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Technical Report #196

**Post-implementation assessment of novel rodent control devices for protection
of high elevation endangered species at Hawai'i Volcanoes National Park**

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ABSTRACT

Invasive species, including rats, threaten the existence of many of Hawai'i's native species pushing them to the brink of extinction. Hawai'i Volcanoes National Park has a long history of successfully managing ecosystems and providing rare species habitat through systematic invasive species control. Landscape level rodent control is prohibitively expensive; however, localized control has proven cost-effective while providing significant resource benefit.

A trapping program using self-resetting Goodnature® A24 technology was implemented at two remote sites in Hawai'i Volcanoes National Park in an effort to protect five endangered plant species and three endangered bird species from black rat (*Rattus rattus*) predation. This trapping method has been successfully implemented on other islands, but implementation requirements are site specific. Techniques and maintenance schedules were investigated specifically for subalpine dry shrubland environments and also high elevation wet forest environments.

Trap performance, recommended grid spacing, and a new chocolate long-life lure formula were evaluated over the course of this investigation. Apparent rodent control trends and subsequent native species responses were captured over the course of four months by conducting biweekly trap visits and analyzing motion triggered camera footage.

Clear declines in rodent activity were documented at each site during the four month intensive monitoring period. At least 38 rodents were removed from the subalpine dry shrubland test site during this period, while at the high elevation wet forest site at least 102 rodents were removed. It is suspected that the number of total kills was underestimated using available monitoring techniques. Trapping activity appeared to prevent major damage to flowers and diminish damage to fruit of endangered Campanulaceae species at the forested test site, however it is unclear what effect trapping efforts had on native bird species at the subalpine shrubland site.

Management recommendations differ by site. For subalpine shrubland sites, trap spacing should not exceed 100m x 100m to control *M. musculus* or *R. rattus*; tighter spacing may be necessary. In high elevation wet forests spacing traps at 50m x 50m is recommended to effectively reduce *R. rattus* populations. Pre-baiting traps is not advised to minimize potential damage done by rodents gnawing on depressurized traps. Concurrent trapping for feral cats and other scavengers, or strategic trapping schedules, are recommended to mitigate potential secondary predator attraction for sensitive sites such as Hawaiian petrel nesting areas. Schedule of trap maintenance should include monthly lure checks and 'refreshment' squeezes, regardless of site ecosystem. Scent of the lure diminishes between refreshment visits in arid environments and may be masked by algae or mold in wet environments. Use of the Goodnature® automatic lure pump should be considered to potentially alleviate this issue. In both environments standard lure bottles were found to last through the 16 week monitoring period. Lure was found to remain attractive to rodents, after refreshment squeezes as long as 36 weeks after deployment at the forested site. Trap maintenance should be scheduled to check CO₂ status no later than 12 weeks after deployment, regardless of site ecosystem, to detect exhausted CO₂ or malfunctioning traps, and at monthly maintenance visits if possible. Use of a surrogate pest such as a rubber rat to test fire through the trap shroud is advised to accurately simulate a strike, and ensure functionality of digital strike counters.

1. INTRODUCTION

1.1 Background

Hawai'i's biological resources are internationally recognized to be of special significance because of their uniqueness and importance in the study of evolutionary processes. Over 90 percent of the native forest birds, flowering plants, and invertebrates are endemic to Hawai'i. Many Hawaiian groups, including silverswords, lobeliads, honeycreepers, land snails, and fruit flies are remarkable examples of adaptive radiation, with a spectacular array of descendant species derived from one or a few successful establishments. Together these species created unique island ecosystems many of which are present within our National Parks.

Unfortunately, many of Hawai'i's endemic species are at a high risk for local extirpation and possible extinction. The isolated island ecosystems evolved with few of the natural predators, competitors, and herbivores found on continental systems. Human arrival (Polynesians followed by Europeans) resulted in dramatic changes to the island ecosystems. Habitat modification combined with the introduction of invasive animal and plant species has resulted in a drastic decline in the health of Hawai'i's native species. Nearly 10% of the flora is extinct and over 30% of the flora is listed as federally endangered. Of 109 known endemic Hawaiian bird species, 55 went extinct following the arrival of Polynesians and an additional 19 were lost after European contact (Reed et al. 2012). Thirty-three endemic Hawaiian bird species are listed under the Endangered Species Act. Additional species are rare and/or listed as endangered by the State of Hawai'i. Although not federally listed as endangered, these include rare species at high risk of global extinction due to their extremely low numbers remaining in the wild.

Hawai'i Volcanoes National Park (HVNP) has a long history of successfully managing ecosystems and providing rare species habitat through systematic invasive species control. For many island endemics, HVNP contains the only protected habitat thereby playing a central role in preventing global extinction and providing critical founders for island-wide recovery. Following intensive ecosystem protection park managers have conducted planting efforts to prevent extinction and restore biodiversity of the endangered flora. Based on these successes HVNP is now a primary re-introduction and recovery site for some of the most endangered species on the planet. HVNP also contains the only known protected nesting habitat for Hawaiian petrels, *Pterodroma sandwichensis*, on Hawai'i Island. Hawai'i Island petrels nest in natural cracks and crevices in the ground and are therefore highly susceptible to introduced predators. On this island, the species is limited to remnant colonies, perhaps 60-80 breeding pairs, pushed to the margins of its former range.

1.2 Problem Statement

Nationally and regionally, there is strong interest among federal and state agencies and private organizations to preserve the remaining genetic diversity of rare Hawaiian species including federally listed endangered and threatened species. In addition, there is great interest throughout the Pacific Islands and the world in developing strategies to protect very rare species. Despite successful ungulate removal and re-introduction efforts, endangered plant and bird species are still at risk from non-native rodents, most notably *Rattus rattus*, *R. norvegicus*, *R. exulans* and *Mus musculus*. Worldwide rats adversely impact native ecosystems and can be devastating to island ecosystems (Townsend et al. 2006). Rodent depredation is recognized as a significant limiting factor especially on island ecosystems. Dozens

of studies across the Pacific and in Hawai`i have illustrated the negative impacts of rat predation (Shiels et al. 2014). They kill vulnerable plants by bark striping and prevent recruitment by eating the seeds. They also devastate bird populations by preying on eggs, nestlings, fledglings and adults (VanderWerf, 2001). The United States Fish and Wildlife Service lists black rats, *R. rattus*, as a limiting factor for endangered plant and seabird species and includes recommendations for their control in recovery plans (USFWS 1983, USFWS 1996). At HVNP, rat predation is frequently observed on vulnerable plants and rats are implicated in egg and chick predation of both ground nesting and forest bird species.

