Ground-based rodent control in a remote Hawaiian rainforest on Maui

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Effective control of introduced mammalian predators is essential to the recovery of native bird species in Hawai'i. Between August 1996 and December 2004, introduced rodents were controlled within three home ranges of the Po'ouli *Melamprosops phaeosoma*, a critically endangered Hawaiian honeycreeper. Rats were controlled using a combination of ground-based rodenticide (0.005% diphacinone) application and snap traps. Beginning in August 2001, we monitored the effectiveness of these rodent control efforts. Relative abundances of Black Rats *Rattus rattus* and Polynesian Rats *R. exulans* were measured in each of five snap-trapping grids seven times over a 35-month period. Rat populations decreased inside of the rodent control areas, but control effectiveness differed between rat species. During the first year of monitoring, target control levels for *R. rattus* were consistently achieved in only one of the rodent control areas. Control techniques were refined in areas failing to meet targets. Subsequently, we achieved target control levels for *R. rattus* more consistently in all three rodent control areas. However, relative abundances of *R. exulans* did not differ between rodent control and reference areas, indicating that our rodent control techniques were insufficient to reduce population levels of this species. These findings signify a need for further improvement of rodent control methods in Hawai'i, especially for Polynesian Rats, and demonstrate the critical importance of periodic monitoring of the response of rodent populations to management. In the future, managers may need to design rodent control operations targeting *R. rattus* and *R. exulans* independently to achieve best results.

Key words: Black Rat, *Rattus rattus,* Polynesian Rat*, Rattus exulans*, Hawai'i, Diphacinone, Rat abundance, Rodent control, Endangered birds, Po'ouli, *Melamprosops phaeosoma.*

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INTRODUCTION

THE impact of introduced mammalian predators on insular species and ecosystems, particularly avifauna, is well documented (Blackburn et al. 2004; Courchamp et al. 2003; King 1985). In particular, rats (*Rattus* spp.) have contributed to the decline and extinction of island birds worldwide, including on the Hawaiian Islands (Atkinson 1985; VanderWerf & Smith 2002). In Hawai'i, rat predation is regarded as a major factor in the decline of endemic forest birds and as a barrier to their recovery (Atkinson 1977; Lindsey et al. 1999; Scott et al. 1986; Tweed et al. 2006). Effective mitigation of rat predation has enabled dramatic recoveries of several Pacific Island forest birds (Innes et al. 1999; Robertson et al. 1994), and is considered an essential component of ecological restoration programmes (Moors et al. 1992; Saunders & Norton 2001). Rodent control is thus a key component of many endangered species recovery and ecosystem management plans in Hawai'i (Tobin 1994; US Fish and Wildlife Service 2006).

On the Hawaiian Islands, native forest birds are largely restricted to remote montane forests (Scott et al. 1986; US Fish and Wildlife Service 2006). Implementing large-scale ground-based rodent control operations in these conservation areas is labour-intensive and expensive due to their inaccessibility and ruggedness (Nelson et al. 2002). Researchers are thus seeking to develop safe and effective methods for the aerial broadcast of rodenticide in native Hawaiian forests in order to achieve rodent control at large scales (Dunlevy et al. 2000; Johnston et al. 2005). During this study, however, snap-trapping and ground-based application of diphacinone (a first-generation chronic anticoagulant rodenticide) were the only rodent control techniques approved for conservation purposes in the State.

We use the case of the Po'ouli *Melamprosops phaeosoma*, a critically endangered Hawaiian honeycreeper, to evaluate ground-based rodent control techniques in a remote Hawaiian wet forest ecosystem. Management activities for the Po'ouli provide a unique case study in which an intensive, long-term rodent control campaign comprised one component of a larger recovery plan (Groombridge et al. 2004; US Fish and Wildlife Service 2006; VanderWerf et al. 2005; VanderWerf et al. 2003). Following the species' discovery in 1973 (Casey & Jacobi 1974), the population and range of the Po'ouli declined rapidly between 1976 and 1985 (Mountainspring et al. 1990). By 1997, the known population consisted of only three individuals

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PACIFIC CONSERVATION BIOLOGY Vol. **14:** 206–214. Surrey Beatty & Sons, Sydney. 2008.

occupying separate, non-overlapping home ranges within the State of Hawai'i's Hanawi Natural Area Reserve (Reynolds & Snetsinger 2001). In an attempt to reduce the threat of predation and competition for food resources, rodent populations were controlled in all three Po'ouli home ranges from August 1996 to December 2004 using a combination of rodenticide bait application and snap-trapping.

