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Broadcast application of a placebo rodenticide bait in a native Hawaiian forest

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Abstract

This study consisted of three replicates of controlled field trials using a pelletized placebo (Ramik® Green formulated without diphacinone) bait treated with a biological marker and broadcast at three application rates — 11.25, 22.5 and 33.75 kg/ha. We determined that Polynesian (*Rattus exulans*) and roof rats (*Rattus rattus*) consumed this bait when broadcast on the ground and assessed the optimal sowage rate to result in maximum exposure of bait to the rats while minimizing bait usage. All Polynesian rats captured in all application rates had eaten the bait. The percentage of roof rats that had eaten the bait increased with application rate, however, 22.5 kg/ha was clearly the optimal application rate. Bait degradation and invertebrate activity was documented and assessed. Published by Elsevier Science Ltd.

1. Introduction

Introduced rats (*Rattus* spp.) have had devastating impacts on insular ecosystems worldwide, including the Hawaiian Islands (Atkinson, 1977; Buckle and Fenn, 1992; Moors et al., 1992; Seto and Conant, 1996). In the Hawaiian Islands, rats have been implicated in the extinction of numerous native species directly through predation and indirectly via competition for habitat and food resources (Atkinson, 1985). The presence of commensal rats in native ecosystems has contributed significantly to declines in endemic Hawaiian flora and fauna (Atkinson, 1977; Baker and Allen, 1976; Scowcroft and Sakai, 1984; Stone, 1985; Scott et al., 1986; Hadfield et al., 1993). Introduced rats spread seeds of invasive alien plants and are (or have been) vectors for human and animal diseases such as leptosporosis and plague in important watershed habitats (Tomich, 1986).

Rodent control, therefore, is considered a high priority for many species and ecosystem restoration plans in Hawaii (Tobin, 1994). Broadcast rodenticides have been used successfully to control introduced rodents for species conservation and habitat restoration in New Zealand (Miller and Anderson, 1992) and could potentially be used in Hawaii. The apparent success of New Zealand rodent control efforts (Innes et al., 1995) prompted the formation of a multi-agency rodenticide working group in Hawaii to seek regulatory approval for the use of similar techniques in this state.

Diphacinone is an anticoagulant, which reduces clotting factors by inhibiting the vitamin K cycle (Hadler and Buckle, 1992). Diphacinone was selected as the rodenticide to pursue for registration because of its effectiveness against rats in Hawaii (Tobin, 1992), relative low risk to non-target species of concern in the natural areas where it will be used — birds (Joerman, 1998; Kaukeinen, 1982), and limited persistence in the environment (Lund, 1988). In 1995, collaborative efforts of the working group culminated in the state registration of Eaton's All-Weather Bait Blocks rodenticide® (0.005% diphacinone) for use in bait stations

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to reduce rat depredation in native Hawaiian ecosystems. At present, two formulations of Eaton's bait (fish-flavored-SLN HI 970007 and peanut butter-molasses flavored-SLN HI-940001) are approved for use in bait stations for conservation purposes in the state of Hawaii. In June 1998, Hacco Inc. also obtained a similar state registration for Ramik® Mini Bars All-Weather Rat and Mouse Killer (SLN HI-980005); a fish flavored compressed cereal grain bait containing 0.005% diphacinone.

Application of rodenticides in bait stations can be an effective technique for reducing rat populations in limited areas (Erickson and Halvorson, 1990) but is extremely labor intensive and impractical for large areas (Nelson et al., in press). There is a critical need to obtain similar registrations for a broadcast use pattern of rodenticides in Hawaiian conservation areas. Since many of the sites where native flora and fauna are threatened by predation are in remote and rugged areas with limited access, the only cost-effective method for rodent control in these sites is the broadcast application of a rodenticide bait (Moors et al., 1992; Tobin, 1994). The Eaton's and Hacco's fish flavored diphacinone bait formulations currently approved for use in bait stations are being considered for registration for broadcast application in Hawaii.