Restoration of rodent-impacted ecosystems requires safe and effective control measures; conventional trapping techniques and rodenticide application often fall short of these requirements. Recent methods include snap traps or using bait stations for Ramik® rodenticide. Both require intensive amounts of labor making them cost-prohibitive to implement on a large scale in remote areas.

Recently developed Goodnature® trap technology provides a means for continuous, non-toxic rodent control that has garnered significant interest from land managers in the Pacific region. Natural resource managers at Hawai`i Volcanoes National Park identified two restoration sites where novel rodent control techniques where Goodnature® technology would be tested to investigate site-specific management techniques. The two sites have vastly different community vegetation and weather patterns providing for variety in test environments and thus broader applicability of techniques developed. Deploying the traps in these two habitats allowed fine-tuning of trap function in both wet and dry climates and assessment of spacing needs in sparse versus dense vegetation sites.

One site was located on a dry, sparsely vegetated (See Appendix A) pāhoehoe lava flow at 8000 ft. elevation (Mauna Loa Keauhou)(See Fig.1) and falls within one of three remnant Hawaiian petrel nesting colonies on the Southeastern flank of Mauna Loa. On Hawai`i Island, due to predation by humans and introduced mammals, the only known nesting sites of this species occur in remnant colonies at HVNP, at the furthest extent of their range. The full impact of rats on Hawaiian Petrels is not known at HVNP, however, rat predation is a primary threat on Kaua`i (Raine, A., Kauai Endangered Seabird Recovery Project Co-coordinator, pers. comm.). The deep burrows utilized as nest sites at HVNP are impossible to see into, therefore exact causes of nest failure are often undetermined. Recently, the park has been using remote cameras to aid in nest monitoring: during the 2013 season rats were documented entering burrows at all 9 camera sites. In addition to Hawaiian petrels, the endangered band-rumped storm-petrel (*Oceanodroma castro*) and the Hawai`i thrush (*Myadestes obscurus*), a Hawai`i Island endemic, inhabit the Mauna Loa Keauhou site.

The second site is located in heavily forested (See Appendix A) wet habitat at 6000 ft. elevation in the Kahuku Unit, (Punalu`u Kahawai) (See Fig. 2). It contains a number of rare species and is a focal site for the re-introduction of the federally endangered *Pittosporum hawaiiense* and four federally listed endangered Campanulaceae species. Among these is `ōhā wai (*Clermontia peleana*) which was once believed to be extinct in the wild and hāhā (*Cyanea shipmanii*) which has less than ten known wild individuals. This site now has several hundred planted seedlings many of which are impacted by bark striping, a characteristic behavior of rats (McDaniel 2014). Seed predation is expected as these plantings mature which has the potential to severely limit recovery. Individual physical rat barriers had previously been erected around a proportion of the seedlings but this approach is not feasible on a large scale or in areas with dense vegetation. In addition to the endangered plants, there are a number of native forest birds at this site that would benefit from rat control including `apapane (*Himatione sanguinea*), `elepaio

(*Chasiempis sandwichensis*), `ōma`o (*Myadestes obscurus*), Hawai`i `amakihi (*Hemignathus virens*), the proposed threatened `i`iwi (*Drepanis coccinea*), the federally listed endangered species Hawai`i creeper (*Oreomystis mana*) and Hawai`i `akepa (*Loxops coccineus*).

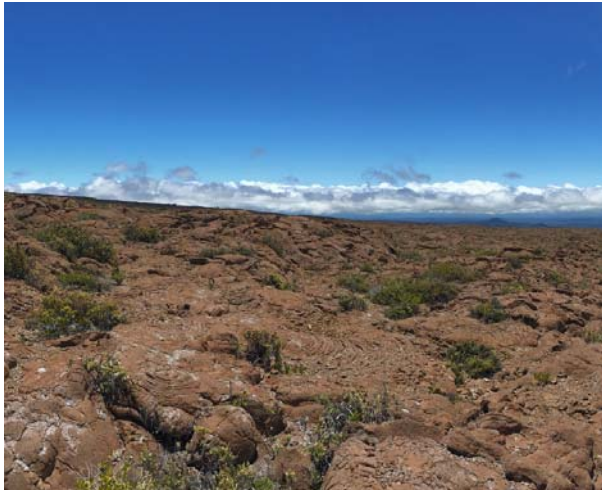


Figure 1: Mauna Loa Keauhou site



Figure 2: Punalu`u Kahawai site

1.3 Goodnature® A24 Trap Technology

In response to the need for continuous pest control alternatives to toxic baits, the New Zealand company Goodnature® developed self-resetting kill trap technology. All traps are certified humane with an A-class rating by the New Zealand Animal Welfare Advisory Committee. The traps are powered entirely by compressed CO₂ gas canisters. Brushing the trigger of the trap creates a pressure gradient, firing a striker piston across the trap shroud. The piston delivers a lethal blow to the pest's skull (Fig. 3, Fig. 4). The dead animal falls from the trap shroud, clearing the entrance, as the piston retracts and resets. An optional digital strike counter detects vibrations from piston motion and tallies a count for every fire. Several trap models were developed by Goodnature® including the A24 which targets rats and stoats. Under ideal conditions each A24 CO₂ canister can power 24 lethal blows; combined with the Goodnature® long-life lure, A24 traps require minimal maintenance. Goodnature® recommends completely replacing CO₂ canisters, and lures every six months, with monthly lure “refreshment” or pre-feeding squeezes. Minimal maintenance makes continuous control feasible in difficult to access areas, and reduces human disturbance to sensitive ecosystems.

