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An assessment of lethal trap performance and efficacy at Haleakalā National Park

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Abbreviations:

HALE	Haleakalā National Park
ALP	Automatic Lure Pump
El	Elevation
Ft	Feet
M	Meters
CPUE	Catch Per Unit Effort

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ABSTRACT

Control of non-native predators is vital for managing resources at Haleakalā National Park and has been ongoing since the 1970s. A 2016 evaluation of the trapping program suggested incorporating lethal traps to improve capturing predators. A revised Predator Control Management Plan was developed based on this evaluation, including lethal traps. Since lethal traps can catch non-target species, including federally listed threatened and endangered species, evaluating these traps was necessary. This project assessed three lethal traps for performance and efficacy: Goodnature® A24, DOC 250, and Belisle 220 Super X body grip traps.

We evaluated the use of exclusionary box designs and careful trap placement to determine if these features would prevent the capture of non-target species. Captures of species for each trap and interactions of target and non-target species with traps were examined to evaluate trap and exclusion device performance. Wildlife cameras paired with all lethal traps showed no interactions or "unacceptable" interactions with traps or trap boxes by native species, including federally listed species.

Capture rates from lethal and live traps were compared in similar areas. Of captures from Goodnature traps, 99% were rats, and 1% were mongooses. Of DOC 250 captures, 71% were mongooses, 25% were rats, and 4% were cats. Body grip traps did not capture any animals during the evaluation period but captured one mongoose during the efficacy period. Goodnature traps had the highest capture rate for rats, followed by DOC 250 and cage traps. DOC 250 had the highest capture rates for mongooses, followed by cage traps.

Staff noted that although lethal traps require considerable labor for initial setup, lethal traps required much less labor to monitor than live traps and were advantageous in remote areas. This study suggests that incorporating lethal traps could greatly benefit the predator control program at Haleakalā National Park.

1. INTRODUCTION

1.1 Background

Haleakalā National Park (HALE) is home to nine species of federally endangered and threatened birds, including the ground-nesting ʻuaʻu (Hawaiian Petrel, *Pterodroma sandwichensis*) and nēnē (Hawaiian Goose, *Branta sandvicensis*) (National Park Service 2020; Fish and Wildlife Service 2020). Hawaiian birds evolved in the absence of mammalian predators and are now susceptible to depredation by introduced rats, mongooses, and cats (Lindsey et al. 2009). Small mammals also indirectly negatively affect Hawaiian bird populations through habitat degradation and by provisioning other predators (Lindsey et al. 2009). A predator control program to protect ground-nesting ʻuaʻu and nēnē at HALE has been ongoing since the 1970s, utilizing live cage traps set along traplines, with foothold traps and snap traps on a limited basis to supplement cage trapping (Kaholoaa et al. 2019; Kelsey et al. 2019).

Predator control management at HALE aims to promote bird survival while maximizing trapping efficiency (Kaholoaa et al. 2019). Predator trapping using a network of cage traps has been effective in maintaining a low rate of mortality from predators and has contributed to increases in ʻuaʻu and nēnē populations (Natividad Hodges & Nagata 2001; Haleakalā National Park 2012; HALE unpubl. data). However, live traps require frequent monitoring and cannot be active during staffing shortages.

In most remote areas of the park, predator control is conducted infrequently or not at all. Some sites are accessible only by helicopter, making the regular monitoring of traps infeasible. The population centers of many native and endangered bird species occur in these remote regions of the park. These include the critically endangered kiwikiu (Maui Parrotbill, *Pseudonestor xanthophrys*) and ʻākohekohe (Crested Honeycreeper, *Palmeria dolei*) found in the remote Upper Kīpahulu Valley, Upper Hāna Rainforest, and Manawainui rainforest areas (Judge et al. 2019). Endangered ʻuaʻu and candidate for endangered status ʻakeʻake (Band-rumped Storm Petrel, *Oceanodroma castro*) occur in remote regions of Nuʻu (Haleakalā National Park 2016).

In 2015, HALE received a National Fish and Wildlife Foundation grant to evaluate and improve the predator control program. Island Conservation evaluated predator control field methods through this grant, and United States Geological Survey staff reviewed trapping data from 2000 to 2014 (Jolley & Hansen 2016, Kelsey et al. 2019). Park staff then wrote the HALE Predator Control Management Plan incorporating the previous two studies.

Island Conservation and the HALE Predator Control Management Plan recommended incorporating lethal traps into the HALE predator control program. Lethal traps are advantageous when frequent trap checks may not be possible due to site remoteness or staff availability (Jolley & Hansen 2016; Kaholoaa et al. 2019). The three lethal traps proposed for use at HALE are Goodnature® A24 traps (Goodnature) to target rats, DOC 250 traps to target mongooses, and Belisle Super X 220 body grip traps (body grip) to target cats. These lethal traps were tested and deemed humane for their target species (Peters et al. 2011; New Zealand Department of Conservation 2019).

This project tests new lethal traps at HALE to determine performance, efficacy, and potential harm to non-target species especially threatened and endangered species. This report describes the testing of the recommended lethal traps for performance and non-target interactions, analyzes short-term efficacy, and offers future recommendations for managers. Testing began in 2017 and ended in 2020.

1.2 Trap Descriptions

1.2.1 Goodnature A24 Traps

The Goodnature is a self-resetting trap that targets rodents (Figure 1L). Rodents enter the trap, activate the trigger, and are struck by a CO_2-powered cylindrical striker (Figure 1R). Carcasses fall beneath the trap and are usually recovered within one meter of the trap. Predators often scavenge carcasses. After each strike, the trap automatically resets for up to 24 strikes per CO_2 cartridge.

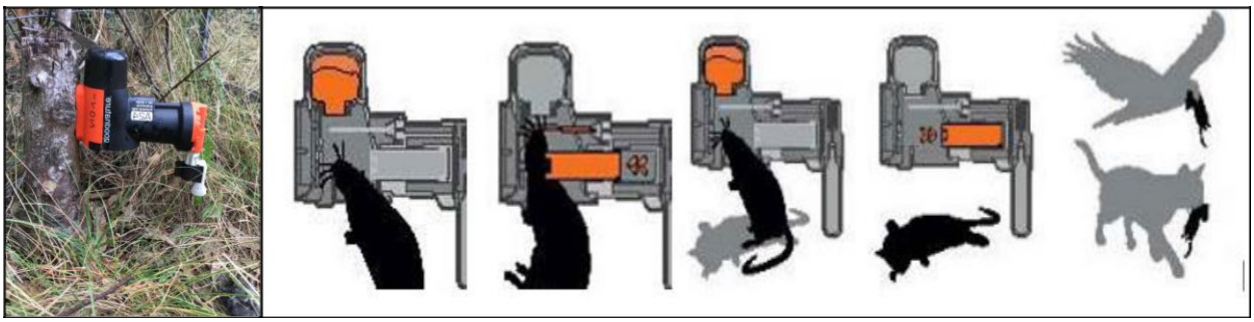

Figure 1. (L) Goodnature trap. (R) Progression of rat capture and scavenging, image courtesy of Goodnature.

Traps were mounted approximately five inches (12.7 cm) above the ground. The bait used at all locations was the Goodnature chocolate rodent lure, either in the static lure bottle or the Automatic Lure Pump (ALP). The static lure bottle is filled with the lure that must be dispensed manually, whereas the ALP self-dispenses bait for up to six months. Because traps were checked regularly, lures could be dispensed manually from the static lure bottle comparably to the bait released from the ALP over time.

Digital strike monitors were placed on the CO_2 canister in alignment with the striker to record the number of times the trap was triggered. Goodnature expects scavengers to remove carcasses from beneath the trap, so the digital strike monitor count was used in this study to determine the number of rodents captured.

1.2.2 DOC 250 traps

The DOC 250 is a powerful spring trap capable of humanely euthanizing mongooses and rats (Figure 2L). The trap is triggered when the animal walks across the bottom pan. All DOC 250 traps were deployed in exclusionary boxes with offset entrances through two layers of hardware cloth, as specified by the New Zealand Department of Conservation best practice to exclude non-target species, guide target species, and provide public safety (New Zealand Department of Conservation n.d.) (Figure 2R).

Figure 2. (L) DOC 250 trap. (R) DOC 250 trap exclusionary box diagram and complete set with the top open, showing the two offset entrances through hardware cloth (to the left of trap) to prevent non-target capture.

1.2.3 Body grip traps

Body grip traps are powerful and available in various sizes (Figure 3L). The body grip is triggered as an animal walks through the trap's opening and contacts the wire trigger. The Belisle 220 Super X was tested as recommended for use at HALE by Island Conservation for feral cats (Jolley & Hansen 2016). Traps can be set in boxes designed to exclude non-target species and prevent accidental trap triggering by the public. Body grip traps may also be open set without an exclusionary box. Three types of sets were utilized for this study: a chimney box, a walk-through box, and an open set in front of an unoccupied ʻuaʻu burrow (Figure 3R).

The chimney box resembles an upside-down "T" with two body grip traps on either side (Figure 3R). The open sides are covered with hardware cloth allowing predators to enter only through the chimney to reach the traps. This design is the most exclusionary box and the bulkiest; however, it was tested because it appeared to be the best design to avoid the capture of threatened or endangered bird species.

The walk-through box is a horizontal rectangular box with openings on either side, resembling a tunnel (Figure 3R). The walk-through box houses two body grip traps, one on either end of the box. This box is set in areas where the landscape will naturally funnel a cat to walk through the box. The walk-through box provides an intermediate level of protection for non-target species such as nēnē, who would likely not travel through the box. Walk-through boxes were not tested in ʻuaʻu habitat as ʻuaʻu have been previously caught in cage traps, which are similar to this design.

The open set traps were set without a box and placed at the entrances of unoccupied ʻuaʻu burrows (Figure 3R) during the off-season months of December and January when ʻuaʻu are absent from their burrows. The traps were set at ʻuaʻu burrows in areas where camera traps had captured images of cats investigating burrows (HALE unpubl. data). Burrows with entrances approximately the size of the trap were selected. Rebar stakes secured the traps. Open sets have a high potential of capturing non-targets and were set flush with the burrow entrance and removed before ʻuaʻu returned to the area. Lures were placed in removable containers and removed with the traps to avoid attracting cats to the burrows beyond the trapping season.

Figure 3. (L) Belisle 220 Super X body grip trap. (R) A chimney box set, walk-through set box, and open set in front of the burrow entrance.

1.3 Locations

Traps were set in eight locations: ‘Ohe‘o, Kanahā, Pōhakuokalā, Hosmer, Halemau‘u, Central Crater, Palikū, and Rim (Figure 4). Sites were selected by elevation, habitat type, endangered bird presence, predator densities, and current predator management levels. Kanahā and Pōhakuokalā are located outside of HALE.

- Lowland: Elevations below 1,000 ft (300 m) with highly disturbed habitat and high predator densities.
    - ‘Ohe‘o (200 ft./60 m el.): Within HALE near the shoreline with high human activity and no endangered birds. Predator management occurs irregularly.
    - Kanahā (100 ft./30 m el.): A State wildlife sanctuary outside HALE. Nēnē and endangered ae‘o (Hawaiian stilt, *Himantopus mexicanus knudseni*) are present, and predator management is ongoing.
- Mid-elevation: Elevations between 4,000-8,500 ft (1,200-2,600 m el.) with mixed vegetation of mostly shrubland with native and non-native trees and grasses; medium predator densities.
    - Pōhakuokalā (4,200 ft./1,280 m el.): Outside HALE, managed by Skyline Eco-Adventure with no endangered birds present and no predator management.
    - Hosmer (6,800 ft./2,070 m el.): Within HALE, areas near and around Hosmer Grove to HALE Headquarters. Nēnē presence and activity are high. Predator management is ongoing.
    - Halemau‘u (7,900-8,500 ft./2,400-2,600 m el.): Within HALE, west of the Halemau‘u trailhead. Presence and activity for nēnē are medium and are low for ‘ua‘u. Predator management is ongoing.