To obtain registration for broadcast application of diphacinone bait pellets for conservation purposes; the efficacy of the product and technique on rodents in native environments must be determined. For broadcast application of diphacinone bait pellets to be effective, the bait must be applied at a sufficient density so that >80% of rats encounter and ingest a lethal quantity of bait over a successive number of days (Marsh, 1986). A series of laboratory bioassays conducted with a commercially available Ramik® Green pelletized bait containing 0.005% diphacinone (EPA Reg. No. 2393-508) determined the minimum dosage (30–37 g of bait) and exposure time (6–7 days of feeding) needed to achieve control of *R. rattus* and *R. exulans* (Swift, 1998). Our field study used these laboratory results as the basis for developing a technique for broad-scale control of rodents in Hawaiian forest ecosystems.

This study consisted of controlled field trials using placebo Ramik® Green pelletized bait (formulated without diphacinone) treated with a biological marker and broadcast at three application rates over three replicates. The objectives were to determine (1) if rodents in native Hawaiian forests consume Ramik® Green rodenticide bait that has been broadcast on the ground and (2) an optimal rate for broadcasting the bait that results in maximum exposure of the bait to the rodents; while minimizing bait usage. Mention of trade names or commercial products is for identification purposes only and does not imply endorsement by the authors or their agencies.

2. Methods

2.1. Study sites

The study was conducted in portions of forestry blocks at the Waiakea Forest Reserve near Hilo, on the Island of Hawaii. Nine forestry blocks (8–16 ha) of trees with similar stocking rates, height and crown diameters and with comparable understory and ground vegetation were selected for the installation of study grids. Grids were separated by at least 400 m to minimize movement of rodents among sites. One hectare (100 m × 100 m) grids were established at each of the nine sites, with minimal clearing of vegetation. Transects and rodent monitoring stations were spaced 10 m apart, for a total of 100 stations per grid. Each rodent monitoring station consisted of one mouse snap trap and one rat snap trap. Numbered wire flags marked stations and transects were marked with flagging tape between stations.

2.2. Bait preparation

The manufacturer (Hacco, Madison, WI), prepared non-toxic, fish-flavored compressed cereal grain bait pellets (placebo bait) for the field test. We applied the biological marker Tetracycline Hydrochloride (TCH 98.2% A.I.) to the placebo bait with an adhesive comprised of lecithin oil (Alcolec-S®) and soybean oil (Wesson®) in a 1:1 solution (alco-soy; Tobin et al., 1996). The marked placebo bait formulation was composed of 98.85% placebo bait, 1% alco-soy solution and 0.15% TCH by weight. The marked bait formulation was prepared in four batches, each batch consisting of 22.7 kg marked bait, using a 0.42 m^3 electric cement mixer. The bait mixture was removed from the mixer and placed in a single layer on paper in 38 × 86 cm metal trays to dry, in a ventilated, temperature controlled (23°C), dark room. All bait mixtures were checked with an UV lamp for uniform coating of TCH. After drying, irregular pellets were removed and the bait was bagged for use in the field.

2.3. Hand broadcast

We based our hand broadcast procedure on the average pellet weight of 11.5 ± 0.03 g ($n = 464$). The target bait distribution densities were 1 pellet/10.6 m^2 (11.25 kg/ha, 10 lbs/ac, low application rate), 1 pellet/5.2 m^2 (22.5 kg/ha, 20 lbs/ac, medium application rate) and 1 pellet/3.5 m^2 (33.75 kg/ha, 30 lbs/ac, high application rate). Staff participating in the bait broadcast field work walked along the transects stopping every 3.3 m to distribute one (low application rate), two (medium application rate), or three (high application rate) pellet(s) 1.25 and 3.75 m to both sides if on a

central transect and to the interior side only if on an end transect. Prior to the actual application, all hand broadcast personnel took part in a training session to assure consistency of the bait application.