Given the importance of effective rodent control in Hawaiian forests, it is critical to monitor rodent populations and optimize control methods. Beginning in 2001, we established population targets for control of rodent species and initiated standardized, recurrent rat population monitoring in each Po'ouli home range. We measured the overall impact of our rodent control efforts on Black Rats *R. rattus* and Polynesian Rats *R. exulans* and used monitoring data to optimize local rodent control efforts. In this paper, we evaluate the impact of our sustained ground-based rodent control efforts on rodent populations, appraise techniques for controlling and monitoring rodent populations in large, inaccessible forest reserves in Hawai'i, and discuss the implications of our findings for management of Hawaiian species and ecosystems.

METHODS

Study Area

The study was conducted in the Hanawi Natural Area Reserve (hereafter Hanawi: 020°45'N, 156°08'W) located on the north-eastern slope of Haleakala Volcano, East Maui, Hawai'i. This remote 3 036 ha montane rainforest preserve was established by the State of Hawai'i in 1986 to protect the entire known range of the Po'ouli and provides habitat for populations of numerous other threatened and endangered native forest birds, plants, and snails (IUCN 2004). The study sites were located in an 800 ha ungulate exclosure in Hanawi, between 1 500 m and 2 000 m elevation. Topography within Hanawi is rugged, steep, and regularly dissected by ridges and erosion gulches. Vegetation is mixed shrub montane wet forest (Jacobi 1985) with a dense native understory and a canopy dominated by 'ohi'a *Metrosideros polymorpha* and Olapa *Cheirodendron trigynum*. Ground cover is dominated by native ferns (*Dryopteris* spp., *Sadleria* spp. and *Athyrium* spp.) and Hairgrass *Deschampsia nubigena*. Climate is largely dependent on prevailing northeast trade winds with aseasonal rainfall exceeding 5 m annually (Giambelluca et al. 1986).

Rodent Control

The rodent control programme was established in 1996 by the State of Hawai'i and U.S. Geological Survey in response to the rapid decline of the Po'ouli population and was continued under the Maui Forest Bird Recovery Project in 1997. In the following sections, the authors use the term "we" to describe the combined efforts of the various agencies. The programme originated as a management tool and later incorporated research techniques with which to evaluate and refine that tool. Beginning in August 2001, we utilized a simple adaptive strategy based on repeated monitoring of rodent populations to establish science-based management goals, identify deficiencies in our rodent control program and adjust management techniques. As a result, the methodology reflects adaptations over time.

Rodent Control: Rodenticide Application

We applied rodenticide bait in three areas encompassing the home ranges (HR) of the three Po'ouli and refer to these "rodent control areas" as HR1, HR2, and HR3 (Figure 1). Networks of poison bait stations were established in HR1 and HR2 in August 1996, and in HR3 in May 1998. We attempted to place bait stations every 50 m along transects spaced approximately 100 m apart. However, the difficulty of establishing straight-line transects in extremely rough terrain and the need to use existing trails meant that actual inter-station distances varied.

The effective rodent control area was calculated in ArcGIS™ 9.1 as the area contained by all peripheral bait stations plus a buffer zone equivalent to the median distance travelled by Black Rats from their centres of activity (59.6 m; Lindsey et al. 1999). A bait application rate was calculated as the average amount (kg) of bait available per session per hectare. Bait application rate increased over time, as the bait networks were improved and modified (Table 1). From August 1996 to May 1997, we applied 454 g (16 oz) of bait in each HR1 and HR2 bait station per session. We replenished bait approximately three days after initial bait placement and thereafter every 23 ± 10 days (range 11–45) in HR1 and every 24 ± 7 days (range 12–35) in HR2. From August 1997 to December 2004, we reduced the amount of bait to 227 g (8 oz) per station, and replenished bait every 78 ± 23 days (range 15–181) in HR1 and every 80 ± 32 days (range 42–237) in HR2. In HR3, we applied 227 g of bait in each station for the entire treatment time (May 1998 to November 2004), and replenished bait every 76 ± 33 days (range 13–170). Total application rates varied with year and site (Table 1).

