Does rat control benefit forest invertebrates at Moehau, Coromandel Peninsula?

S.R. Rate

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A B S T R A C T

Many of New Zealand's indigenous invertebrates are predated on by introduced mammals, but the impacts of this on their populations remain little understood. The effect of rat (*Rattus* spp.) control on invertebrates was examined in two forest types near Moehau, Coromandel Peninsula, between 2002 and 2007. Rat control had no effect on the relative abundance, diversity and body length of pitfall-trapped invertebrates, except for a significant reduction in numbers of ants (Formicidae). There was strong spatial and temporal variation in several of the invertebrate indices measured, and site and sample date were the main factors separating samples based on invertebrate community composition. These results suggest that rat control has not benefited invertebrate populations at Moehau. However, it is possible that some invertebrates that are susceptible to predation by rats were not adequately sampled, that predatory pest mammals were not reduced to low enough levels to elicit a measurable invertebrate response, or that invertebrate responses would only be measurable over a longer time span. Therefore, further research into the effect of rodent control on mainland invertebrate populations is required. Several recommendations are made to improve future studies.

Keywords: rodent control, rat, *Rattus* spp., invertebrates, Moehau, Formicidae, ants, mainland

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1. Introduction

New Zealand's indigenous invertebrates continue to suffer losses through predation by introduced mammals. Some indigenous species are particularly vulnerable because, in the absence of mammalian predators, they have evolved to become large-bodied, flightless, often ground-dwelling, and nocturnal (Gibbs 1998). In addition, the main defence mechanism of some invertebrates (such as weta: Orthoptera) against endemic predators (e.g. tuatara and birds) is to remain still when threatened. To complicate matters, some weta have a strong odour. Neither of these traits is advantageous when dealing with introduced predators that rely on both sight and smell to locate prey (McGuinness 2001).

Evidence that rodents impact on invertebrate populations in New Zealand originally came from research investigating the effects of rodent eradications on islands (e.g. Newman 1994; Green 2002; Rufaut & Gibbs 2003; Sinclair et al. 2005). In more recent years, this research has been supplemented by studies investigating the effects of rat control on land snail populations (e.g. Sherley et al. 1998; Bennett et al. 2002) and an increasing number of mainland studies investigating the effect of rodent control on arthropods (e.g. Spurr 1996; Hunt et al. 1998; King 2007), although several of these were designed to detect potential adverse effects as a result of poisoning (Spurr & Berben 2004; Powlesland et al. 2005). Eradication of rats has been implicated in altered invertebrate abundance (Green 2002; Watts 2004), species richness (Sinclair et. al. 2005) and diversity (Hutcheson 1999), and changes in age class structure and behaviour (Rufaut & Gibbs 2003). However, these responses have not always been positive (Craddock 1997; Sinclair et al. 2005). Furthermore, many invertebrate groups have shown no response to rodent control or exclusion of rodents (e.g. Green 2002; van Aarde et al. 2004).

To increase understanding of invertebrate responses to rodent control on the mainland, invertebrates were collected from treatment sites (where rats were controlled) and non-treatment sites in two forest types at Moehau, Coromandel Peninsula.

2. Objectives

The aim of this study was to determine the effects of rat control on forest invertebrates at Moehau, Coromandel Peninsula. Specific questions to be answered were:

- Does rat control result in changes in invertebrate abundance?
- How do invertebrate community structure and composition change after rat populations are managed?
- Do different invertebrate groups respond to rat control in different ways?

3. Methods

3.1 STUDY SITE

The Moehau Ecological Area is situated at the northern end of the Coromandel Peninsula, c. 70 km north of Thames on the east coast of the North Island (Fig. 1). Characteristic landforms of the peninsula include long ridges and steep streams radiating out to the coast, steep and broken hillslopes, floodplains, harbours, and estuaries (Amoore & Denyer 2006). Volcanic rocks of the Coromandel Group overlay Jurassic siltstone, sandstone and conglomerate. On the Moehau Range there are intrusions of a quartz diorite pluton. Soils on hillslopes and steeplands are mainly clayey and infertile, with depth decreasing with increasing steepness of the terrain. The climate is mild, moist and oceanic, with annual rainfall of 1250–2500 mm and summer droughts (McEwen 1987). Moehau (892 m a.s.l.) is the highest point.

The study area was bisected by Stony Bay Creek, with the treatment area to the north and the non-treatment area to the southeast of the creek (Fig. 1). Study sites were stratified by altitude/vegetation type (200 m a.s.l./mature kanuka (*Kunzea ericoides*) forest versus 400 m a.s.l./podocarp/hardwood forest) and treatment (rat control versus no rat control). Thus, 'Knt' (200 m a.s.l.) and 'Pnt' (400 m a.s.l.) were in kanuka and podocarp/hardwood forest, respectively, in the non-treatment area; and 'Pt' (400 m a.s.l.) and 'Kt' (200 m a.s.l.) were in podocarp/hardwood forest and kanuka, respectively, in the rat control area (Table 1). The treatment area comprised 357 ha, while the non-treatment area encompassed 489 ha.

