on them (Table 1a) or in the number of invertebrates per bait (Table 1b). Consequently, the results from the two forests have been combined. There were, however,

Table 1: *Probability values* (P) *from analysis of variance of factors influencing invertebrates feeding on baits, July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast. (Key: d.f. = degrees of freedom, F = F-ratio).*

Factor	d.f.	F	*P*
(a) Factors influencing the percentage of baits with invertebrates on them			
Forest	1	0.080	0.779
Bait	3	13.862	<0.001
Time (day *cf.* night)	1	71.119	<0.001
Forest x Bait	3	2.051	0.116
Forest x Time	1	5.244	0.025
Bait x Time	3	0.621	0.604
Forest x Bait x Time	3	2.475	0.069
(b) Factors influencing the number of invertebrates feeding on baits			
Forest	1	0.567	0.454
Bait	3	13.482	<0.001
Time (day *cf.* night)	1	58.611	<0.001
Forest x Bait	3	0.940	0.427
Forest x Time	1	1.493	0.226
Bait x Time	3	0.561	0.643
Forest x Bait x Time	3	2.310	0.085

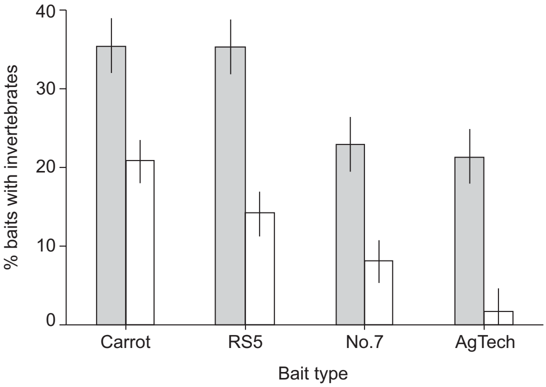

Figure 2: *Percentage of baits (mean ± S.E.) with invertebrates on them at night (1800–2200) (black bars) and during the day (1000–1600) (white bars), July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast.*

significant differences between bait types (carrot, RS5, No.7, and AgTech) and time (night *cf.* day) both in the percentage of baits with invertebrates on them and in the number of invertebrates per bait.

The percentage of baits with invertebrates on them was significantly greater at night than during the day (Table 1a, Fig. 2). Of the baits not eaten by vertebrates, 21–35%, depending upon the bait type, had invertebrates on them at night, but only 2–21% had invertebrates on them during the day. Invertebrates were present on more carrot baits and RS5 cereal-based baits than on the other two bait types (Table 2, Fig. 2). There was no interaction between bait type and time, but there was an interaction between forest and time (Table 1a). This interaction was caused by the difference between the percentage of baits with invertebrates on them at night compared to during the day being less in Kopara Forest than in Bell Hill Scenic Reserve.

The number of invertebrates per bait was also greater at night than during the day (Table 1b, Fig. 3). More invertebrates were present on carrot and RS5 cereal-based baits than on the other two bait types (Table 3). There was no interaction between bait type and time, or between forest and time (Table 1b).

The number of invertebrates per bait was similar on each of the 3 nights of observation (repeated measures, $F_{2,72} = 2.107$, $P = 0.129$). There was no interaction between bait type and night ($F_{6,72} = 1.111$, $P = 0.365$). When invertebrates were present

Table 2: *Percentage of baits with invertebrates feeding on them at night, July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast. (Percentages do not add up because some baits had more than one invertebrate taxon feeding on them. Totals with the same letter are not significantly different, as determined by Bonferroni pairwise comparisons,* P *>0.05).*

Invertebrate taxa	Carrot	RS5	No.7	AgTech
Stylommatophora	0.1	0.1	0.4	0.5
Isopoda	4.0	0.0	0.0	0.0
Amphipoda	0.1	0.1	0.4	0.1
Opiliones	7.6	1.7	3.8	1.2
Acarina	2.8	0.5	0.1	0.7
Collembola	2.6	1.2	0.9	1.9
Dermaptera	6.6	2.0	3.8	4.8
Orthoptera	1.7	5.7	5.3	6.5
Coleoptera	7.7	1.2	2.0	1.7
Formicidae	1.9	23.8	4.0	2.4
Others	6.8	2.0	4.4	1.9
Any invertebrate	35.4[a]	35.2[a]	22.9[a,b]	21.3[b]

on baits, there was mostly only one per bait (Fig. 4). The average number of invertebrates per bait at night was 0.42 for all invertebrates and all bait types combined.