2.4. Bait monitoring

One quarter of each grid was subdivided into 192, 3.3 m × 2.5 m units. Twenty of these locations per grid were randomly selected. At ten locations, a bait pellet was placed within the assigned subdivision and marked with a numbered wire flag to monitor bait disappearance. Notes on pellet disappearance, movement, or other evidence of visitation by rodents were recorded. Five of these pellets, randomly selected prior to the study, were photographed daily (weather permitting). At the remaining ten locations, to prohibit removal, pellets were placed inside wire cages (21 × 29 × 21 cm with 6 mm wire mesh) lined with litter from the forest floor and marked with a numbered flag to monitor bait deterioration and invertebrate activity. All monitored pellets were checked daily for 2 weeks after application.

Bait degradation was assessed using three criteria: (1) softness (2) swelling and (3) surface area damage. For each monitored pellet, softness was obtained by inserting a probe into the pellet until the hard interior of the pellet was met and measuring this distance with calipers. Pellet length and width measurements were taken with calipers to track swelling of the 10 uncaged pellets. Length and width measurements were not obtained for pellets within cages, as repeated removal of pellets from cages caused extensive damage. Instead, swelling was qualitatively assessed for these pellets on a relative scale from 1 (least swollen) to 5 (most swollen). Also recorded was an estimate of the percent of surface area damaged with notes as to the nature of the damage and a qualitative assessment of the overall pellet condition. Overall pellet condition was assessed on a scale from 1 (best condition) to 5 (worst condition) based on the above monitoring criteria and the pellet's condition relative to other pellets being monitored. The presence of invertebrates on the pellets and other factors affecting the condition of the pellet (e.g. mold) were also recorded. In addition to data on bait pellet condition, information collected at each bait-monitoring site included a site description; was comprised of percent overstory canopy cover, understory cover, site elevation, substrate and drainage. Weather data, including rainfall and minimum/maximum temperatures were recorded daily at each plot during bait monitoring.

2.5. Trapping

Seven days after bait application, rat and mouse snap traps were placed within 1 m of each rodent monitoring station and prebaited with grated coconut. Ten days after bait application, rodent traps were baited with chunk coconut, set and maintained for four consecutive nights. Traps were checked as soon as possible after sunrise to reduce losses to scavengers. All captured animals were placed in individual locking plastic bags with labels (date, observer, plot, station) and stored in a cooler until transported to freezer storage pending necropsy. The relative density index used for trapping comparisons was a corrected trap success (Nelson and Clarke, 1973):

corrected trap success = captures / (traps set - half the number of inoperable traps) × nights set × 100.

2.6. Laboratory evaluation of animals

Species, whole body weight, and sex of all rodents captured during our study were recorded. Rats with descended testes were classified as adults and rats with abdominal testes were classified as juveniles. Initial examination entailed inspection of exposed incisors, prior to extraction, under long-wave UV light for characteristic TCH marking (Lefebvre et al., 1988). Tobin et al. (1996) found TCH marking above the gingival line at 14 days and on the mandibular condyles, coronoid processes and at the base of all incisors they inspected at 3 days after ingestion of TCH. If present, TCH marks were classified as strong or weak. Following the initial exam all animals were necropsied (rats found with strong marks during the initial exam of the first replicate were not examined further). The stomach and small and large intestines were opened and visually inspected for the presence of bait, which was easily identifiable by its color and composition. The condition of the internal organs was evaluated. The reproductive tract of female rats was inspected for placental scars or signs of pregnancy. Female rats with signs of prior or current reproduction were considered adults. Upper and lower incisors and left and right dentary bones were removed, cleaned and examined further for fluorescence.

3. Results

3.1. Trapping

Sixty-three roof rats and 20 Polynesian rats were captured in the rat snap traps during 3157 trap nights from June to August 1999. Roof rats accounted for 75% of all rat captures, while 25% were Polynesian rats. Mean corrected rat trap success for roof rats was 1.8 ± 0.3 (Table 1) and did not differ significantly

Table 1
Corrected trap success and capture summary of roof rats (*Rattus rattus*) in rat snap traps on nine plots (three replicates of three treatments)

