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Research Article

Bird and rat carcass persistence in a Hawaiian rainforest managed for rodents using Goodnature A24 self-resetting traps

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Abstract

Lethal trapping of island invasive rodents is a critical practice used by management organizations to protect native biota. Carcass detection from lethal trapping is dependent on the trapping method, carcass palatability, and scavengers present. Goodnature A24 self-resetting rat traps are an effective tool in remote areas and complex terrain because traps can be visited at 4–6 month intervals and produce multiple carcasses during that interval. The goal of this study was to determine whether we are a) underestimating target mortality with carcass counts and b) failing to detect non-target mortality between A24 trap checks at two field sites on the island of Kauai. Both sites have established Goodnature A24 trap grids with 300 A24s deployed by the Kauai Forest Bird Recovery Project (KFBRP), and one site is fenced to exclude invasive ungulates. KFBRP conducts routine trap checks every four months, finding 0–3 rat or mouse carcasses at each trap. We assumed that traps kill more animals than indicated by carcass counts because 75% of traps have counters to record when traps fire, and counter tallies usually exceed carcass counts. In 2018 and 2019, several bird carcasses were found under traps; therefore, we needed to investigate the likelihood that non-target mortality went undetected. In May 2019, we placed 60 carcasses (30 non-native birds and 30 rats) at a fenced site, and 60 carcasses (30 bird, 30 rat) at an unfenced site, in both gulches and uplands. Carcasses were periodically surveyed for 120 days after deployment. The unfenced site had greater removal rates, notably in gulches; 33 of 60 carcasses remained detectable, compared to 52 of 60 carcasses at the fenced site. Bird and rat carcasses did not differ in persistence, and taxon did not affect scavenger preference. These results suggest that significant non-target mortality has not gone undetected in our A24 trap grid because we are likely to detect most target and non-target carcasses after four months in fenced areas, and especially upland unfenced areas. However, we are less likely to detect carcasses in the unfenced gulches where ungulate scavengers are prevalent, and increased monitoring may be needed in such gulches.

Key words: scavenging, decay, carrion, Hawaiian Islands, invasive pest species, non-target mortality, rodent management

Introduction

Managing invasive rodents is a widespread goal to protect native and endangered species, especially on islands (Capizzi et al. 2014), and lethal trapping and toxicants are common tools used to control rodent populations in Hawaii (e.g., VanderWerf 2009; Banko et al. 2019). Introduced rats pose a direct threat to native birds in Hawaii because they depredate eggs, chicks, and incubating females (Tweed et al. 2006; VanderWerf 2009; Hammond et al. 2015). Trapping methods produce carcasses that remain on or around the trap, which is often the only indication of a successful trapping event (Gillies et al. 2014). However, environmental factors, such as local microclimate, weather, and scavenger communities, affect decay rate and detection probability of trap kills when a manager revisits a trap (Villegas-Patraca et al. 2012). The absence or lack of persistence of animal carcasses at trap checks is concerning because target kills may be underestimated, and non-target animals could be killed by a trap without detection by a manager.

Traditionally, single-set snap-traps have been used worldwide to control rodent pests in urban, agricultural, and natural areas, and when placed in grids, have been successfully used to suppress rat populations and protect natural resources in Hawaiian forests (Pender et al. 2013; Shiels et al. 2017). Automated self-resetting traps, such as Goodnature A24 rat+stoat traps (hereafter A24s or A24 traps), have gained in popularity over single-set traps in recent years for providing native species protection from rats (Shiels et al. 2019). A24s have proven successful in suppressing introduced rodent populations in natural areas of New Zealand (Carter et al. 2016) and Hawaii (Shiels et al. 2019). However, carcass persistence is a more challenging issue for A24s than snap traps because the former are checked far less frequently (e.g. every four months vs. weekly or bi-weekly). A24s are installed on trees or stakes, so carcasses fall freely from an A24 after it has been triggered. This configuration allows the carcass to roll away from the trap, enabling scavengers to easily remove the whole carcass. Without carcass persistence, little evidence remains that an A24 has been fired unless outfitted with a counter or monitored with a camera. In contrast, a snap-trap holds a carcass and often retains identifiable body parts even when scavenging occurs.

On Kauai Island of Hawaii, which has eight remaining endemic forest bird species, A24 trap grids were deployed at two remote sites in the Alakai Wilderness Preserve where high densities of forest birds remain (Figure 1). The traps were installed on trees across the varied topography of the preserve, including on parts of the Alakai Plateau, in deep-sided gulches that drain it, and on the ridgelines that border the gulches (Figure 2). The number of carcasses physically counted below the trap during service checks often did not match the number tallied by the counter, leading observers to assume scavenging, decay, or counter malfunction occured (Crampton and Pias 2014; Crampton and Hite 2016). Many factors in the environment may affect the duration of a small animal carcass, including the scavenging community, seasonality, biome, and the type of carcass and coverings (e.g.,

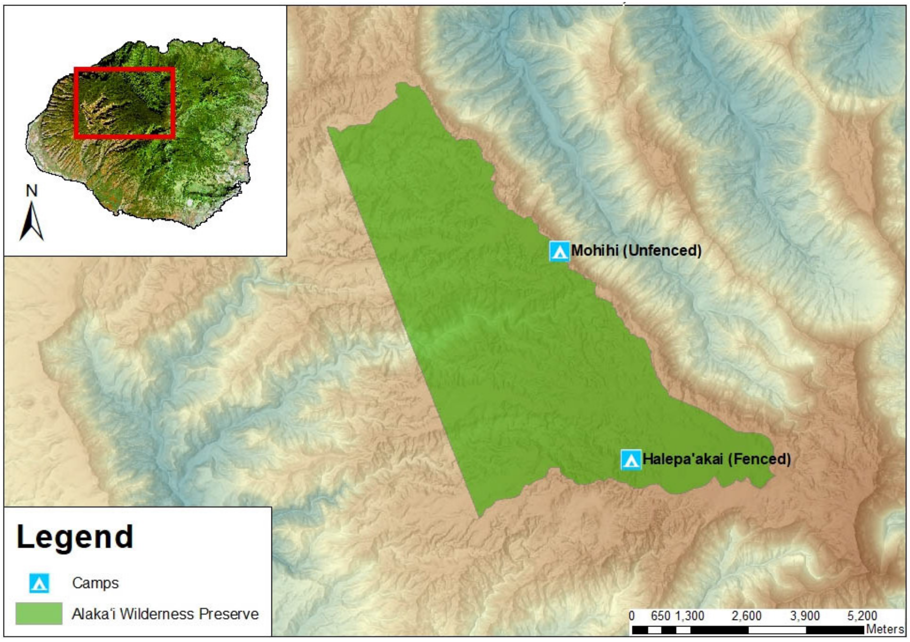

Figure 1. Alakai Wilderness Preserve on the island of Kauai, Hawaii, and locations of fenced and unfenced field sites. Created by Roy Gilb.

feathers or fur) (Abernethy et al.2016). The local environment of gulch or upland could support different scavenging communities and affect carcass persistence.