At least 45 species of invertebrates were found on baits (Appendix 1). It is not possible to rank the order of abundance of species because not all have yet been identified. However, the most common species was the ant *Huberia brouni* Forel (Hymenoptera: Formicidae). This species comprised 35.4% of the invertebrates present on all baits, and 79.7% of the invertebrates on RS5 baits. Other common taxa were Orthoptera (at least eight species

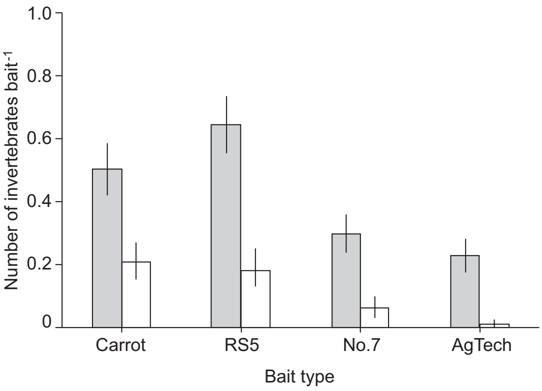

Figure 3: *Number of invertebrates per bait (mean ± S.E.) at night (1800–2200) (black bars) and during the day (1000–1600) (white bars), July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast.*

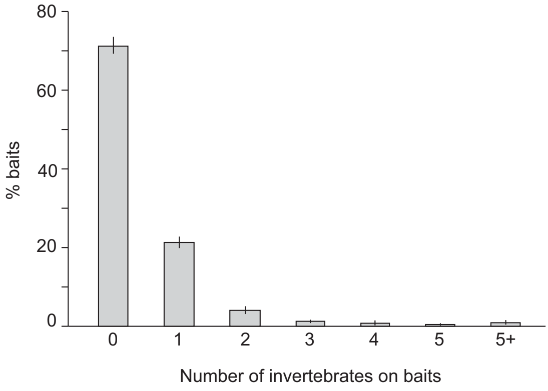

Figure 4: *Frequency distribution of the number of invertebrates per bait (mean ± S.E.) for all bait types combined at night (1800–2200), July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast.*

Table 3: *Number of invertebrates per bait at night, July 1996, Bell Hill Scenic Reserve and Kopara Forest, West Coast. (Totals with the same letter are not significantly different, as determined by Bonferroni pairwise comparisons,* P *>0.05).*

Invertebrate taxa	Carrot	RS5	No.7	AgTech
Stylommatophora	0.01	0.01	0.01	0.01
Isopoda	0.04	0.00	0.00	0.00
Amphipoda	0.01	0.01	0.01	0.01
Opiliones	0.13	0.02	0.04	0.01
Acarina	0.04	0.01	0.01	0.01
Collembola	0.03	0.01	0.01	0.02
Dermaptera	0.06	0.02	0.04	0.05
Orthoptera	0.02	0.06	0.05	0.07
Coleoptera	0.08	0.01	0.02	0.02
Formicidae	0.02	0.53	0.05	0.01
Others	0.07	0.02	0.05	0.01
All invertebrates	0.51[a,b]	0.70[a]	0.29[b]	0.24[b]

of weta including *Zealandosandrus gracilis* Salmon, *Gymnoplectron* sp., and *Pleioplectron* sp.), Coleoptera (at least nine species of beetles including *Saphobius nitidulus* Broun, *Nestrius* sp., and *Phrynixus* sp.), Dermaptera (at least one species of the earwig *Parisolabis* sp.), Opiliones (at least three species of harvestmen not yet identified), and Acarina (at least three species of mites not yet identified). The ants and weta were mostly on cereal-based baits, while the beetles, earwigs, harvestmen, and mites were predominantly on carrot baits (Tables 2 and 3). Weevils (Coleoptera: Curculionidae) and isopods (Isopoda) were found only on carrot baits. All species were found on baits more frequently at night than during the day. Millipedes (Diplopoda), Centipedes (Chilopoda), spiders (Arachnida: Araneida), harvestmen, and weta were found on baits only at night.

Fewer invertebrates were present on baits flavoured with 0.1% cinnamon than on baits without cinnamon (split plot, $F_{1,48} = 6.221$, $P = 0.016$) (Fig. 5a). However, similar numbers of invertebrates were present on green-dyed and non-dyed baits (split plot, $F_{1,48} = 0.716$, $P = 0.402$) (Fig. 5b). There was no interaction between cinnamon and green dye ($F_{1,48} = 0.926$, $P = 0.341$), cinnamon and bait type ($F_{3,48} = 0.965$, $P = 0.417$), green dye and bait type ($F_{3,48} = 0.838$, $P = 0.480$), or cinnamon, green dye, and bait type ($F_{3,48} = 0.064$, $P = 0.979$).