- Central Crater (7,100 ft./2,200 m el.): Within HALE, near the center of Haleakalā Crater. Presence and activity for nēnē are medium and are high for ʻuaʻu. Predator management is ongoing.

- Palikū (6,380 ft./1,945 m el.): Within HALE, at the east end of Haleakalā Crater. Presence and activity for nēnē are high and are low for ʻuaʻu. Predator management is ongoing.

- High elevation: Elevations above 8,500 ft (2,600 m el.) with sparse vegetation and low predator densities.

  - Rim (9,500 ft./2,895 m el.): Within HALE, near the crater rim of Haleakalā. Presence and activity for ʻuaʻu are high, with high numbers of ʻuaʻu burrows (nests). ʻUaʻu are present at burrows between March and October. Nēnē are occasionally in the area. Predator management is ongoing.

Ecosystem management at the mid- and high elevation sites within HALE has been ongoing since the 1970s. Management includes controlling non-native predators, feral ungulates, and non-native plant species. Over 90% of nēnē nests at HALE are found in mid-elevation areas, with few at higher and lower elevations. The majority of ʻuaʻu nests at HALE are found in high-elevation regions. For a further description of locations, see Appendix A.

Figure 4. Map of Maui Island showing performance testing locations; yellow = lowland, green = mid-elevation, and purple = high elevation sites.

2. MATERIALS AND METHODS

The Goodnature, DOC 250, and body grip traps were first set with camera traps in a trial phase from March 2017 to March 2018 to assess trap performance and non-target interactions. Traps were set at ʻOheʻo, Kanahā, Pōhakuokalā, Hosmer, Palikū, and Rim during this time. At the end of this phase, traps at ʻOheʻo, Kanahā, and Pōhakuokalā were removed, and more traps were added to the other areas within HALE.

Trap capture data from March 2017 through February 2020 were compared with trap data from the existing cage and foothold traps open concurrently and in similar habitats and locations to determine efficacy. The trap locations used for the efficacy analysis were Hosmer, Halemauʻu, Central Crater, and Palikū.

2.1 Trap Deployment

Descriptions of trap deployments in this section were used to determine trap performance and non-target interactions.

2.1.1 Goodnature

Fourteen Goodnature traps were tested at lowland and mid-elevation locations at Kanahā (3 traps for 28 days), Pōhakuokalā (3 traps for 88 days), Palikū (2 traps for 120 days), Hosmer (2 traps for 365 days), and ʻOheʻo (2 traps for 302 days, 2 traps for 203 days, Table 1). Initially, two traps were deployed at ʻOheʻo on 5/25/17, two more were set in the same area on 9/1/17, and all four were removed on 3/23/18. Traps were not tested at high elevations.

At Palikū, where nēnē are abundant, traps were baited but left unarmed for the first 48 days to determine nēnē interactions with the trap. At Kanahā, where endangered aeʻo and nēnē occur, traps were set with a heavy-duty metal coil "weka excluders" attached to the base of the trap to prevent aeʻo or nēnē catches (Figure 5). "Weka excluders" were designed and sold by Goodnature to prevent non-target capture of weka, a flightless bird in New Zealand. Traps with the "weka excluders" were mounted slightly higher to accommodate the metal coil below the trap. The Goodnature "weka excluder" is no longer available for purchase. A similar "blocker" is now available but was not tested. Data recorded for Goodnature traps included trigger count from the digital strike monitor, number of carcasses below the trap, and bait status (presence or absence).

Figure 5. Goodnature trap with "weka excluder" and camera trap nearby to record non-target interactions.

2.1.2 DOC 250

Twelve DOC 250 traps in boxes were tested at ‘Ohe‘o (5 traps for two days, 3 traps for three days), Palikū (3 traps for 158 days), Hosmer (1 trap for 156 days), and Rim (1 box only for 80 days, Table 1). Traps at all locations were armed from the deployment date, except at Rim, where one trap was placed unarmed near an ‘ua‘u burrow to determine ‘ua‘u interactions with the box and to prevent accidental harm to ‘ua‘u. ‘Ohe‘o trapping days varied based on the length of the camping trips; trips were for 2-3 days.

Traps were baited with various baits and lures, including sardines, canned cat and dog food, dry dog kibble mixed with used cooking oil, vienna sausage, and commercial baits and lures. Data collected were trapped status (open or closed), bait status (bait present or not), and catches. If possible, data on the sex and age of the capture was recorded. Traps were tested, rebaited, and reset at each check.

2.1.3 Body grip

Fourteen body grip traps were tested at HALE (Table 1). During the trial phase, body grip traps were set in three ways (Figure 3R): a chimney box, a walk-through box, and an open set in front of an ‘ua‘u burrow with no box. Traps were tested at ‘Ohe‘o (6 traps for two days, four traps for three days, in chimney boxes), Palikū (2 chimney boxes without traps for 152 days), Hosmer (2 traps for 152 days, walk-through set), and Rim (2 traps for 52 days, open set). ‘Ohe‘o trapping days varied based on the length of the camping trips; trips were for 2-3 days.

All traps were armed during the trial phase except those at Palikū, where nēnē are abundant. The two chimney boxes at Palikū were placed without traps to determine nēnē interactions with the box and to prevent accidental capture of nēnē.

Traps in boxes were baited with canned cat and dog food, dry dog kibble mixed with used cooking oil, vienna sausage, and commercial baits and lures. The open set traps were baited with commercial lures on a wool piece or within a container inside the burrow and were removed with the trap. Data collected included trap status (open or closed), bait status (bait present or not), and catches. If possible, data on the sex and age of the capture was recorded. At each check, traps were tested, rebaited, and reset.

Table 1. Location and elevations of Goodnature, DOC 250, and body grip traps during the trial phase. The number under each trap type is the number of traps in each location/number of days engaged.

Area		Elevation ft (m)	Goodnature/days	DOC 250/days	Body grip/days
Lowland	Kanahā	100 ft (30 m)	3/48	---	---
	‘Ohe‘o	200 ft (60 m)	4/302, 203	8/2, 3	10/2, 3
Mid-elevation	Pōhakuokalā	4,200 ft (1,280 m)	3/88	---	---
	Palikū	6,380 ft (1,945 m)	2/120	3/158	2*/152
	Hosmer	6,800 ft (2,070 m)	2/365	1/156	2/152
High elevation	Rim	9,500 ft (2,895 m)	---	1*/80	2/52

*box only, no traps

2.2 Performance

2.2.1 Captures

To determine trap performance for lethal traps, traps and trap boxes were checked for stability, design, placement, and other features that would affect capturing animals. Modifications made to traps and the number of animals caught per trap were recorded.

2.2.2 Interactions

Camera traps were utilized to record all species interactions with lethal traps during the trial phase. All cameras were no-glow infrared models to minimize disturbance to wildlife. The camera models used were Bushnell Trophy Cam HD Aggressor, Wildgame Innovations #W5EGC, and the Reconyx Hyperfire HC500. Camera traps were set at all test sites to record photos or videos when motion was detected near the lethal traps. Depending on the vegetation structure, cameras were placed 3-15 ft (1-5m) away and pointed at the trap (Figure 5).

Camera trap photos and videos were sorted to identify images that included wildlife. Wildlife photos were sorted by species, and the number of images per species at each type of trap was recorded. Individual animals were not differentiated.

Wildlife species were designated as target or non-target depending on the trap type. The target species for each trap are as follows:

- Goodnature – Rodents
- DOC 250 – Mongooses, rodents
- Body grip – Feral cats

Wildlife species that were not targeted for capture by that trap were considered "non-target" species. Images of non-target species were examined to determine if interactions with the trap were acceptable or unacceptable.

Three criteria were used to determine if non-target interactions with the traps were unacceptable.

Were non-target species:

1. Attempting to enter the exclusionary box or "weka excluder."
2. Engaging in an activity that could engage the trap
3. Caught in the trap

If a non-target species enacted one or more criteria, the action was deemed unacceptable. If the camera trap footage observed unacceptable actions, especially by threatened or endangered species, mitigations were made, or the trap was removed to prevent accidental non-target capture.

2.3 Existing traps

Cage traps and foothold traps have been used for routine predator control management at HALE for many years; therefore, an additional trial phase for these traps was unnecessary. These traps provided a means to compare the efficacy of the lethal traps.

2.3.1 Cage traps

A cage trap is a non-lethal trap used at HALE to capture rats, mongooses, and cats (Figure 6L). Predator control at HALE has relied on cage traps, and they remain the most widely used trap within the park. Havahart™ and Tomahawk Live Trap™ traps ranged in size from a 7" x 7" opening to a 10" x 12" opening. Traps may be used in endangered bird habitats with modifications to block or partially block the entrance to keep birds out (Kaholoaa et al. 2019). Cage traps are typically set along transects or clusters (Figure 6R).

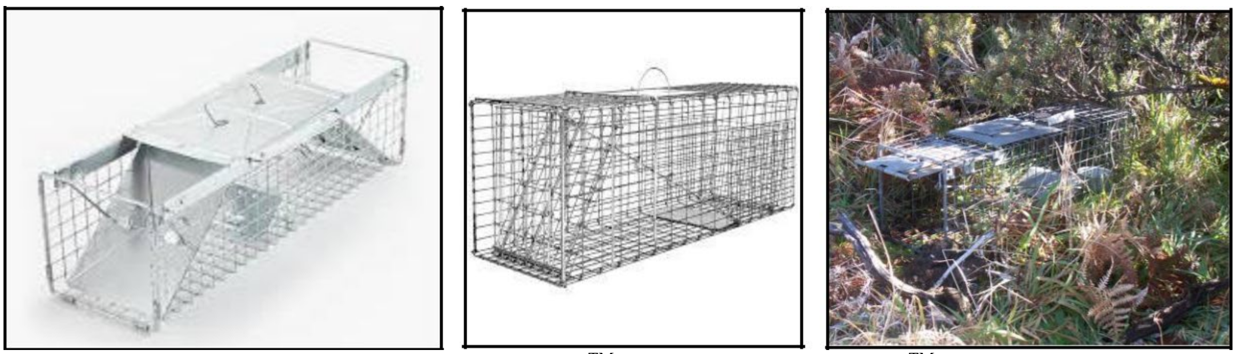

Figure 6. (L) Cage traps used at HALE. L-R: Havahart™ trap, Tomahawk Live Trap™. (R) Cage trap set in the field.

2.3.2 Foothold traps

Padded foothold traps are non-lethal traps used at HALE to target cats. Foothold traps are more effective than cage traps at catching feral cats at HALE and are used on smaller scales (Goodale et al. 2014). Victor #1 and Bridger #1.65 traps are used (Figure 7L). Foothold traps are set either as a trail set, dirt hole set, or cubby set in select locations (Kaholoaa et al. 2019; Figure 7R).

Figure 7. (L) Foothold trap types used at HALE: Victor #1, Bridger #1.65. (R) Trail set (trap is covered with leaves).

2.4 Efficacy

To determine efficacy, capture rates from lethal traps were compared with live traps. Only data from traps in similar areas were compared: Hosmer, Halemauʻu, Central Crater, and Palikū (Figure 4; Appendix B).

Capture data were collected from direct catches by all traps, excluding the Goodnatures. Goodnature catches were determined by the total number of triggers recorded on the digital strike counter rather than the carcasses retrieved. In a study at Hawaii Volcanoes National Park, researchers used trigger counts as an approximation of Goodnature captures and estimated that of those triggers, only 78% of carcasses were recovered (Coad et al. 2017). In a Kalaupapa National Historical Park report during testing on Oʻahu, scavenging was seen after 2-3 days, with 48% of previously observed carcasses missing on the subsequent check (Franklin 2013). This suggests that using carcasses as a count of captures would be an underestimation, so the digital strike monitor was utilized instead. The trigger counts approximate rodent captures as individual species cannot be determined, and accidental triggers cannot be estimated.