We used 0.005% diphacinone for conservation purposes under the U.S. Environmental Protection Agency's (EPA) special local needs (SLN)

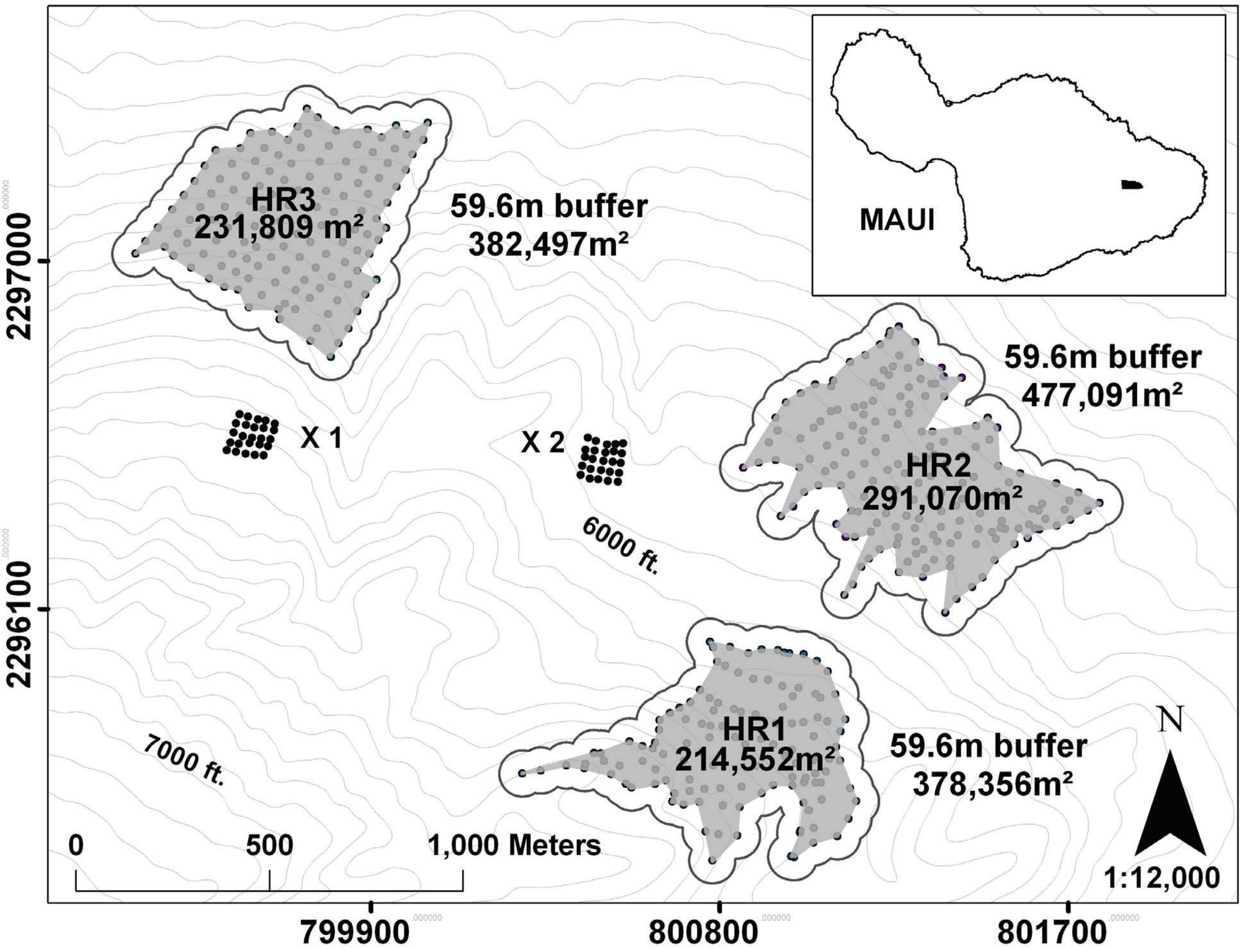

Fig. 1. Map of rodent control areas (HR1, HR2, HR3) and rodent monitoring reference grids (X1, X2) in Hanawi Natural Area Reserve, East Maui, Hawai'i (monitoring grids HR1 $_{m}$, HR2 $_{m}$, and HR3$_{m}$ not shown). Contour lines represent 100ft elevation change. Inset: The island of Maui and location of the study area (black).

Table 1. Poison bait application rates in Hanawi, 1996–2004.