The A24 has been investigated by several land management agencies in Hawai`i including Kalaupapa National Park, National Tropical Botanical Garden, O`ahu Army Natural Resources Program (OANRP), and Auwahi Wind Energy Project (AWP). Overall Goodnature® A24 traps were found to be effective and efficient after mechanical malfunctions had been addressed. Auwahi Wind Project found that Goodnature® A24 traps yielded the highest catch per unit effort when compared with several other small mammal traps (VanZandt 2015). At each of these sites technique refinement was necessary to maximize effectiveness given site-specific conditions.



Figure 4: A24 Trap anatomy Image courtesy of Goodnature®



Figure 3: A24 Trap function Lure attracts rats to trap; trap fires when trigger is brushed; trap clears and automatically resets after a humane kill; trap can attract and dispatch up to 23 additional rodents before needing service; carcasses are often scavenged from below the trap. Image courtesy of Goodnature®

The largest implementation of this method in Hawai'i is by O'ahu Army Natural Resources Program. At their site they have documented both a decrease in rat density (Franklin 2013) and reduced impact on the critically endangered *Cyanea superba* (Pender et al. 2012). Maintenance requirements for CO₂ cartridges and bait replenishment for this site differs from Goodnature® baseline predictions (Bogardus, T., O'ahu Army Natural Resources Program Small Vertebrate Pest Stabilization Specialist, pers. comm. 2014), and is likely to be different for each management site. Additionally, non-target

organisms such as slugs and ants (Hosten, P., Kalaupapa National Historic Park Terrestrial Ecologist, pers. comm.) have been found to consume bait, further complicating predictions of exact maintenance requirements for other sites. Both the HVNP sites either have no ants or a very low density. Determining site-specific requirements at the Punalu`u Kahawai and Mauna Loa Keauhou sites is very important to effective control measures.

1.4 Investigation Objectives:

The objective of this investigation was to refine techniques for this relatively new method of rat control at the Punalu`u Kahawai and Mauna Loa Keauhou sites, and to provide an informational tool for land managers of similar sites. Specifically the goals were to evaluate performance of Goodnature® A24 traps, test attractiveness of the new chocolate bait formulation, determine best trap maintenance schedules, and to document potential trends in rodent control while using trap spacing similar to that tested by other Hawaii projects. Possible impacts on rodent populations and subsequent native species responses at each site were examined using nonconventional methods more suited to the short study duration and limited manpower available for this project.

Additionally the two trap testing plots also aimed to provide immediate protection for eight federally listed endangered species and a number of rare species (Table 1).

Table 1. Species benefitting from rat control at Punalu`u Kahawai and Mauna Loa Keauhou sites

Status	Common name	Scientific name	Type
endangered	`Ōhā wai	<i>Clermontia lindseyana</i>	plant
endangered	`Ōhā wai	<i>Clermontia peleana</i>	plant
endangered	Hāhā	<i>Cyanea shipmanii</i>	plant
endangered	Hāhā	<i>Cyanea stictophylla</i>	plant
endangered	Hō`awa	<i>Pittosporum hawaiiense</i>	plant
endangered	`Ua`u	<i>Pterodroma sandwichensis</i>	bird
endangered	Hawai`i Creeper	<i>Oreomystis mana</i>	bird
endangered	`Akepa	<i>Loxops coccineus</i>	bird
endangered	`Akē`akē	<i>Oceanodroma castro</i>	bird
proposed threatened	`I`iwi	<i>Drepanis coccinea</i>	bird
rare	`Apapane	<i>Himatone sanguinea</i>	bird
rare	`Elepaio	<i>Chasiempsis sandwichensis</i>	bird
rare	`Ōma`o	<i>Myadestes obscurus</i>	bird
rare	`Amakihi	<i>Hemignathus virens</i>	bird

2. METHODS

2.1 Trap Deployment

2.1.1 Spacing and Placement

Goodnature® recommends spacing traps such that there is at least one trap per home range size of the target pest, which varies depending on resource availability. For particularly food rich sites or those with particularly vulnerable species, multiple traps within a rat's home range are necessary to achieve desired control. Grid spacing of 100m x 50m, or fifteen traps per home range, for example, was recommended for the O`ahu Army Natural Resource Program's forested test site. At the subalpine Auwahi Wind Project site, A24s were spaced on a 150m x 150m grid over the larger management unit, with additional trap types spaced at 50m x 50m in buffer areas surrounding petrel nest sites for added protection. Home range sizes of target pests were unknown at the Auwahi site, and unknown for both of the test sites selected for this investigation. Trap spacing decisions for this investigation were based on assumptions that rodent densities are correlated with food availability, and thus habitat type. For the Punalu`u Kahawai site, similar grid spacing to OANRP's project was selected; for the Mauna Loa Keauhou site similar grid spacing to AWP's project was selected.

To determine the precise position of a trap at a desired trapping location Goodnature® literature recommends using lure-containing rodent detection cards, however this technique is not feasible over large management units. Traps placed in areas that provide cover, and a sense of safety for rodents are more likely to attract their attention; locations such as this were selected when available for each trap placed at the Mauna Loa Keauhou site and the Punalu`u Kahawai site.

Sixteen Goodnature® A24 rat traps were deployed at the Mauna Loa Keauhou site, in the vicinity of active Hawai`ian petrel nests. Grid spacing of 100m x 100m was selected at this site based on assumptions that rodent densities were relatively low in this resource-poor environment, compared to OANRP's test site. Traps were situated within or at the edge of small clumps of vegetation to provide cover for visiting rodents. At the Punalu`u Kahawai site 36 Goodnature® A24 traps were stationed on a 50m x 50m grid as greater rodent density was expected given greater resource availability at the site. Traps were centered in outplanting plots at the site in an effort to safeguard sensitive plants. Placement of traps near structures such as fallen logs or aerial roots served to provide additional cover in this densely vegetated environment.