Rates of capture were compared by comparing catch per unit effort (CPUE). CPUE is a standard method of evaluating capture rate at a comparable value to normalize the number of traps and predators (Pierce et al. 2012; Natividad Hodges 1994; Skalski & Robson 1992). For this evaluation, the catch per unit effort is:

$$CPUE = \frac{CATCH}{EFFORT}$$

CATCH = *# of animals caught*

EFFORT = (*# of available traps*) x (*# of days bait is placed in traps*)

 # OF AVAILABLE TRAPS = (*total # of traps – # traps with predators*) x (*average number of days traps are open with bait*)

CPUE was calculated for each trap type by species captured. The average number of days traps were open and available for capture was 5.75 $\pm$ 2.49 days for cage traps and 7.7 $\pm$ 5.8 for DOC 250 traps. Goodnature, body grip, and foothold traps were open and available for the entire duration.

Since capture rates were low, CPUE per 1,000 trapping days was calculated. CPUE of each trap and species were compared to determine efficacy. Trap types with the highest CPUE are considered the most efficient.

3. RESULTS

3.1 Performance

3.1.1 Captures

Captures from all lethal traps were recorded with trap locations, days in the field, and predators captured (Table 2).

Table 2. Summary of days in the field and the number of captures for Goodnature, DOC 250, and body grip traps during the trial phase.

Trap Type	Days in field	Total captures	Rats	Mongoose	Cats
Goodnature	2622	114	113	1	0
DOC 250	649	28	7	20	1
Body grip	382	0	0	0	0

Fourteen Goodnature traps were tested for 2,622 trap days, recording 114 triggers. Of those triggers, 113 were rats, and 1 was a mongoose (Table 2). Sixty rat carcasses were observed at Goodnature traps, confirming that 53% of triggers were attributed to rat strikes (Table 3). The mongoose was found below the Goodnature trap at Pōhakuokalā Gulch at Skyline Eco-Adventure in Kula (Pōhakuokalā #2). Of the 14 traps, four traps recorded zero triggers (Pōhakuokalā #3 and Kanahā #1-3). The two traps located at Palikū, initially placed unarmed in the pasture, were modified after determining interactions with mules (see *Interactions*).

Table 3. Trap locations, number of days in the field, triggers, and carcasses found at Goodnature traps.

Trap Location	**Days**	**Triggers**	**Carcasses**
Hosmer (RM)	482	29	17
Hosmer (Hosmer)	482	39	27
Palikū (Water Tank)	120	7	9
Palikū (Lua)	120	4	4
‘Ohe‘o #1	302	3	0
‘Ohe‘o #2	302	5	0
‘Ohe‘o #3	203	7	0
‘Ohe‘o #4	203	9	0
Pōhakuokalā #1	88	5	2
Pōhakuokalā #2	88	6	1
Pōhakuokalā #3	88	0	0
Kanahā #1	48	0	0
Kanahā #2	48	0	0
Kanahā #3	48	0	0
TOTAL	**2622**	**114**	**60**

Twelve DOC 250 traps were set for 649 total trap days and captured 28 animals (Table 4). Of the catches, 20 were mongooses, 7 were rats, and 1 was a juvenile cat (Table 2). The trap that captured the juvenile cat was modified by decreasing the size of the entrance holes.

Table 4. Trap locations, number of days in the field, number of mongooses, rats, and cats captured by DOC 250 traps.

Trap Location	Days	Rats	Mongooses	Cats
Palikū #1	158	0	1	0
Palikū #2	158	1	0	0
Palikū #3	158	4	1	0
Hosmer #1	156	2	0	0
‘Ohe‘o #1	2	0	0	0
‘Ohe‘o #2	2	0	1	0
‘Ohe‘o #3	2	0	1	0
‘Ohe‘o #4	2	0	0	0
‘Ohe‘o #5	3	0	3	0
‘Ohe‘o #6	3	0	2	0
‘Ohe‘o #7	3	0	6	1
‘Ohe‘o #8	2	0	5	0
Totals	**649**	**7**	**20**	**1**

Fourteen body grip traps were set for 382 trap days and recorded no catches (Table 5). No modifications were made to traps or trap boxes.

Table 5. Trap locations, number of days in the field, and number of carcasses for body grip traps.

Trap Location	Days	Carcasses
Rim #1 (Kalahaku West 060)	32	0
Rim #2 (Kalahaku West 055)	32	0
‘Ohe‘o #1 (LZ)	1	0
‘Ohe‘o #2 (LZ)	1	0
‘Ohe‘o #3 (Campground)	1	0
‘Ohe‘o #4 (Campground)	1	0
‘Ohe‘o #5 (Kanalulu House)	2	0
‘Ohe‘o #6 (Kanalulu House)	2	0
‘Ohe‘o #7 (Across Baseyard)	2	0
‘Ohe‘o #8 (Across Baseyard)	2	0
‘Ohe‘o #9 (Baseyard Lua)	1	0
‘Ohe‘o #10 (Baseyard Lua)	1	0
Hosmer #1	152	0
Hosmer #2	152	0
Total	**382**	**0**

3.1.2 Interactions

Wildlife cameras captured images of the target and non-target species for each lethal trap (Table 6). The total number of images captured per species per camera trap was examined rather than the number of individuals.

Cameras with Goodnature traps captured 23 species, cameras with DOC 250 traps captured images of eight species, and cameras paired with body grip traps caught ten species (Table 6). All target species (feral cats, mongooses, and rats) were captured in pictures associated with all trap types.

Table 6. List of species and number of images captured by camera traps paired with lethal traps (sorted by target species, native and non-native). N = native; Nn = non-native; T=federally listed as *Threatened*, E = federally listed as *Endangered*. Target species are highlighted.

Target/Non-target	**Species**	**Goodnature**	**DOC 250**	**Body Grip**
Target	Feral cat (*Felis catus*) Nn	502	16	41
	Mongoose (*Herpestes auropunctatus*) Nn	22	438	155
	Rat (*Rattus sp.*) Nn	1614	973	3494
Native non-target	Nēnē (*Branta sandvicensis*) N, T	2478	14	6366
	ʻUaʻu (*Pterodroma sandwichensis*) N, E	0	10	0
	Aukuʻu (*Nycticorax nycticorax hoactli*) N	3	0	0
	Hawaiʻi ʻamakihi (*Chlorodrepanis virens*) N	0	6	0
	Kōlea (*Pluvialis fulva*) N	69	0	75
	Pueo (*Asio flammeus sandwichensis*) N	4	0	0
Other non-target	Domestic cow (*Bos taurus*) Nn	0	0	9
	Domestic mule/horse (*Equus sp.*) Nn	14	0	2213
	Feral goat (*Capra hircus*) Nn	71	0	0
	Feral pig (*Sus scrofa*) Nn	612	0	0
	House mouse (*Mus musculus*) Nn	36	0	0
	Common myna (*Acridotheres tristis*) Nn	46	0	0
	Feral chicken (Gallus *sp.*) Nn	6	0	0
	Gray francolin (*Francolinus pondicerianus*) Nn	2	0	0

	House finch (*Haemorhous mexicanus*) Nn	0	0	5
	House sparrow (*Passer domesticus*) Nn	10	0	0
	Japanese bush warbler (*Horornis diphone*) Nn	1	0	0
	Japanese white-eye (*Zosterops japonicus*) Nn	3	8	0
	Melodious laughing thrush (*Garrulax canorus*) Nn	102	0	0
	Northern cardinal (Cardinalis cardinalis) Nn	126	0	0
	Red-billed leiothrix (*Leiothrix lutea*) Nn	302	84	122
	Ring-necked pheasant (*Phasianus colchicus*) Nn	40	0	70
	Spotted dove (*Spilopelia chinensis*) Nn	148	0	0
	Zebra dove (*Geopelia striata*) Nn	10	0	0
Totals		6221	1549	12550

3.1.2.1 Goodnature

Cameras paired with Goodnature traps captured 6,221 images of animals. Goodnature traps were the only trap tested in areas both in and outside of the park boundary. Traps were baited and armed from the beginning of the trial phase at all locations except at Palikū. Traps at Palikū were baited only (not armed) for the first 48 days in areas where nēnē frequent to determine if nēnē would be attracted to the bait or the trap. Once determined that nēnē did not show interest in the Goodnature, the traps were moved to different locations and armed for the remaining 120 days. The Goodnature harmed no native birds.

There were 2,478 images of nēnē, all captured at Palikū, where the majority of nēnē nest and roost. Nēnē appeared to be transiting through the area rather than interacting with the trap (Figure 8L). Twelve images showed nēnē passing within a few feet of the trap but never contacting the trap. The remaining photos were of nēnē feeding and loafing away from the trap. One video showed a nēnē interested in the camera rather than the Goodnature, perhaps attracted by the reflective layer over the camera sensor.

One pueo (*Asio flammeus sandwichensis*) was seen in a four-photo sequence in the Hosmer area of the park in a trap cluster that includes a Goodnature and a cage trap (Figure 8R). The cage trap was open during the sequence; therefore, the pueo was not attracted by a live rat within the cage. However, the pueo may have been attracted to the area to scavenge carcasses of animals killed by the trap or in response to increased rodent activity due to Goodnature deployment.

Figure 8. Images of nēnē at Palikū (L) and pueo at Hosmer (R) were captured on cameras paired with Goodnature traps.

There were 69 images of kōlea (*Pluvialis fulva*), all collected at Palikū. All indicated that kōlea did not interact with the trap but appeared to be feeding in the grassy area around the Goodnature trap (Figure 9L). There were three images of auku'u (*Nycticorax nycticorax hoactli*), all at Kanahā. These images captured the bird walking through the area (Figure 9R). As with pueo, auku'u may be attracted to the trapping area to scavenge rodent carcasses or in response to increasing rodent activity because of Goodnature deployment.

Figure 9: Images of kōlea at Palikū (L) and auku'u at Kanahā (R) in the vicinity of the Goodnature traps.

There were 1,614 images of rats (*Rattus sp.*) and 36 photos of the house mouse (*Mus musculus*) captured near the Goodnature traps throughout the trial phase. Both rodents were seen on and around the trap, appearing interested in the shroud of the Goodnature, as well as the bait within the trap (Figure 10R). Rats were also observed climbing on top of the trap (Figure 10L). Rats were documented with their heads inside the shroud, but images of strikes were not captured.

Figure 10: Images of rats climbing on (L) and looking into shroud (R) of Goodnature traps at ‘Ohe‘o.

Cameras captured 502 images of cats investigating the trap and areas around the trap. Based on these images' location, it is likely that the cats are either feral or stray and not pets. Cats were seen investigating the trap, walking by the trap, and walking near the trap, potentially looking for carcasses (Figure 11L). There were no images of cats scavenging rodent carcasses from beneath the Goodnature traps. Twenty-two images of mongooses were also seen near the Goodnature traps. In a 30-second video, one mongoose placed its head into the entrance to the trap shroud, then walked away. Another video captured a mongoose retrieving a small rodent carcass from beneath the Goodnature before scampering away (Figure 11R). During the trial phase, a single mongoose was captured by a Goodnature set at Pōhakuokalā but was not documented on camera. These larger predators were likely attracted by the bait or perhaps by scavenging opportunities provided by rodent carcasses.

Figure 11: Images of a cat investigating Goodnature (L) and a mongoose scavenging small rat below trap (R) at ‘Ohe‘o.

Fourteen images of mules (Equus sp.) were captured near the Goodnature traps. A mule is first seen feeding inches away from the mounted trap in photos and videos, nudging the trap repeatedly, and finally dislodging the Goodnature from its mount (Figure 12L). While the trap posed no danger to the mules, a dislodged trap is ineffective for capturing animals and could threaten other species.

There were 612 images of pigs (*Sus scrofa*) captured near Goodnature traps in ‘Ohe‘o (Figure 12R). Pigs were not documented directly interacting with the Goodnature traps but were seen rooting around in the leaf litter around the Goodnature. Although no images were recorded, pigs may have scavenged carcasses beneath the traps. Seventy-one images of feral goats were seen in Hosmer but were outside of the HALE boundary fence and did not interact with the trap.