Discussion

Three important conclusions can be drawn from these results. First, only a few of the invertebrate species likely to be present in the forest litter were found on baits. Some whole groups, such as native earthworms (Oligochaeta: Megascolecidae), were not detected feeding on baits. Wakelin *et al.* (in press) also did not find earthworms on their baits. This may indicate that native earthworms are not attracted to baits, or may reflect the difficulty of observing invertebrates feeding underneath baits. The different assemblages of invertebrates found on carrot and cereal-based baits presumably reflect the feeding preferences of the different invertebrates. The ant *Huberia brouni*, for example, probably preferred RS5 cereal-based baits because of their high sugar content.

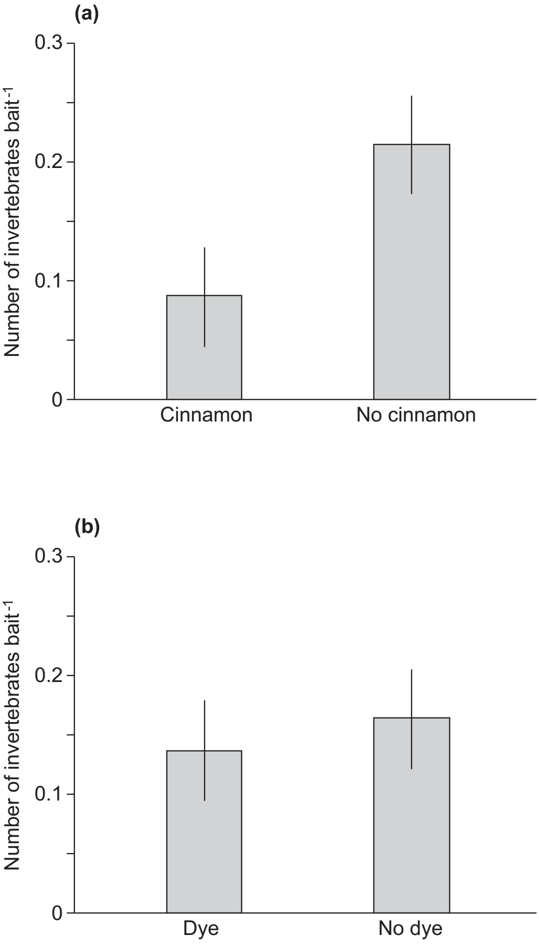

Figure 5: *Number of invertebrates per bait (mean ± S.E.) for all bait types combined at night (1800–2200), September 1996, Bell Hill Scenic Reserve, West Coast: (a) with and without cinnamon flavour, (b) with and without green dye.*

The second important conclusion from this study is that the total number of invertebrates found on baits was low compared to the number likely to be present in the forest litter. The number of invertebrates per hectare feeding on baits can be estimated as follows. Based on a bait application rate of 5 kg ha^{-1} and an average bait weight of 6 g (as in standard possum control operations using No.7 cereal-based baits), the initial bait density would have been 833 baits ha^{-1}. Consumption of baits by possums, rodents, and birds would reduce the initial density of baits, but this has been ignored in the following calculations. Given an initial bait density of 833 baits ha^{-1} and an average of 0.3 invertebrates $bait^{-1}$ (as observed on No.7 cereal-based baits in this study), then there would have been 250 invertebrates ha^{-1} eating baits at any one instant at night. Moeed and Meads (1986) estimated the equivalent of about 547 million invertebrates ha^{-1} in broadleaf-podocarp litter in the Orongorongo Valley in winter. If a similar density of invertebrates is present in rata-kamahi forests in winter, and each invertebrate fed on baits for 1 minute, then the total number of invertebrates feeding on baits during 1 night (720 minutes) would be less than one-thousandth of the number present in the litter. The proportions differ for different taxa and different bait types, but this does not alter the conclusion that only a low proportion of the invertebrates likely to be present in the litter fed on baits. Thus, we predict that aerial 1080-poisoning for possum control is unlikely to have any long-term deleterious impact on invertebrate populations. There is also likely to be a only low risk of secondary poisoning to insectivorous predators from either 1080-poisoning or brodifacoum-poisoning operations.

The third important conclusion from this study is that different bait types and treatments attracted different numbers of invertebrates. Overall, there were fewer invertebrates feeding on No.7 and AgTech cereal-based baits than on the other bait types. The addition of 0.1% cinnamon oil to baits reduced the incidence of invertebrates feeding on baits by more than 50%. The repellency of cinnamon oil to invertebrates has been observed before (E.B. Spurr, *pers. obs.*). Cinnamon oil reduces the risk of direct poisoning of invertebrates and also the risk of secondary poisoning of insectivorous non-target species.