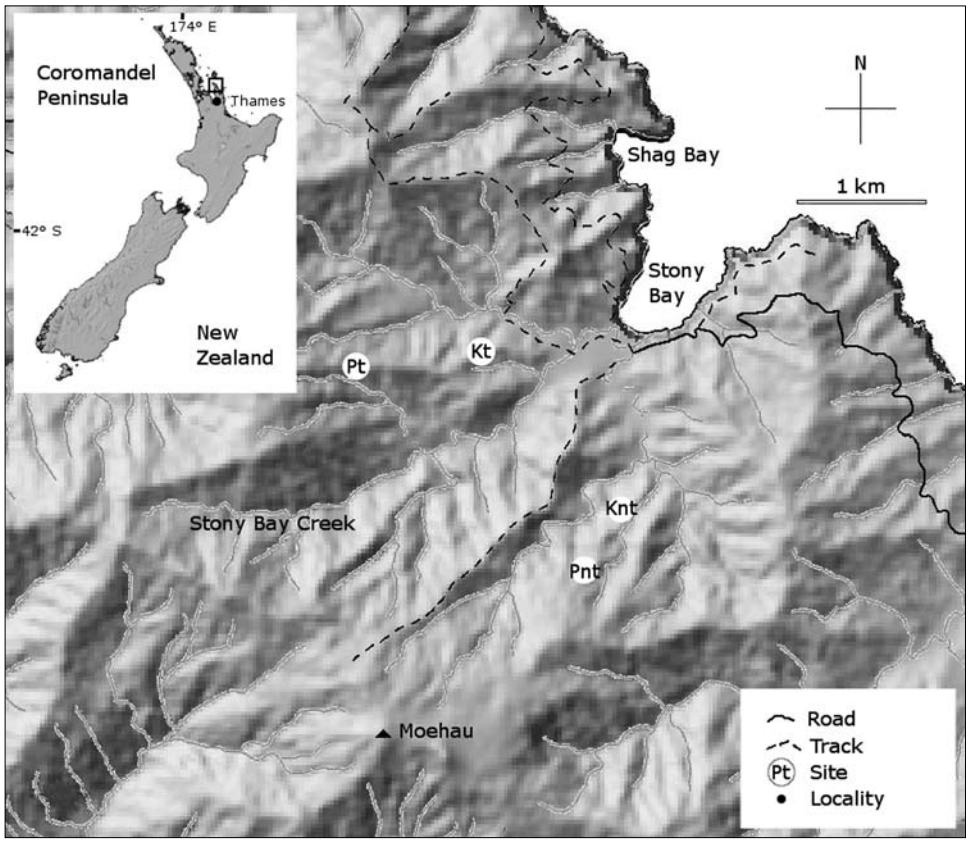

Figure 1. Location of the study sites at Moehau, Coromandel Peninsula. Knt: kanuka (*Kunzea ericoides*) forest, non-treatment; Pnt: podocarp/hardwood forest, non-treatment; Pt: podocarp/hardwood forest, treatment; Kt: kanuka forest, treatment.

TABLE 1. INVERTEBRATE SAMPLING SITE DETAILS AT MOEHAU.

SITE	TRAPS (*n*)	ALTITUDE (m a.s.l.)	TREATMENT	FOREST TYPE	COORDINATES
Knt	1–20	200	Nil	Kanuka (*Kunzea ericoides*)	E2727394 N6516766
Pnt	21–40	400	Nil	Podocarp/hardwood	E2727034 N6516280
Kt	61–80	200	Rat control	Kanuka	E2726140 N6518000
Pt	41–60	400	Rat control	Podocarp/hardwood	E2725271 N6517923

Mature kanuka forest at Knt and Kt is typically c. 10 m tall, with occasional mahoe (*Melicytus ramiflorus*) and rewarewa (*Knightia excelsa*) in the canopy, and abundant silver fern (*Cyathea dealbata*) in the understorey, along with mingimingi (*Leucopogon fasciculatus*), hangehange (*Geniostoma ligustrifolium*) and kanono (*Coprosma grandifolia*). Climbing rata (*Metrosideros* spp.), five-finger (*Pseudopanax arboreus*), mahoe, hound's tongue fern (*Microsorum pustulatum*), rangiora (*Brachyglottis repanda*) and mangemange (*Lygodium articulatum*) are also present. Hooked sedges (*Uncinia* spp.) and bush rice grass (*Microlaena avenacea*) are dominant in the ground cover vegetation.

Podocarp/hardwood forest at Pnt and Pt contains kohekohe (*Dysoxylum spectabile*), and occasional miro (*Prumnopitys ferruginea*), Hall's totara (*Podocarpus hallii*), northern rata (*Metrosideros robusta*), pukatea (*Laurelia novae-zelandiae*), mahoe and rewarewa in the canopy. The understorey is dominated by *Cyathea smithii*, silver fern, patches of wheki (*Dicksonia squarrosa*) and a wide range of broadleaved species (but mostly kanono and hangehange). There is a scree substrate under much of the forest (Pim de Monchy, formerly Waikato Conservancy, DOC, pers. comm. March 2008).

Pest animals known to be present within the study area include ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*), house mice (*Mus musculus*), brushtail possums (*Trichosurus vulpecula*), feral cats (*Felis catus*), mustelids (*Mustela erminea*, *M. nivalis*, *M. furo*), feral pigs (*Sus scrufa*), and European hedgehogs (*Erinaceus europaeus*), all of which feed on indigenous invertebrates (King 1990).

3.2 INVERTEBRATE MONITORING

At each site, 20 pitfall traps were set out along a 90-m transect, with paired traps placed 5 m apart and perpendicular to the line at 10-m spacings. Trap design was adapted from Moeed & Meads (1985) to the specifications of Green (2000). In essence, a soil corer was used to create a hole in the soil, into which a section of PVC tubing was placed, with its upper edge at ground level. A plastic drinking cup was then placed into the tubing, to which was added a 50-mL mixture of monoethylene glycol antifreeze (30%) and water (70%), a drop of detergent (to reduce surface tension), and a teaspoon of salt (sodium chloride).

Invertebrate monitoring began in October 2002 and continued to August 2007. During this time, trap contents were collected at approximately monthly intervals by Department of Conservation (DOC) staff or contractors, and later rinsed with water and stored in alcohol prior to sorting. Invertebrate samples were sorted to morphospecies (or recognisable taxonomic units, RTUs) (after Oliver & Beattie 1996) by three different personnel using a low-magnification binocular microscope. Only obvious morphological characters, such as body size, shape and colour, were used to classify RTUs. Body length (defined as the distance between the anterior of the head and the posterior of the abdomen) was measured to the nearest millimetre by laying specimens on a grid sheet. Invertebrates < 3 mm in length, springtails (Collembola) and mites (Acari) were excluded from counts. Various criticisms have been raised regarding the use of morphospecies in ecological studies (see Krell 2004 for a good overview), but they have gained widespread use mainly because less funding is required for projects. Morphospecies have been used previously to evaluate the impacts of rodent control on invertebrate populations in New Zealand (e.g. Sinclair et al. 2005).

3.3 RAT CONTROL

Rat control was carried out in the northeast Stony Bay Creek catchment, beginning with 1080 in June 2005 after a cereal pre-feed. Subsequent poisons used were Racumin (Coumatetralyl), Pindone and Diphacinone. Poison was placed in Philproof feeder stations, which were laid out at 75-m intervals on lines 75 m apart. The timing of all control operations is outlined in Table 2.

TABLE 2. DETAILS OF RAT (*Rattus* spp.) CONTROL OPERATIONS CARRIED OUT AT NORTHEAST STONY BAY CREEK CATCHMENT, MOEHAU, APRIL 2005 – OCTOBER 2007.