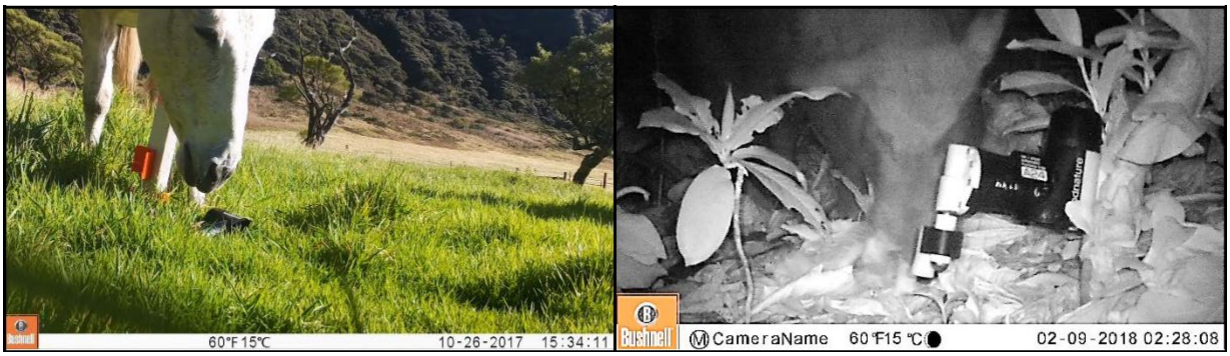

Figure 12: Images of a mule after dislodging Goodnature from the mount at Palikū (L) and a pig near a Goodnature at ‘Ohe‘o (R).

Seven hundred ninety-six images of non-native birds were recorded during the trial phase (Table 6). Non-native birds did not appear to be attracted to the Goodnature trap. Images showed birds landing or transiting through the area. There are 754 images of non-native birds showing the bird in the photo's foreground, not near the trap (Figure 13).

Figure 13: Images of non-native birds seen in the foreground near Goodnature traps at Kanahā. (L) Northern cardinal (R) Common Myna

<u>3.1.2.2 DOC 250</u>

Camera traps paired with DOC 250 traps recorded 1,549 images of animals. DOC 250 traps were tested at priority trapping areas known as habitats for nēnē and ‘ua‘u. No native birds were injured or killed by the DOC 250. All boxes were baited and armed from the beginning of the trial phase except for the DOC 250 box placed in the Rim area. The box in the ‘ua‘u colony was not armed and was placed within 10 feet of two different ‘ua‘u burrows to determine if ‘ua‘u interacted with the box.

There were 14 images of nēnē and ten images of ‘ua‘u passing by but not interacting with the DOC 250 boxes. All photos of nēnē and ‘ua‘u fell within acceptable target interactions, as native bird behavior did not appear altered by the presence of the trap. All images of nēnē showed birds walking through the area without stopping near the boxes (Figure 14L). Similarly, the ‘ua‘u did not exhibit interest in the trap and displayed normal behavior (Figure 14R).

Figure 14. Images of nēnē near set DOC 250 at Palikū (L) and 'ua'u (R) walking past trap boxes. The DOC 250 on the left was baited and set, and the DOC 250 on the right along the Rim was unarmed (R).

There were six images of ‘amakihi captured. In a twelve-second video, an ‘amakihi landed away from the trap and hopped towards the DOC 250 before flying offscreen. ‘Amakihi also perched in the foreground for short periods (Figure 15).

Figure 15: Images of ‘amakihi near a DOC 250 trap at Palikū.

There were 438 images of mongooses and 16 photos of cats caught on camera. Camera images showed mongooses and cats circling and investigating trap boxes. One video recorded a mongoose entering the trap box's first door, then attempting to remove bait through the hardware cloth from the outside at the rear of the trap. Another video showed a closed trap with a mongoose captured while a second mongoose dragged the bait out of the trap (Figure 16L). One video recorded a capture of a mongoose at Palikū.

The images of cats were primarily seen on the cameras in the ‘Ohe‘o area. Cats were likely attracted to the DOC 250 boxes by the bait inside of the box. A single cat approaches a DOC 250 from multiple angles in a one-minute sequence, including examining the bait at the rear of the trap (Figure 16R). There were no attempts to enter the box documented. One juvenile cat was captured in a DOC 250 at ‘Ohe‘o; however, no images were recorded.

Figure 16. Images of a mongoose pulling a bait bag out of a trap box at Palikū (L) and a cat peering into a DOC 250 trap box at ‘Ohe‘o (R).

There were 92 images of non-native birds: eight images of a Japanese white-eye (Figure 17R) and 84 images of a red-billed leiothrix (Figure 17L). Although both birds were seen near the trap in their respective photo sequences, no images showed the birds entering or attempting to enter the trap.

Figure 17. Images of non-native birds near DOC 250 boxes at Palikū. Red-billed leiothrix (L), Japanese White-eye (R).

3.1.2.3 Body grip traps

Camera traps paired with body grip traps recorded 12,550 images of animals. Body grip traps were tested at priority trapping areas at HALE in known habitats for nēnē and ‘ua‘u. No native birds were killed or injured by the body grips. All traps were baited and armed from the beginning of the trial except the two boxes placed at Palikū. The two boxes at Palikū were not set with traps and placed in areas where nēnē tend to frequent to determine if nēnē would interact with the box.

There were 6,366 images of nēnē and 75 images of kōlea near body grip traps. Only nēnē were observed investigating or in close vicinity to the trap boxes. Of those instances, two sequences showed nēnē directly interacting with the body grip box. One image recorded a nēnē standing on the exclusionary box's lid for about two minutes (Figure 18L). At the same time, the presumed mate of that bird also pecked at the box. In a different sequence of photos and videos spanning three minutes, a single nēnē is seen repeatedly nibbling at the top of the box and the screw that secures the box lid (Figure 18R).

Figure 18. Nēnē stands on (L) and pecks at (R) chimney boxes at Palikū. These boxes did not have traps.

These interactions were deemed acceptable because they did not fall into any of the three criteria for unacceptable trap interactions. Seventy-five images of kōlea were seen in the traps' vicinity but showed no interest in the boxes.

Forty-one images of cats were recorded at Palikū, Hosmer Grove, and ‘Ohe‘o: 35 photos and six videos. Nineteen images were of cats investigating trap boxes. Eighteen images were of cats sitting on the edge of the trap boxes, and four images showed a cat in the vicinity but not interacting with the box. A five-second video captured a cat jumping out of the chimney box at ‘Ohe‘o while a second cat was seen looking into the chimney (Figure 19L). The cat was not captured due to the staff's poor bait placement; the bait was set in the middle of the box directly beneath the chimney when it should have been placed on either end of the trap, forcing the cat to walk through a body grip to access the bait. A second cat was seen at Palikū sitting on the box lid (Figure 19R). The cat at Palikū did not try to enter the box, likely due to the box not being baited during the trial phase. The 17 images recorded at Hosmer Grove showed a cat possibly sitting on the top edge of the trap box. Still, the camera was not positioned to show the box to confirm this interaction or to record any animals walking through the box.

Figure 19. Feral cat jumping out of the set and baited box at ‘Ohe‘o (L) and sitting on an unbaited and unarmed box at Palikū (R)

There were 155 images of mongooses recorded at ‘Ohe‘o and Hosmer Grove. The sequence of pictures at ‘Ohe‘o showed a mongoose walking on the lid of the body grip box and then peering into the chimney but not entering the trap (Figure 20L). Another sequence of 143 images spanning nearly 40 minutes showed two mongooses entering the walk-through box at Hosmer Grove but not triggering the trap, presumably taking the bait from within the box (Figure 20R).

Figure 20. Images of mongoose peering into the chimney of a trap box at ‘Ohe‘o (L) and walking into a trap box at Hosmer (R). Both boxes contained traps that were set and baited.

Camera traps recorded 3,494 images of rats around the trap boxes. Rats were recorded investigating and climbing in and on the trap boxes. However, the body grip traps are not designed to capture rats. There were images of rats walking through a walk-through set box at Hosmer, likely stealing the bait (Figure 21L). Photos captured rats climbing through the T-shaped hole on the side of the chimney box designed to hold the springs of the body grip traps (Figure 21R). Rats enter all box sets and likely steal the bait, making the traps less attractive to the target predator.


Figure 21: Rat in walk-through set (L) and climbing into chimney box (R) at Hosmer

Two thousand two hundred thirteen images of mules and horses were recorded while the trap boxes were set in the pastures at Palikū. Mules and horses were recorded investigating the boxes, often picking up and moving them (Figure 22L). This interaction was unacceptable since tampering with boxes affects trapping efficacy and could harm the mules. Therefore, the trap boxes were moved to two locations outside the Palikū pasture. There were nine images of a cow recorded at the ‘Ohe‘o LZ (landing zone). The cows did not interact with the body grip trap box but did appear interested in the box (Figure 22R).

Figure 22: Horse picking up body grip box at Palikū (L) and cow investigating box at ‘Ohe‘o (R). The camera that recorded the right image was not set correctly; the time stamp was incorrect.

There were 197 images of three non-native birds: house finch (5), red-billed leiothrix (122), and ring-necked pheasant (70). The birds were seen in front of, sitting on, and around the trap boxes, often using the boxes as a perch (Figure 23L). Seventeen images showed red-billed leiothrix and house finches walking towards and looking at the camera, likely showing interest in the camera trap. Eight images captured the red-billed leiothrix entering the walk-through set at Hosmer (Figure 23R). The bird was not captured by the trap and could have been simply curious about the box, seeking shelter, or perhaps investigating the box for nesting. No other birds were seen entering the trap boxes.

Figure 23: Images of house finch perched on (L) and red-billed leiothrix walking into (R) walk-through body grip box at Hosmer.

3.2 Efficacy

Only captures from comparable areas where traps were placed were used to compare traps' efficacy (Table 7, Appendix B.) These include areas at HALE, which are at mid- and high elevation sites. Since low elevation sites are not included, the number of captures, especially for mongooses, will differ from those reported in the previous *Performance* section.

Table 7. Captures from traps in comparable locations are used to calculate CPUE.

Trap Type	Rodents	Mongooses	Cats	Other*	Trap Days
Goodnature	432	1	0	-	12,094
DOC 250	136	23	0	-	5,760
Cage Trap	544	72	5	8	29,878
Body grip	0	1	0	-	5,425
Foothold	1	1	1	-	19,687

*Other eight catches were House mouse (*Mus musculus*)

Overall, Goodnature traps had the greatest CPUE, with rats being most captured (Figure 24). DOC 250 traps were the most efficient for multispecies lethal traps, and body grip traps had the lowest CPUE.

For rats, CPUE was greatest for Goodnature traps (34.81), with CPUE 1.47 times greater than DOC 250 (23.61) and 1.91 times greater than cage traps (18.21). DOC 250 CPUE was 1.3 times greater than cage traps. Rats were not captured by the body grip traps, which is unsurprising as they are not designed to catch rats.

For mongooses, CPUE was greatest for DOC 250 traps (3.99) and was 1.6 times greater than cage traps (2.41). Both DOC 250 and cage trap CPUE was notably greater than foothold (0.05) and body grip (0.18) traps. One mongoose was found at the base of a Goodnature trap, suggesting that Goodnature traps could be set to capture mongooses.

Very few feral cats were captured during this study. Cage and foothold traps captured cats, with CPUE for cages three times greater than footholds. DOC 250 and body grips did not catch cats.

As with mongooses, images showed feral cats climbing on boxes containing DOC 250 and body grip traps but not getting captured.

Traps that captured all species were cages and footholds. In this study, overall CPUE for cage traps (0.02) was higher than for foothold traps (0.0001). For traps that targeted both mongooses and feral cats, cage and foothold traps captured both species. Body grip and DOC 250 traps captured mongooses only, with Goodnatures and DOC 250s capturing rats (Figure 24).