In late 2018 and early 2019, several bird carcasses were found under A24s with evidence of trauma from the trap (KFBRP *unpubl. data*). A previous study, Kreuser et al. (2020), was conducted with bird carcasses over a 130-day period to determine the likelihood of finding non-target kills within our A24 trap grid at a fenced site which excluded pigs (*Sus scrofa* L., 1758) and goats (*Capra aegagrus hircus* L., 1758). Kreuser et al. (2020) discovered there was a high likelihood of finding a bird carcass after four months of being placed in a rainforest managed for rodents and ungulates.

To our knowledge, there has been no long-term study of rat and bird carcass detectability in a Hawaiian rainforest, and our goal was to inform whether we are a) underestimating target mortality with carcass counts and b) failing to detect non-target mortality within our A24 grids when checked at four month intervals. Therefore, we sought to determine the factors affecting carcass persistence and detectability of rat and bird remains (including bones, fur, or feathers). Our objectives were to: 1) determine if clear evidence of rat and bird carcasses persists at four months (i.e. when A24 traps are serviced), as a function of taxon, site, and the local environments of gulch or upland; 2) compare patterns of decay between taxa and local environments; 3) determine the species of scavengers in fenced and unfenced areas and their effect on carcass persistence. Based on these objectives, we had four a priori expectations. First, we expected that some evidence (e.g., fur or feathers) of each carcass would persist for four months in ungulate-free (fenced) forest, but that carcasses would rarely persist for four months in an unfenced forest where ungulates were present. Second, we expected

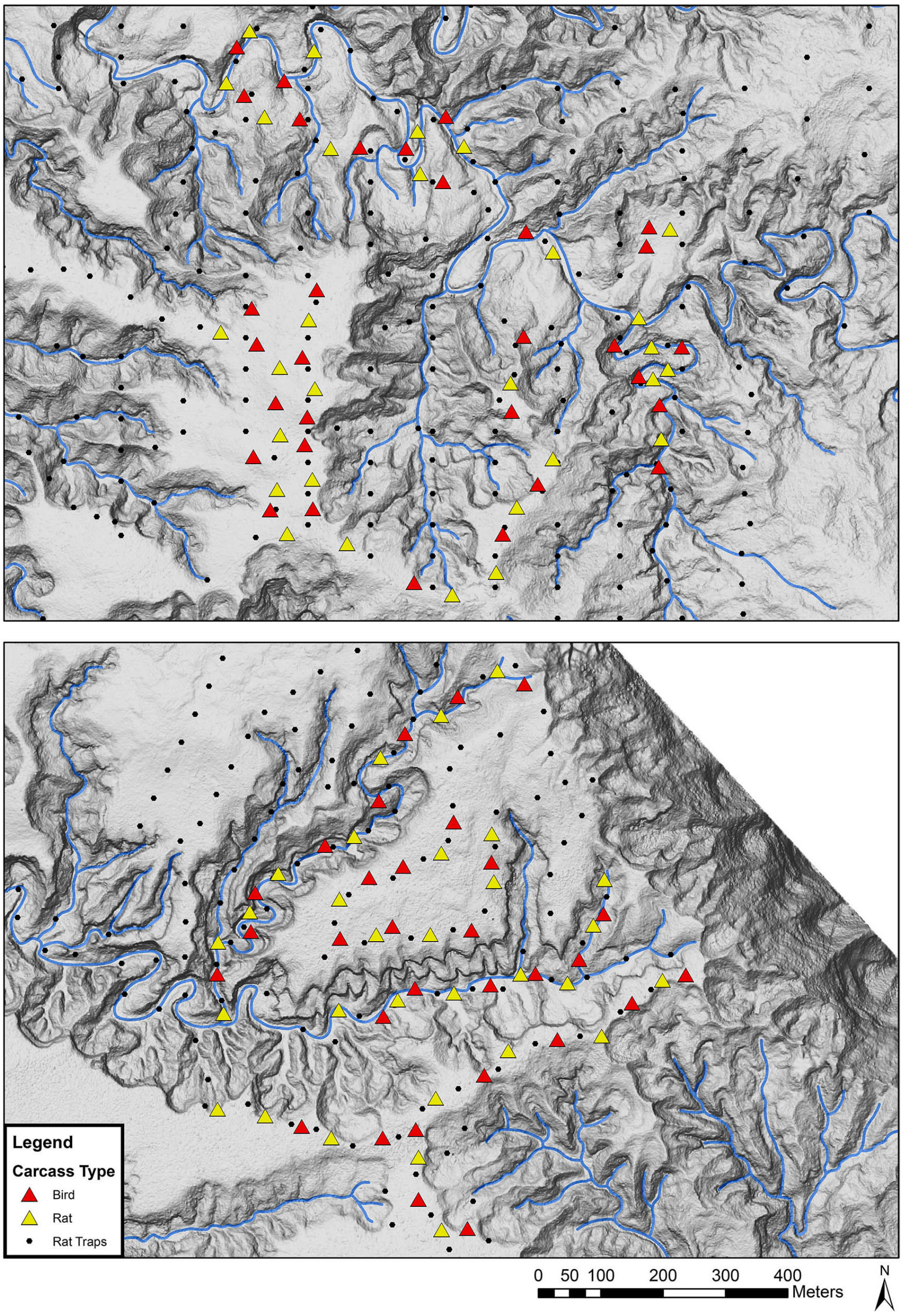

Figure 2. Locations of rat and bird carcasses distributed in the fenced site (above) and unfenced site (below) in the gulch and upland environments, Alakai Wilderness Preserve on the island of Kauai, Hawaii. The top right corner of the bottom figure displays the boundary of state and private land and the extent of our Digital Elevation Model layer. Created by Roy Gilb.

that decay would be quicker in rats than birds, because the properties of fur would allow a quicker breakdown than feathers. Third, we expected that rat carcasses would be scavenged more readily than bird carcasses given the anticipated low palatability of feathers and hence the persistence of rat carcasses would be lower. Finally, we expected that gulches where ephemeral streams are present would experience greater scavenging than the upland forest because of the greater habitat and vegetation diversity would favor a more active scavenger community.