Month	Treatment (kg/ha)	Plot	Nights	Corrected trap nights	Captures	Corrected trap success	*SE*	Male	Female	Adult	Juvenile
June	11.25	7	4	361	6	1.50	0.5	3	3	6	0
July		5	4	348	11	2.75	1.9	8	3	11	0
August		2	4	336	3	0.75	0.5	2	1	3	0
Subtotal			12	1045	20	1.67	1.6	13	7	20	0
June	22.5	6	4	382	8	2.00	0.7	5	3	8	0
July		4	4	378	5	1.25	0.8	3	2	5	0
August		1	4	347	5	1.25	0.3	3	2	3	2
Subtotal			12	1107	18	1.50	0.3	11	7	16	2
June	33.75	8	4	357	7	1.50	0.3	4	3	7	0
July		9	4	348	15	4.00	1.1	6	9	11	4
August		3	4	300	3	0.75	0.5	2	1	3	0
Subtotal			12	1005	25	2.08	0.6	12	13	21	4
Totals			36	3157	63	1.80	0.3	36 (57%)	27 (43%)	57 (90%)	6 (10%)

Table 2
Corrected trap success and capture summary of Polynesian rats (*Rattus exulans*) in rat snap traps on nine plots (three replicates of three treatments)

Month	Treatment (kg/ha)	Plot	Nights	Corrected trap nights	Captures	Corrected trap success	*SE*	Male	Female	Adult	Juvenile
June	11.25	7	4	361	0	0.00	0.0	0	0	0	0
July		5	4	348	5	1.25	0.5	3	2	4	1
August		2	4	336	6	1.50	0.7	4	2	5	1
Subtotal			12	1045	11	0.92	0.3	7	4	9	2
June	22.5	6	4	382	2	0.50	0.3	0	2	2	0
July		4	4	378	2	0.75	0.5	2	0	2	0
August		1	4	347	1	0.25	0.3	0	1	1	0
Subtotal			12	1107	5	0.50	0.2	2	3	5	0
June	33.75	8	4	357	1	0.50	0.3	0	1	1	0
July		9	4	348	3	0.75	0.5	0	3	0	3
August		3	4	300	0	0.00	0.0	0	0	0	0
Sub totals			12	1005	4	0.42	0.2	0	4	1	3
Totals			36	3157	20	0.60	0.1	9 (45%)	11 (55%)	15 (75%)	5 (25%)

between treatments (ANOVA; $F = 0.20$; $df = 2, 8$; $P = 0.83$). Mean corrected rat trap success for Polynesian rats was 0.6 ± 0.1 (Table 2) and did not differ significantly between treatments (ANOVA; $F = 0.76$; $df = 2, 8$; $P = 0.50$). We captured one adult female roof rat and three adult female Polynesian rats in the mouse snap traps during 2708 trap nights. Mean corrected mouse trap success for Polynesian rats was 0.1 ± 0.09, and did not differ significantly between treatments (ANOVA; $F = 2.29$; $df = 2, 8$; $P = 0.18$). In addition to rats, we captured three mongooses in rat traps and one mouse was found in a bait monitoring cage. No mice were captured in rat or mouse snap traps.

3.2. Marking

To determine if an animal had eaten the bait, we considered two types of 'marked' animals. Animals whose teeth and/or dentary bones exhibited the fluorescence of TCH marking and animals with bait present in the gastro-intestinal (GI) tract. The number of animals with TCH evidence and those found to have bait in the GI were combined for analysis. Percentages of captured roof rats known to have eaten the bait in the low, medium and high application rate plots were 71.4% ± 10.1 ($n = 21$), 94.4% ± 5.6 ($n = 18$) and 96.0% ± 4.0 ($n = 25$), respectively (Table 3). These differences in marking rate were not statistically significant (ANOVA; $F = 2.22$; $df = 2, 8$; $P = 0.19$). One hundred percent of Polynesian rats ($n = 23$) in all treatments were known to have eaten the bait (Table 4). Bait was found in the GI of one Polynesian rat and six roof rats that had not been marked by TCH. Six roof rats and nine Polynesian rats were TCH marked but had no evidence of bait in the GI when necropsied. There was no GI or TCH evidence that any of the mongooses captured had eaten bait. The single mouse found in the bait monitoring cage had eaten the entire bait pellet being monitored there.