It is possible that the abundance of invertebrates on baits could have been underestimated. Some taxa, such as earthworms, amphipods, collembolans, and cockroaches, may have been able to detect the approach of the observer and/or light, and move away unnoticed. A time-lapse video recorder and infra-red light could be used to overcome any influence of observers, but would greatly reduce the number of baits that could be sampled and/or increase the time required for sampling. Invertebrates that feed underneath baits (e.g., earthworms) would also be more difficult to detect than invertebrates that feed on top of baits.

The conclusions of this study are preliminary because the results apply only to the two rata/kamahi forests studied and only to the time that the study was done. The results, especially the species composition and abundance of invertebrates eating baits, may be different in other rata/kamahi forests and at other times. They may also be different in other forest types. Thus, Wakelin *et al.* (in press) found some species eating baits in a podocarp/hardwood forest near Ohakune that were different from the species we found in rata/kamahi forest at Kopara and Bell Hill, and vice versa. However, as in our study, they found relatively few species of invertebrates on baits. The most common were the ant *Huberia brouni* on cereal-based baits, and the beetle *Saphobius squamulosus* (Broun) on carrot baits. They also found only a low number of invertebrates on baits (average about 1.5 invertebrates per bait for baits with invertebrates on them).

Our prediction that aerial vertebrate pest control operations are unlikely to have any long-term deleterious impacts on invertebrate populations needs verifying. The invertebrate species that should be monitored in a particular control operation will need to be determined by identifying which species are attracted to the bait type being used (e.g., carrot or cereal) in the location where the control operation is to take place.

Acknowledgements

We thank the Foundation for Research, Science and Technology for funding; the Department of Conservation for permission to work in Bell Hill Scenic Reserve and Kopara Forest; G. Sherley for discussions about experimental design; J. Berry, T. Crosby, G. Hall, and G. Ramsey for invertebrate identification; R. Barker and W. Ruscoe for statistical advice; C. Eason, P. McGregor, and D. Morgan for commenting on drafts of the manuscript; C. Bezar for editorial services; and W. Weller for final word-processing.

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Appendix 1: *List of invertebrate species collected from on or under baits used for vertebrate pest control, Kopara Forest and Bell Hill Scenic Reserve, West Coast, New Zealand.*

Class	Order	Family	Species
Gastropoda	Stylommatophora		Snail 1
			Snail 2
			Slug 1
Turbellaria	Tricladida		Flatworm 1
Crustacea	Isopoda		Isopod 1
			Isopod 2
	Amphipoda	Talitridae	Amphipod 1
Arachnida	Araneida	Thomisidae	*Sidymella* sp.
	Opiliones		Harvestman 1
			Harvestman 2
			Harvestman 3
	Acarina		Mite 1
			Mite 2
			Mite 3
Diplopoda			Millipede 1
Chilopoda			Centipede 1
Symphyla			Symphylan 1
Collembola	Collembola	Entomobryidae	Collembolan 1
		Entomobryidae	Collembolan 2
		Sminthuridae	Collembolan 3
Insecta	Blattodea	Blattidae	Cockroach 1
	Dermaptera	Labiduridae	*Parisolabis* sp.
	Orthoptera	Stenopelmatidae	*Hemideina crassidens* (Blanchard)
		Stenopelmatidae	*Zealandosandrus gracilis* Salmon
		Stenopelmatidae	*Zealandosandrus* sp.
		Rhaphidophoridae	*Isoplectron* sp.
		Rhaphidophoridae	*Talitropsis* sp.
		Rhaphidophoridae	*Gymnoplectron* sp.
		Rhaphidophoridae	*Pleioplectron* sp.
		Rhaphidophoridae	*Weta* sp.
	Hemiptera		Heteropteran 1
	Coleoptera	Carabidae	*Neoferonia* sp.
		Pselaphidae	Beetle 1
		Scarabaeidae	*Saphobius nitidulus* Broun
		Elateridae	*Thoramus perblandus* Broun
		Curculionidae	*Nestrius* sp.
		Curculionidae	*Phrynixus* sp.
		Curculionidae	Weevil 1
		Curculionidae	Weevil 2
		Curculionidae	Weevil 3
	Diptera		Dipteran 1
	Lepidoptera	Psychidae	*Grythotheca* sp.
		Oecophoridae	*Gymnobathra* sp.
	Hymenoptera	Formicidae	*Huberia brouni* Forel
		Formicidae	*Prolasius advena* (Smith)