DATE/PERIOD	PRE-FEED/POISON	CONCENTRATION	AMOUNT
28 April – 11 May 2005	RS5 pre-feed cereal pellets	N/A	Two fills per station
26 May 2005	1080	1.5 g/kg in cereal pellets	300 g per station
27 June 2005	Racumin (Coumatetralyl)	0.375 g/kg block	300 g per station
22 July 2005	Racumin (Coumatetralyl)	0.375 g/kg block	300 g per station
25 August 2005	Racumin (Coumatetralyl)	0.375 g/kg block	100 g per station
1 December 2005	Racumin (Coumatetralyl)	0.375 g/kg block	100 g per station
10 January 2006	Racumin (Coumatetralyl)	0.375 g/kg block	100 g per station
20 February 2006	Racumin (Coumatetralyl)	0.375 g/kg block	100 g per station
March 2006 – May 2007	Pindone; Diphacinone	0.5 g/kg in cereal pellets; 0.05 g/kg paste	Two-monthly pulsing alternating between 500 g of Pindone pellets and 300 g of Diphacinone paste 2 months later

3.4 RAT AND POSSUM MONITORING

Rats were monitored using tracking tunnels, following the procedures outlined in Gillies & Williams (2001). At each site, six tracking lines were used with ten tunnels set 50 m apart per line. The percent tracking rate is the mean percentage of tunnels tracked at each tracking line.

Possums were monitored using the standardised residual trap catch (RTC) method (NPCA 2002), with 3–5 trap lines at each site and 20 traps at 10-m intervals per line. The %RTC represents the number of traps that captured a possum per 100 trap nights. One pre-treatment (27 January 2004, three trap lines) and one post-treatment (30 August 2005, five trap lines) possum monitoring operation was carried out.

3.5 DATA ANALYSIS

3.5.1 Data preparation

Data and results from the 2002–2005 period were incomplete. Data were only considered to be suitable for analysis when invertebrate counts were available for all sites within a sample period. Therefore, when data from one site were missing, the entire month's data for all sites were discarded. Invertebrate lengths were averages for all specimens of a given taxon within a sample date.

3.5.2 Univariate analyses

Analysis of variance (ANOVA) was undertaken to determine the response of invertebrates to rat control. The philosophy in undertaking the analysis was to keep the model as simple as possible, to aid in interpretation and to account for correlation between, and interdependence of, factors/variables included in the model. In particular, individual traps within lines were not independent, so the data for all traps within a particular line were pooled. In addition, observations within site/treatment combinations were correlated (e.g. if beetles were initially collected in high numbers at one site, then it is more likely that beetles would again be trapped in high numbers at that site than at a site that previously had low numbers of beetles in the preceding collection period), so blocks of data (i.e. October–January of each year) were used for each analysis. This assumes that the correlation between years is much lower than that between months. Another reason for using blocks of data was that the incorporation of data from more than one sorter into each block of data will have reduced the influence of sorter error. The October–January blocks were selected based on availability of data (see section 3.5.1) and the need to at least partially incorporate seasonal periods when taxa were more active and likely to be collected (cf. Cartellieri & Lövei 2003). It should also be noted that treatments were unreplicated (there was only one treatment and one non-treatment area) and this could not be controlled for in analyses.

The following ANOVA model was used:

Response = period + forest type + treatment + period:treatment + error

where 'response' is the invertebrate variable (e.g. morphospecies richness; see below); 'period' is before or after the initiation of rat control; 'forest type' is kanuka or podocarp/hardwood forest sites; 'treatment' is treatment (rat control) or non-treatment areas; 'period:treatment' represents the interaction between period and treatment; and 'error' accounts for all unexplained variation in the data. A Dunn-Šidák correction ($\alpha' = 1 - (1 - \alpha)^{1/k}$, where $\alpha = 0.05$ and k is the number of tests) was used to lower the Type I error of the statistic of significance for all comparisons in the series of tests undertaken (Quinn & Keough 2002). Since inclusion of the interaction term reduces the power to detect significant main effects, the interaction term was removed from the model when it was not significant. For ANOVA, it is assumed that the error term has a normal distribution and constant variance. This was examined graphically (i.e. normal Q-Q plot, residuals versus fitted values, predicted versus residuals), and data were transformed where this assumption was not met. However, not all data could be normalised using $\log_{10}$-transformation, so that some planned analyses (e.g. those for Hemiptera) were not carried out. The model had insufficient degrees of freedom to detect differences in invertebrate parameters within a particular forest type (i.e. the before:after comparison had to be consistent across forest types).

To determine the effect of treatment on the entire invertebrate community at each site, the following response variables were used: total invertebrate catch (hereafter referred to as 'abundance', N), morphospecies richness (T), Shannon diversity index (H′), Dominance ($D = \text{sum}((n_i/n)^2)$, where n_i is number of individuals of taxon i), Equitability ($J = H'/\ln T$), Buzas and Gibson's evenness (eH'/S), Fisher's alpha diversity index (α, defined by $T = \alpha * \ln(1+N/\alpha)$), Margalef's richness index ($R1 = T - 1)/\ln(N)$), and Simpson's index (1 – D). All indices were calculated as mean per trap per site.

As the critical differences between treatments might only be reflected in invertebrate biomass and/or by particular taxonomic groups, several ordinal and family groups were selected for analysis *a priori*, based on their relatively high numbers across sites and treatments, and the wide range of size classes present. These groups were the Amphipoda, Araneae, Carabidae (Coleoptera), Coleoptera, Diplopoda, Diptera, Formicidae (97.4% of trapped Hymenoptera), Isopoda, Opiliones, Orthoptera, and Scarabidae (Coleoptera). To test whether large prey items were affected by possum predation, two further analyses were undertaken based on Coleoptera and Orthoptera > 20 mm in length (after Watts 2004).

The final univariate analyses undertaken were based on invertebrate body length, which may also have been affected by treatment (e.g. through reduced predation of larger invertebrates in the treatment area). Due to the difficulties associated with accurately measuring fine-scale variation in small invertebrates, only commonly trapped invertebrates with an average length > 10 mm were selected for these analyses, i.e. the Carabidae, Diplopoda and Orthoptera.

All ANOVA analyses were undertaken using S-Plus® Professional 6 (Insightful Corporation 2001).

