Effect of grazing on ship rat density in forest fragments of lowland Waikato, New Zealand

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Published on-line: 27 January 2010

Abstract: Ship rat (*Rattus rattus*) density was assessed by snap-trapping during summer and autumn in eight indigenous forest fragments (mean 5 ha) in rural landscapes of Waikato, a lowland pastoral farming district of the North Island, New Zealand. Four of the eight were fenced and four grazed. In each set of four, half were connected with hedgerows, gullies or some other vegetative corridor to nearby forest and half were completely isolated. Summer rat density based on the number trapped in the first six nights was higher in fenced (mean 6.5 rats ha^{-1}) than in grazed fragments (mean 0.5 rats ha^{-1}; $P = 0.02$). Rats were eradicated (no rats caught and no rat footprints recorded for three consecutive nights) from all eight fragments in January–April 2008, but reinvaded within a month; time to eradication averaged 47 nights in fenced and 19 nights in grazed fragments. A second six-night trapping operation in autumn, 1–3 months after eradication, found no effect of fencing ($P = 0.73$). Connectedness to an adjacent source of immigrants did not influence rat density within a fragment in either season (summer $P = 0.25$, autumn $P = 0.67$). An uncalibrated, rapid (one-night) index of ship rat density, using baited tracking tunnels set in a 50 × 50 m grid, showed a promising relationship with the number of rats killed per hectare over the first six nights, up to tracking index values of c. 30% (corresponding to c. 3–5 rats ha^{-1}). The index will enable managers to determine if rat abundance is low enough to achieve conservation benefits. Our results confirm a dilemma for conservation in forest fragments. Fencing protects vegetation, litter and associated ecological processes, but also increases number of ship rats, which destroy seeds, invertebrates and nesting birds. Maximising the biodiversity values of forest fragments therefore requires *both* fencing and control of ship rats.

Keywords: fencing; isolation; predator density; rapid indexing; *Rattus rattus*; tracking; trapping

Introduction

Fragments

The decline of indigenous biodiversity in agricultural landscapes is a pervasive and challenging global environmental issue (Naeem 2002; Hooper et al. 2005; Dickman et al. 2007). In New Zealand, lowland rural landscapes include many small remnants of original forested ecosystems that are poorly represented on public conservation land (Department of Conservation & Ministry for the Environment 2000; Green & Clarkson 2006). Therefore, fragments represent a disproportionately large repository of lowland threatened ecosystems and species (Walker et al. 2006), and are critical elements in regional and national restoration strategies (Ministry for the Environment & Department of Conservation 2007).

Interactions between fragmentation, grazing, biotic invasions and other disturbances, known to exacerbate ecosystem deterioration and population extinctions, have been quantified in Australia and America for some time (Hobbs & Mooney 1998; Hobbs 2001; Hobbs & Yates 2003), but only recently in New Zealand (MacLeod & Moller 2006; Blackwell et al. 2008). In New Zealand, introduced weeds and pests, including farmed stock, have long been recognised as key threats (Hackwell & Bertram 1999), but the ecological consequences of managing them are little understood beyond the general benefits of stock exclusion for vegetation (Smale et al. 2005, 2008).

Ship rats

Ship (black, roof) rats (*Rattus rattus*; mammal nomenclature follows King (2005)) are unwelcome pests on islands around the world (Atkinson 1989), where they threaten populations of birds (Bell 1978; Seto & Conant 1996; Penloup et al. 1997; Martin et al. 2000), invertebrates (Palmer & Pons 1996; Olson et al. 2006) and endemic vegetation (Garcia 2002). They are ubiquitous and abundant in New Zealand podocarp–broadleaved forests, reaching densities of c. 6 rats ha^{-1} in January (Hooker & Innes 1995; Brown et al. 1996). They are arboreal, nocturnal omnivores; key predators of small forest-passerines (Innes et al. 1999; Armstrong et al. 2006b); and probably of lizards, invertebrates and seeds (Innes 2005; Wilson et al. 2006).

Ship rat ecology is reasonably well known in large forests, but hardly studied in forest fragments. The rats are much less common in open, early-successional habitats and grassland than in complex, diverse forests in both New Zealand (King et al. 1996; Innes 2005) and Australia (Downes et al. 1997; White et al. 1997; Cox et al. 2000). We therefore predicted that, after eradication, fewer ship rats would reinvade fragments surrounded by grazed pasture than those linked to continuous forest. Confirmation of this would encourage rat control in isolated fragments, with valuable consequences for biodiversity conservation in rural areas. Also, previous research (Boulton 2006) showed that ship rats might be less common in forest fragments open to grazing by stock.