3.3. Bait monitoring

3.3.1. Disappearance

Ten unprotected pellets were monitored at each site for each replicate, comprising a total of 30 uncaged monitored pellets per treatment. The rate of disappearance of these monitored pellets was highest in the medium application rate plots (Fig. 1). A total of 25 of the 30 (83%) bait pellets were taken during monitoring of these plots. Average daily take of monitored bait for the medium application rate plots was 1.8 ($SE = 0.4$) bait pellets per day. Twenty of the 30 monitored (67%) bait pellets were taken during the monitoring of the low application rate plots with an average daily take of 1.4 ($SE = 0.3$) pellets per day. The high application rate plots exhibited the lowest take of monitored bait, 10 out of 30 monitored pellets (33%) were taken, with an average daily take of 0.7 ($SE = 0.2$) pellets per day. Monitored pellets were taken as early as day 1 and as late as day 14. Differences among bait disappearance trends were not statistically significant

Table 3
Number of captures and percent of roof rats (*Rattus rattus*), from all snap traps, known to have eaten bait tetracycline hydrochloride (TCH) marked and TCH + gastro-intestinal (GI) marked on nine plots (three replicates of three treatments)

Month	Treatment (kg/ha)	Plot	Nights	Captures	TCH marked		TCH marked + GI	
					% marked	*SE*	% marked	*SE*
June	11.25	7	4	6	100.0	0.0	100.0	0.0
July		5	4	11	54.5	15.8	63.6	15.2
August		2	4	4	50.0	28.9	50.0	28.9
Sub totals			12	21	66.7	10.5	71.4	10.1
June	22.5	6	4	8	100.0	0.0	100.0	0.0
July		4	4	5	100.0	0.0	100.0	0.0
August		1	4	5	80.0	20.0	80.0	20.0
Sub totals			12	18	94.4	5.6	94.4	5.6
June	33.75	8	4	7	100.0	0.0	100.0	0.0
July		9	4	15	73.3	11.8	93.0	6.7
August		3	4	3	25.0	25.0	100.0	0.0
Sub totals			12	25	76.9	8.7	96.0	4.0
Totals			36	64				

Table 4
Number of captures and percent of Polynesian rats (*Rattus exulans*), from all snap traps, known to have eaten bait tetracycline hydrochloride (TCH) marked and TCH + gastro-intestinal (GI) marked on nine plots (three replicates of three treatments)

Month	Treatment (kg/ha)	Plot	Nights	Captures	TCH marked		TCH marked + GI	
					% marked	*SE*	% marked	*SE*
June	11.25	7	4	0	–	–	–	–
July		5	4	6	100.0	0.0	100.0	0.0
August		2	4	8	100.0	0.0	100.0	0.0
Sub totals			12	14	100.0	0.0	100.0	0.0
June	22.5	6	4	2	100.0	0.0	100.0	0.0
July		4	4	2	100.0	0.0	100.0	0.0
August		1	4	1	0.0	–	100.0	–
Sub totals			12	5	80.0	22.4	100.0	0.0
June	33.75	8	4	1	100.0	–	100.0	–
July		9	4	3	100.0	0.0	100.0	0.0
August		3	4	0	–	–	–	–
Sub totals			12	4	100.0	0.0	100.0	0.0
Totals			36	23				

when application rates were compared (ANOVA, $F = 3.11$; $df = 2, 8$; $P = 0.12$). We found no evidence of any non-target vertebrates taking any bait.

3.3.2. Invertebrates

There were 21 taxa of invertebrates observed on bait pellets throughout 2127 observations of caged and uncaged pellets (Table 5). Ants ($n = 254$) were the most common invertebrate observed on bait pellets, followed by slugs ($n = 144$) and snails ($n = 73$). The only native invertebrate species observed on bait pellets were native snails [*Succinea thaanumi* ($n = 8$) and *Tornatelaria* spp. ($n = 1$)]. Ants and slugs were the only invertebrates to cause noticeable damage or 'take' of bait. Slugs were observed consuming bait and ants were observed removing small pieces of bait and carrying it off during visual inspection of pellets.

