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Do the Remains Remain? The Fate of Bird Carcasses in a Hawaiian Rainforest that is Fenced for Ungulates and Managed for Rodents using A24 Self-resetting Traps

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ABSTRACT: The introduction of rodents to islands poses a threat to native fauna, which often have no adaptation to defend their offspring or themselves from predation. To combat predation of nests and brooding females, the Kauai Forest Bird Recovery Project (KFBRP) has deployed 425 Goodnature A24 self-resetting rat traps at two field sites where high densities of native forest birds remain. One site is fenced to exclude invasive ungulates. KFBRP conducts routine trap checks every four months to assess bait and trap function and count carcasses. Typically, we find 0-3 rat or mouse carcasses at a trap, but in November 2018, we found a dead bird under a trap at the fenced site. We assume that traps kill more animals than indicated by carcass counts, because 75% of traps have counters that record when traps fire, and counter tallies exceed carcass counts. Thus, we hypothesize that some carcasses are scavenged or decompose between trap checks, and as a result we are a) underestimating target mortality with carcass counts and b) failing to detect non-target mortality. To test our hypotheses, we placed 30 non-native bird carcasses on transects in the fenced trapping grid in early December 2018. Carcasses were surveyed every at 10, 20, 45, 90, and 130 days after deployed. At the end of survey period, 19 (63%) carcasses could be easily detected, suggesting that we are detecting most carcasses after four months unless they are scavenged. Furthermore, our findings suggest that we would detect non-target mortality if it was prevalent.

KEY WORDS: A24 self-resetting trap, carcass scavenging, decay, endangered species, Hawaiian Islands, invasive species, non-target mortality, rodent management

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INTRODUCTION

Most of the world's landmasses, including >80% of the world's islands and continents, have been invaded by four species of invasive rodents: Norway rats (*Rattus norvegicus*), black rats (*R. rattus*), Pacific rats (*R. exulans*), and house mice (*Mus musculus*). In addition to being widespread, these four rodents are the most damaging rodent species to the environment and economy (Capizzi et al. 2014). Furthermore, in island ecosystems, such as those in Hawaii, invasive rats pose a direct threat to many native and endangered species, including birds (VanderWerf 2001, Banko et al. 2019).

Removing invasive rats for the protection of native and endangered species is a key management goal for many islands across the world (Capizzi et al. 2014). In Hawaii, rat traps and toxicants are common control tools for resource protection from rat predation (VanderWerf 2001, Banko et al. 2019). Snap-traps, 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). However, more recently, the Goodnature A24 self-resetting rat+stoat traps (hereafter A24s or A24 traps) have often replaced or augmented labor-intensive snap-traps (Shiels et al. 2019), and A24s have been used to successfully suppress invasive rat populations in natural areas in New Zealand (Carter et al. 2016) and Hawaii (Shiels et al. 2019).

Both snap-traps and A24s produce dead rat and mouse carcasses that are available for scavengers. Additionally, in some rare instances, native birds have been unintentionally killed by the A24s, as indicated by their carcasses remaining below the traps (Gillies et al. 2014). Rat and bird carcasses remain for an unknown amount of time after being killed by traps, and many factors may affect the duration of carcass persistence, such as the abundance and diversity of the scavenging community, seasonality, biome, and the type of carcass and coverings (e.g., feathers or fur) (Abernethy et al. 2016). Additionally, there may be little or no evidence that a trap was triggered if the trap gets checked by the servicing staff after a scavenger removes the carcass. Thus, if traps are checked infrequently, carcass counts may underestimate the number and nature of trap kills.

In our study, we placed bird carcasses in a rainforest on Kauai Island, Hawaii, to assess the persistence and fate of carcasses. Our study was motivated by the mortality of a highly endangered bird at an A24. Because A24s are typically serviced at four-month intervals, the duration a rat or bird carcass persists after being killed by a trap is unknown but of interest to managers hoping to suppress rats and avoid non-target bird kills by the traps. The specific objectives of our study were to: 1) determine how often clear evidence of placed carcasses persist at four months (when traps are serviced), 2) determine relative frequency of scavenging, and how scavengers affect carcass persistence, and 3) determine the decay rates of carcasses that persisted to four months. We hypothesized that some carcasses are scavenged or decompose between trap checks, and as a result we are a) underestimating target mortality with carcass counts and b) failing to detect non-target mortality. Based on these hypotheses, we had four a priori expectations. First, we expected that some evidence (such as feathers) of most carcasses would persist for four months in this ungulate-free (fenced) forest. Second, we expected scavengers to have a large effect on the detectability of carcasses because we expected they would remove entire carcasses. Third, we expected that the valleys would experience greater scavenging than the upland forest because of the greater resource abundance in the valleys where ephemeral streams are present would attract scavengers. Finally, we expected the carcasses to decay rapidly with no soft tissue remaining at four months, but we expected bones and feathers to persist past 4 months.