2.1.2 Mounting

Recommended mounting practice by Goodnature® involves affixing mounting hardware directly to trees at trapping sites. To address the lack of trees at the Mauna Loa Keauhou sites, and to avoid damage to existing native trees at the Punalu`u Kahawai site, custom mounts were constructed for this investigation. Short stakes were often used in lieu of suitable trees in other A24 investigations in Hawai`i. However, due to constraints on weight of supplies and difficulty in ensuring complete sanitation of wood stakes, capped plastic pipes were used instead for this investigation. Pipes were cut to 75cm lengths such that one end was pointed; on the other end holes were drilled through the plastic below the cap to facilitate installation of Goodnature® mounting hardware. Final installed trap height of 10 to 14 cm above ground level, per Goodnature® recommendations, was followed.



Figure 5: Trap placement Mauna Loa Keauhou



Figure 6: Trap placement at Punalu`u Kahawai

2.1.3 Pre-baiting

After trap installation, traps were left baited but not set until the next site visit. This practice, known as pre-baiting, allows rodents to become familiar with scent of the lure, comfortable around traps, and communicate presence of a new food source to other members of their species in the area. Pre-baiting may help to quickly ‘knock-down’ a large portion of rodents in an area. For other kill traps pre-baiting is often implemented at least two days prior to setting traps. Adopting this practice, and modifying it to suit site accessibility, traps at both Mauna Kea Keauhou and Punalu`u Kahawai were left pre-baited for two weeks. Per Goodnature® recommendations, lure was also smeared below the shroud entrance.

2.1.4 Bait formulation

Bait used during this investigation was the recently reformulated Goodnature® chocolate long-life lure; at the time of this study no published reports in Hawai`i included the use of this bait. Goodnature® peanut butter formulations tested by other Hawai`i land managers were no longer available.

2.2 Monitoring Activities

2.2.1 Inspection

Traps were visited biweekly to detect any mechanical malfunctions and record kill counts. At every visit the number of carcasses recovered, tally on digital strike counter and general condition of bait and CO₂ were recorded, lure was also refreshed per Goodnature® recommendations by squeezing a small quantity of fresh lure through the mouth of the lure bottle, and smearing some below the trap. Upon each visit during the first two months, traps were test fired to ascertain striker functionality and to verify counter accuracy, then randomly thereafter to determine CO₂ maintenance needs.

2.2.2 Motion triggered cameras

In addition to biweekly monitoring of traps for carcass and digital strike counter data, motion-triggered cameras were used to monitor rodent-trap interactions at both sites. This monitoring method had limited power in determining population changes, but was useful for verifying kills counted, attractiveness of bait, and behavior of rodents around traps. At the Mauna Loa Keauhou site, four of sixteen traps were monitored by camera, starting during the pre-bait period. At the Punalu`u Kahawai site six traps were monitored by camera, also starting during the pre-bait period. At all sites camera locations were rotated randomly during the monitored active trapping period.

Motion-triggered cameras were also used to observe rat interactions with endangered species. Cameras were stationed at petrel burrows at the Mauna Loa Keauhou site to monitor rat and petrel activity. Cameras were rotated to different burrows within the trapping unit throughout the monitored active trapping period of sixteen weeks. At the Punalu`u Kahawai site cameras were rotated among several outplanted endangered *C. lindseyana* and *C. shimpanii* individuals to capture interactions between rats and the plants, especially fruits or flowers.

2.3 Evaluation

Non-treatment control periods and secondary control areas were not available or feasible for either site due to limitations in manpower and study duration. Monitoring of trapping sites did begin during the pre-bait period however, this is likely not an accurate baseline for rodent activity. Rigorous assessment of pre- and post-trapping population levels was therefore not possible.

Trends for kill data were generated from the number of strikes on digital counter (minus test fires) over time. For trap locations, rodent activity was measured by number of trap visits over time as captured on motion-triggered cameras; multiple camera triggers occurring within ten minutes of each other were considered parts of a single visit. Kill data were compared to camera activity to determine whether kill trends accurately reflected rodent activity observed at each site. This comparison made possible the detection of behavioral changes that might have been misinterpreted as changes in population density.

Non-target species, such as cats and mongooses, responses to trapping activity were investigated for potential trends. While these larger vertebrate pests are considered targets for other trapping programs at HVNP, they were not target species of this A24 investigation. Native species response were also examined.

3. RESULTS AND DISCUSSION

3.1 Control Trends

After 16 consecutive weeks of trapping, with 16 total traps open, total digital strike counter tally (minus registered test fires) at the Mauna Loa Keauhou site indicated that 38 rodents had been removed from the site. Nearly 74% of these carcasses were recovered, including 20 *M. musculus* and eight *R. rattus*. At the Punalu`u Kahawai site, after 17 consecutive weeks of trapping with 36 open traps digital strike counter data indicated that 102 rodents had been removed from the site. Only 37% of these

carcasses were recovered, including 35 *R. rattus*, two *M. musculus* and a single Small Indian Mongoose, *Herpestes javanicus*.

Precise size of rodent population at each site was not measured prior to the onset of trapping. Therefore trends in kills and activity serve only as an approximation of effects on rodent populations. Game camera footage from the “pre-bait” period is the only available reference for rodent densities prior to the onset of trapping. For a given species, frequency of activity on motion-triggered cameras, and number of carcasses recovered was assumed to roughly correlate with population density. Motion-triggered camera footage from trap locations during the pre-bait period and beyond revealed that *M. musculus* were the most abundant rodents at the Mauna Loa Keauhou site. *Rattus rattus* activity was much lower; motion-triggered cameras stationed at resources and pre-baited traps detected mice 12 times more often than rats. In contrast, at Punalu`u Kahawai *R. rattus* were detected 28 times more often than mice.

Motion-triggered camera data show clear declines in *M. musculus* activity at the Mauna Loa Keauhou site along with maintenance of low *R. rattus* activity in the first six weeks of trapping. This pattern is mostly consistent with digital strike counter and carcass recovery trends aside from a spike in digital strike counter numbers occurring near the end of the monitoring period (See Fig 7). Continued monitoring at this site is needed to track this increased activity and determine whether current spacing is adequate for control.