Materials and methods

Study site

The study was conducted at two established sites managed for rodents by Kauai Forest Bird Recovery Project in the Alakai Wilderness Preserve on the island of Kauai, Hawaii (22°06′52″N; 159°33′56″W). Sites consist of wet montane forest dominated by *Metrosideros polymorpha* Gaudich (ohia lehua) trees. Elevation ranged from 1123 m to 1303 m (VanderWerf et al. 2014). Average annual rainfall is 4348 mm (Giambelluca et al. 2013). The Alakai Wilderness Preserve has mild seasonality—average temperatures range between 31.7 °C and 7.2 °C throughout the year (Kokee State Park, HI Monthly Weather Forecast). The two sites will be referred to as the "fenced" and "unfenced" sites. The fenced site is 5.45 km^2 enclosed by a 1.5 m tall metal fence with additional 1.2 m tall plastic netting on the majority of the fence (total height 2.7 m) to exclude goats and pigs. A short section of the fence does not have the additional 1.2 m netting, and it is possible for black-tailed deer (*Odocoileus hemionus columbianus* Richardson, 1829) to jump over the fence at that section. However, the fence is regularly monitored for breaches, and snares within the fenced area are checked regularly. The unfenced site is not protected from, or managed for, ungulates.

Both sites are managed for rodents with the use of automatic, self-resetting Goodnature A24 traps (Carter et al. 2016; Shiels et al. 2019). In 2015 at the fenced site, 150 A24 traps were installed over 0.7 km^2. At the unfenced site, 124 A24 traps were installed in October 2018 to control rodents over 0.65 km^2. Traps were spaced 50 m apart along each transect; transects were 100 m apart. "Upland" A24 traps were attached to trees throughout the plateau and along ridgelines, and "gulch" traps were attached to trees along the streams (Figure 2). Since their deployment, these traps have been regularly checked at four-month intervals where the observer assessed bait, serviced the trap, and counted carcasses. Goodnature "counters" were attached to 75% of the 274 A24 traps and recorded when traps fired; they only indicate that the trap fired, but not the date or nature of the kill.

Experimentally placed study species

We acquired 62 bird carcasses from USDA APHIS's Airport Wildlife Hazard Program at Lihue Airport, Kauai, which were comprised of 41 *Geopelia striata* L., 1776 (zebra dove) and 21 *Paroaria coronata* Miller, 1776 (red-crested cardinal). All birds were cage-trapped and euthanized with CO_2, and then frozen until deployment at our field sites. These species were selected because their size was the most similar to the identified birds killed by A24s. The numbers of zebra doves and red-crested cardinals varied due to availability of carcass supply from USDA APHIS's Airport Wildlife Hazard Program at the time of this study. In our previous study (Kreuser et al. 2020), zebra doves (n = 15) and red-crested cardinals (n = 15) were used, and no significant difference was found in decomposition or detectability by species or weight throughout a four month period. A total of 63 *Rattus rattus* L., 1758 (black rat) carcasses were received from USDA following their use in a rodent diet study. These rats had been euthanized by snap traps in dryland ecosystems on Maui and Hawaii islands and their stomachs removed for dietary assessments (Shiels et al. 2017). These rats were frozen until deployment at our field sites. Visible wounds or lesions on carcasses were noted upon deployment in the field. Carcass masses were (mean ± SD): red-crested cardinals (39.1 ± 2.97 g, range = 35–42 g, n = 16), zebra doves (52.3 ± 5.3 g, range = 44–65 g, n = 16) (see Kreuser et al. 2020) and black rats (104.7 ± 22.6 g, range = 63–141 g, n = 55).

In mid-May 2019, we deployed 30 bird (10 red-crested cardinal and 20 zebra doves) and 30 rat carcasses at each site and monitored the carcasses until mid-September 2019. The carcasses were placed in-between trap locations along transects, alternating between rat and bird, and they were evenly distributed in the two dominant environments (gulch vs. upland). Carcasses placed within the fenced site (n = 60) were an average (± SD) distance of 25.1 ± 11.1 m from the closest trap and 46.7 ± 11.8 m from another carcass. At the unfenced site, carcasses (n = 60) were placed an average distance of 26.9 ± 8.5 m from traps and 48.3 ± 13.4 m from another carcass. We conducted a pilot study at the fenced site six months prior (see Kreuser et al. 2020) and did not reuse any carcass locations for our study. Carcass locations were marked by a pin flag, also known as a marking flag, which is a 9 × 9 cm square of brightly colored plastic attached to the top of a thin, sturdy 60 cm long wire. Individual station numbers were written on the flags and placed next to each carcass to help locate the carcass on subsequent visits. A 25 cm plastic stake was used instead of a pin flag to mark those carcasses that were monitored by cameras, and their sturdy and small size reduced incidentally triggering the motion sensors on the camera (Figure 6).

Carcass presence and decay observations

We checked carcasses at days 15, 35, 75, 95, 120 in the fenced area, and 15, 30, 60, 120 days in the unfenced area. Dates of the checks varied between sites based on personnel and schedule availability while accomplishing other required fieldwork at these remote sites. Carcass checks at the beginning of the study were more frequent to observe the decay of soft tissue and to capture the expected heightened scavenging of carcasses while soft tissue remained present and appetizing to scavengers relative to carcasses at the end of the study when no soft tissue remained. These checks were within 2–3 m of the placement locations, which is comparable to the methods used by the staff servicing the A24 traps. At each visit we recorded data for “distinct detection”, “presence”, and “body condition”. Distinct detection was classified as detecting the carcass or evidence of the carcass within 10 seconds of searching, which is most representative of current A24 trap servicing methods. Presence was determined by thorough searching (> 30 seconds), including through the leaf litter, for the physical body or bones of the carcass. Body condition was scored on a 0–6 scale to assess the state of decay of the carcass (modified from Wilson et al. 2007) as follows: 6 – fresh and as originally placed, no wounds/lesions (only used during deployment); 5 – few lesions, and minimal decay; 4 – skin, tissue, or bone visible, and body more than 75% intact; 3 – majority of soft tissue remaining and more than 50% of body intact if scavenged; 2 – soft tissue or muscles still present with prominent bones, and feathers or fur still bound to skin or cartilage; 1 – only bones and feathers or fur remain, no soft tissue left; 0 – the carcass and bones are gone, but feathers or fur may remain.