METHODS

Study Site

The study was conducted at an established 5.45-km^2 site enclosed by an ungulate proof fence and managed for rodents by Kauai Forest Bird Recovery Project in the Alakai Wilderness Preserve on the island of Kauai, Hawaii (22°05'28"N, 159°33'42"W). These sites consist of wet montane forest dominated by ohia (*Meterosideros polymorpha*) trees. Elevation ranges from 1,123 m to 1,303 m (VanderWerf et al. 2014). The fence is regularly monitored for breaches, and snares within the enclosed fence are regularly checked. This location is where the highest densities of native forest birds remain on Kauai, and rodents have depredated eggs, chicks, and incubating females of several of these bird species (Tweed et al. 2006, Hammond et al. 2015). To combat the threat of rodent predation, automatic, self-resetting Goodnature A24 traps have been used at this site since 2015 (Carter et al. 2016, Shiels et al. 2019).

Experimentally Placed Study Species

We procured 32 invasive bird carcasses, 16 zebra dove (*Geopelia striata*) and 16 red-crested cardinal (*Paroaria coronata*), from USDA Wildlife Services' bird-airstrike prevention program at Lihue Airport, Kauai. All birds were cage-trapped and euthanized with CO_2, and then frozen until deployment at our field sites. The bird carcasses were deployed on December 18, 2018 and monitored until May 8, 2019. The bird carcasses were initially weighed, and their body conditions were assessed before and after deployment (see Table 1). Carcass masses were (mean ± SE): red-crested cardinals (39.1 ± 0.74 g, range = 35-42 g, 16). Colored plastic straps (zipties) were placed on one leg of the carcass to uniquely mark individuals. Each carcass was placed at the base of a uniquely flagged tree with additional flagging on the nearest tree (usually 1-2 m away) to help locate the carcass on subsequent visits. The carcasses were placed along trap transects alternating species, 15 red-crested cardinals and 15 zebra doves. Carcasses were placed evenly in the two dominant environments (gulch vs. upland). Carcasses were an average distance (± SE) of 25.5 m ± 1.6 m from A24 traps and an average 47.1 m ± 4.0, n = 31) from another carcass. Additionally, one carcass of each bird species was placed in a wire cage, which allowed the carcasses to experience the similar conditions with the exception of vertebrate scavengers.

Carcass Presence and Decay Observations

Carcasses were checked at predetermined intervals after deployment at days 10, 20, 45, 90, and 130. Carcass checks were more frequent in the beginning of the study when we expected more scavenging activity and rapid decay and less frequent towards the end. During each check, we recorded three items: detection of carcass within 10 seconds of searching ('distinct detection', which is most representative of current trap servicing methods); presence of carcass after thorough (>30 seconds) searching, including through the leaf litter ('presence'); and body condition. Body condition was scored on a 0-6 scale (modified from Wilson et al. 2007) as follows: 6 = fresh and as originally placed, no wounds/lesions, only used during deployment; 5 = untouched by scavengers, has 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 still bound to skin or cartilage; 1 = only bones and feathers remain, no soft tissue left; 0 = the carcass and bones are gone, but feathers may remain.

Statistical Analysis

To assess the distinct detection, of carcasses at/until 130 days, we performed a Cox proportional hazards survival analysis (in R package survival), using the predictor factors environment (gulch vs. upland) and carcass species (red-crested cardinal vs. zebra dove) (Dalgaard 2018). A chi-square test was performed on the final body condition at 130 days in relation to the species, environment, and initial body condition. We considered $p \leq 0.05$ as significant.

Table 1. Life table survival estimated from Cox proportional hazards regression analysis. The number of carcasses not found during a check throughout the experiment is tallied in the events column.