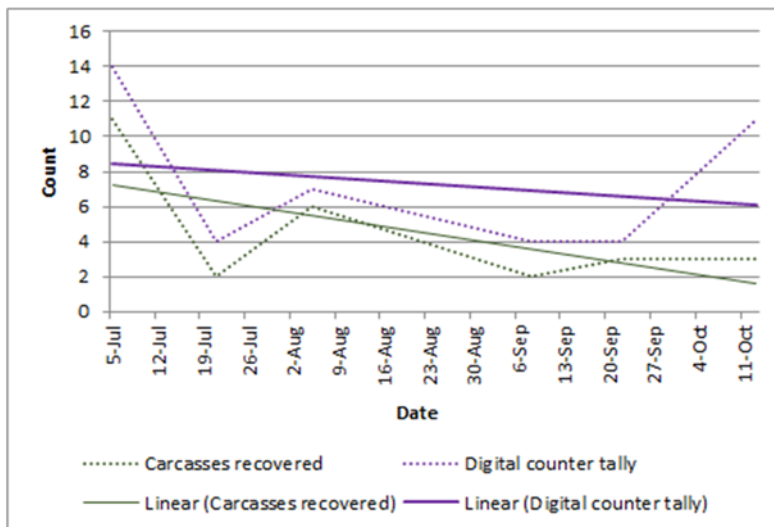


Figure 7: Rodent kill trends for all traps in Mauna Loa Keauhou July- October 2016

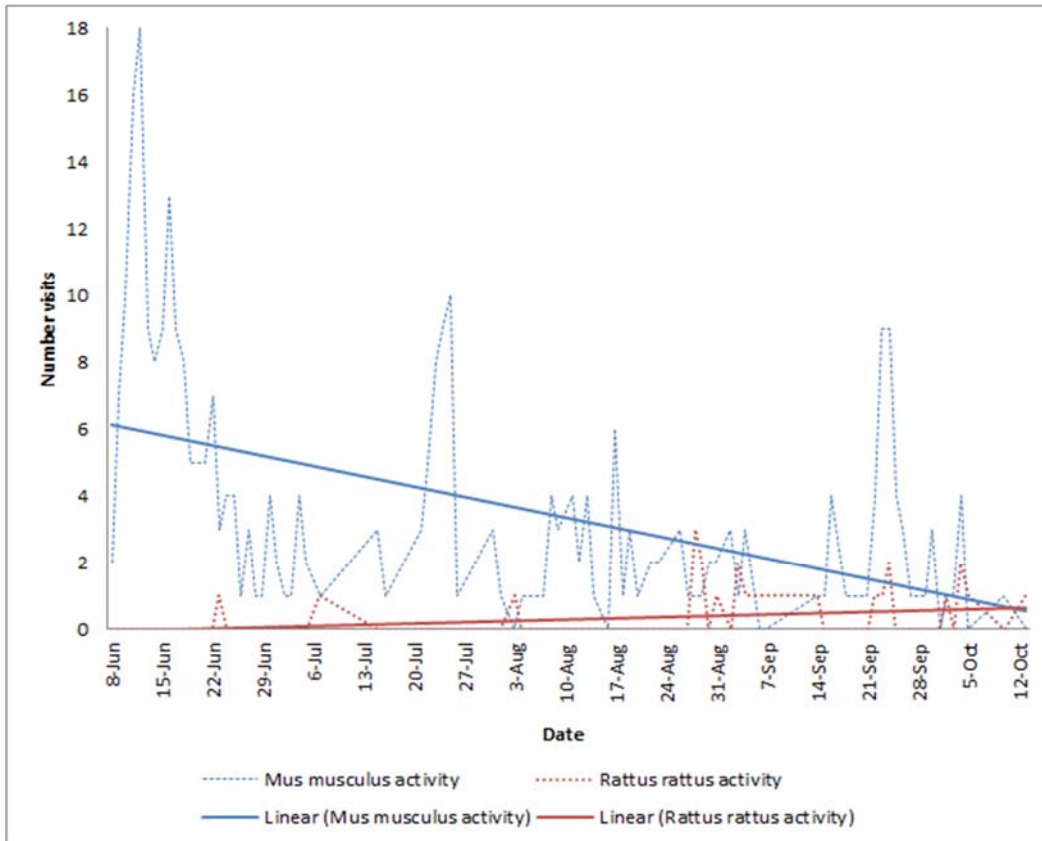


Figure 8: Rodent activity trends in Mauna Loa Keauhou. Active trapping started June 21st 2016

Clear declines in *R. rattus* activity at Punalu`u Kahawai were also noted on game camera footage, in close agreement with digital strike counter and carcass recovery data (See Fig. 9). Mongoose activity at the site was low overall, but became more frequent as trapping progressed.

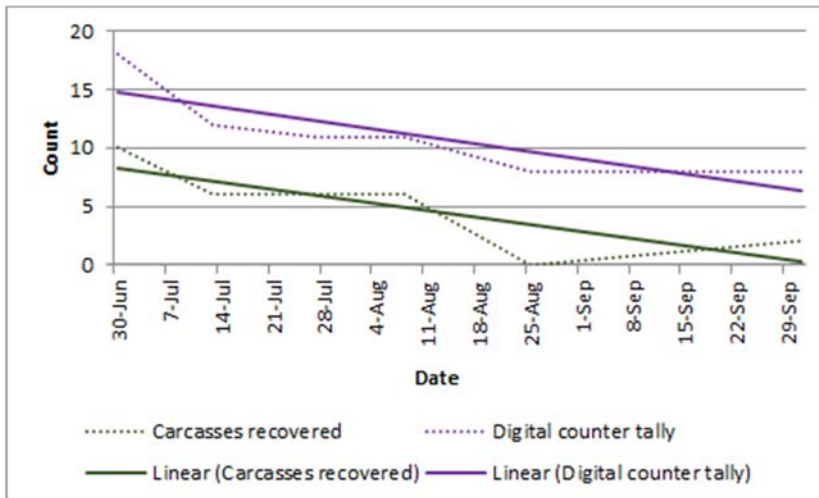


Figure 9: Rodent and Mongoose kill trends for a trap subset at Punalu`u Kahawai June-Sept 2016