Game cameras for identifying scavenger species

We installed 28 Reconyx Hyperfire™ PC800 cameras on a subset of the carcasses, seven on bird carcasses and seven on rat carcasses at each site for a total of 14 at each site. Cameras were stationed 1 m from the carcass to identify scavengers and monitored from May 14 to August 1, 2019. If a carcass was no longer present during a check, the camera was moved to the closest carcass of the same taxon. The cameras were set on motion detection, high sensitivity, five pictures per trigger, and rapid fire; they also were programmed to take one image each hour of the day for reference of carcass position. SD cards were replaced during each visit to the carcass and batteries were replaced as needed.

When reviewing camera images, events and interactions of scavengers with or near the carcass were recorded and methodology was based off those in Abernethy et al. (2016). In brief, all images were examined for vertebrate species, time and date of observation, and whether or not the vertebrate interacted with the carcass. We specified an event as a vertebrate pictured in the frame of view. A new event occurred when a new species entered the frame of view or the same species had been absent from the frame of view for at least five minutes. We specified an interaction as a vertebrate touching or showing interest in the carcass and was within ~ 5 cm of the carcass (e.g., sniffing). We also noted if a carcass was removed from the frame of view by the vertebrate.

Statistical analysis

To assess the presence and distinct detection of carcasses until 120 days, we performed Cox proportional hazards survival analysis stratified by site (fenced vs. unfenced) (Kleinbaum and Klein 2012) in R package survival. We used the fitted survival model to calculate predicted survival probability at time of survey dates. We used the predictor factors: environment (gulch vs. upland) and carcass taxa (bird vs. rat) (Kleinbaum and Klein 2012; Dalgaard 2008).

We used ordered logistic regression to analyze the body condition stages over the time after deployment and between sites, taxa, and local environments of the carcasses that were not wholly or mostly scavenged. A general linearized model with Poisson distribution was used to analyze the final body condition of carcasses at 120 days by taxa, site, and local environment.

For our game camera results, we used log-linear analysis to compare counts of carcass interactions among vertebrate scavengers by scavenger species. We included scavenger type (e.g., rat, pig) and carcass type (bird vs. rat) in our analysis of each site as a function of interactions with carcasses. Due to the different scavenger communities, each site was analyzed separately, so the abundance of pig interactions with carcasses did not overshadow the fenced site's scavenger interactions. Sample sizes were not equal or large enough for the local environment comparison (i.e. gulch vs. upland) within site, so environment was not included in the analysis of scavenger identity. Scavenging of the whole carcass was rare, unless scavenged by a pig, so we compared interactions with the carcass. Often animals were seen passing through the camera field of view but not interacting. Only confirmed scavenger interactions with a carcass were used in the analysis, otherwise results using events were skewed towards sites and cameras with passing visitors that showed no interest in the carcasses. Subsequent analyses were run with partial data sets that excluded stations where recording had not begun at day 1 (i.e. the stations receiving cameras after the original camera stations had carcasses fully scavenged). We used the first 15 days of camera data for one data set and the other data set contained interactions over the full 60-day monitoring period at the 14 original, camera-monitoring stations. No difference in results were found using the partial data sets; therefore, for reported results we used all scavenging data collected including the cameras moved to new stations after the originally set camera stations had their carcasses scavenged. We considered $p \leq 0.05$ as significant for all analyses; t values were found by using the TDist package in R with the function qt.

Results

Carcass detection

After 120 days, 88% of carcasses were distinctly detectable in the fenced site and 55% of the carcasses were distinctly detectable at the unfenced site. Across both sites, 85 of the 120 carcasses (71%) remained detectable. Taxa of carcass (rat vs. bird) did not affect carcass detectability ($p = 0.99$, $t = 7.09$, $df = 2$): 72% of bird carcasses and 71% of rat carcasses were detectable at 120 days. The interaction of site and local environment (gulch vs. upland) significantly affected the ability to detect a carcass ($p = 0.03$, $t = 2.95$, $df = 3$). This significant interaction was driven by the lower likelihood of detecting