Site	Bait periods	No. bait sessions	No. bait stations	Total bait available per session (kg)	Area covered (ha)	Application rate (kg/h)
HR1	Aug 96–May 97	12	116	52.62	37.25	1.41
	Aug 97–Apr 98	5	117	26.53	37.25	0.71
	Jul 98–Oct 99	7	119	26.99	37.25	0.72
	Dec 99–Apr 01	7	121	27.44	37.25	0.74
	Jul 01–Feb 02	4	121	27.44	37.84	0.73
	Apr 02–Dec 02	4	122	27.67	37.84	0.73
	Mar 03–Dec 04	8	121	27.44	37.84	0.73
HR2	Aug 96–May 97	11	111	50.35	44.41	1.13
	Aug 97–Jan 03	27	125	28.35	44.41	0.64
	Sept 03–Dec 03	2	163	36.97	44.41	0.83
	Feb 04–May 04	2	170	38.55	45.42	0.85
	Jul 04–Nov 04	3	175	39.69	47.71	0.83
HR3	Jun 98–May 99	5	55	12.47	19.48	0.64
	Jul 99	1	115	26.08	33.89	0.77
	Nov 99–Jan 03	17	133	30.16	38.67	0.78
	Apr 03–Nov 04	8	132	29.94	38.25	0.78

programme. We periodically changed bait types and flavours between sessions in order to overcome any potential development of behavioural and physiological resistance to bait acceptance over time (Innes et al. 1999). Over the course of the rodent control programme, we used three bait formulations: Eaton's All-Weather Bait Blocks® in fish (EPA SLN HI-97-0007) and peanut butter/molasses (EPA SLN HI-94-0001) flavours and Ramik® Mini Bars All-Weather Rat and Mouse Killer (EPA SLN HI-98-0005).

Rodent Control: Snap-trapping

We established a network of snap traps in each rodent control area to supplement poisoning efforts. Victor® snap traps were baited with chunk coconut and placed horizontal to the ground and concealed under weather-resistant covers to prevent incidental trapping of non-target animals (e.g. forest birds). In HR1 and HR2, 106 and 113 traps were placed approximately every 50 m, offset 25 m between bait stations (2.82 traps/ha and 2.54 traps/ha respectively). Snap-trapping was initiated in December 1996 in both HR1 and HR2 with an intensive trapping effort; traps were checked and reset for four consecutive nights. After this initial effort, traps were checked and reset once per session on the same schedule as bait stations to provide additional low-level rodent control. Trapping was conducted in HR1 and HR2 from December 1996 to April 2001, after which it was discontinued. Trapping was resumed in HR1 in September 2002 based on findings of this study indicating that the bait application programme alone provided unsatisfactory control of rodent populations. In HR3, 145 snap traps were placed every 25 m along bait station transects in the core of the home range (7.3 traps/ha), and trapping followed the same procedures as in HR1 and HR2 over the entire duration of the programme (1998-2004) (Table 2).

Rodent Population Monitoring

In August 2001, we established five 1 ha monitoring grids to measure relative rodent abundances and to evaluate the effectiveness of rodent control operations in Hanawi. One monitoring grid ($HR1_m$, $HR2_m$, and $HR3_m$) was positioned near the center of each of the three rodent control areas. Two reference grids (X1, X2) were positioned in similar habitat in unmanaged areas to measure unmanaged rodent populations (Figure 1). Monitoring grids were established at sufficient distances apart to prevent movement of rats among grids based on estimates of rat home range size and movement patterns (Hooker & Innes 1995; Lindsey et al. 1999); distances between reference grids and the closest rodent control monitoring grid ranged from 445 m to 689 m (mean 601 m).

Each 1 ha monitoring grid consisted of 25 Victor® snap traps spaced every 25 m in a 5 by 5 arrangement. Traps were placed on the ground or on logs within 1 m of the ground. All traps were placed horizontal to the ground and concealed under plastic covers to prevent incidental trapping of forest birds. During each trapping session, traps were pre-baited with coconut for three nights prior to being set. Traps were then baited with coconut and set for six consecutive nights. All traps were checked daily and reset and/or re-baited as necessary. Captured animals were collected and identified on the day of capture. Rodent population monitoring was conducted simultaneously in all

Table 2. Relative abundances (R/100CTN) of Black Rats *R. rattus* and Polynesian Rats *R. exulans* over 35 months of rodent population monitoring in Hanawi. Population targets were defined as a proportion of the reference mean for each session. One percent (1%) population targets and sites achieving greater than 99% population reduction in **bold.** Rodent control techniques were refined in HR1 and HR2 following the August 2002 rodent population monitoring session (See Methods).