Ship rat management requires a cheap and practicable method of calculating an index of population density to enable repeated, standardised monitoring of rat abundance. The standard footprint-tracking protocol used by the New Zealand Department of Conservation (Gillies & Williams unpubl.) is a robust, verified (Innes et al. 1995; Brown et al. 1996) technique suitable for large forest areas, but it requires long (500 m minimum), randomly oriented lines of tunnels that cannot be fitted inside small fragments. Tracking tunnels at 50-m spacing on grids rather than lines are more feasible in fragments. Indices derived this way were first trialled over 3 years starting in 2002 (Boulton 2006; Boulton et al. 2008) as predictors of robin nest success, but the index has never been calibrated against actual rat abundance.

Objectives

We indexed the density of ship rats (henceforth called 'rats') in grazed versus ungrazed (fenced), and isolated versus connected, forest fragments in a New Zealand pastoral landscape, then eradicated rats from these and observed the consequent reinvasion. Our objectives were to see whether (1) grazing reduces rat density and/or (2) pasture limits reinvasion; and also (3) to compare a grid-based, tracking tunnel index of rat density with the number of rats killed in the first six nights of trapping, assumed to be an approximate estimate of actual density. This paper describes part of a wider study of the ecological effects of management (fencing and pest control) on key ecological processes in 53 forest fragments in the Waikato, New Zealand (e.g. Didham et al. 2009).

Methods

Study areas

The eight forest fragments chosen were all within 20–30 km SE of Hamilton City in the central Waikato region, North Island, New Zealand. They were cutover remnants of previously continuous broadleaved evergreen native forest, from which large emergent conifers such as rimu (*Dacrydium cupressinum*) were logged in 1910–1920, but not since (M. Smale, pers. comm.). Continuous canopies 20–25 m high were dominated by tawa (*Beilschmiedia tawa*), mangeao (*Litsea calicaris*), māhoe (*Melicytus ramiflorus*), pukatea (*Laurelia novae-zelandiae*), rewarewa (*Knightia excelsa*) and tree ferns.

Fragments averaged 5.3 ha in size (range 2.4–9.9 ha), and were all isolated in grazed pasture and separated from another forest by on average 111 m (range 10–250 m; Table 1). Predominant use of the surrounding pastoral matrix was dairy or sheep farming, and stock was excluded from half of the fragments by conventional 7-wire post-and-batten fences. Fragments classified as 'connected' were linked to a nearby forest by 10–210 m of linear vegetation such as a shelterbelt, but in one case (Fragment 8) only a rough road separated the fragment from another area of native forest (Table 1). Three of the four fragments classified as 'grazed' had sheep or cattle in the fragment throughout our research. The fourth (Fragment 5) had been heavily grazed by cattle prior to our research starting, and was grazed again by one cattle beast just before the second (autumn) trapping session. None of the fragments had been subject to effective (trapping, poisoning) pest control programmes targeting brushtail possums (*Trichosurus vulpecula*) and ship rats in the 2 years prior to our research.

Experimental stages

Overall, five stages of the experiment proceeded in all fragments in the following order:

1. A one-night tracking tunnel index of rat density
2. Daily kill-trapping until no rats were trapped, at which point daily tracking as an independent check for rat presence was added
3. Ongoing kill-trapping to local extinction, defined as the day on which no rats had been trapped or tracked for the three previous consecutive nights
4. Monthly setting of tracking tunnels to detect reinvasion
5. A repeat of 1–3 above, for a fixed kill-trapping period of 10 nights.

Tracking indices

Connovation™ plastic tracking tunnels with Black Trakka™ inked cards were set on a square 50-m grid throughout each fragment in December 2007 to allow rats at least 3 weeks to get used to them. The total number of tunnels needed to fill out the grid in each fragment varied with the area of the fragment (Table 1). The tunnels were baited with peanut butter and set for one night only, according to the current Department of Conservation protocol used in large forests, on the

Table 1. Study areas and results of trapping and tracking ship rats through two eradication attempts.