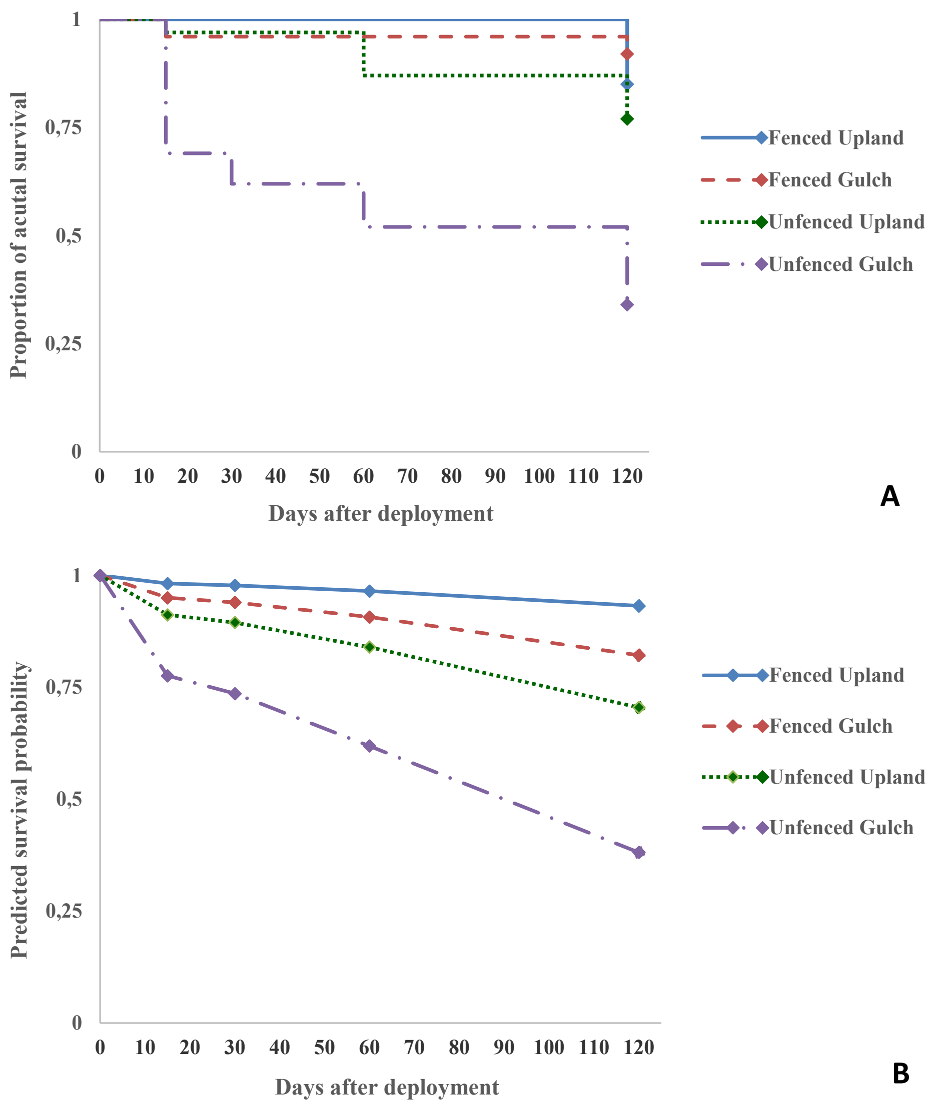

Figure 3. Proportional survival of the 120 rat+bird carcasses when analyzed for actual survival (A), and predicted survival (B), over 120 days for the two sites (fenced and unfenced) and two environments (upland and gulch) in the Alakai Wilderness Preserve on the island of Kauai, Hawaii. The final survival (± SE) at 120 days for actual (A) included: fenced upland = 0.84 ± 0.07, fenced gulch 0.92 ± 0.06, unfenced upland = 0.77 ± 0.10, unfenced gulch = 0.34 ± 0.26; and for predicted (B) included: fenced upland = 0.93 ± 0.02, fenced gulch 0.82 ± 0.06, unfenced upland = 0.71 ± 0.07, unfenced gulch = 0.38 ± 0.08.

a carcass in the gulches of the unfenced site (38%) than for other site-environment combinations, which did not significantly differ from each other (Figure 3). At the unfenced site, three carcasses were physically present, (remains found after thorough searching > 30 s), but they were not considered detectable by typical effort an observer would use while servicing a trap (i.e. < 30 s search time of 2–3 m radius). At the fenced site, five carcasses were marked present because remains were found through in-depth searching and were scored as not detectable (i.e. found after > 30 s of search time). Like detections, presence of carcasses was disproportionally affected by site; however, when stratified there was no significant interaction between site and environment ($p = 0.06$, $t = 2.60$, $df = 2$), or local environment alone on the presence of carcasses ($p = 0.16$, $t = 1.31$, $df = 2$).

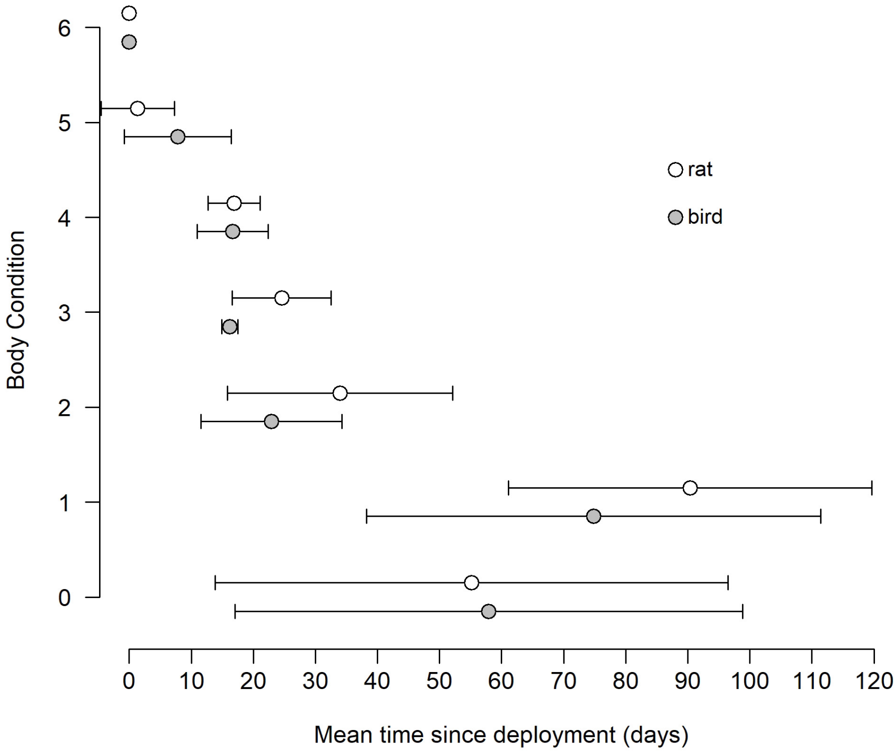

Figure 4. Mean days (± SD) after carcass deployment with corresponding carcass body conditions for rats and birds in Kauai rainforest. Body conditions were: 6 – fresh, just placed; 5 – few lesions, minimal decay; 4 – skin, tissue, or bone visible, ≥ 75% intact; 3 – majority of soft tissue remaining, ≥ 50% intact; 2 – skin or soft tissue still present, prominent bones; 1 – only bones and feathers/fur remain, no soft tissue; 0 – the carcass and bones are gone, but feathers or fur may remain. Body conditions of 0 were only included once for individual carcasses that were no longer present.

The pin flags and stakes used to mark carcass locations experienced similar levels of whole carcass scavenging at the unfenced site. At 15 days, 29% of carcasses marked with plastic stakes and monitoring cameras (n = 14) were scavenged, whereas 24% of carcasses (n = 46) marked with pin flags and no monitoring cameras present had been scavenged. Of the 15 scavenged within the first 15 days, 26% had plastic stake markers and 79% pin flags markers, which is similar to the proportion of stakes to pin flags, 23% and 77% respectively.