		Rodent Control Areas				Reference Areas			Target
Species	Session	$HR1_m$	$HR2_m$	$HR3_m$	Mean (±SE)	X1	X2	Mean (±SE)	1%
R. rattus	August 2001	5.59	0.68	**0.00**	2.09 (±1.76)	26.67	9.93	18.30 (±8.37)	**0.18**
	December 2001	6.52	6.55	**0.00**	4.36 (±2.18)	9.59	9.77	9.68 (±0.09)	**0.10**
	May 2002	2.04	0.72	**0.00**	0.92 (±0.60)	9.59	0.70	5.15 (±4.45)	**0.05**
	August 2002	0.68	3.57	1.37	1.87 (±0.87)	8.82	1.43	5.13 (±3.69)	**0.05**
	May 2003	**0.00**	**0.00**	**0.00**	0.00 (±0.00)	8.42	4.96	6.69 (±1.73)	**0.07**
	February 2004	1.37	**0.00**	**0.00**	0.46 (±0.46)	4.84	5.50	5.17 (±0.33)	**0.05**
	June 2004	**0.00**	1.38	**0.00**	0.46 (±0.46)	6.25	3.52	4.89 (±1.36)	**0.05**
R. exulans	August 2001	4.20	1.36	1.34	2.30 (±0.95)	3.92	3.55	3.73 (±2.64)	**0.04**
	December 2001	4.35	7.27	2.71	4.78 (±1.33)	2.21	9.77	5.99 (±4.24)	**0.06**
	May 2002	2.04	14.44	2.04	6.17 (±4.13)	8.12	7.02	7.57 (±5.35)	**0.08**
	August 2002	1.35	5.71	3.41	3.49 (±1.26)	6.62	6.45	6.53 (±4.62)	**0.07**
	May 2003	0.67	**0.00**	2.03	0.90 (±0.60)	1.40	4.96	3.18 (±2.25)	**0.03**
	February 2004	2.05	1.34	2.70	2.03 (±0.39)	1.38	0.00	0.69 (±0.49)	**0.01**
	June 2004	4.15	5.52	1.36	3.68 (±1.22)	1.39	2.11	1.75 (±1.24)	**0.02**

five monitoring grids seven times between August 2001 and June 2004 (Table 2).

To account for differences in sampling effort and to facilitate comparisons among sites, rodent populations are expressed as indices of relative abundance (Hopkins & Kennedy 2004). Capture rates were calculated as the number of rat captures (R) per 100 trap nights (TN) corrected (C) for all sprung traps (Beauvais & Buskirk 1999; Nelson & Clark 1973) and notated as R/100CTN.

Rodent Population Targets

Beginning in August 2001, we used population monitoring data to establish population targets for both *R. rattus* and *R. exulans* to evaluate the effectiveness of rodent control operations in each Po'ouli home range. Targets were defined independently for each session based on unmanaged rodent population levels measured concurrently in the two reference grids. For each species, we set population targets at 1% of the mean relative abundance measured in the reference grids (i.e. 99% reduction in unmanaged populations; Table 2) based on evidence that non-native predators must be reduced to extremely low densities over several consecutive years to recover endangered bird populations (Innes et al. 1999; Saunders & Norton 2001). Such monitoring-based population targets provided real-time metrics against which to measure the effectiveness of our rodent control operation.

In August 2002, following one year of rodent population monitoring, we refined rodent control techniques in HR1 and HR2 as both sites had consistently failed to meet population targets. We identified major gaps in station spacing in both networks using GIS. Despite the existence of such gaps in HR1, we were limited in our ability to adjust the bait station spacing due to the ruggedness of the terrain and because increased foot traffic in some areas would damage sensitive habitats. Instead, we resumed removal snap-trapping in HR1 in September 2002. In HR2, 38 new bait stations were installed in January 2003 to fill gaps in the bait network and an additional twelve bait stations were installed between December 2003 and May 2004 in response to Po'ouli observations at the edge of its known home range (Table 1).

Analysis of Rodent Population Monitoring Data

We tested the overall effect of rodent control efforts in Hanawi (2001-2004) using repeated-measures analysis of variance (RM-ANOVA). We used an autoregressive covariance structure (SAS 1998) with the index of relative rodent abundance as the dependent variable and effects of treatment, time, and their interaction as independent variables. We performed natural log (ln +1) transformations of catch indices to account for skewed distributions (Skalski & Robson 1992). Analyses were conducted separately for each species, with $\alpha = 0.05$. House Mice *Mus musculus* and unidentified rats were accounted for in calculations of corrected trap nights, but excluded from all further analyses. We evaluated the effectiveness of rodent control efforts within each grid through direct comparison against monitoring-based population targets.