Fragment	1	2	3	4	5	6	7	8
Area (ha)	3.5	4.9	9.9	4.3	4.8	5.7	2.4	7.0
Fenced/Grazed	Grazed	Fenced	Grazed	Fenced	Grazed	Fenced	Grazed	Fenced
Connected to source	Connected (barberry hedge)	Connected (pine shelterbelt)	Isolated	Isolated	Connected (willow)	Isolated	Isolated	Connected (native forest)
Distance from source (m)	115	210	100	250	40	55	105	10
Number of traps	25	44	75	42	48	48	23	54
Number of tracking tunnels	15	23	42	23	26	28	13	30
Dates tracking indices taken (2008)	9 Jan, 12 Feb, 17 Mar, 10 Apr	9 Jan, 12 Feb, 10 Apr	9 Jan, 10 Mar, 28 Apr	9 Jan, 17 Mar, 28 Apr	13 Feb, 20 Mar, 23 Apr, 20 May	13 Feb, 7 May	13 Feb, 23 Apr, 20 May	13 Feb, 20 May
1st index	1/16 = 6.2	13/23 = 56	5/40 = 12.5	13/23 = 56	0/26 = 0	15/27 = 55	1/13 = 7.6	22/29 = 76
Traps set for 1st eradication	10 Jan	10 Jan	10 Jan	10 Jan	14 Feb	14 Feb	14 Feb	14 Feb
Nights to complete 1st eradication	6	27	29	41	3	54	39	67
Total rats trapped	1	49	33	60	0	110	30	83
Rats ha^{-1} first six nights	0.3	6.3	1.3	4.2	0	11.5	1.3	4.5
2nd index	3/16 = 19	12/23 = 52	8/42 = 19	9/22 = 41	4/25 = 16	7/28 = 25	2/13 = 15	0/30 = 0
Traps set for 2nd eradication	11 Apr	11 Apr	29 Apr	29 Apr	21 May	8 May	21 May	21 May
Total rats trapped	23	17	35	26	15	23	2	10
Rats ha^{-1} first six nights	4.6	3.1	2.3	4.0	2.3	3.7	0.8	0.9

dates shown in Table 1. The tracking index was calculated as a simple proportion of all the tunnels that had been tracked by rats.

Estimating rat populations by total removal

Victor Professional rat snap traps (passed by NAWAC[1] standards as humane kill traps for rats) were set in tunnels at and between tracking tunnels (i.e. on a 50 × 25 m grid) throughout each fragment, in numbers and on dates shown in Table 1. The traps were set inside tunnels just large enough to accommodate the trap, to discourage non-target species, guide target rats to the treadle, protect traps from rain, and provide public safety. They were baited with peanut butter, checked and rebaited daily.

To compare the density of rat populations, we used the total number of rats caught over the first six nights of trapping only. We treated this six-night total as a reliable estimate of initial density, for three reasons: (1) to avoid the error that we expected would be introduced as the probability of detection declined (as commonly observed after six days of trapping: Watkins et al. 2009) and immigrant rats reinvaded the trapped-out fragments; (2) to minimise possible seasonal variation in immigration rate; and (3) to enable pooling of the data from fragments trapped for different lengths of time.

Effects of fencing and isolation on rat density

Four of the eight fragments were fenced and four grazed. In each set of four, half were connected to nearby forest and half completely isolated. We conducted two replicate eradication attempts, starting at different seasons. The first (summer) operation started in fragments 1–4 in January (mid-summer) and in fragments 5–8 in February (late summer); the second (autumn) operation started in fragments 1–4 in April after reinvasion, and in fragments 5–8 in May. The effects of the eradication attempts on the six-night kill, and the relationship of the six-night kill with the tracking index taken immediately beforehand, were analysed as generalised linear models with Poisson distribution and log link, allowing for extra-Poisson variation, in GenStat v11 (2008). The analyses were done separately for the two eradication attempts.

Results

Summer eradication and rat density

Altogether, 517 rats were removed from the eight fragments between January and May 2008 (mean 46, range 0–110; Table 1). The mean time needed to meet our definition of eradication in each of the eight fragments in the first eradication was 33 nights (range 3–67). Time to eradication averaged 47 nights in fenced and 19 nights in grazed fragments.

During the first six nights of the first (summer) eradication, the number of rats killed varied from 0 to 11.5 rats ha^{-1} (Table 1). Summer rat density based on the six-night kill was significantly higher in fenced (6.5 rats ha^{-1}, SE 1.4) than in stock-grazed fragments (mean 0.5 rats ha^{-1}, SE 0.4; $P = 0.02$; Table 2). Connectedness to an adjacent forest, a presumed source of immigrants, had only a minor and insignificant effect on summer rat numbers, and not in the expected direction (higher in isolated fragments, $P = 0.25$; Table 2). There was no significant interaction effect ($P = 0.61$) between grazing and isolation treatments.