Carcass decay

Average body condition for rat and bird carcasses decreased rapidly through the first 30 days after deployment (Figure 4). Bird carcasses scored a mean (± SD) body condition of 5.95 ± 0.21 at deployment, whereas rat carcasses had a mean body condition of 5.22 ± 0.41. This initial ranking at deployment did not significantly affect detectability of carcasses (p = 0.95, t = 1.62, df = 117). At 30 days in the unfenced site 45% of carcasses remaining were classified as a body condition of 1, having no soft tissue and only bones and feathers remaining. In the fenced site, 56% were a body condition of 1 at 35 days (Figure 5). Soft tissue was present on 13% of the remaining carcasses at the unfenced check at 60 days, and on 10% of the

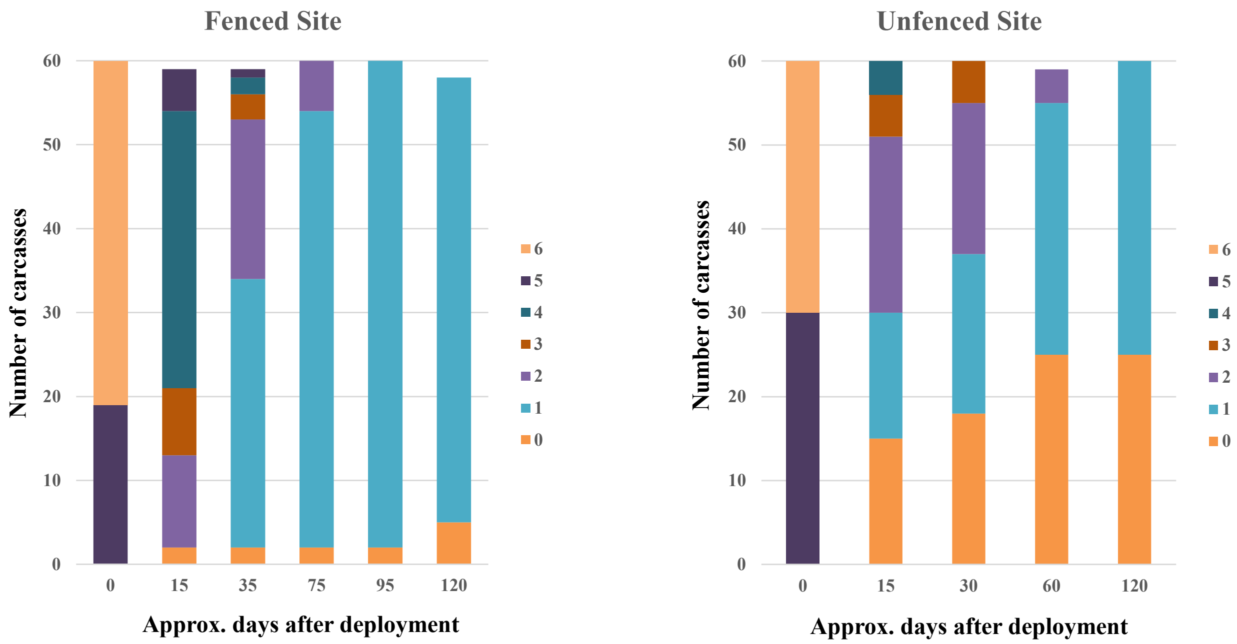

Figure 5. Body conditions of carcasses (rat+bird) at the unfenced and fenced site over the survey period. Occasionally, due to miscommunication, a small number of carcasses were not visited at their intended interval; thus, not all columns add up to 60 carcasses. Body conditions were: 6 – fresh, just placed; 5 – few lesions, minimal decay; 4 – skin, tissue, or bone visible, ≥ 75% intact; 3 – majority of soft tissue remaining, ≥ 50% intact; 2 – skin or soft tissue still present, prominent bones; 1 – only bones and feathers/fur remain, no soft tissue; 0 – the carcass and bones are gone, but feathers or fur may remain.

remaining carcasses at the fenced site at 75 days. The fenced site had an additional check at 95 days that the unfenced site did not have, but the 95-day check did not notably vary from the 75-day check. By 95 days in the fenced site, no soft tissue remained, and all remaining carcasses were scored as a 1, and the number of carcasses that were scored as a body condition of 0 did not increase from the 75-day check.

The body condition stages were affected by the number of days after deployment ($p < 0.001$, $t = 13.22$). Neither the environment ($p = 0.79$, $t = 0.27$) nor the taxon ($p = 0.27$, $t = 1.11$) had a significant effect on the body condition stages. There were no significant effects on the final body condition of carcasses at 120 days by taxa ($p = .92$, $t = 1.40$, $df = 115$), site ($p = 0.23$, $t = 0.75$, $df = 115$), or local environment ($p = 0.25$, $t = 0.66$, $df = 115$). Initial body condition was not included because it was correlated with taxa ($p = 0.001$, $t = 3.16$, $df = 117$).

Transition ratios are the proportions of carcasses that move to new stages, relative to the proportion of carcasses that remain in the same stage in subsequent checks over the 120 days. Body conditions of 5 and 6 have the highest ratios of transitioning to 0. For the body conditions of 4, 3, and 2, ≥ 50% of carcasses transitioned to a 1 in the following check (Table 1).

Game cameras and scavenger identity

There were five types of scavengers seen on camera (scored as "events")—rodents, pigs, birds, cats, and deer—and all interacted with carcasses except

Table 1. Transition ratios of all carcass checks from both sites within and between body condition stages over 120 days. Transition ratio is the proportion of carcasses that move to a new stage, relative to the proportion of carcasses that remain in the same stage in a subsequent check.

Body condition to	Body condition from 6	5	4	3	2	1	0
6							
5	0.04	0.05					
4	0.29	0.33	0.03				
3	0.09	0.13	0.13	0.10	0.01[a]		
2	0.24	0.31	0.34	0.33	0.32		
1	0.19	0.07	0.50	0.52	0.62	0.95	0.05[a]
0	0.16	0.11		0.05	0.05	0.05	0.95

[a] Occasionally a carcass would be scored at a higher body condition than the carcass was scored during the previous check, so body condition increased between checks due to observer discrepancy.

Table 2. Scavenger presence or interaction as recorded by trail cameras on rat (n = 15) or bird (n = 17) carcasses at the fenced and unfenced sites, Kauai rainforest, Hawaii. Relative abundance was determined by the number of events per scavenger category within a site divided by the total number of scavenger events at that site. A carcass interaction was defined as an animal showing interest by touching, or its head coming within 5 cm, of the carcass.