RESULTS

Rodent Control

Between 1996 and 2004, snap traps removed a minimum of 1483 rodents from the study area, including 551, 276, and 300 rats (*Rattus* spp.) from HR1, HR2, and HR3 respectively. These numbers do not include animals captured during rodent population monitoring and are considered underestimates because scavenging and decomposition impeded our ability to count and identify all captures to species. Although diphacinone consumption varied, bait was consistently taken throughout the duration of the project, indicating acceptance of rodenticide baits.

Rodent Population Monitoring

We captured 193 *R. rattus,* 181 *R. exulans*, six undetermined *Rattus* (partially scavenged or juvenile rats), and 19 *M. musculus* during 5000.5 corrected trap-nights. We did not capture any Norway Rats *R. norvegicus* in our study area, further corroborating evidence of their rarity in Hawaiian montane wet forests (Sugihara 1997; Tomich 1986). The effectiveness of rodent control varied by species; *R. rattus* was more successfully controlled than *R. exulans* (Table 2).

Black Rats

Mean Black Rat abundances were significantly lower in rodent control areas than in reference areas (RM-ANOVA; $F = 11.09$; $df = 1, 3$; $p = 0.045$). There was no effect of time or interaction of time and treatment on relative abundances of Black Rats. Between August 2001 and August 2002, population targets (i.e. 99% reduction) for Black Rats were consistently achieved only in HR3, in three of four sessions (Table 2). During the same time period, targets were not achieved in any of the four sessions in HR1 and HR2. Following adjustment of rodent control techniques in January 2003 in HR1 and HR2 (see Methods, Rodent Population Targets), population targets were achieved in three of three sessions in HR3 and two of three sessions in HR1 and HR2.

Polynesian Rats

Mean Polynesian Rat abundances did not differ between rodent control and reference areas (RM-ANOVA; F = 1.61; df = 1, 3; p = 0.294), but did vary over time (RM-ANOVA; F = 2.96; df = 6, 18; p = 0.034). Mean Polynesian Rat densities in rodent control and reference areas appeared to fluctuate in synchrony, suggesting *R. exulans* was responding to regional environmental effects rather than rodent control (Figure 2). Population targets for Polynesian Rats were achieved during only one rodent monitoring session at one site (Table 2), and adjustments to control techniques had no effect on Polynesian Rat populations in rodent control areas.

DISCUSSION

Efficacy of Rodent Control in Hanawi Natural Area Reserve

This study demonstrated that combined ground-based application of diphacinone and low-effort trapping was sufficient to reduce Black Rat populations in Hanawi but that these control techniques were largely ineffective for Polynesian Rats. This finding is consistent with