3.5.3 Multivariate analyses

To determine the effect of rat control on invertebrate community composition, two-way crossed analysis of similarities (ANOSIM) was undertaken, with site and year as factors. Months within years were considered to be replicate samples. Bray-Curtis similarities of abundance were used because this distance measure ignores instances where species are absent from two or more samples, which are of little interest (Quinn & Keough 2002). Data were fourth-root transformed before undertaking analyses, to downplay the importance of abundant species while retaining most of the original abundance information (Clarke 1993). An ANOSIM R value of below 0.25 indicates groups that are barely separable, $R > 0.5$ indicates groups that are overlapping but clearly different, and $R > 0.75$ indicates groups that are well separated (Clarke & Warwick 1994). Two matrices were constructed using both pre- and post-control data, and the results were compared between the two periods.

For illustrative purposes, non-metric multi-dimensional scaling (nMDS) of invertebrate samples was also undertaken, using the same similarity matrices used for ANOSIM. This plots samples based on their similarity—samples that are close together are more similar in species composition than samples that are further apart.

All ANOSIM and nMDS analyses were undertaken using PRIMER version 6.1.10 (PRIMER-E Ltd 2007).

4. Results

4.1 INVERTEBRATE ABUNDANCE AND DIVERSITY

A total of 141 478 invertebrates were collected in pitfall traps between 2002 and 2007. The mean number of invertebrates caught per trap showed marked seasonal variation at all sites, with highest catches generally obtained in summer (Fig. 2). There was also between-year variation, with abundance peaking in the summer of 2005/06 (Fig. 2), which coincided with the lowest tracking indices for rats (see section 4.4). The mean number of invertebrates per trap also varied within each October–January block, with lowest catches occurring in the 2002/03 and 2006/07 blocks at each site (Table 3). Invertebrates identified to lower taxonomic levels are listed in Appendix 1.

A total of 63 149 invertebrates were available for analysis in the October–January blocks of data. After Dunn-Šidák correction, the ANOVA model revealed a significant difference in mean abundance of Formicidae between treatment and non-treatment areas both before and after the initiation of rat control, with lower numbers in the non-treatment areas (Table 4, Fig. 3). There was also a significant reduction in abundance of Formicidae in the treatment areas following the initiation of rat control. The mean number of Orthoptera was significantly greater in kanuka forest than podocarp/hardwood forest (Table 4, Fig. 3). No other differences were significant after correcting for multiple tests (Table 4).

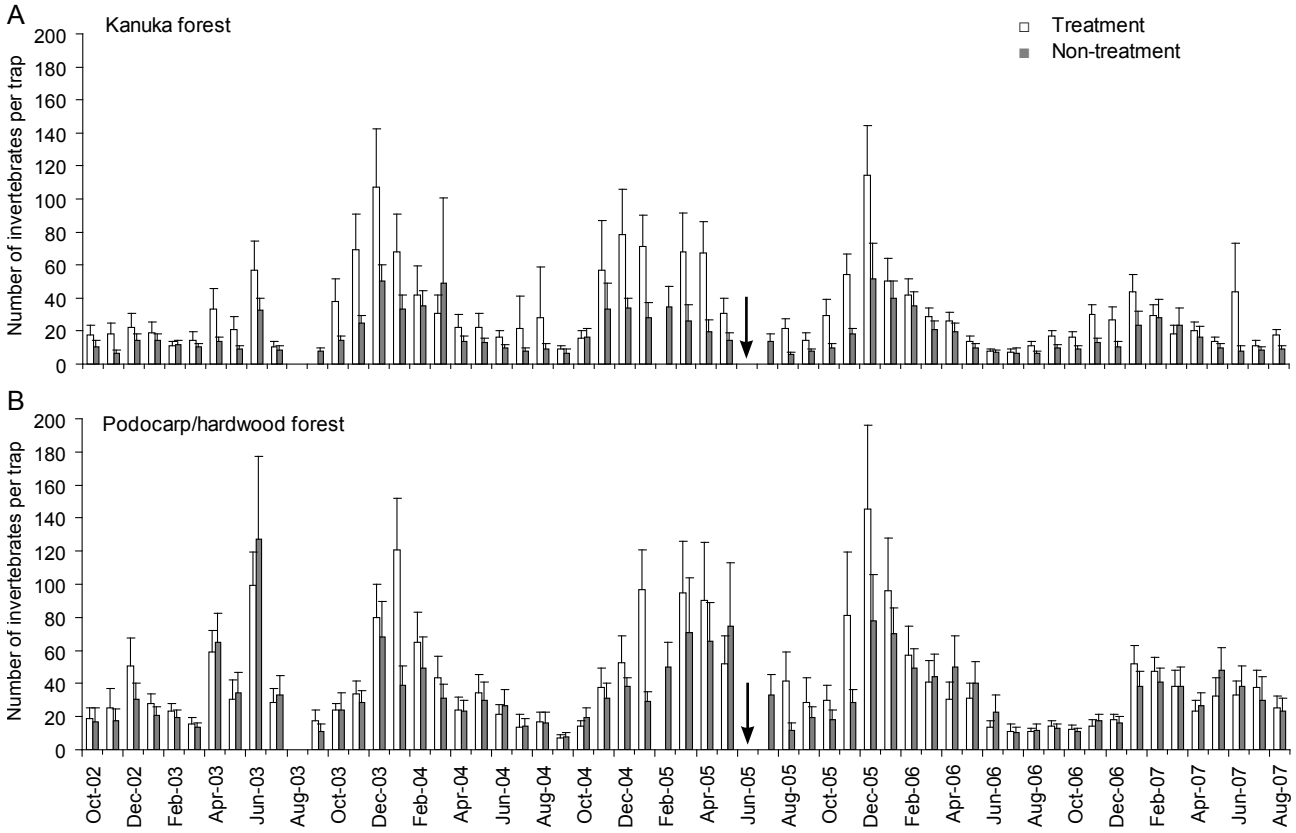

Figure 2. Mean (+ 95% CI) number of invertebrates per pitfall trap for A. kanuka (*Kunzea ericoides*) forest and B. podocarp/hardwood forest, October 2002 – August 2007, Moehau. Arrow indicates where rat control began (June 2005) and gaps indicate missing data. Confidence intervals were calculated from individual trap catches.

TABLE 3. MEAN (± SEM) NUMBER OF INVERTEBRATES CAPTURED PER TRAP DURING OCTOBER–JANUARY AT EACH SITE BEFORE AND AFTER RAT (*Rattus* spp.) CONTROL WAS INITIATED.