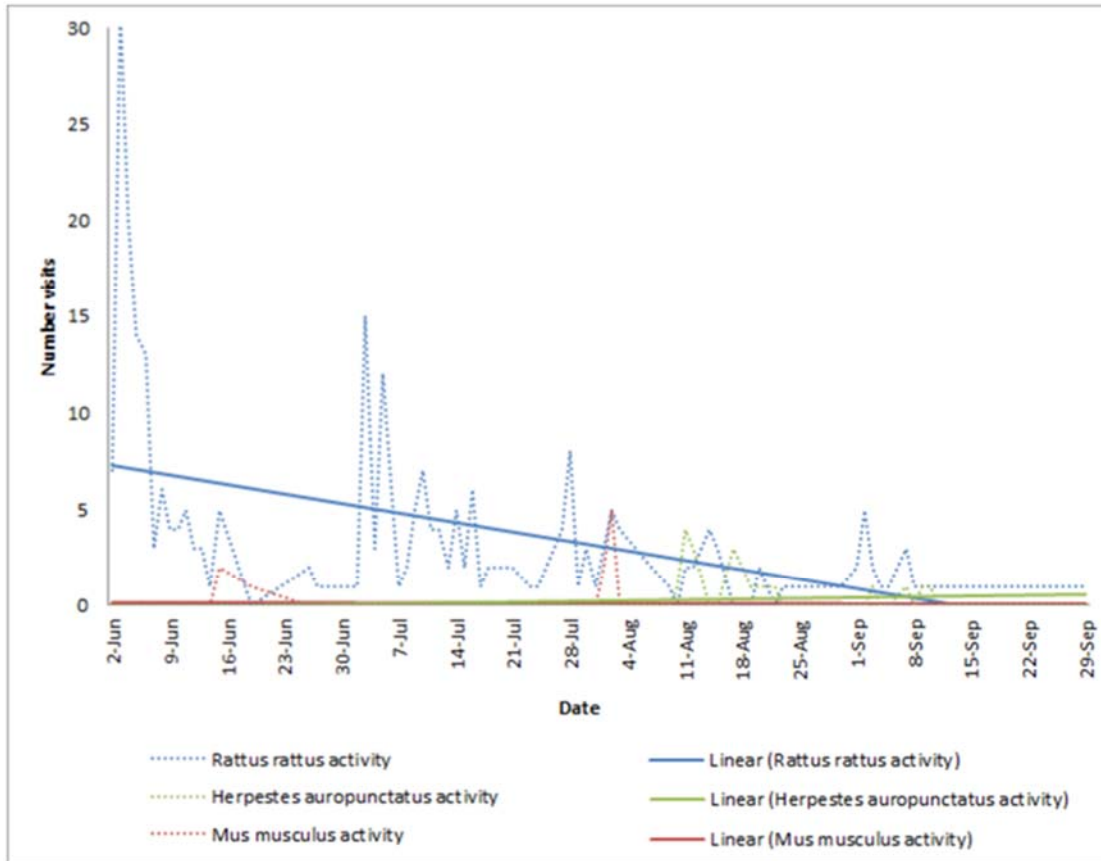


Figure 10: Activity trends in Punalu`u Kahawai. Active trapping began June 15th, 2016.

No adjustments were made to grid spacing during the investigation as declines in rodent populations appeared consistent during the first twelve weeks of trapping. It is thought that the apparent spike in kill counts at the Mauna Loa Keauhou site was due to *M. musculus* activity undetected by the chosen monitoring methods. While *R. rattus* were considered the primary target of trapping efforts, and no significant spikes in their activity or kills were detected, more intensive management with tighter grid spacing, and expansion of the trapping grid may be necessary to provide more consistent control. While rat activity at Mauna Loa Keauhou was low overall, a trendline reveals a slight increase in activity during the final seven weeks of monitoring. Continued monitoring should be conducted to detect longer-term trends, and to determine whether camera rotation to rodent hotspots could be a contributing factor.

Monitoring by conventional means such as tracking tunnels or chew cards independent of trap locations would better inform managers of rodent populations in and around trapping areas over the lifetime of the trapping program.



Figure 11: Rat mid-strike at Punalu`u Kahawai



Figure 12: Rat carcass at Mauna Loa Keauhou

3.2 Non-target Species Responses

Goodnature® literature notes that scavenging of carcasses from below the trap is a probable occurrence in areas where secondary predators are present. As predicted, carcasses recovered during monitoring visits numbered fewer than the digital strike count (minus the number of test fires), indicating that carcasses had indeed been scavenged from below the traps. At least one feral cat, *Felis catus*, was observed on motion-triggered camera footage scavenging mouse carcasses from a single trap in the Mauna Loa Keauhou site. Scavenging activity by a cat, or possibly cats, was observed twice during the monitoring period; first just one week after traps were opened and again two months later. No prior monitoring was available to generate trend data for cat activity at the site, however presence of even a single cat within the petrel nesting area is concerning. Scavenging by mongoose occurred frequently at



Figure 13: Feral cat at Mauna Loa Keauhou



Figure 14: Mongoose at Punalu`u Kahawai

the Punalu`u Kahawai site. Mongooses were often recorded inspecting traps and carcasses, sometimes in small groups. Mongoose scat was noted at multiple traps on each monitoring visit. At least one mongoose kill was documented. Rats were recorded scavenging mouse carcasses on several occasions at the Mauna Loa Keauhou site, and are suspected to act as scavengers regularly at both sites.