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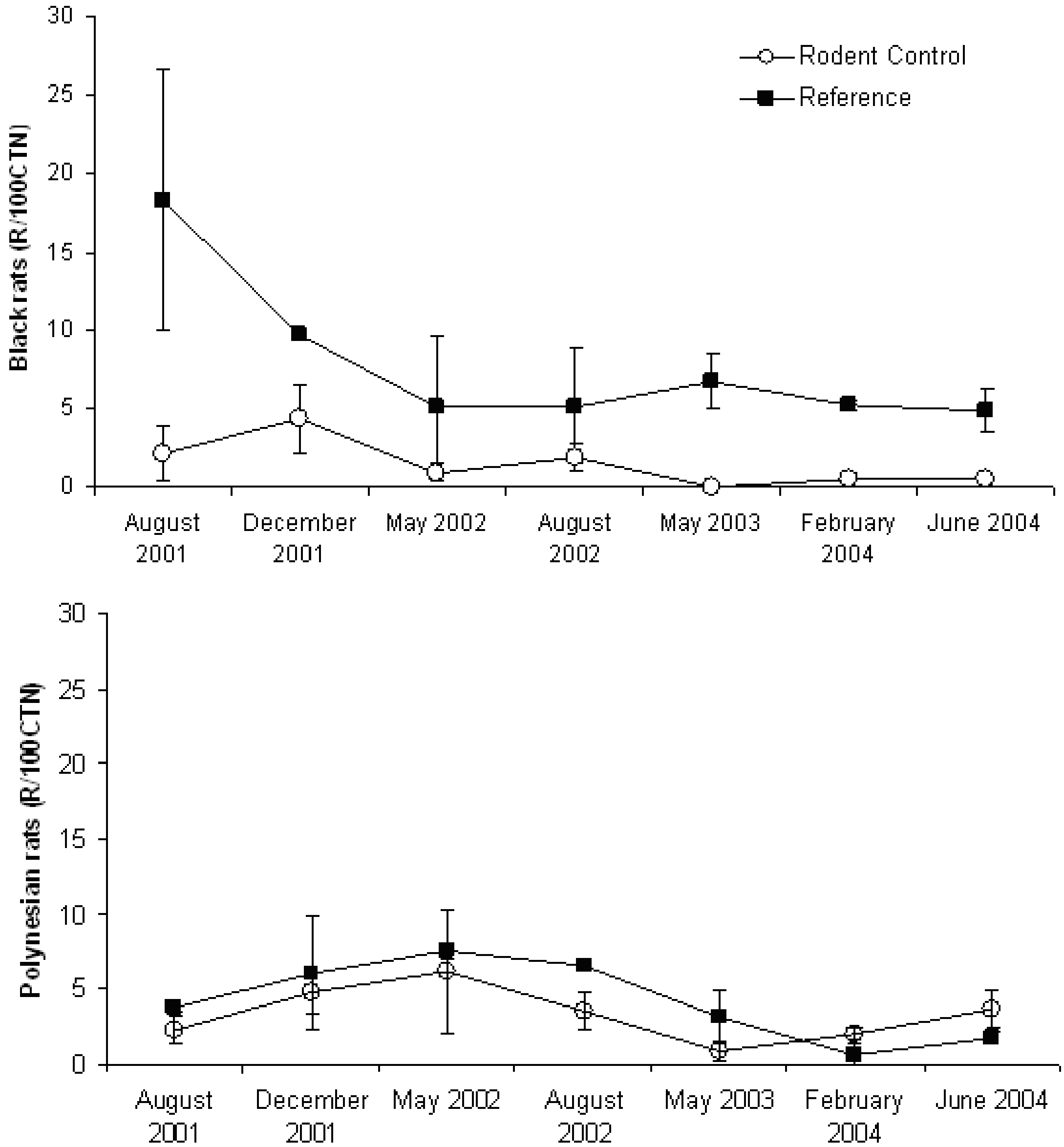

Fig. 2. Mean relative abundances (±SE) of **(a)** Black Rats *R. rattus* and **(b)** Polynesian Rats *R. exulans* in rodent control monitoring grids (n = 3; $HR1_m$, $HR2_m$, $HR3_m$) versus reference monitoring grids (n = 2; X1, X2), August 2001 to June 2004.

earlier studies in Hanawi (MFBRP unpublished data) and the findings of Nelson et al. (2002) on the island of Hawai'i.

Black Rat populations were most effectively controlled in HR3 where both rodenticide application and snap-trapping were implemented for the duration of the study. Between August 2001 and August 2002, Black Rat abundances were generally higher and more variable in both HR1 and HR2. We attributed the lower effectiveness of rodent control in these two areas to irregular bait station spacing and/or inconsistent snap-trapping. However, we were unable to test the causes of the observed differences among grids due to lack of sufficient replication and randomization of treatments.

We attributed our inability to control Polynesian Rats to problems associated with bait presentation and acceptance. Inter-specific competition with Black Rats (Russell & Clout 2004; Harper et al. 2004) may have reduced access to bait stations, but seems unlikely because Black Rat populations were reduced to low levels during the rodenticide application campaign. Nelson et al. (2002) suggested that snap-trapping may better control Polynesian Rats, but our low-intensity removal snap-trapping did not appear to have a significant impact on abundance of this species. Because our study sites were within a matrix that was not managed to reduce rat populations, the role of differential immigration of Black and Polynesian Rats into the grids could not be assessed. Our failure to adequately control Polynesian Rats in any of the three sites warrants further study. In the future, managers may need to design control operations independently for each species.

Implementation of a simple adaptive strategy, including a recurrent cycle of monitoring, evaluating and adjusting, was a valuable tool for improving the effectiveness of our rodent control programme in Hanawi over time, especially for Black Rats. Adjustments to rodent control methods made after August 2002, including increased bait station density in HR2 and renewed snap-trapping in HR1, appeared to improve the effectiveness of Black Rat control in both areas. In HR1 and HR2, we achieved greater than 99% control of Black Rats during two of the three final monitoring sessions, and population fluctuations were less variable.