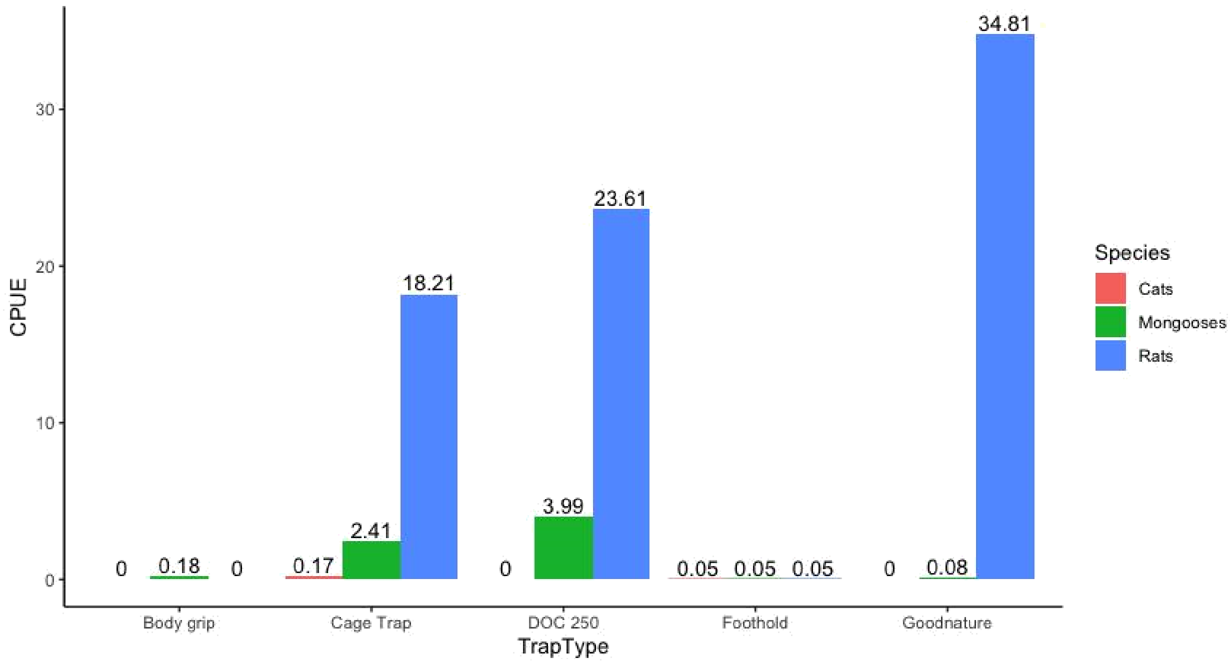

Figure 24. Catch per unit effort per 1,000 trapping days for each trap type for all species.

4. DISCUSSION

4.1 Trap Assessments

4.1.1 Goodnature

This study showed Goodnature traps to be most effective at catching rats, likely because of the self-resetting function that works for up to six months with an automatic lure pump (Automatic Trap Company 2020). HALE staff found Goodnature traps simple to operate, with new staff feeling comfortable with trap operation after a single training session.

All traps except body grips can capture rats, but Goodnature traps are the most effective with the least labor expended. Leaving a trap in the field without monitoring is advantageous in remote areas. Carcasses beneath the trap are attractive and provide a food source for other predators; therefore, it is crucial to concurrently trap mongooses and cats (Kaholoaa et al. 2019). Another advantage is decreased disturbance to habitat because sites can be visited infrequently.

Infrequent checks also reduce the risk of disease transmission to staff from handling rat carcasses (Franklin 2013). Despite an upfront cost of about $170 (as of 2020), Goodnature traps recover those costs via reduced labor versus maintaining the same number of snap traps in less than a year (Franklin 2013).

Two non-target species were captured in the Goodnature trap: one mongoose at Pōhakuokalā during the trial phase and one common myna at Hosmer after the trial phase. The camera trap did not record footage of the mongoose at Pōhakuokalā. While mongooses are not a target species for the Goodnature, they are targets for HALE predator control, so the capture was deemed acceptable. The capture of the common myna at Hosmer occurred after the trial phase, so no camera was paired with the trap. During the trial phase, non-target bird species (native and non-native) did not show interest in the Goodnature traps. However, monitoring for non-target capture of native birds remains essential. More detail on these captures can be found in the non-target captures section below.

There were no catches in the Goodnature traps at Kanahā, surprising as high levels of rats were expected near sea level. At this location, no carcasses were observed, and no triggers were registered on the digital strike monitors. Perhaps the abundant alternative food sources available reduced the attractiveness of the bait. Rats were captured on camera exploring the traps, but no images recorded rats being caught. All three traps at Kanahā were outfitted with the metal coiled "weka excluder" extending from the base of the trap to the ground. For a rat to enter the trap, it must enter the coil at ground level. Pictures show rats on the exterior of the "weka excluder" only. The "weka excluder" likely deterred rats from entering the trap.

4.1.2 DOC 250

The DOC 250 had the highest capture rate of mongooses of all traps studied and is the most effective trap for capturing mongooses. DOC 250 traps are more attractive to mongooses than cage traps, likely because of the trap box. Mongooses use dens and may be attracted to boxes because of the resemblance to dens (Hays & Conant 2007). Similarly, mongooses were more likely to enter a DOC 250 box with its offset doors than enter the open entrance of a cage (Peters et al. 2011).

Most staff found DOC 250 traps easy to operate after initial training, while some had difficulty with the strength needed to set the trap. The boxes are relatively heavy, with the original boxes used at HALE weighing approximately 25 lbs. (9.07 kg). A lighter box design, about 15 lbs. (6.8 kg), was recently developed; however, HALE staff find this box less durable. The lighter-weight box design degraded quicker than the original boxes. The boxes continue to be modified, and other materials are being explored to find a durable yet portable design.

Two non-target species were captured in the DOC 250 traps: a juvenile cat at ʻOheʻo during the trial phase and a common myna at Palikū after the trial phase. No camera footage was recorded for the juvenile cat captured at ʻOheʻo. While feral cats are not a target species for the DOC 250, they are targeted for removal in the HALE predator control program. The DOC 250 that captured the common myna at Palikū was set after the trial phase without a camera. The hardware cloth may have detached before capturing the myna bird, emphasizing the importance of trap maintenance. More detail on these captures can be found in the non-target captures section below.

DOC 250 traps would be best utilized to target mongooses over rats. When a rat is captured, that trap becomes unavailable for mongoose capture until it is reset. DOC 250 trap sensitivity could be set to trigger at a higher threshold to lower rat captures. Currently, trap sensitivity is set to trigger at the animal weight of 3.5 oz (100 g). Since larger rats weigh approximately 4.5 oz (130 g), setting the threshold sensitivity to 7 oz (200 g) may be adequate for excluding rats, yet able to capture juvenile to adult mongooses. The typical body mass for adult mongooses is 10.6 to 31.7 oz (300 to 900 g; Nellis 1989). DOC 250 traps could also be paired with Goodnature traps to optimize the trapping ability of the DOC 250 traps.

DOC 250 traps are excellent options for replacing cage traps in areas where staffing presence is limited or accidental captures of non-target species may occur. Cage traps require servicing at least once a week, while DOC 250 traps can be left in the field for long periods with long-lasting baits or lures. DOC 250 traps are bulky and require more initial effort for staff to deploy, which can be difficult in backcountry areas. However, DOC 250 traps can be serviced less frequently than cage traps after initial deployment.

4.1.3 Body grip

Body grip traps captured only one animal, a non-target mongoose, despite having a similar number of trap days as DOC 250 traps. Foothold traps captured one cat and one non-target mongoose. In the efficacy comparison, cage traps had the highest catch per unit effort of cats, although the captures were still exceptionally low; there are likely other factors impacting cat captures during this time that were not explored for this report. Previous research found that footholds were much more effective than cage traps at capturing cats within the park (Goodale et al. 2014). An advantage of the body grip trap is that it does not require constant monitoring compared to footholds or cage traps. Both foothold and cage traps are live traps and require more frequent monitoring for humane purposes.

Staff found the body grip trap the most complex and dangerous of all the traps to set and handle. Extra precautions must be made in training personnel for safety and to minimize accidental human (non-trapper) interactions with the trap.

Cats were seen on camera on body grip trap boxes at Palikū, ʻOheʻo, and Hosmer. Multiple interactions were recorded, including investigating, jumping on, sitting on, and looking into the chimney entrance of the box. One cat was observed leaping out of the box at ʻOheʻo but was not captured because of poor bait placement. It is possible that cats were not caught at ʻOheʻo due to the short amount of time traps were deployed (1-2 days). There were no images of cats entering traps in any other location, possibly due to bait unavailability (no longer attractive or stolen by other animals). Images showed rats and mongoose entering the box and accessing the bait without triggering the trap, demonstrating that, like other traps, body grips can be susceptible to bait theft, causing the trap to be less attractive to predators.

A study conducted at HALE in 2002 outlined different levels of feral behavior in cats, ranging from a released domesticated cat to a wild cat that is free-roaming in human-inhabited areas to a feral cat born and raised in wilderness areas (Bailey et al. 2002; Appendix C). Bailey et al. (2002) found that cats currently or previously associated with humans were more likely to scavenge for food than cats with no history of human interactions. Cats observed at ʻOheʻo (a location with high human activity) interacted with the body grip box multiple times and were likely wild cats. The interactions recorded at Palikū (an area with low human activity) differed from those at ʻOheʻo. The cat investigated the box but showed no interest in entering, suggesting that it was a feral cat. Body grip traps housed in boxes may effectively capture wild cats who scavenge for food but not feral cats who hunt for food.

Since body grip traps had low success and were difficult to set, these traps may be best used for targeted trapping rather than part of a routine trapping program. For example, traps could be placed at entrances of unoccupied ʻuaʻu burrows during the off-season (as done during this study). Traps could also be set along trails where there is no human activity (except for staff placing traps) and no threatened or endangered animals that could be captured in traps (such as highly remote rainforest areas of the park).

4.2 Other considerations

4.2.1 Unit Effort versus Person Effort (Labor)

"Unit effort" (as in CPUE) refers to the trap, regardless of the person-effort required to service traps. "Person-effort" or labor is the amount of personnel time necessary to service or bait a trap. Although person-effort was not quantified for this report, each trap type requires varying amounts of person-effort to monitor the trap (clear captures, rebait, and reset trap) and different frequencies of trap monitoring (how often the trap is checked). Live traps must be monitored at a much higher frequency than lethal traps.

DOC 250 and Goodnature traps had the highest CPUE. Goodnature traps are self-resetting and can go unchecked for up to six months with an ALP, requiring the least person-effort by far of all traps. In this study, Goodnature traps were not utilized to their full potential, with checks occurring weekly in most locations. This perhaps contributed to the high capture rate due to frequent bait refreshing, and person-effort for monitoring was far above the manufacturer's intent. The other traps require similar person-effort each time the trap is monitored, but the cage and foothold traps require a much higher overall person-effort due to frequent checks.

Cage traps have a lower CPUE for mongooses and rats than DOC 250 and Goodnature traps and have a higher person-effort. Footholds have a slightly higher CPUE for cats than body grip traps but have a much higher person-effort. Both catch per unit effort and person-effort must be considered when making decisions on trapping.

4.2.2 Malfunctions and Inconsistencies

Three cameras were paired with DOC 250 traps and did not capture any images. Two were at ‘Ohe‘o, and one was at Hosmer. It is possible that the cameras malfunctioned or were set incorrectly.

Three DOC 250 traps at ‘Ohe‘o were set for a similar time as five other DOC 250 traps set at ‘Ohe‘o but were checked multiple times per day, rather than once per trip. Thus, captures were removed more frequently, making the three traps available more often, capturing more mongooses. ‘Ohe‘o has a relatively larger mongoose population than the other sites in this study and does not represent mongoose populations within the entire park. Despite the relatively high number of mongooses, two DOC 250 traps at ‘Ohe‘o recorded no catches, likely because of poor trap placement or bait selection.