3.3 Native Species Responses

At the Punalu`u Kahawai site, monitoring associated with trapping captured footage of native bird species, most often *Drepanis coccinea*, clearly nectar feeding from an outplanted *C. lindseyana* flowers. Interestingly, footage also captured *R. rattus* visiting the same flowers at night, apparently foraging for nectar as well. It is possible that this behavior was reduced by trapping activity as this interaction was documented only twice near the start of active trapping however no prior formal monitoring data is available for comparison. Immature fruits of *C. lindseyana* were frequently found dislodged from plants, though it is unclear whether rats, birds, slugs, or wind was to blame; no obvious rat damage was observed on fruits during monitoring visits. *Rattus rattus* were however, documented removing and eating *C. shipmanii* fruits on one occasion, and *C. lindseyana* fruit on one occasion, after several months of active trapping. Removal of *C. shipmanii* fruit by Kalij pheasant, *Lophura leucomelanos*, in addition to rats was also observed. The fate of *C. shipmanii* fruit and seed after ingestion by rats is not known; research by Shiels (2011) suggests that seeds as small as *C. shipmanii*'s may pass through *R. rattus* gut intact, though seeds of the closely related *Cyanea superba* subsp. *superba* are shown to have no germination capabilities after ingestion by captive rats (Pender et al. 2012). These behaviors were observed rarely during the several months of monitoring; no rat-damaged fruit was encountered in person on monitoring visits to the test site, and no evidence of bark-stripping was detected.



Figure15: `I`iwi visiting *C. lindseyana* flowers



Figure 16: Rat visiting *C. lindseyana* flowers

Interestingly, native *Drosophila* species appeared to be feeding on rodent carcasses at the Punalu`u Kahawai site, particularly *D. silvestris* and *D. tanythrix*, as well as other some other unidentified fungus feeding flies.

Within the Mauna Loa Keauhou site two nests appeared to be active during this investigation. Rats were observed entering both inactive and active burrows. Motion-triggered camera observations

showed no marked decrease in this activity over the course of trapping, and nest success was undetermined at the close of active monitoring. Adjustments to both grid size and spacing are likely necessary to reduce this.

3.4 Post-implementation Assessment

3.4.1 Grid spacing

For subalpine shrubland areas similar to Mauna Loa Keauhou, trap spacing of 100m x 100m over the greater management unit may reduce *M. musculus* populations, and appears to keep *R. rattus* activity low. However it is not clear what effects trapping will have on *R. rattus* activity as trapping continues; their sporadic behavior as scavengers of *M. musculus* makes predicting their future interactions with traps difficult. Tighter spacing in buffers around burrows, or expansion of the trapping grid may be useful in controlling more rats, but also has the potential to attract scavenging cats closer to nesting sites.

High elevation wet forest sites like Punalu`u Kahawai likely require tighter grid spacing overall than subalpine shrubland sites, based on resource availability. Spacing traps at 50m x 50m in close proximity to sensitive plants appeared to reduce *R. rattus* activity at this site, and also appeared to prevent major damage to flowers and fruit, seen at this site previously for *C. lindseyana*.

3.4.2 Mounting

Plastic pipe mounts occasionally rattled loose, especially on traps that had fired more often. Sacrificing the lightweight nature of the pipe for thicker plastic may be necessary for longer lifetime of a stable mount. Wood alternatives like Trex® decking have been used successfully by The National Tropical Botanical Garden and O`ahu Army Natural Resource Program (Franklin 2013).

3.4.3 Pre-baiting

It is recommended that the pre-bait period, where traps are left baited but depressurized, be minimized or eliminated in areas suspected to have high rodent density to avoid physical damage to traps. One trap at the Punalu`u Kahawai site was nearly rendered inoperable by rodents chewing through the lure bottle cradle by way of the trap shroud in the two weeks the trap was left baited but depressurized. Rodent damage to traps can likely be eliminated altogether by ensuring that traps are pressurized whenever bait is present. Goodnature® pre-feeding protocol of smearing bait below a pressurized trap may provide for sufficient rodent attraction.

3.4.4 Long-life Lure

Monthly lure refreshment by squeezing fresh bait to the bottle mouth is recommended by Goodnature®; during this investigation lure was refreshed biweekly, with every monitoring visit. Schedule of trap maintenance should include these monthly lure checks and refreshment squeezes, regardless of site ecosystem. Attractiveness of the lure may be diminished between refreshment visits by algae and mold overgrowth in wet environments, and by drying in arid environments. Despite these tendencies lure appeared to retain some attractiveness even weeks after refreshment, as evidenced by motion-triggered camera footage. However small spikes in trap visits did appear to follow lure refreshment.

Due to drying at the arid subalpine site lure is suspected to have needed replacement before the Goodnature® advertised 24 week lifespan. During the 16 week intensive monitoring period only one lure at each site needed replacement. Lure was left in the activated traps for continued control beyond the intensive monitoring period at the Punalu`u Kahawai site, and was found to retain its attractiveness to rodents at least 36 weeks after deployment. Goodnature® recommendations of replacing the long-life lure no later than every 24 weeks may not apply to all site ecosystems.

Goodnature® has recently developed automatic lure pumps for their A24 units to eliminate the need for monthly refreshment visits, implementation of this optional feature could provide more consistent, fresh lure and cut back further on manpower needed for trap maintenance. Recently installed lure pumps at the OANRP site are reported to be functioning very well (Bogardus, T., OANRP Small Vertebrate Pest Stabilization Specialist, pers. comm.).

3.4.5 Test Firing

Goodnature® literature recommends brushing the trigger from above with a stick or pen to test-fire traps; during which the piston is fired across the trap shroud impacting the opposite side of the trap. The vibrations generated during a test fire by these instructions may differ significantly from those generated when a pest is struck. During test fires, it was noted that digital strike counters did not always increment. This problem persisted despite repositioning of counters, but was significantly reduced after implementing new test firing protocols. Use of a surrogate pest such as a rubber rat to test fire through the trap shroud is advised to more accurately simulate a true strike.