	Scavenger	Events	Interactions with bird carcasses	Interactions with rat carcasses	Total Interactions	Interaction Rate	Relative Abundance
Fenced Site							
	Rodent	148	29	3	35	0.24	0.72
	Bird	47	5	3	8	0.17	0.23
	Cat	11	0	0	0	0	0.05
	Total	206	34	6	43	0.21	
Unfenced Site							
	Rodent	87	6	8	14	0.16	0.52
	Pig	34	9	7	16	0.47	0.20
	Bird	17	0	3	3	0.18	0.10
	Cat	7	2	0	2	0.29	0.04
	Deer	21	0	0	0	0	0.13
	Total	166	17	18	35	0.21	

the deer (Table 2). Rodents were the most abundant scavengers seen on camera at both sites. The rodent events were primarily rats; only five recorded events were mice (*Mus musculus* L., 1758), and no mice interacted with the carcasses on camera. Rodents were the most interactive scavenger with carcasses (rats + birds) at the fenced site, and pigs were the most interactive scavenger with carcasses at the unfenced site. Although cats were observed and scored as events at both sites, cats only interacted with carcasses at the unfenced site. Pigs fully scavenged five carcasses on camera, three birds and two rats. No carcasses were fully taken by rats, birds, cats, or deer on camera (Figure 6). The latest day a pig was observed removing a carcass on camera was 43 days after deployment. The other four interactions of a pig consuming a whole carcass were 2, 5, 8, and 11 days after the carcasses were deployed. At the fenced site two carcasses, both birds, were not present at the 15-day check. Evidence (few feathers) suggested that these two carcasses were scavenged by rats or possibly cats.

Log-linear analysis revealed at the unfenced site there were no significant effects of carcass taxa (rats vs. birds) on the number of carcass interactions by each of the vertebrate scavengers ($p > 0.05$ for each comparison). Majority

Figure 6. Scavengers of Kauai rainforest, Hawaii, interacting with carcasses, including (A) a feral cat sniffing a bird carcass, (B) the endangered puaiohi (*Myadestes palmeri* Rothschild, 1893) bird possibly scavenging grubs from a rat carcass (C) a feral pig wholly consuming a bird carcass, and (D) maggots emerging from a rat carcass. Photographs taken by Reconyx Hyperfire game cameras.

of ungulate events (85%) were recorded in the gulch environment. At the fenced site, rodent scavengers significantly interacted with carcasses more than other scavengers (i.e. cat and birds) ($p = 0.02$, $t = 8.50$, $df = 3$), and the bird carcasses had significantly more interactions from scavengers ($p = 0.002$, $t = 3.70$, $df = 3$). However, 50% of rodent events (n = 74) at the fenced site occurred at one bird carcass with a monitoring camera, which captured 66% of the rodent interactions with a bird carcass (n = 19).

Discussion

The aim of our study was to determine the detectability of rat and bird carcass remains after four months in a Hawaiian rainforest managed for rodents with A24s and fenced to exclude ungulates at one of our two sites. We found clear evidence that the majority of rat and bird carcasses persisted in our sites so that managers would be likely to detect carcasses near A24s with the current four month trap servicing interval. In comparison to other rodent and bird carcass persistence studies, our findings are unusual. Typically, the majority of carcasses are scavenged by vertebrates within five days (Balcomb 1986; Flint et al. 2010; Abernethy et al. 2016) or two weeks (Tobin and Dolbeer 1990; DeVault and Rhodes 2002). We found taxon (rat vs. bird) did not have an effect on carcass decay processes and persistence, and the taxa were recognizable through the remains, bones, feathers, or fur until 120 days.

We found our sites differed in carcass persistence, and fewer carcasses at the fenced site (12%) were removed by scavengers or became undetectable. In the unfenced forest, detectability was lower, and the carcass removal rates were relatively high (43%). Within these sites, similar to DeVault et al. (2004), we found that the composition of the vertebrate scavenging community in local environments, gulch versus upland, affected the rates of carcass persistence. Pigs were the main culprit for carcass removal in the unfenced environment and were more frequent scavengers in gulch habitat. Also, gulches often have both greater resources and invasive rat abundance (Shiels 2017), which suggest gulches are locations where target and nontarget kills by A24 traps may have a greater incidence of going unnoticed than upland forest sites. These findings have important implications for rodent control using A24 traps that have service intervals of up to four months, which covers most situations in Hawaii (e.g., Shiels et al. 2019). Both target (rat) and non-target (bird) mortalities from the traps are more likely to go undetected in unfenced, pig-inhabited forests, and most are likely to be detected in pig-free fenced forests.

In Hawaii, many critical habitats with native and endangered species are enclosed with fencing to prevent ungulate damage or native species predation (Pejchar et al. 2020), but other locations, including one site used in our study, remain unfenced. At our unfenced site, if checked within 30 days, 13% of carcasses were detected even when wholly or partially scavenged, which later led to them being undetectable at 120 days. The ability to detect clear evidence of a carcass increases when less time has passed since placement, as found previously in Kreuser et al. (2020), especially in areas where scavengers are prevalent (Balcomb 1986; Tobin and Dolbeer 1990). However, if an area is not frequented by scavengers, reduced time between checks only slightly helps ensure carcass detection. Therefore, trap check intervals should occur as needed for specific sites and program objectives. If finding or recovering most carcasses is an important objective, thorough searching of the forest floor also increases carcass detection.

There was no difference between taxa or local environments having an effect on the decay process. On both taxa, soft tissue remained for an extensive amount of time in our study. Soft tissue remained on 40% of carcasses at 30 and 35 days and on 17% of carcasses at 60 and 75 days. Although the rodents' stomachs had been removed prior to placing the carcasses in the field, we do not believe this had an effect on the decay process between taxa because both rats and birds were frozen before deployment. Šuláková et al. (2014) found pre-frozen carcasses begin decay from the outside in, while fresh carcasses begin decomposition within the digestive system moving outwards through putrefaction. The lengthy retention of soft tissue also could be attributed to the climate conditions or makeup of the invertebrate scavenger community (Richards and Goff 1997; Pechal et al. 2014). Cooler temperatures related to higher elevation generally slow arthropod colonization of carcasses, which further extends the decay process (Richards and Goff 1997; Pechal et al. 2014), and a slower decay process allows carcasses to remain enticing to scavengers (DeVault et al. 2004). In lower elevation and warmer sites on other Hawaiian Islands, soft tissue is devoured rapidly by arthropods compared to higher elevation rainforests (Richards and Goff 1997; Abernethy et al. 2016). Our study did not analyze arthropod scavenging, but we did note if arthropods were visible. The most frequently observed arthropods were maggots, flies, and millipedes. Maggots consumed the most carcass biomass of the invertebrates in a Hawaiian rainforest (Richards and Goff 1997) and consumed 80% of mice soft tissues in temperate woodlands (Putman 1978). Some of the arthropods that colonize rat and bird carcasses also may be an attractive food source to visiting vertebrate scavengers.