Autumn (post-recolonisation) rat populations

Ship rats reinvaded all cleared fragments within a month, regardless of fencing or isolation. The mean time between initial eradication and the second index was 63 nights, range 30–92 nights. After reinvasion, the relative densities of the re-established rat populations were quite different from those measured in the same fragments 3 months previously (Table 1), so that in contrast to summer, the autumn rat densities in fenced versus grazed fragments after reinvasion were not significantly different ($P = 0.73$), and nor did isolation significantly influence density ($P = 0.67$; Table 2). The autumn populations were not pursued to local extinction.

Relationship between trapping index and six-night kill

The relationship between the trapping index and the six-night kill is shown in Fig. 1, separately for the summer and autumn data. Both the index and the density values are measured with uncertainty, but no measure of these uncertainties can be estimated from the individual fragment data. It is tempting to use the binomial distribution to calculate an error bar for each of the indices, but this requires an assumption of equal probability of detection for each tunnel, an assumption unlikely to be true. The percent variance explained for the summer data is 45% compared with 25% for the autumn data, but the lack of fit is similar (Fig. 1).

Discussion

Ship rat density in fenced versus grazed fragments

The rat density we observed in small, fenced Waikato forest fragments (6.5 rats ha^{-1} based on six-night kills) was the highest yet measured on the New Zealand mainland (Innes 2005). Other estimates in similar but larger North Island forests are 1.7 rats ha^{-1} (mean of 29-month study, Orongorongo valley; Daniel 1972); 6.2 rats ha^{-1} (summer, Rotoehu Forest, Bay of Plenty; Hooker & Innes 1995); 4.8 rats ha^{-1} (summer, Kaharoa, Bay of Plenty; Brown et al. 1996); and 2.9 rats ha^{-1} (spring, Puketi Forest, Northland; Dowding & Murphy 1994).

More food and/or less predation may explain why rat density was so much higher in fenced (6.5 rats ha^{-1}) versus grazed (0.5 rats ha^{-1}) fragments in the initial summer population, as previously suggested by Boulton (2006). Boulton (2006) showed that tracking indices of rat abundance were consistently lower in grazed than ungrazed sites among 15 fragments that she studied near Benneydale (Waikato) over 3 years. Rat populations may be limited by food supply, because increases in their numbers can follow both natural seed masting (King & Moller 1997; Blackwell et al. 2003; Harper 2005) and removal of a competitor, the brushtail possum (Sweetapple & Nugent 2007). Reduced predation by cats *Felis catus* (Efford et al. 2006) or stoats *Mustela erminea* (I. Flux, C. Gillies, unpubl. data) may also increase rat numbers.

Ship rats are famously adaptable, occupying tussock grassland on subantarctic Macquarie Island (Pye et al. 1999), sugar cane plantations and forest from sea level to 2500 m in Hawai'i (Lindsey et al. 1999) and many other, mostly disturbed coastal habitats in Australia, northern

Table 2. Effects of treatments on number of rats killed per hectare over the first six nights of trapping

	Summer Estimate	SE	Autumn Estimate	SE
Fenced	6.50	1.40	2.75	0.76
Grazed	0.48	0.40	2.36	0.73
Connected	2.51	0.87	2.45	0.77
Isolated	4.47	1.18	2.66	0.77
Significance of effects (*P*)				
Fenced/grazed		0.02		0.73
Connected/Isolated		0.25		0.67
Interaction		0.61		0.23

[1]NAWAC = National Animal Welfare Advisory Committee, established under the Animal Welfare Act 1999, reporting to the Minister of Agriculture and Forests http://www.biosecurity.govt.nz/regs/animal-welfare/nz/nawac