3.4.6 Digital strike counters

Test-firing using the above technique revealed that strike-counters did properly increment for nearly all test strikes. Whether most strikes of *M. musculus* were being recorded by the digital strike counter was an unresolved question at the close of the intensive monitoring period at the subalpine site. Inconsistency between game camera verified kills, carcasses and counter tally was noted, and attributed to traps not being designed specifically for mouse-sized pests; infrequent discrepancies were also noted at the wet forest site. In correspondence with Goodnature, the possibility of counters failing to increment for mice was deemed unlikely but not impossible based on their laboratory testing. It is suspected that digital strike counters may slightly underestimate the number of total kills for both rats and mice, but discrepancies were insignificant enough to justify continued use of the counters to monitor kills and to identify traps placed in 'hot zones', traps needing repositioning, and traps that had potential malfunctions.

3.4.7 CO₂ Cartridges

Goodnature® recommends replacing the CO₂ cartridge every six months (26 weeks) regardless of whether the striker has fired its potential 24 strikes or not. Half of all CO₂ cartridges at Mauna Loa Keauhou had exhausted available CO₂ by the 12th week after installation, despite digital strike counters having registered only three to ten strikes. Several of these traps with fresh CO₂ cartridges were found to have exhausted their replacement cartridges within the next two weeks, with no indication that they had fired 24 times. No adjustments to the tightness of CO₂ cartridges appeared to resolve this issue. It is suspected that the high elevation and drastic temperature swings at this site contributed to the shorter lifespan of CO₂ cartridges and inconsistent trap performance. It is also possible that digital strike counters

grossly underestimate the number of strikes fired, due to the abundance of mice at the site. More than half of all Punalu`u Kahawai A24 units had exhausted their CO₂ cartridges by the 16th consecutive week of trapping, however traps from this site fired roughly twice as many times as those in the Mauna Loa Keauhou site, based on digital strike counter data. An additional A24 unit was found to have a CO₂ malfunction at Punalu`u Kahawai; the trap was found to have exhausted all CO₂ with less than ten registered strikes, and within six weeks of cartridge installation. The second cartridge lasted an additional ten weeks. In all cases, Goodnature® offered troubleshooting guidance and replacement for any malfunctioning traps. After the intensive monitoring and initial knock down phase of this investigation, traps were left longer than 24 weeks after CO₂ recharge to test the maximum lifespan of a cartridge at the site. Several cartridges were left in traps up to 60 weeks, providing continuous control; corrosion on the threads of the cartridge and trap fitting made uncoupling the two impossible without causing damage to the trap.

Schedule trap maintenance to check CO₂ status more frequently than Goodnature® recommends; for sites similar to the Mauna Loa Keauhou CO₂ status should be checked, by test firing traps, no later than 12 weeks after installation. The same is recommended for sites similar to Punalu`u Kahawai. Test-firing the traps at each monthly maintenance visit is the only method of determining whether CO₂ has been exhausted, and can help detect malfunctioning traps. Recommendations to replace CO₂ cartridges after 24 weeks should be adjusted to accommodate both rodent density and potential climatic effects on traps. It is not recommended however, that cartridges be left in traps much longer than 24 weeks even when CO₂ is remaining to avoid corrosion and potential damage to traps.

3.4.8 Addressing Secondary Predators

Concurrent trapping for feral cats and other scavengers, similar to AWP trapping programs, during active A24 trapping is recommended to offset scavenger attraction for sensitive sites such as Hawaiian petrel nesting areas. Motion-triggered camera data from previous nesting seasons on Mauna Loa confirm suspicions that feral cats are responsible for nestling depredation; footage shows a cat clearly removing a Hawaiian petrel chick from its nest (Judge *et al.* 2012). Exclusion of cats from the A24 trapping area may be an alternative to multi-species trapping programs. For example A24 trapping within the recently constructed cat enclosure on Mauna Loa would ensure cats cannot access sensitive nesting areas to scavenge pest carcasses at traps. It may also be possible to mitigate attraction of secondary predators by scheduling A24 trapping during seasons where birds are less vulnerable to predation.

3.4.9 Returning Materials to Goodnature®

Goodnature® was willing to replace any trap or digital strike counter with a reproducible malfunction that persisted despite troubleshooting. Customers are, however, encouraged to wait until items could be sent back in larger quantities, such as with multiple digital strike counters with dead batteries, to make the most of high cost of international shipping. After the intensive monitoring period of this investigation a Goodnature distributor was established in the United States and may make returns and replacements less troublesome.

4.0 Suggestions for Future Monitoring

Monitoring trends in digital strike counter data throughout the year would be necessary to detect seasonal changes in rodent density. To fully understand the effects of trapping on rodent populations conventional monitoring techniques such as tracking tunnels or chew cards should be used. Further monitoring of rodent activity and trap interactions with motion-triggered cameras will also be necessary to determine whether current grid size and spacing are capable of reducing rodent activity to undetectable levels. To better understand the role of introduced rodents in both ecosystems, motion-triggered camera monitoring should continue to include native species. Monitoring in this way may provide enough information for land managers to make resource protection decisions even if rodent population levels are unknown.

Determining the outcome of *R. rattus* and *P. sandwichensis* interactions inside burrows could help land managers quantify the utility of A24 trapping near nesting sites. While rats have been identified as a primary threat in colonies on Kaua`i, on Hawai`i island rats were documented repeatedly entering active burrows that successfully fledged chicks despite assumed negative rat impacts (HVNP unpublished report 2015). The current impact of rats on nesting Hawaiian petrels has not been fully evaluated. Further assessment is necessary to determine if the risk is great enough to justify the potential attraction of scavenging cats to sensitive areas.

The use of A24s to control rats is a promising technique at Punalu`u Kahawai, and would likely prove effective at similar wet forest sites. Quarterly monitoring of trapping success and native species response at Punalu`u Kahawai continues to be conducted, especially as additional outplanted Campanulaceae species begin flowering and fruiting, providing novel food sources for remaining rodents. Motion-triggered camera data suggest that *R. rattus* may be in direct competition with native birds for access to nectar and fruit sources. To what extent this affects bird foraging behavior or plant reproduction remains unknown as well.

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