Knt = kanuka (*Kunzea ericoides*) forest, non-treatment; Pnt = podocarp/hardwood forest, non-treatment; Kt = kanuka forest, treatment; Pt = podocarp/hardwood forest, treatment.

SITE	PRE-CONTROL			POST-CONTROL	
	2002/03	2003/04	2004/05	2005/06	2006/07
Knt	11.45 ± 1.83	30.74 ± 7.61	28.04 ± 4.08	29.86 ± 9.62	14.14 ± 3.24
Pnt	21.46 ± 3.18	39.90 ± 9.82	29.69 ± 3.83	48.81 ± 14.87	20.83 ± 6.02
Kt	19.25 ± 1.08	71.38 ± 14.20	55.69 ± 14.00	109.53 ± 37.25	31.87 ± 6.07
Pt	30.69 ± 6.90	64.47 ± 22.33	50.36 ± 17.38	88.18 ± 23.86	24.26 ± 9.25

TABLE 4. SIGNIFICANCE OF DIFFERENCES IN THE ABUNDANCE (N), RECOGNISED TAXONOMIC UNIT RICHNESS (T), DIVERSITY AND EVENNESS MEASURES OF INVERTEBRATES BETWEEN PERIODS, FOREST TYPES, TREATMENTS AND A PERIOD:TREATMENT CONTRAST AT MOEHAU.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.003$ (= critical P after Dunn-Šidák correction); NS not significant.

GROUP	INDEX	FACTOR			
		PERIOD	FOREST TYPE	TREATMENT	PERIOD: TREATMENT
Community	Dominance	NS	NS	NS	NS
	Equitability	NS	*	*	NS
	Evenness	NS	NS	NS	NS
	Fisher	NS	NS	NS	NS
	Margalef	NS	NS	NS	NS
	Shannon	NS	*	NS	NS
	Simpson	NS	NS	NS	NS
	T	*	**	*	NS
	N	NS	NS	**	NS
Amphipoda	N	NS	NS	NS	NS
Araneae	N	*	*	NS	NS
Carabidae	N	NS	NS	NS	NS
Coleoptera	N	NS	**	*	NS
Coleoptera	T	*	**	NS	NS
Coleoptera > 20 mm	N	NS	**	*	NS
Diplopoda	N	NS	NS	NS	NS
Diptera	N	NS	NS	NS	NS
Formicidae	N	**	*	***	***
Isopoda	N	NS	NS	NS	NS
Opiliones	N	NS	**	**	NS
Orthoptera	N	NS	***	*	NS
Orthoptera > 20 mm	N	NS	NS	NS	NS
Scarabidae	N	NS	*	NS	NS

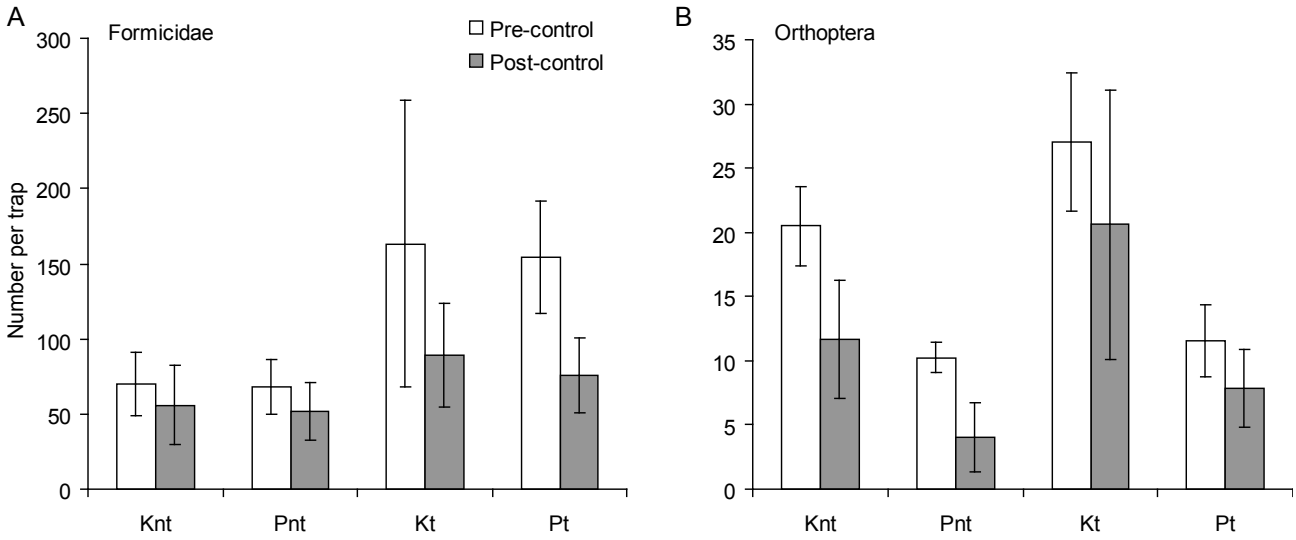

Figure 3. Mean (± 95% CI) number of A. Formicidae and B. Orthoptera caught per pitfall trap at each site before and after rat control was initiated at Moehau. Knt: kanuka (*Kunzea ericoides*) forest, non-treatment; Pnt: podocarp/hardwood forest, non-treatment; Kt: kanuka forest, treatment; Pt: podocarp/hardwood forest, treatment. Confidence intervals were calculated from individual trap catches.

4.2 INVERTEBRATE BODY LENGTH

There were no significant interactions between period and treatment for the body length of any of the invertebrate groups measured after Dunn-Šidák correction for multiple tests (Table 5).

TABLE 5. SIGNIFICANCE OF DIFFERENCES IN MEAN LENGTH OF INVERTEBRATES BETWEEN PERIODS, FOREST TYPES, TREATMENTS AND A PERIOD:TREATMENT CONTRAST AT MOEHAU.

* $P<0.05$, ** $P<0.017$ (= critical P after Dunn-Šidák correction); NS not significant.

GROUP	FACTOR			
	PERIOD	FOREST TYPE	TREATMENT	PERIOD:TREATMENT
Carabidae	NS	*	NS	NS
Diplopoda	NS	NS	NS	NS
Orthoptera	*	*	*	NS

4.3 INVERTEBRATE COMMUNITY COMPOSITION

ANOSIM revealed that invertebrate community composition was significantly different between most site pairings both before and after the initiation of rat control (Table 6). Differences in invertebrate community composition were greatest between forest types and were greater after rat control was initiated. The fact that this latter difference occurred across all site pairings suggests it was not a treatment effect. Sampling period also had a strong effect on the composition of the invertebrate community (Table 6).