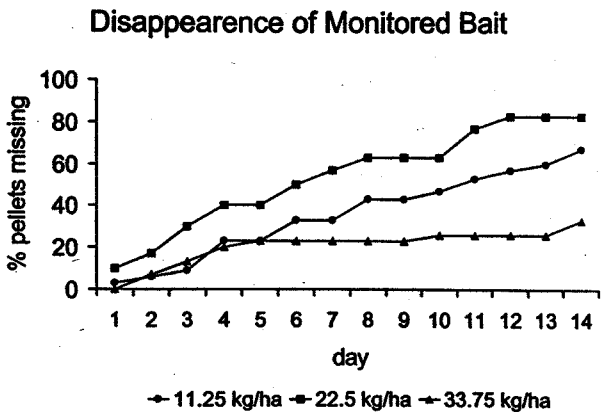

Fig. 1. Disappearance of monitored bait over time, on nine plots (three treatments over three replicates).

3.3.3. Bait degradation

Softness, swelling and surface area damage of bait was documented on all plots at 20 pellets per treatment (10 protected and 10 unprotected) for all three replicates during our study. Measurements for each replicate were combined for analysis to insure sufficient sample size to support this metric. Within an average of 10 days, pellets were soft enough for a probe to be inserted to the center of the pellets (mean softness = 11.2 mm, $n = 26$, $SE = 2.0$). In addition to softening over time, bait became swollen as it absorbed water. The mean pellet diameter of pellets not within cages increased from 25 mm ($n = 60$, $SE = 0.02$) before exposure to 27.5 mm ($n = 26$, $SE = 0.05$) after 10 days in the field. Qualitative assessment of pellets within cages also indicated an increase in bait size over time. Mean swelling score of these pellets was 2.9 ($n = 69$, $SE = 0.1$) on a scale of 1 (low)–5 (high) after 10 days of exposure. Over 90% (mean = 90.3, $SE = 2.1$) of the surface area of bait pellets was damaged within 10 days. Cracking due to swelling and contracting during changes in weather was the most common agent of deterioration noted. Mold was observed on 74% (64/87) of pellets by day 10 of monitoring. The mean number of days to the first appearance of mold was 5 days.

Rainfall measurements recorded during bait monitoring are summarized here for comparison with

degradation data. These measurements were taken during the dry season. Mean rainfall for all plots during the first 10 days of monitoring was 57.4 mm (2.26″) and ranged from 27.9 mm (1.1″) to 104.1 mm (4.1″) for each plot. Mean rainfall for all 14 day monitoring periods was 113.8 mm (4.48″) and ranged from 62.7 mm (2.47″) to 175.3 mm (6.9″) for each monitoring period.

4. Discussion

We recommend an application rate of 22.5 kg/ha (20 lbs/ac) to maximize bait exposure to rats, while minimizing excess bait usage. Ninety-four percent of roof rats trapped were known to have eaten the bait at this application rate. This represents a 23% increase in roof rat bait ingestion over the low application rate (11.25 kg/ha, 10 lbs/ac), with only a 2% decrease when compared to the high application rate (33.75 kg/ha, 30 lbs/ac) plots. All Polynesian rats captured in our study were found to have eaten the bait. This may indicate better Polynesian rat control in native forest habitats in Hawaii with this technique, bait station use appears to be a less effective management tool for this species (Lindsey et al., 1971; Nelson et al., in press).

Disappearance of uncaged monitored bait revealed that take of these pellets was highest in the medium application rate, followed by the low and high application rates, respectively. This may be due to the application densities and ratio of monitored to unmonitored pellets. For the low application rate plots this ratio was 94:1, for the medium application rate, 192:1 and for the high application rate, 285:1. In the low application rate plots, the low density of pellets would decrease the probability of rats locating pellets, however, the ratio of unmonitored: monitored would increase the probability that a monitored pellet would be encountered. In the high application rate plots, the high density of pellets would increase the probability of rats locating pellets, however, the ratio of unmonitored: monitored would decrease the probability that it would be a monitored pellet encountered. Bait was taken on all of the 14 days of monitoring except day 9.