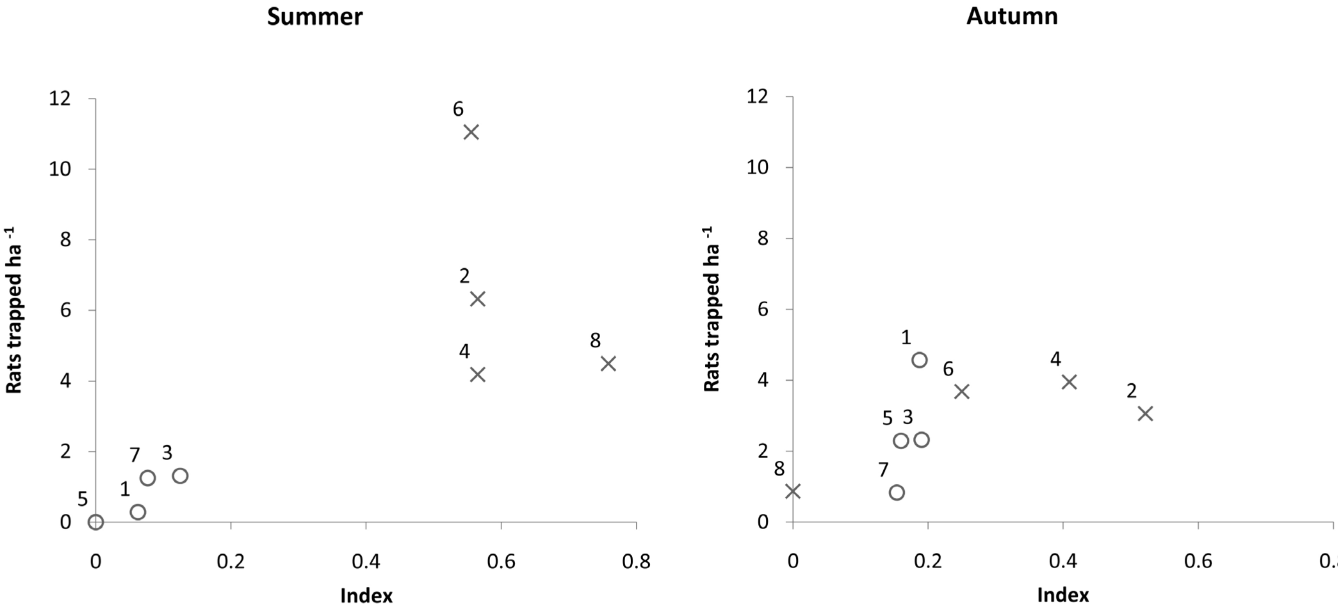

Figure 1. Relationship between a one-night tracking index taken immediately before the start of trapping, and the number of rats per hectare killed during the first six nights of trapping. Crosses indicate fragments that were fenced against grazing, and circles indicate unfenced fragments that were grazed.

Africa, southern Europe and North and South America (Brooks & Rowe 1987; Downes et al. 1997). Although habitat generalists, they are most abundant where there is complex vegetation structure and diverse seasonal fruiting patterns (King et al. 1996; Cox et al. 2000; Harper et al. 2005) and where competition from native rodents is minimal (Downes et al. 1997). Microhabitats preferentially used in New South Wales forests included dense leaf litter and understorey, and abundant vertical stems (Cox et al. 2000), all characteristics of fenced Waikato fragments. Our wider study revealed that fencing will in time significantly increase the density of seedlings and saplings of understorey and subcanopy trees (B. Burns, C. Floyd, M. Smale, unpubl. data), increasing litter biomass and invertebrate abundance (Didham et al. 2009), thus increasing ship rat food (Innes 2005). Alternately or additionally, rats may be able to escape predators more effectively in dense vegetation (Cox et al. 2000).

It is also possible that the lower tracking and trapping rates in grazed fragments are both due to differences in behaviour rather than density, such as that rats spend more time up trees in grazed fragments. This could be explored by setting traps or tracking tunnels up trees.

Rat density after reinvasion in autumn was not greater in fenced than in grazed fragments. One possible explanation is that reinvasion rates to fenced and grazed fragments were the same, but that the re-established residential populations sampled in autumn had not yet had time to develop the density differential between fenced and unfenced fragments previously observed in summer. If the reinvasion process is strongly influenced by the dispersal of juveniles, the larger number of unsettled young rats available after the end of the breeding season may well drive immigration rates higher in autumn than in summer, but we do not know that. The four reinvaded populations were not only similar to each other in density (which the original populations were not), but also clearly different from the originals in age/gender structure, as will be described elsewhere.