The effects of sampling period and site on community composition are evident in the nMDS plot of monthly invertebrate samples collected after rat control had begun (Fig. 4). The vertical axis clearly separates samples on the basis of year, while the horizontal axis separates samples on the basis of forest type.

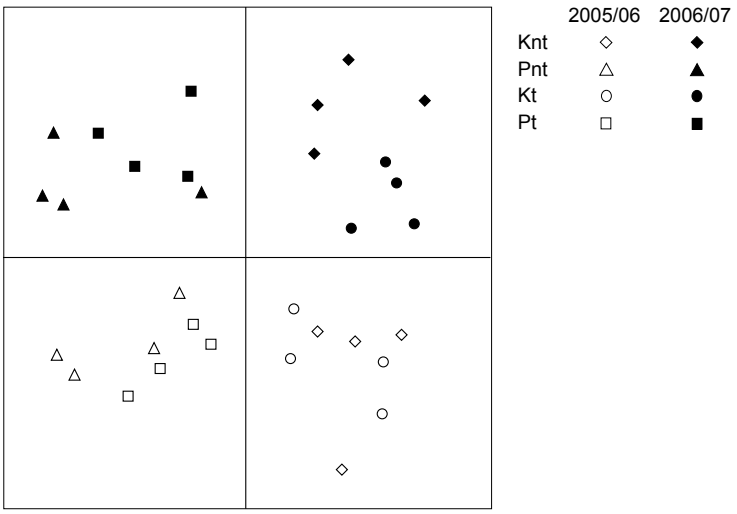

Figure 4. Non-metric multi-dimensional scaling (nMDS) of invertebrate monthly samples collected after initiation of rat control at Moehau in late 2005/early 2006 and late 2006/early 2007.

TABLE 6. ANALYSIS OF SIMILARITIES RESULTS FOR INVERTEBRATE COMMUNITY COMPOSITION BEFORE AND AFTER THE INITIATION OF RAT (*Rattus* spp.) CONTROL AT MOEHAU.

Knt = kanuka (*Kunzea ericoides*) forest, non-treatment; Pnt = podocarp/hardwood forest, non-treatment; Kt = kanuka forest, treatment; Pt = podocarp/hardwood forest, treatment.
* $P<0.05$, ** $P<0.01$, *** $P<0.007$ (= critical P after Dunn-Šidák correction); NS not significant.

FACTOR	PAIRWISE COMPARISONS	PRE-CONTROL		POST-CONTROL	
		R	*P*	*R*	*P*
Site		0.281 (global)	***	0.740 (global)	***
	Knt, Pnt	0.243	***	0.870	***
	Knt, Pt	0.368	***	0.911	***
	Knt, Kt	0.188	*	0.661	***
	Pnt, Pt	0.038	NS	0.255	*
	Pnt, Kt	0.500	***	0.938	***
	Pt, Kt	0.517	***	0.833	***
Time		0.668 (global)	***	0.836 (global)	***
	2002/03, 2003/04	0.898	***		
	2002/03, 2004/05	0.846	***		
	2003/04, 2004/05	0.258	***		
	2005/06, 2006/07			0.836	***

4.4 RATS AND POSSUMS

In the non-treatment area, the percentage of tunnels tracked by rats remained high throughout most of the study period (Fig. 5). Although it was not possible to statistically compare pre-control tracking rates with post-control rates (as only one pre-control tracking rate was obtained for the treatment area), it appears that rat abundance decreased in the treatment area after June 2005, coinciding with the commencement of rat control.

A single pre-control and post-control possum monitoring operation was also undertaken in the treatment area during the study period (Table 7). This indicated that possum numbers were relatively low prior to rat control and were reduced to very low levels 2 months after rat control was initiated.

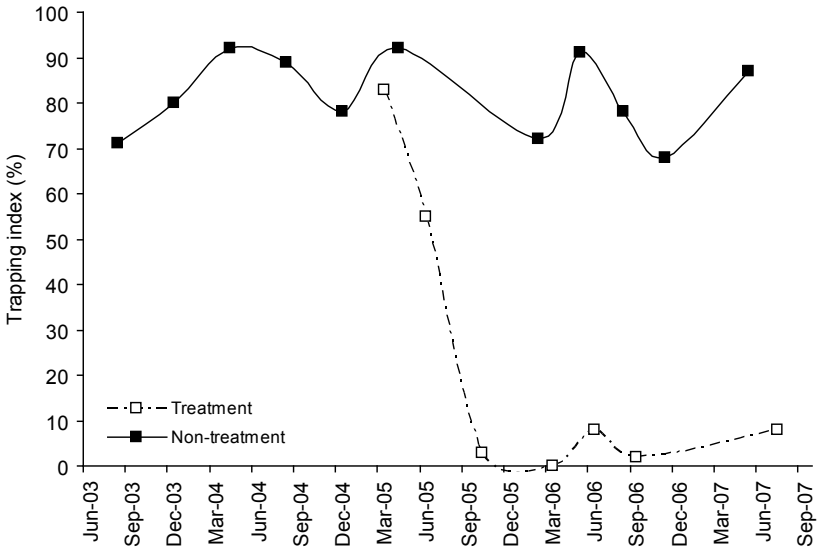

Figure 5. Rat tunnel tracking indices at Moehau, August 2003 – July 2007.

TABLE 7. POSSUM (*Trichosurus vulpecula*) MONITORING RESULTS IN THE 350-ha NORTHEAST STONY BAY CREEK CATCHMENT, MOEHAU, FROM JANUARY 2004 TO AUGUST 2005.

DATE	NO. OF LINES	TRAP NIGHTS	RESIDUAL TRAP CATCH		95% CI
			PRE-CONTROL	POST-CONTROL	
27 January 2004	3	174.5	2.04%		0.18%
30 August 2005	5	150.0		0.00%	

5. Discussion

In this study, neither invertebrate abundance nor diversity was found to increase as a result of rat control. In fact, there was a significant decrease in numbers of Formicidae following rat control operations. Several invertebrate indices displayed spatial and temporal variation, and although only one of these differences was significant following Dunn-Šidák correction, these findings suggest substantial differences between sites prior to the initiation of rat control. This is supported by the finding that site and sample date were the primary factors separating samples based on invertebrate community composition. These outcomes may suggest that either rat control did not benefit mainland invertebrate populations at Moehau, or a combination of methodological and environmental factors did not allow the responses of many invertebrates to be detected.