Implications for Conservation of Hawaiian Species and Ecosystems

Over the last two decades, conservation practitioners have developed a range of technologies and techniques for the eradication of introduced rodents in island ecosystems, resulting in the eradication of rodents from at least 284 islands worldwide (Howald et al. 2007). Although the majority of successful rodent eradication campaigns have been carried out on small (<100 ha) islands, eradication has been achieved on increasingly large islands (up to 11,300 ha) (Towns & Broome 2003; Howald et al. 2007). In most cases, the second-generation anti-coagulant brodifacoum has been used; diphacinone was used in only five campaigns (Howald et al. 2007).

In contrast, conservation programmes in Hawai'i have aimed primarily at rodent control, whereby rodents are consistently reduced to low population levels. Persistent immigration of rats into managed areas from surrounding unmanaged areas requires continuous effort. During this study, application of diphacinone within bait stations was the only approved method of rodenticide delivery for conservation purposes. Using this method, we found attaining effective rodent control in a large, remote rainforest reserve to be extremely labour intensive and costly. The 123 ha ground-based rodent control and monitoring programme in Hanawi cost on average US$40,000 per year ($325/ha/year) to set up and maintain between 1996 and 2004.

In New Zealand, a range of pest species are successfully controlled to protect biodiversity in "Mainland Island" reserves, including rat control with bait stations and/or snap traps in areas up to 1400 ha (Gillies 2002; Saunders & Norton 2001). In Hanawi, however, the logistical difficulties and human impact of widespread ground control are assumed prohibitive.

Rodent control and eradication campaigns have had significant positive impacts on avian populations elsewhere (Innes et al. 1999; Robertson et al. 1994), but few studies in Hawai'i have investigated the impact of rodents on the life history parameters of native forest birds or the population-level responses of forest birds to rodent control. One study of O'ahu 'Elepaio *Chasiempis sandwichensis ibidis* illustrates the complexity of the issue; despite improved nest success as a result of ground-based rat control, the 'Elepaio population remained stable, suggesting additional factors were also limiting (VanderWerf & Smith 2002). Furthermore, it is assumed that rodent control efforts in Hawaiian forests have generally not been conducted at large enough temporal and spatial scales to improve the conservation status of an endangered species or population segment (US Fish and Wildlife Service 2006).

Rodent control will likely continue to be a critical component of species and ecosystem conservation efforts in Hawai'i. In order to maximize the conservation impact of limited resources, there is an immediate need to improve the cost-effectiveness and overall efficacy of ongoing rodent control operations throughout the State. Thus, it is necessary to scale-up rodent control efforts in sensitive habitat areas and accelerate efforts to critically evaluate alternate rodent control methods.

Post-Script

The primary objective of this rodent control programme was to provide long-term protection for the three known Po'ouli by reducing competition and the threat of predation from introduced rats. Although the survival of these three Po'ouli cannot be directly attributed to these efforts, the birds persisted in the wild for at least seven years after the initiation of the rodent control programme. Two of the birds were last observed in the wild in December 2003 and February 2004, respectively. The third individual died in captivity in November 2004 (VanderWerf et al. 2005). At the time of each of their last confirmed sightings, all three birds were at least eight years old. The species is now believed to be extinct. In 2008, aerial broadcast of diphacinone was registered for conservation purposes in the State of Hawai'i.

ACKNOWLEDGMENTS

The Maui Forest Bird Recovery Project operates under the auspices of the Pacific Cooperative Studies Unit, University of Hawai'i. Funds for this research were provided by the U.S. Fish and Wildlife Service and the Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife. The authors would like to thank T. Pratt and P. Baker for their significant contributions to the rodent control programme; the many project staff and volunteers that made this study possible through their assistance in the field; E. Campbell and P. Dunlevy for advice on study design; M. Graham and J. VanderMark for ArcGIS™ analysis; Windward Aviation Inc. and Pacific Helicopters Ltd. for safe transport to and from Hanawi; Haleakala National Park, Haleakala Ranch and The Nature Conservancy of Hawai'i for logistical support; and the Hawai'i Natural Area Reserves System Commission for long-term support of this work. Data collected between 1996 and 1998 was provided by the U.S. Geological Survey, Pacific Island Ecosystems Research Center. A. Burbidge, D. Duffy, D. L. Leonard, B. Malcolm, T. Pratt, E. A. VanderWerf and H. Wright provided helpful comments on previous manuscript drafts. Mention of trade names or commercial products is for identification purposes only and does not imply endorsement by the authors or their agencies.

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