Researchers at Hawaii Volcanoes National Park used trigger counts to approximate Goodnature trap captures and estimated that carcasses recovered were 78% of trigger counts (Coad et al. 2017). This methodology was used at HALE to approximate captures. However, since only a portion of carcasses were recovered and images did not capture any strikes, it was impossible to determine what animal triggered the trap. All triggers besides the single known mongoose were considered rat captures in this report. Since mongoose populations at HALE are relatively low, rat captures were unlikely to be significantly overestimated. It is also unlikely that larger mongoose carcasses were scavenged and should have remained beneath traps for observers to record.

Franklin (2013) found that scavenging of Goodnature trap captures at the Pahole Natural Area Reserve on O‘ahu was seen after 2-3 days, with 48% of previously observed carcasses missing on a subsequent check. At HALE, 614 total triggers were recorded, and 217 animals recovered, a much lower ratio (35%) of carcasses recovered, although checks did not occur as frequently. Camera traps captured images of one mongoose scavenging a rodent carcass beneath a Goodnature trap in ‘Ohe‘o, suggesting that other carcasses may have been scavenged from beneath the traps. Images of a pueo were captured, perhaps attracted by the rats or scavenging carcasses below the Goodnature trap. Pictures of pigs possibly scavenging carcasses around the Goodnature traps were seen. While actual scavenging was only documented on camera once during the entirety of this study, it seems likely that scavenging of carcasses occurred on other occasions without being captured on camera.

4.2.3 Non-target captures

There were five instances of non-target species killed by lethal traps. A mongoose and cat capture occurred during the trial phase, while the other three occurred since the implementation of traps throughout the park.

During the trial phase, a mongoose was presumably killed by a Goodnature set at Pōhakuokalā, outside of the park boundary. Routine trapping was not occurring at Pōhakuokalā, so perhaps the novelty of a new item or potential food source attracted the mongoose. No mongoose captures by a Goodnature have been recorded within the HALE boundaries. Mongoose populations are likely more prolific at lower elevations, accounting for the capture. While mongooses are not a target species for the Goodnature traps, mongooses are targeted for capture, so the capture was deemed acceptable. Although a Goodnature killed only one mongoose, there is potential for more kills in areas with high mongoose densities. At Puʻu Kukui Watershed Preserve, Goodnature traps captured multiple mongooses after being set for less than 8 hours (Matt Padgett, pers. comm.). The Puʻu Kukui Watershed Preserve spans from 480-5,788 feet elevation (146-1,764 m el.) and contains rainforest, shrubland, and bogs that serve as significant water sources for West Maui (Maui Land and Pineapple INC 2010). Although this preserve is lower in elevation than HALE, the habitat it protects is similar, suggesting a potential for mongoose captures by Goodnatures at HALE.

At Hosmer, one non-native myna bird was found at the base of a trap and presumed to be killed by the trap. Myna birds are omnivorous and have been known to scavenge, so they may have been curious or attracted by the rodent carcasses (Lin 2007). This Goodnature was set in an area without ʻuaʻu but with a large presence of nēnē. While concerning that a lethal trap killed a bird, camera trap data showed that nēnē do not display interest in the traps and are likely unable to enter the shroud of the trap. Other non-target species, including native birds, did not display interest in Goodnatures but instead appeared to be transiting through the area around the trap. However, monitoring for non-target captures of native bird species by Goodnature traps remains essential.

One juvenile cat was captured in a DOC 250 at ʻOheʻo. In this study, ʻOheʻo has a larger cat population than at higher elevations sites, and most of those cats are likely wild, not feral (Bailey et al. 2002; Appendix C). Other programs using DOC 250s have also reported cat catches. In the 2016 trapping season, Auwahi Wind removed one cat from the Kahikinui Petrel Management Area with a DOC 250 (Tetra Tech 2017). While cats are considered a non-target species for a DOC 250, they are targeted for removal in the HALE predator control program. Camera trap images showed that cats were interested in the traps, perhaps trying to access bait, but did not show cats attempting to enter the DOC 250 trap. Since 2017, the hardware cloth doors on the DOC 250 traps have been made smaller than the initial traps.

A common myna was caught in a DOC 250 at Palikū. While other passerines and similar-sized birds (including kōlea) were captured in images near the DOC 250 traps, the trap did not kill any other species. Myna birds are omnivorous and have been known to scavenge, so curiosity may have attracted the myna bird to the DOC 250 (Lin 2007). The trap's hardware cloth doors were detached when the myna was recovered from the DOC 250. Access to the DOC 250 trap increases for target and non-target species without the exclusionary doors. While it is unclear whether the doors separated before or following the capture, it seems likely that it was prior versus being a result of predators trying to scavenge the carcass. This emphasizes the importance of trap maintenance to deter non-targets from entering the trap. Adjusting the trap sensitivity of the DOC 250 to capture mongoose and large rats could lessen the chance of catching other similar-sized birds, such as the kōlea, since myna birds are relatively small, with adult mynas weighing 3.7 oz (106 g, females) to 4.5 oz (126.75 g males; Kannan & James 2020). This is comparable to adult rats that weigh 3.9 oz (111g, females) to 4.5 oz (130g, males; Shiels 2010) and are captured in DOC 250 traps. Adjusting DOC 250 traps' sensitivity to capture mongooses could lessen the chance of catching other similar-sized birds such as the kōlea.

A body grip trap killed one mongoose at Palikū. Images showed mongooses walking on and in the body grip box at ʻOheʻo and Hosmer. The bait likely attracted the mongoose, and the trap may have been sensitive enough for the mongoose to trigger. Since cats are the target species, it may be challenging to mitigate mongoose captures without excluding cats. However, although mongooses are considered a non-target species for body grip traps, mongooses are targeted for removal in HALE predator control programs; therefore, the capture was deemed acceptable.

4.2.4 Snap traps

Snap traps in boxes are used extensively in Hawaiʻi to target rodents. Although this study did not compare the Goodnature trap with snap traps, a snap trap grid is currently employed at HALE in Palikū. Previous research on Oʻahu showed that the Goodnature traps were more effective and efficient for rat control than a large-scale snap trap grid (Franklin 2013). Monitoring a Goodnature trap grid took 65% less labor than monitoring a snap trap grid, considering that Goodnature traps require less monitoring over time (Franklin 2013).

5. MANAGEMENT RECOMMENDATIONS

5.1 Increase the use of lethal traps

Traps set for more extended periods increase the number of trapping days. Increasing the number of traps and increasing trapping time maximizes trapping days. With limited staff, increasing the least labor-intensive traps are ideal. Lethal traps are less labor-intensive than live traps and are recommended in high-priority areas, such as near and within endangered bird habitats. While the traps have been tested for safety in areas of concern, experienced trappers should evaluate areas to optimize trap placement and maintain a high safety standard.

Modifying lethal trapping efforts to capture the target species is recommended to achieve peak trapping efficiency. While rodent removal is still a net benefit for endangered birds, the effectiveness of both DOC 250 and cage traps could be increased when available always to capture the larger predators rather than capturing rats. Since the trap is unavailable once a rat is caught, increasing “paired” trapping is recommended to minimize rat captures in traps designed for larger animals. Increasing Goodnature traps to capture rodents increases DOC 250 and cage traps' availability to capture mongooses and cats. Rodent carcasses beneath the Goodnature could serve as an attractant for scavengers. Traps may also become unavailable due to bait loss; from data for cage traps between 2000-2014, bait theft, likely from rodents, occurred 62% of the time (Kelsey et al. 2019). Goodnature traps would decrease bait theft by rodents from the other traps. While Goodnature traps are more expensive than traditional snap traps and cage traps, after initial setup, less effort is needed to service the traps if used accordingly, saving personnel time.

Body grip traps are likely not the best trap for extensive, ongoing cat control at HALE due to lack of captures and a potentially higher risk of serious staff injury. However, body grip traps could be utilized in certain situations, such as in a targeted response to cat sightings, signs, or depredations in a remote area not often visited by staff (e.g., Kīpahulu Valley, Nuʻu). In these remote areas, traps would be most effectively used as an open set rather than in a chimney box, as cats in these areas would likely be the most feral of cats and not readily enter boxes.

Goodnature, DOC 250, and body grip traps can protect specific resources when set in a grid or similar for coverage. For example, at Palikū, Goodnature traps can be expanded to replace the current snap trap grid. This, along with the help of more DOC 250 and body grip traps, could protect the area for nēnē and efficiently maintain a trapping presence when staffing is limited. Similarly, this strategy could be implemented in forest bird habitats to preserve rare bird home ranges.

Improving trap placement to target predator hotspots could help increase the number of target predators caught. Determining microhabitats for the specific target predator is essential. For example, chew cards can help locate the best location of Goodnature traps. This is particularly important in areas that will be serviced infrequently.

New lethal traps should be tested when available. The New Zealand Department of Conservation is one resource for new traps (NZ Dept. of Cons. 2020.) The NZ AutoTraps AT220 trap is now available and is a self-resetting and self-rebaiting lethal trap that targets rats and possums (NZ AutoTraps 2020; Figure 25). The AT220 can operate for up to 12 months between servicing and could target rats, mongooses, and cats. At this writing, ten traps were purchased for testing at HALE. As with all new lethal traps, these AT220 traps will be paired with camera traps with remote access to images and tested before mass implementation.

Figure 25. AT220 self-baiting, self-resetting trap by NZ Auto Traps.

5.2 Modify trap designs

Body grip traps were unsuccessful at capturing cats. Researching additional deployment methods, including other exclusionary practices or different trap sets, is recommended. Some future box designs include an L-shaped box (similar to a chimney box but with only one arm with a body grip trap), a smaller walk-through box housing one instead of two traps, and a bucket set, where the body grip trap is set in a modified five-gallon bucket. Open sets on body grip traps outside of exclusionary boxes may increase the chances of catching trap-shy cats and increase the risk to trappers. The Hono a Pali Mitigation Project on Kauaʻi successfully used body grips in open sets that funnel predators through the trap (Pias et al. 2017). However, there is a higher risk of non-target bycatch utilizing this method, so this method must be tested at HALE before incorporating it.

Body grip traps can be modified to a pan trigger (Expand-A-Pan 2015; Figure 26) rather than a whisker trigger, giving the cat an unobstructed view through the trap. Experimenting with a pan trigger on the body grip may increase cat captures. Adjusting the trigger sensitivity is also recommended if it does not increase the risk to non-target species or staff handling the traps.

Figure 26. Body grip trap with pan trigger.

The current exclusionary box design for the DOC 250 traps was successful in trapping rats and mongooses; however, the sides are too close to the back frame of the trap. The setters can be challenging to maneuver, making it difficult to bring the kill bar into the set position. Making the exclusionary box slightly larger will allow for greater ease of setting the DOC 250 traps. DOC 250 trap boxes must also be durable if the traps are set in remote areas and infrequently serviced. Some of these exclusionary boxes that have been in the field for about a year have already begun to degrade. Using wood materials with a defined grain is not recommended as it tends to crack over time from the force exerted by the DOC 250 traps. Researching more durable building materials or wood treatment options could maintain box conditions over more extended periods. Finding a building material that balances durability and portability is recommended. Hardware cloth doors tend to fall off as well. If the hardware cloth is unsecured, non-target species are at higher risk for trap interactions. Finding a better way to secure the hardware cloth and a frequent maintenance schedule is necessary to ensure the safety of non-target birds.

5.3 Explore bait longevity solutions

One benefit of lethal traps is that traps can be deployed in remote areas that may not be monitored frequently. Pairing Goodnature traps with DOC 250 or body grip traps may reduce bait theft, but bait longevity becomes more crucial with less frequent monitoring.

Bait attractiveness decreases over time as it degrades, greatly lowering the trap attractiveness to predators. For non-self-baiting traps, this necessitates finding longer-lasting baits. Staff found commercially made baits and lures to be long-lasting, but in an analysis of captures at HALE, highly durable commercial baits had the lowest predator captures. In contrast, less durable canned cat and dog food had the highest captures (Kelsey et al. 2019). More baits must be explored to find the right combination of durability and attractiveness. Footholds at HALE are baited with both a long and short-distance lure, and this method has been effective at catching cats (Goodale et al. 2014). Along with changing exclusionary designs, using long and short-distance lures may help attract cats to the body grip trap area.