Similar findings of rat control having no effect or resulting in a reduced abundance and diversity of invertebrates have been obtained from comparable studies both on islands and the New Zealand mainland, although a high proportion of these studies were limited by lack of adequate control sites or pre-treatment measurements. For example, following the eradication of rats from Kapiti Island in 1996, there was a significant decrease in invertebrate catch frequency and diversity, especially for the Carabidae and Amphipoda, although not for the Formicidae (Sinclair et al. 2005); on the mainland, Craddock (1997) observed lower numbers of some taxa (millipedes, springtails and flies) in treated areas than in control areas; Rufaut & Gibbs (2003) failed to detect any marked increase in Wellington tree weta (*Hemideina crassidens*) density following the eradication of rats from Nukuwaiata (Chetwode Islands); and three studies undertaken on the mainland (Spurr 1996; Hunt et al. 1998; Spurr & Berben 2004) found no significant differences in measured invertebrate parameters between treatment and non-treatment sites. Those studies that have detected positive and significant treatment effects generally found that they were group-specific (typically weta and beetles, but sometimes also spiders and caterpillars) (e.g. Craddock 1997; Atkinson & Towns 2001; Green 2002; Watts 2004) or species-specific (typically snails and weta) (e.g. Newmann 1993, 1994; Walker 1997, cited in Bennett et al. 2002; Bennett et al. 2002).

Little is known of the ecology of New Zealand Formicidae, but a previous study investigating the reduction in *Huberia striata* (Formicidae) numbers as a result of 1080 poisoning showed an increased death rate of up to 12% on exposure to the toxin (Booth & Wickstrom 1999). The decrease in ant numbers at treatment sites at Moehau exceeded this figure (i.e. a 29–32% reduction), although comparison between studies is complicated by differences in toxin type and duration. In addition, comparisons made between laboratory experiments and field studies should be made with caution because field studies have less control of confounding variables.

It is possible that the behaviour of invertebrates may have changed following the control of rats, which may have affected the results. For example, if invertebrates foraged less as a result of more abundant food supplies, trap catches may have remained at pre-control levels despite invertebrate abundance having increased. It is not known how long a study would need to be to remove this potential confounding effect.

It is also possible that pitfall trapping did not adequately sample those invertebrates that are preferentially consumed by rats and therefore most likely to respond to treatment. Examples include large specimens (Orthoptera and Coleoptera in this study) or known prey, such as tree weta (Powlesland et al. 2005). It should also be noted that pitfall traps, like rat tracking indices, only provide a coarse index of relative abundance and do not reflect the actual density of animals at the site (Green 2000). Some important invertebrate parameters that may have shown differences between treatments were not measured, e.g. behaviour or population age structure (cf. Rufaut & Gibbs 2003). In addition, the length of the study may not have been long enough relative to the life cycles of invertebrate taxa susceptible to predation. These problems could probably only be avoided with a detailed knowledge of the invertebrate taxa present at the study sites and the potential effect of rat predation on their populations.

Additionally, there are other potential problems associated with the control and monitoring of rats. Rat numbers may not have been reduced (see Gillies et al. 2006) to levels where invertebrate populations could recover (levels are likely to differ for individual invertebrate taxa). Mouse numbers were not monitored and could have remained high despite rat control (e.g. Hunt et al. 1998; King 2007) or numbers could have increased due to competitive release following a reduction in rat numbers. Numbers of possums and other pest animals, which were monitored infrequently or not at all, could also have remained high despite rat control, with some unforeseen effect on invertebrate populations. Furthermore, numbers of insectivorous birds may have increased as a consequence of rat control, which could have maintained or increased predation levels on invertebrates (as proposed by Sinclair et al. 2005). It is also not known whether the spatial arrangement of pitfall traps was relevant to the temporal and spatial scale of rat control. The bait station spacing and bait restocking regime may not have had a local effect over the sites where pitfall traps were placed.

The use of non-specialists to sort invertebrate samples to morphospecies can generate a high identification error rate (Hunt et al. 1998), and this may have introduced a further source of uncertainty to the data. However, this analysis used blocks of data that incorporated data from two or more sorters, which would have reduced this potential problem.

It is also probable that large temporal and spatial variation in invertebrate numbers helped obscure any treatment effect (e.g. van Aarde et al. 2004; Sinclair et al. 2005). A range of environmental parameters that are likely to have influenced invertebrate distributions (such as plant species composition and climatic variables) would ideally have been measured and controlled for in analyses.

This study would have been improved by increasing the number of samples, by using more homogenous groups to lower sample standard deviations (e.g. making sure kanuka forest sites really were similar), by measuring covariates in the experimental study and adding them to the statistical model to reduce the error variance, and/or by maximising replication (Jones & Toft 2006) through the inclusion of replicate treatment and non-treatment sites elsewhere.

The generality of these results is limited because they are only applicable to the Moehau study area. The study is also only applicable to the described form of rat control and the rodent species that would be controlled using these methods (Sinclair et al. 2005).

6. Conclusions

Rat control at Moehau appears to have resulted in a reduction in the number of ants (Formicidae). Treatment did not affect the abundance, richness, diversity, composition or size of any other invertebrate group. Therefore, based on the results of this study, there is no indication that this method of rat control benefits invertebrate populations at Moehau. However, it is possible that some invertebrates that are susceptible to predation by rats were not sampled adequately, that predatory pest mammals were not reduced to low enough levels to elicit a measurable invertebrate response, or that the time scale of this study was not long enough relative to the period of the life cycles of the invertebrate species affected by rat predation. Therefore, to improve future studies, the following recommendations, which have been made by previous researchers, are reiterated:

- The diet of rats at the study site should be verified through a pilot study and this information should be used to ensure that sampling strategies reflect the preferred invertebrate prey in the study area (Hunt et al. 1998).
- A variety of invertebrate sampling techniques should be used (Hunt et al. 1998).
- Mammal species should be monitored using standard techniques in each treatment block throughout the study period, so that changes in invertebrate indices can be correlated with changes in mammal numbers (Hunt et al. 1998; Jones & Toft 2006).
- Changes in the abundance of insectivorous birds that may result from reductions in pest mammal densities should be measured and included in the statistical model.
- Replication should be maximised, even at the expense of treatment levels (Jones & Toft 2006). A power analysis should be undertaken as part of the study design process to determine an appropriate sample size.
- The use of mammal exclosures should be considered (Jones & Toft 2006; King 2007), to allow far greater control of mammal densities within study treatments.