Effects of fragment isolation on rat density and reinvasion

We have confirmed that ship rats readily reach forest fragments by dispersing across grazed pasture separated from nearby source populations by at least 250 m, whether connected by vegetated corridors to adjacent forest or not. Therefore, our hypothesis that isolated fragments could be protected from reinvasion by isolation was not supported. Ship rat home ranges in New Zealand are typically 100–300 m long (Daniel 1972; Dowding & Murphy 1994; Hooker & Innes 1995), or larger if density is low (Pryde et al. 2005). What is surprising is that the rats moved freely across grazed pasture, temporarily increasing their exposure to predation by cats and stoats. Further exploration of this requires targeted study with individually marked rats, preferably monitored with radio transmitters.

Efficacy of the grid-based tracking index

A one-night grid-based tracking tunnel method is promising as a simple, rapid and cost-effective technique for distinguishing between high and low ship rat populations in small fragments. Current knowledge (Brown et al. 1996; Innes et al. 1999; Armstrong et al. 2006a) suggests that managers must reduce rats well below approximately 4 rats ha^{-1} to achieve conservation gains, so for them it is a significant finding of practical value to know that grid-based tracking rates below 30% reliably correspond to c. 3–5 rats ha^{-1}. The shape of the correlation between higher tracking indices and real density requires further research, although any index value > 30% is enough to trigger conservation concern and management action if possible, so accuracy at the higher densities is less important. Better indexing techniques are desirable and may be possible.

Uneven distribution of rats over the one night of tracking possibly explains the greater scatter of the highest index values. At the site with the highest rat count, distribution was definitely patchy (one of the seven trap lines through Fragment 6 was conspicuously more successful than the others), whereas the site with the highest index, Fragment 8, had very even distribution of captures. Rats can have overlapping home ranges, and sometimes forage and sleep in groups (Dowding & Murphy 1994; Hooker & Innes 1995). However, our sample sizes were small, and precluded more sophisticated model fitting.

Management implications

As in large New Zealand forests, ship rats in fragments can be removed but will rapidly reinvade (Innes et al. 1995, 1999; Sweetapple & Nugent 2007), necessitating repeated control for most biodiversity restoration objectives. Therefore, to maximise ecosystem health in managed forest fragments, reinvasion must be prevented by increasing the scale of rat control to include adjacent source forests, or by making the fencing rat-proof. Recent evidence suggests that ship rats are readily eradicated from forested islands (Clout & Russell 2006) and from large, pest-fenced mainland sanctuaries (Speedy et al. 2007), and that forest fragments could be permanently cleared of rats if reinvasion can be prevented.

Our most important and unexpected finding was that in summer (a critical time for bird nesting), ship rats were much more abundant in fenced, ungrazed than unfenced, grazed fragments. Thus, while fencing may encourage the regeneration of vegetation (Smale et al. 2005, 2008), the associated large increase in ship rat density threatens nesting birds, seeds, invertebrates and other fauna. Effective fragment restoration clearly demands fencing against farmed stock *plus* control of ship rats, and probably also of other introduced pest mammals. Targeting possums alone in fragments may actually further increase ship rat numbers, as observed in large native forests (Sweetapple & Nugent 2007).

Our demonstration of the potential value of grid-based, one-night tracking indices to detect low to moderate rat populations (0–4 rats ha^{-1}) provides a promising tool for fragment managers, enabling them to estimate rat density rapidly, repeatedly and non-destructively for a range of management purposes. Further research is required both to validate the technique at higher rat densities and to explore similar indices with other widespread introduced mammals in small New Zealand forest fragments.

Acknowledgements

We gratefully acknowledge the landowners and managers who generously gave us free access to their forest fragments: Yvonne and Alec Adams, Lyndon Bergerson, Shane Blair, Paul and Jo Bodle, Mr R.A. Boyte, Bill Boyte, Department of Conservation, Des McAllister, Allen Marr, Greg and Jackie Nicholls, Brett and Narelle Pollock, Deborah and John Stretton, Kerry Walker, Kevin Wiltshire. Chris Floyd helped locate study sites and assisted in other ways. Scott Bartlam, Sam Cave, Toni Cornes, Stacey Foster and particularly Jordan Edgar helped with the substantial fieldwork required for this project, including daily trap-clearing that lasted several months. Doug Armstrong, Bill Lee and Elaine Murphy greatly improved this paper with useful comments; Christine Bezar and Anne Austin valuably edited drafts, and Anouk Wanrooy patiently drafted Figure 1. In particular, we thank Doug for reminding us of the valuable unpublished PhD research of Rebecca Boulton. The research was funded by the Foundation for Research, Science and Technology under UOW X0609.

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Editorial Board member: David Wardle
Received 12 February 2009; accepted 24 October 2009

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