5.4 Reassess

This report assessed the short-term efficacy of three types of lethal traps at HALE. A long-term analysis should be done to reevaluate the effectiveness of these traps (Kaholoaa et al. 2019). The addition of more lethal traps in various locations, a more extended trapping period, and increased capture data may increase captures.

Imperfections found in the trapping methods and designs can be addressed through evaluations, and staff can use the derived information to make future improvements. From this report, modifications can be made to increase lethal trap efficacy. Reassessing can determine if modifications improved trap efficacy, and changes can be made if necessary.

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LITERATURE CITED

Automatic Trap Company. 2020. How the A24 Automatic Rat & Mouse Trap Works. Automatic Trap Company INC, Sonoma. Available from https://www.automatictrap.com/ (accessed June 2020).

Bailey T, Natividad C, Plana G. 2002. New Methods and Insights for Controlling Feral Cats (*Felis catus*) in Endangered Bird Habitat. Haleakalā National Park. Poster Presentation for Hawaiʻi Conservation Conference. Honolulu, Hawaiʻi.

Coad H, McDaniel S, Misajon K, Forbes-Perry C. 2017. Post-implementation assessment of novel rodent control devices for protection of high elevation endangered species at Hawai`i Volcanoes National Park. HCSU technical report #196. Pacific Cooperative Studies Unit, University of Hawai`i, Honolulu, Hawai`i.

Expand-A-Pan. 2015. Bodygrip 220. Expand-A-Pan, Grenada. Available from https://www.expandapantraps.com/products/copy-of-mb-650 (accessed March 9, 2021)

Fish and Wildlife Service. 2020. ECOS Environmental Conservation Online System. United States Fish and Wildlife Services, Washington. Available from https://ecos.fws.gov/ecp/report/species-listings-by-state?stateAbbrev=HI&stateName=Hawaii&statusCategory=Listed (accessed August 26, 2020)

Franklin K. 2013. Informational report on the use of Goodnature® A24 rat traps in Hawaiʻi. Pacific Cooperative Studies Unit. Research Corp. of the University of Hawaiʻi, Oʻahu Army Natural Resources Program, Wahiawā, Hawaiʻi.

Goodale K, Natividad Bailey C, Kaholoaa R, Tamayose J, Orwig S. 2014. Capture Rates Using a Variety of Traps, Baits and Lures. Haleakalā National Park. Poster Presentation for the Hawaiʻi Conservation Conference. Honolulu, Hawaiʻi.

Haleakalā National Park. 2020. Unpublished Haleakalā National Park Databases. Predator Control, Nēnē Monitoring, ʻUaʻu Monitoring.

Haleakalā National Park. 2016. Management and Removal of Feral Animals in Upper Elevations of Nuʻu, Maui. Environmental Assessment. Available from https://www.nps.gov/hale/learn/management/upload/NPS_NuuEA_June2016_FinalForPubli cComment-4-2.pdf

Haleakalā National Park. 2012. Information for Programmatic Section 7 Consultation Haleakalā National Park, Maui, Hawai'i. Biological Assessment Sent to USFWS. 171p.

Hayes W. S. T, Conant S. 2007. Biology and Impacts of Pacific Island Invasive Species. 1. A Worldwide Review of Effects of the Small Indian Mongoose, *Herpestes javanicus* (Carnivora: Herpestidae). Pacific Science **61** DOI: 10.1353/psc.2007.0006.

Jolley W, Hanson C. 2016. Haleakalā National Park Predator Control Review Method. Island Conservation. Unpubl. report to HALE. 82 pp.

Judge S. W, Camp R. J, Warren C. C, Berthold L. K, Mounce H, Hart P. J, Monello R. J. 2019. Pacific Island Landbird Monitoring Annual Report, Haleakalā National Park and East Maui Island, 2017. Technical report NPS/PACN/NRR-2019/1949. National Park Service, Fort Collins, Colorado.

Kaholoaa R. L, Natividad Bailey C, Kekiwi E. K, Purdy K. K, Judge S. W, Tamayose J. A, Schwarz C. J. 2019. Predator Control Management Plan: Haleakalā National Park. Natural Resource Report NPS/HALE/NRR—2019/2005. National Park Service, Fort Collins, Colorado.

Kannan R, James D. A. 2020. Common Myna (*Acridotheres tristis*), version 1.0. In Birds of the World (S. M. Billerman, Editor). Cornell Lab of Ornithology, Ithaca, New York. Available from https://doi.org/10.2173/bow.commyn.01

Kelsey E. C, Adams J, Czapanskiy M. F, Felis J. J, Yee J. L, Kaholoaa R. L, Natividad Bailey C. 2019. Trends in mammalian predator control trapping events intended to protect ground-nesting, endangered birds at Haleakalā National Park, Hawai'i: 2000-14. Open-File Report 2019-1122. U.S. Geological Survey, Sacramento, California.

Lin T. 2007. Acridotheres tristis. University of Michigan Museum of Zoology, Ann Arbor, Michigan. Available from https://animaldiversity.org/accounts/Acridotheres_tristis/#102dc40e29ec888331053af636c83ff5 (accessed February 3, 2021)

Lindsey G. D, Hess S. C, Campbell E. W, Sugihara R. T. 2009. Small mammals as predators and competitors. Pages 274–292 *in* T. Pratt, P. Banko, C. Atkinson, J. Jacobi, and B. Woodworth, editors. Conservation Biology of Hawaiian forest birds: implications for island avifauna. Yale University Press, New Haven, Connecticut.

Maui Land and Pineapple Company, INC. 2010. Pu'u Kukui Watershed Preserve Fiscal Years 2012-2018 Management Plan. Maui Land and Pineapple Company, Kahului, Hawai'i. Available from Puu-Kukui-LRMP.pdf (hawaii.gov) (accessed February 3, 2021)

National Park Service. 2020. NPSpecies Information on Species in National Parks. Available from https://irma.nps.gov/NPSpecies/ (accessed August 26, 2020)

Natividad Hodges C. S. 1994. Effects of introduced predators on the survival and fledging success of the endangered Hawaiian Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*). Thesis. University of Washington, Seattle, Washington.

Natividad Hodges C. S, Nagata Sr. R. J. 2001. Effects of predator control on the survival and breeding success of the endangered Hawaiian dark-rumped petrel. Studies in Avian Biology DOI: 10.2307/1366887.

Nellis D. W. 1989. *Herpestes auropunctatus*. Mammalian Species 342:1–6. https://doi.org/10.2307/3504091

New Zealand Department of Conservation. 2019. Animal Welfare for Traps. Department of Conservation, Wellington. Available from https://www.doc.govt.nz/nature/pests-and-threats/predator-free-2050/toolkit-predator-free-2050/trapping-and-poisoning/animal-welfare-for-traps/

New Zealand Department of Conservation. n.d. Predator Traps Doc series trapping systems. CMI Springs LTD, Auckland. Available from DOC 250 predator traps (accessed February 24, 2021)

New Zealand Department of Conservation. 2020. Chose traps and toxins. Department of Conservation, Wellington. Available from https://www.doc.govt.nz/nature/pests-and-threats/predator-free-2050/toolkit-predator-free-2050/trapping-and-poisoning/choose-traps-and-toxins/ (accessed August 24, 2020)

NZ AutoTraps Products and Services. 2020. NZ Autotraps, Hamilton. Available from https://nzautotraps.com/ (accessed August 13, 2020)

Peters D, Wilson L, Mosher S, Rohrer J, Hanley J, Nadig A, Silbernagle M, Nishimoto M, Jeffrey J. 2011. Small Indian mongoose – management and eradication using DOC 250 kill traps, first lessons from Hawaii. Pages 225-227 *in* Veitch, C. R., Clout, M. N. and Towns, D. R. (eds.). Island invasives: eradication and management. IUCN, Gland, Switzerland.

Pias K. E, Dutcher A, Taylor G. 2017. Hono O Nā Pali Seabird Mitigation Project 2016 Annual Report. State of Hawaiʻi Natural Area Reserve System. Division of Forestry and Wildlife. Department of Land and Natural Resources, Lihue, Kauaʻi.

Pierce B. L, Lopez R. R, Silvy N. J. 2012. Estimating animal abundance. Pages 284-310 in N. J. Silvy, editor. The Wildlife Techniques Manual, Research, 7th edition. The John Hopkins University Press, Baltimore, Maryland.

Shiels A. B. 2010. Ecology and impacts of introduced rodents (Rattus spp. and Mus musculus) in the Hawaiian Islands. Ph. D. Dissertation. University of Hawaiʻi, Honolulu, Hawaiʻi. 218 p.

Skalski J. R, Robson D. S. 1992. Techniques for wildlife investigations, design and analysis of capture data. Academic Press, Inc. San Diego, California.

TetraTech. 2017. Auwahi Wind Farm Habitat Conservation Plan FY 2017 Annual Report. Department of Land and Natural Resources, Honolulu, Hawai‘i.

APPENDICES

Appendix A: Site Descriptions

Lowland

<u>‘Ohe‘o</u>

‘Ohe‘o is located on the east side of Maui in the Kīpahulu District of HALE. This area includes a campground, visitor center, and an employee baseyard. The area was utilized to test lethal traps because of the high density of predators and the lack of endangered ground-nesting birds that could be accidentally captured, making it a low-risk trapping area. All traps were set and paired with a camera trap at approximately 200 ft (61 m) elevation.

<u>Kanahā Pond State Wildlife Sanctuary</u>

Three Goodnature traps were set at Kanahā Pond on March 9, 2017, near sea level. Because nēnē and other native Hawaiian birds are present in the area, traps were outfitted with “weka excluders,” a heavy-duty metal coil at the base of the trap, to prevent birds from entering the trap. Each trap was set and paired with a camera trap. Traps were removed after 48 days on April 26, 2017.

Mid-elevation

<u>Skyline Eco-Adventures at Pōhakuokalā Gulch</u>

Three Goodnature traps were set on May 18, 2017, at Skyline Eco-Adventures, located about eight miles below Haleakalā National Park at approximately 4,200 ft (1,280 m) elevation. Traps were set along the top of the southern edge of Pōhakuokalā Gulch. One was placed just inside the gulch, one was set along the road running parallel to the gulch, and the third was positioned in wattle trees between the road and the gulch. All traps were paired with camera traps. Traps and cameras were set for 88 days and removed on August 14, 2017.

<u>Hosmer Grove</u>

Traps were tested in the frontcountry of HALE near Hosmer Grove and along the park boundary fence at approximately 6,800 ft (2,073 m) elevation. The Hosmer area is typified by non-native forest surrounded by intact, native shrubland. Hosmer has long been considered a priority trapping area, as it is a hot spot for forest birds. The shrubland provides essential nesting and feeding habitat for the nēnē. From the 2018-2020 nēnē breeding seasons, seven nesting attempts were documented with one renest attempt. This trapline consisted of 14 cage traps and one foothold and now consists of 12 cage traps and one foothold. The one Goodnature, one DOC 250, and two body grip traps deployed during the trial phase remain operational in the field. Three DOC 250s were deployed in the Hosmer area following the trial phase.

Resources Management Baseyard

The Resources Management baseyard is located at approximately 6,785 ft (2,068 m) elevation. This area is developed with offices and buildings. There is open space between offices and a large mule pasture. The baseyard is surrounded by native shrubland, which provides a valuable resource for native and non-native wildlife. Nēnē are commonly seen in the baseyard and pasture, utilizing the surrounding area for feeding and nesting. From the 2018-2020 breeding seasons, nine nesting attempts were documented in this area. This trapline consisted of 25 cage traps and now consists of 18 cage traps surrounding the baseyard area. One Goodnature was deployed during the trial phase and remains operational in the field. After the trial phase, an additional Goodnature and two body grip traps were added to the Baseyard trapline.