Vertebrate scavenging had a large effect on detectability of carcasses. In agreement with other studies of small bird and mammal carcass persistence, scavenging was most frequent in the first two weeks (Tobin and Dolbeer 1990; DeVault et al. 2004; Villegas-Patraca et al. 2012). Most full removal of carcasses happened in the first 15 days, indicated by the number of carcasses that were scored as a body condition of 0 during the first check (two instances at the fenced site and 15 at the unfenced site). Four of the five full scavenging events caught on camera were before the 15-day check. Similar to the findings of our study, scavengers do not seem to have a preference between small bird and small mammal carcasses (Villegas-Patraca et al. 2012), but rather have preference for particular environments where they are actively scavenging (DeVault et al. 2004). In our study, the gulch habitat at the unfenced site had higher sightings of ungulates on cameras than the upland habitat, and pigs were observed interacting with carcasses 47% of the time captured on camera.

Our sites within the Alakai Wilderness Preserve have a unique scavenging community of pigs, cats, rats, and passerine birds, and in contrast to most of the other Hawaiian Islands, there are no mongoose (*Herpestes auropunctatus* Hodgson, 1936). Differences in the scavenging community has led to differences in carcass persistence in other Hawaiian rainforests with similar climate and weather. On the island of Hawaii, mongoose and rats were the dominant scavengers in the rainforest environment; rodents removed 35 whole carcasses and mongoose removed 40 carcasses within five days of placement (Abernethy et al. 2016). The absence of mongoose on Kauai, and forest sites that have experienced several years of continuous rodent suppression, perhaps explains why whole carcass removal was less frequent in our study (e.g., 11 bird and 6 rat carcasses within 15 days of placement) than in Abernethy et al. (2016). As outlined in our previous bird carcass study (Kreuser et al. 2020), few whole carcasses (16%) were removed within the fenced site, where rats and cats were the only scavengers. Additionally, rats captured on our cameras were never seen to take a whole carcass in either site. Prominent scavengers of small animals in Hawaii are mostly non-native and invasive (Abernethy et al. 2016). Carcass removal trials on Oahu under wind turbines found 72 of 73 carcasses placed were removed within 20 days (Gorresen 2015). On Maui, trapping of mongoose near wind turbines led to increased carcass persistence, and 68% of rat carcasses were detected after 28 days (Kaheawa Wind Power I 2019). Suppression or removal of dominant scavengers leads to more available carcasses (Olson et al. 2012), and in Hawaii areas managed for invasive vertebrates (i.e. rat and pig removal) should have most carcasses persist and remain detectable beneath an A24 trap.

Our study does not exactly replicate the process of looking for a carcass at an A24 trap; from personal observation, bodies do not always fall directly below the trap and may be at some distance from it, depending on the trap height, angle, and proximate terrain (AMK *pers. obs.*). Carcasses were likely easier to find in our study because unless wholly scavenged, the evidence remained quite close to the marker flag. However, when carcasses do fall near traps, there often will be evidence of the kill for at least 120 days. In our previous study (Kreuser et al. 2020), carcasses were not marked with pin flags, but were placed next to a flagged tree and were more difficult to find at the final check; only 63% of carcasses were detectable (vs. 83% of bird carcasses at the fenced site in this study). We observed no difference in whole scavenging of carcasses marked with pin flags or plastic stakes at the unfenced site. Pin flags, stakes, and cameras could have possibly been cues for scavengers; however, traps producing carcasses would also indicate food is nearby to scavengers. When compared to scavenging rates in the Kreuser et al. (2020) study, the pin flags and stakes did not appear to cause noticeable attraction or deterrence to the carcasses, but this may deserve further testing. Another limitation of our study was the use of previously frozen carcasses. Freezing may have affected the rate at which soft tissue remained on the carcasses, and the number of larvae deposited by flies into carcasses, in comparison to fresh trap kills (Šuláková et al. 2014). We do not expect this to largely affect the proportion of carcasses wholly scavenged or the proportion of carcasses that are identifiable and detectable after soft tissue is gone. Further camera monitoring at traps could be done to observe invertebrate and vertebrate scavenger activity with fresh carcasses.

Surveying carcasses to measure trap success (or rodent population control) in natural areas is not a reliable metric because of vertebrate and invertebrate scavenging. In a fenced forest that is managed for rodents and protected from ungulates, carcass counts would underestimate four-month-old kills by 12%. In unfenced gulches carcass counts could underestimate animals killed at the beginning of the four-month period by 62%. Although traps may kill more animals when the lure is fresh immediately post-trap check, they kill animals throughout the four-month period, increasing our chances of finding carcasses. This is particularly true of Goodnature Automatic Lure Pumps, which dispense lure consistently for four months, and which we used briefly from fall 2017–spring 2019. At our sites, typically 0–3 rat or mouse carcasses are found at each trap visitation (every 4 months); some are quite fresh while others are very decomposed. We had assumed that carcass counts underestimated the number of A24 kills because 75% of our traps have counters, and often the counter tallies exceed carcass counts (Crampton and Hite 2016). Ogden (2018) found that counters could underestimate A24 kills by up to 30%, and a counter tally less than the number of carcasses found under that trap would unequivocally indicate counter error. However, Gronwald and Russell (2022) found counters accurately recorded 90% of A24 triggering, so a counter tally greater than the number of carcasses counted would indicate scavenging or counter error. It is less likely that counters overcount in our sites where they would rarely be bumped or knocked to add a false tally, so scavenging or decomposition would most likely account for the discrepancy between our counter tallies and carcass counts. A24 kill estimates based on carcass presence or counter tallies may not accurately reflect trap effectiveness or the rodent population because rodents have been recorded frequently passing A24s and not always triggering A24s while visiting them (Gronwald and Russell 2022). Monitoring tools independent of trapping methods, such as track tunnels (Shiels et al. 2019), should be used to understand A24 trap effectiveness and general rodent management efficacy.

Lethal trapping of rodents is a prevalent practice and produces carcasses available to scavengers. The trap's food-based lure or the carcasses that accumulate near A24 traps can attract unwanted scavengers, such as birds, which then could be led into the trap. Managers should identify the scavenging community and habitat of native and introduced animals to assess their expected ability to detect kills of target and non-target animals when using A24 traps. Trap checks and servicing should also reflect land managers' goals for carcass detection. In our case, we confirmed that it is probable we would find a target or non-target animal kill if it occurred in most parts of our A24 trap grids. To improve accuracy of our data and safeguard against trapping non-target species, we may want to increase the frequency of checks at unfenced gulch traps.

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