The objective of the bait degradation monitoring was to ascertain if the bait would be available to rats for the necessary exposure time required to reach the lethal dosage determined in laboratory trials. Minimum exposure time necessary for control is 6–7 consecutive days of consumption (Swift, 1998). In addition to minimum exposure time, wild *Rattus* spp. normally require additional time to become accustomed to a novel food item before overcoming their neophobic predisposition (Cowen, 1977). This time period varies according to the species and situation, but Lund (1988) recommended 4–8 days for becoming accustomed to a new type of food. Therefore, minimum bait life after application should be approximately 10–15 days. Our data suggest Ramik® Green would meet these criteria for bait life following application. Even though the bait was highly degraded after day 10, it was taken as late as the last day of

Table 5
Summary of invertebrates observed on monitored bait pellets and number of observations

Common name	Phylum	Class	Order	Family	Genus	Species	Observations
Earth worm	Annelida	Oligochaeta	–	–	–	–	8
Ant	Arthropoda	Insecta	Hymenoptera	Formicidae	–	–	254
Springtail	Arthropoda	Insecta	Collembola	–	–	–	51
Beetle	Arthropoda	Insecta	Coleoptera	Carabidae	–	–	12
Silverfish	Arthropoda	Insecta	Archeognatha	Machilidae	–	–	4
Caterpillar	Arthropoda	Insecta	Lepidoptera	–	–	–	3
Cricket	Arthropoda	Insecta	Orthoptera	Gryilldae	–	–	3
Fly	Arthropoda	Insecta	Diptera	–	–	–	2
Earwig	Arthropoda	Insecta	Dermaptera	–	–	–	1
Leafhopper	Arthropoda	Insecta	Homoptera	Cicadellidae	–	–	1
Moth	Arthropoda	Insecta	Lepidoptera	–	–	–	1
Millipede	Arthropoda	Diplopoda	–	–	–	–	53
Sow bug	Arthropoda	Crustacea	Isopoda	–	–	–	13
Slug	Mollusca	Gastropoda	Pulmonata	Limacidae	–	–	52
Leopard slug	Mollusca	Gastropoda	Pulmonata	Limacidae	Limax	maximus	9
Yellow slug	Mollusca	Gastropoda	Pulmonata	Limacidae	Deroceras	laeve	88
Snail	Mollusca	Gastropoda	Pulmonata	–	–	–	19
Succineid	Mollusca	Gastropoda	Pulmonata	Succineidae	Succinea	thaanumi	14
Tornatelid	Mollusca	Gastropoda	Pulmonata	Achatinellidae	–	–	1
Garlic snail	Mollusca	Gastropoda	Pulmonata	Zonitidae	Oxychilus	alliarius	39
Flatworm	Platyhelminthes	Turbellaria	Planaria	–	–	–	13

monitoring — day 14. Persistence of a rodenticide in the environment needs to be limited due to non-target, secondary poisoning and sub-lethal dosage concerns. Our study showed that the pelletized placebo bait deteriorated after this time period under these weather conditions, such that most pellets had disappeared, completely disintegrated or became wholly enveloped in mold. This field trial suggested that broadcast application of pelletized diphacinone bait in native Hawaiian forests may be an effective technique for rodent control in these and other conservation areas.

Future studies will investigate the efficacy of this application technique with bait formulations containing diphacinone, however, diphacinone at 0.005% has been shown to be palatable to rodents (Bentley and Larthe, 1959). The non-target risk to the avian community and the non-target risks and secondary poisoning potential concerning invertebrates will also be investigated in separate studies. Lindsey and Mosher (1994) determined that there was minimal secondary hazard risk to the Hawaiian hawk or 'Io (*Buteo solitarius*) due to scavenging of poisoned rat carcasses. Of 641 invertebrates observed on bait in this study, only 15 were native invertebrates and only non-native slugs, snails and ants were observed to take bait.

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