Supply Trail

Supply Trail is a public trail used by staff and visitors that connects the road to Hosmer Grove with the Halemauʻu trail from 6,800 ft (2,073 m) to 7,780 ft (2,371 m) elevation. Most of the area is shrubland, and the trail crosses over a few small gulches. Shrubland is important for nēnē as it provides an essential feeding and nesting habitat. This area has long been a priority trapping area since the shrubland provides ample habitat for the nēnē. A trapline consisting of 28 cage traps and one foothold starts at 7,350 ft (2,240 m) elevation and runs down to Hosmer Grove's road. This provides a trapping effort to protect the nēnē from introduced mammalian predators. Once the lethal traps' trial phase was completed, one DOC 250 was incorporated into the trapline.

Headquarters

Park headquarters is at approximately 7,000 ft (2,135 m) elevation. The area is developed with the Headquarters Visitor Center, offices, buildings, parking, and housing units. There is regular employee and visitor traffic. The developed area is surrounded by subalpine shrubland and is commonly used by nēnē for nesting and foraging. From the 2018-2020 nēnē breeding seasons, four nesting attempts (nest or family) were seen in the area. A trapline consisting of 25 cage traps is set in the area. Trapping efforts in the area are carefully planned and placed to avoid unwanted visitor interactions. Two Goodnature traps were placed under the Headquarters Visitor Center and the Administration buildings.

Puʻu ʻŌʻili

Puʻu ʻŌʻili is a cinder hill at approximately 7,230 ft (2,204 m) elevation, about 1,000 ft (330 m) southwest of the Headquarters Visitor Center. This location is within the subalpine shrubland and is a vital nesting resource for the nēnē. Predator surveys revealed feral cat signs on the slopes of this puʻu, making it a priority trapping area. The trap cluster consists of five cage traps and two footholds. After the trial phase concluded, one Goodnature and two body grip traps were added to this trapping cluster.

Road

Traps have been placed at different locations along the side of the road that runs through the park. The road mostly goes through shrubland until higher elevations. Trapping efforts are planned and placed to avoid unwanted visitor interactions. This trapline consisted of 16 cage traps and seven footholds and now consists of nine cage traps and four footholds from approximately 6,870 ft (2,094 m) to 8,410 ft (2,563 m) elevation and is monitored using a vehicle. Some trap locations checked with this trapline in the past have since been added to the traplines in the same vicinity. Once the trial phase was completed, one Goodnature trap was incorporated into the trapline at the Halemauʻu location.

Eucalyptus Gulch

This area is located at approximately 8,500 ft (2590 m) elevation, about 1.3 mi (2.1 km) south of the Headquarters Visitor Center. This area is in the transitional zone between subalpine shrubland and sparsely vegetated cinder desert. Non-native eucalyptus trees are common within the gulches. Nēnē are not common in the area, but nests have been found in the surrounding regions, and roosting signs are sometimes seen. Approximately 1,600 ft (488 m) NNE of Eucalyptus Gulch is a recently discovered nesting area for ʻuaʻu, where feral cat signs have been observed during predator surveys. Trapping has occurred in this area since at least 2003, and it is considered a feral cat hotspot. The trap cluster in this area consists of five cage traps and one foothold. Once the trial phase concluded, one Goodnature trap was incorporated into this trap cluster.

Palikū

Palikū is located on the east side of Haleakalā Crater near Kaupō Gap at approximately 6,380 ft (1,945 m). The area is remote and accessible via two trails, 10 and 12 miles (16 and 19 km). The site is one of the crater's wettest places and transitions from shrubland to the rainforest with Kīpahulu Valley to the east. There are a visitor cabin, campground, and ranger cabin for park employee use. This area is a habitat for nēnē, ʻuaʻu, and Hawaiian forest birds. Palikū is the original reintroduction site for the nēnē on the island of Maui, and the majority of the Haleakalā nēnē population is in this area. The Palikū trapline originally consisted of 39 cage traps. During the trial phase, Goodnature traps, DOC 250, and body grip chimney boxes were tested at Palikū. Two Goodnature traps and three DOC 250 traps remain. Four traps were later added to the two body grip chimney boxes (two traps each) and deployed in the area. Since the trial phase's conclusion, six more DOC 250s and two Goodnature traps have been added to the trapline.

Nā Mana o Ke Akua

Nā Mana o Ke Akua is located at approximately 7,400 ft (2,255 m) elevation in the central area of Haleakalā Crater. The site is remote and accessible by trail approximately 6 miles (9.6 km) from Keoneheʻeheʻe Trailhead. ʻUaʻu and nēnē nest in the area. An unmaintained trail runs through the area, connecting the Sliding Sands trail with the Halemauʻu trail. While most visitors do not utilize this trail, trapping efforts are still modified to avoid unwanted visitor interaction. The Nā Mana trapline originally consisted of 10 cage traps. Lethal traps have been added to supplement the Nā Mana trapline that now includes two DOC 250, two Goodnature, and two body grip traps. The Goodnature traps are paired with the DOC 250 traps to supplement each other, with the Goodnature traps targeting rats and the DOC 250 traps targeting mongooses.

Kapalaoa

Kapalaoa is located at 7,250 ft (2,210 m) elevation on the southern edge of the crater. The area is remote and accessible by trail, approximately 6 miles from Keonehe‘ehe‘e Trailhead (9.6 km). The site is bordered by cliffs, a known nesting area for ‘ua‘u. Nēnē frequent the lawn in front of the visitor cabin and nest in shrubs nearby. The habitat is primarily cinder desert with sparse vegetation. Kapalaoa features a visitor cabin that is used year-round. The flats surrounding the cabin are classified as alpine grasslands, featuring *Deschampsia nubigena*, a common feeding area for nēnē. This trapline initially consisted of 19 cage traps. Two DOC 250 and three Goodnature traps were added to supplement the trapline. The two DOC 250 and two Goodnature traps were paired together in an attempt for the Goodnatures to prevent bait theft from the DOC 250 traps.

High elevation

NVC ‘Ua‘u colony

NVC (North Visitor Center) is an ‘ua‘u colony within Haleakalā National Park, on and within the western slopes of Haleakalā crater at approximately 9,700 ft (2,957 m). The colony is found on steep cliffs and has extensive rock features surrounded by cinders. NVC has 157 known burrows monitored throughout the ‘ua‘u nesting season. This colony was used to understand potential interactions between the ‘ua‘u and DOC 250 traps. One DOC 250 trap in a box was placed in the colony but not set. The trap was removed after 80 days. This area is accessible via the park road.

KW ‘Ua‘u Colony

KW (Kalahaku West) is an ‘ua‘u colony within Haleakalā National Park on the western slopes of Haleakalā crater at approximately 9,325 ft (2,842 m) elevation. This colony is outside the crater rim and is divided into four distinct sections by the park road. Ninety-one known burrows within the colony are monitored throughout the ‘ua‘u nesting season. This colony was used as a test site for setting body grip traps outside the exclusionary box. Two body grip traps were set at two different burrows during the offseason of ‘ua‘u nesting and were removed before the nesting season. This area is accessible via the park road.

Rim

Rim is the area just along the northern crater rim, from the intersection with the Halemau‘u Trail, to the Haleakalā Visitor Center, from approximately 8,000 to 9,740 ft (2,438 to 2,970 m). This area spans subalpine shrubland to the cinder desert at higher elevations. This is one of the primary ‘ua‘u nesting areas with nests along both sides of the crater rim and potential nēnē habitat on the northern slopes. This trapline initially consisted of 35 cage traps and one foothold.

It has been modified and includes 14 DOC 250, 15 Goodnature, and three foothold traps. The 15 Goodnature traps were deployed during this writing, so they were not included in the efficacy analysis.

HVC

Haleakalā Visitor Center (HVC) is located at approximately 9,740 ft (2,970m) elevation on the crater rim's western edge. This is a popular area for viewing Haleakalā Crater and has a parking area, restrooms, and a visitor center. Visitor traffic increases in this area during sunrise and sunset since Haleakalā is the main attraction for these activities. This developed area is in the middle of a cinder desert with Pā Ka'oao hill (cinder cone), hiking trails, a park road, the Haleakalā summit, and a boundary/feral animal control fence nearby. Endangered 'ua'u use this area during the nesting season. Since this area has high visitor traffic, traps are strategically placed to avoid unwanted interactions. One Goodnature trap was added to the trap cluster consisting of four cage traps along the fence on the west side of HVC.

Appendix B: Catch per Unit Effort Data

Captures

Trap Type	Rodents	Mongooses	Cats	Other	Total Captures
GOODNATURE	432	1	0	-	433
DOC 250	136	23	0	-	159
CAGE	544	72	5	8	629
BODY GRIP	0	1	0	-	1
FOOTHOLD	1	1	1	-	3

Trap availability during study

Trap Type	Days Serviced	Days Serviced - Captures	Average Days Trap Open	Standard Deviation	Trap days
GOODNATURE	12094	12094	*	*	12094
DOC 250	906	746	7.72	5.8	5760
CAGE	5426	5425	5.75	2.5	29878
BODY GRIP	5822	5193	*	*	5425
FOOTHOLD	19690	19687	*	*	19687

*Asterisks represent traps open and available for the entire duration of the study

Goodnature Trap files from HALE database 3/8/17 – 2/29/20

Year	Files
2017	Palikū, Hosmer, RM Baseyard[3], ‘Ohe‘o, Kanahā, Pōhakuokalā
2018	Palikū, Hosmer, RM Baseyard[3], Eucalyptus Gulch[1], Pu‘u ‘Ōili[3], HVC[4]
2019-2020	Palikū, Hosmer, RM Baseyard[3], Eucalyptus Gulch[1], Pu‘u ‘Ōili[3], HVC[4], Road[1], Nā Mana[2], Kapalaoa[2], Headquarters[3]

DOC 250 Trap files from HALE database 3/8/17 - 2/29/20

Year	Files
2017	Palikū, Hosmer
2018	Hosmer, Palikū, Supply[3]
2019-2020	Hosmer, Palikū, Supply[3], Rim, Kapalaoa[2], NaMana[2]

Body grip Trap files from HALE database 3/8/17 – 2/29-20

Year	Files
2017	‘Ohe‘o, Kalahaku West[4]
2018	Palikū, Hosmer, Pu‘u ‘Ōili[3]
2019-2020	Palikū, Hosmer, Pu‘u ‘Ōili[3], RM Baseyard[3], Nā Mana[2]

Cage Trap files by location from HALE database 3/8/17 – 2/29/20

Year	Files
2017	H[3], Palikū
2018	H[3], Palikū
2019-2020	Hosmer, Palikū, Supply Trail[3], Kapalaoa[2], NaMana[2]

[1] Same as *Halemau'u* in Introduction figure 4

[2] Same as *C Central* in Introduction figure 4

[3] Same as *Hosmer* in Introduction figure 4

[4] Same as *Rim* in Introduction figure 4

Appendix C: Feral cat categories description chart (Bailey et al. 2002)

Type of Cat	Description
House Cat	Cats owned as pets in and around a particular residence
Stray Cat	House cats that stray from home but remain in residential areas
Released/Abandoned	Cats that are released or abandoned by people in residential areas
Wild Cat	Stray and released/abandoned cats that roam freely near residential areas and are becoming untamed
Wild Cat 1	Stray cats that have reached an untamed status and remain in residential areas as scavengers
	Eats food from people but flees when approached
Wild Cat 2	Released/abandoned cats that have reached an untamed status and remain in residential areas as scavengers
	Will not eat food from people but will come at night to scavenge
Wild Cat 3	Cats that were either born from Wild type 1 or 2 cats OR are wild type 1 or 2 becoming feral by moving to remote areas, hunting food
Feral Cat	Cats that have learned to hunt for survival in remote areas and build dens as homes. These cats show signs of not returning to residential areas
Feral Cat 1	Offspring of feral cats that are born in remote areas and are taught to hunt and den for survival
	Only caught with scents and attractants.
Feral Cat 2	Plus-generation born in remote areas. These are strictly hunters and will account for most of the predation in remote areas.
	Most recognized signs are multiple dens and trails of carcasses
	Not attracted to scents and attractants or footholds and cage traps. Mostly found near dens and waterways. Trapping only successful when den is found.