Implementation of these recommendations will, in the long term, not only save resources and time, but will make it more likely that key research questions will be unambiguously answered.

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Appendix 1

INVERTEBRATE TAXA COLLECTED AT MOEHAU DURING THE STUDY PERIOD

? = uncertainty in determination. * = Exotic species.

ORDER	FAMILY	SPECIES	COMMON NAME
Acari			Mite
Amphipoda			Amphipod
Annelida			Worm
Araneae			Spider
Archaeognatha	Meinertellidae		Bristletail
Blattodea	Blattidae		Cockroach
Chilopoda			Centipede
Coleoptera	Anthicidae	*Cotes proba*	Beetle
	Brentidae		Giraffe weevil
	Cantharidae	*Asilis ?fulvithorax*	Beetle
	Carabidae	*Lecanomerus sharpi*	Carabid beetle
	Carabidae	*Avlaropudus calathoides*	Carabid beetle
	Carabidae	*Megadromus capito*	Carabid beetle
	Carabidae	*Holcaspis* sp.	Carabid beetle
	Carabidae	*Cicindela spilleri*	Carabid beetle
	Carabidae	*Dicrochile maura?*	Carabid beetle
	Cerambycidae	*Tenebrosoma* sp.	Longhorn beetle
	Cerambycidae	*Xylotoles* sp.	Longhorn beetle
	Cerambycidae	*Tenebrosoma* sp.	Longhorn beetle
	Curculionidae	*?Dolioceuthus* sp.	Weevil
	Curculionidae	*Cineopterus* sp.	Weevil
	Curculionidae	*Exomesites ?optimus*	Weevil
	Curculionidae	*Gromilus* sp.	Weevil
	Curculionidae	*Hygrochus* sp.	Weevil
	Curculionidae	*Lyperobates* sp.	Weevil
	Curculionidae	*Paelocharis* sp.	Weevil
	Curculionidae	*Phronira* sp.	Weevil
	Curculionidae	*?Phrynixus* sp.	Weevil
	Curculionidae	*Sosgenes* sp.	Weevil
	Elateridae	*Conoderus ?maritimus*	Click beetle
	Elateridae	*'Ctenicera'* sp.	Click beetle
	Hydrophilidae	*Exidrus gibbosus*	Beetle
	Hydrophilidae	*Tormissus linsi*	Beetle
	Latridiidae	*Melanophthalma* (or near)	Beetle
	Leiodidae	*Mesocolan ?alacre*	Beetle
	Leiodidae	*Zeadolopus* sp.	Beetle
	Lucanidae		Stag beetle
	Melyridae		Beetle
	Scarabaeidae	*Costelytra* sp.	Scarab beetle
	Scarabaeidae	*Saphobius* sp.	Scarab beetle
	Scarabaeidae	*Sericospilus* sp.	Scarab beetle
	Scarabaeidae	*Stethaspis longicornis*	Scarab beetle
	Scirtidae		Beetle
	Staphylinidae	*Anotylus* sp.	Rove beetle
	Staphylinidae	*Hyperomma* sp.	Rove beetle

Continued on next page

Appendix 1—continued

ORDER	FAMILY	SPECIES	COMMON NAME
	Staphylinidae	*Maorothius* sp.	Rove beetle
	Tenebrionidae	*Archaeoglenes costipennis*	Beetle
	Zopheridae	*Pycnomerus* sp.	Beetle
	Zopheridae	*Syncalus* sp.	Beetle
Collembola	Onychiuridae		Collembola
	Sminthuridae		Collembola
	Tomoceridae		Collembola
Dermaptera			Earwig
Diplopoda			Millipede
Diplura			Bristletail
Diptera			Fly
Hemiptera	Aradidae	*Neocarventus angulatus*	Bug
	Ceratocombidae	*Ceratocombus aotearoae*	Bug
	Cercopidae	*Myerslopia* sp.	Bug
	Cicadidae		Cicada
	Cixiidae	*Cixius inexspectatus*	Bug
	Delphacidae		Bug
	Enicocephalidae	*Systelloderes maclachlani*	Bug
	Lygaeidae	*Regatarma forsteri*	Bug
	Lygaeidae	*Romna variegata*	Bug
	Lygaeidae	*Targarema stali*	Bug
	Lygaeidae	*Truncala hirsuta*	Bug
	Pentatomidae	*Glaucias amyoti*	Bug
	Reduviidae	*Ploiaria antipodum*	Assassin bug
	?Rhyparochromidae	?*Targarema* (immature)	Bug
Hymenoptera	Diapriidae	*Entomacis* sp.	Wasp
	Formicidae	*Heteroponera brouni*	Ant
	Formicidae	*Huberia striata*	Ant
	Formicidae	*Pachycondyla castanea*	Ant
	Ichneumonidae		Wasp
	Pompilidae	*Sphictostethus nitidus*	Wasp
	Scelionidae		Wasp
	Vespidae	*Vespula vulgaris**	Common wasp
Isopoda			
Lepidoptera			
Nematoda			
Onychophora			Peripatus, velvet worm
Opiliones			Harvestman
Orthoptera	Acrididae		Grasshopper
	Anostostomatidae		Ground weta
	Rhaphidophoridae		Cave weta
Phasmatodea	Phasmatidae		Stick insect
Platyhelminthes			
Pseudoscorpiones			
Stylommatophora		*Cavellia roseveari* (Suter, 1896)	
		Laoma mariae mariae (Grey, 1843)	Snail
		Liarea sp. aff. *egea* (Grey, 1850)	Snail
		Otoconcha dimidiata (L. Pfeiffer, 1853)	Snail
		Phenacohelix perplexa (R. Murdoch, 1897)	Snail
		Phrixgnathus levis (Suter, 1913)	Snail
		Rhytida (R.) *greenwoodi greenwoodi* (Grey, 1850)	Snail
		Suteria ide (Grey, 1850)	Snail
		Thalassohelix zelandiae (Grey, 1843)	Snail
		Thalassohelix ziczag (Gould, 1848)	Snail
		Therasiella tamora (Hutton, 1883)	Snail
Syphonoptera			

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