Days	n.risk	n.event	n.censor	Survival	SE	upper CI	lower CI
10	30	6	0	0.83	0.08	0.98	0.70
45	24	2	0	0.76	0.11	0.94	0.62
90	22	2	0	0.70	0.13	0.90	0.55
130	20	1	19	0.67	0.14	0.87	0.51

RESULTS

Carcass Detection

At 130 days when the study ended, 63% of the bird carcasses were distinctly detectable. Specifically, 47% of red-crested cardinals and 80% of the zebra doves were distinctly detected. The two environments were similar with 60% of individuals in the gulch environment and 67% in the upland environment remaining detectable. Neither species nor local environment (gulch vs. upland) significantly affected the ability to detect the carcass at 130 days ($p = 0.07$, $t = -4.36$, $df = 1$; $p = 0.93$, $t = 4.82$, $df = 1$ respectively). The estimated carcass survival to 130 days by the Cox proportional hazards model was 67% (Table 1, Figure 1), with the estimated survival of detectable carcasses compared to the actual survival of carcasses detected.

After 10 days of deployment, 24 (80%) bird carcasses remained as distinct detections. At 20 days, the same 24 carcasses were still considered a distinct detection. At 45 days after deployment 22 (73%) carcasses were considered detectable. At 90 days 20 (67%) bird carcasses remained as distinct detections. Although 21 (70%) carcasses were still physically present at 130 days, two did not classify as a distinct detection by the observer.

Carcass Scavenging

Whole and partial scavenging was observed on nearly half of the carcasses (14 of 30), five of which were considered distinct detections at 130 days. During the 10-day check, five absent carcasses were attributed to removal by rodents or cats, as suggested by trail camera evidence from other carcasses in the area. In one case the carcass was found among roots of the tree where it was placed, suggesting rodent scavenging. At two different carcass stations, clear evidence remained including trails of feathers. For one of these carcasses, the tail feathers found at the 10-day check were found at the 20-day and 45-day checks. No evidence of these five carcasses that we assumed were scavenged before the 10-day check remained detectable at 130 days. Four carcasses were partially scavenged, and these remained detectable during following checks after initial scavenging observed. However, those four carcasses were not distinct detections at 130 days.

During the 10-day and 20-day checks when soft tissue remained, observers more confidently documented evidence of whole and partial scavenging. Once soft tissue disappeared, they could not assess scavenging from looking at the carcass. Carcasses that were not detected at the 45-day and later checks were not attributed to scavengers because we assumed without soft tissue, they were no longer attractive to vertebrate scavengers.

Carcass Decay

At deployment most carcasses had a body condition of 6; however, seven carcasses had large enough postmortem wounds due to transportation in a backpack to be scored as 5. This initial ranking did not have a significant effect on distinct detections or the decay process ($p = 0.43$, $t = -0.19$, $df = 6$). Carcasses decayed rapidly, and at 20 days, 12 carcasses (50% of those remaining) were classified as a body condition of 2, defined as prominent bones with some soft tissue (Figure 2). By the third check, which was 45 days after deployment, 86% of the remaining carcasses were classified as a body condition of 1, having no soft tissue and only bones and feathers remaining. At 90 days and 130 days after deployment, 90% of the carcasses were classified as a body condition of 1. Species and environment (gulch vs. upland) had no significant effect on body condition at 130 days ($p = 0.13$, $t = -2.4$-, $df = 1$; $p = 0.95$, $t = 5.98$, $df = 1$ respectively).

The control carcasses (i.e. those placed in metal cages to prevent scavenging) followed the same pattern of decay as the experimental carcasses but were in better condition than the majority of the uncaged carcasses. Cages prevented tree leaves from covering the carcasses and affecting decay processes. In cages, both species received scores of 6 at deployment, 5 at 10 days, 3 at 20 days, 2 at 45 days, and 1 at 90 and 130 days.

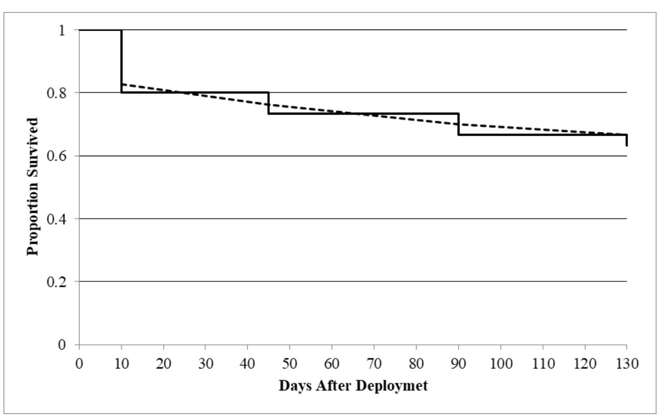

Figure 1. Solid line is the Kaplan-Meier plot showing the actual proportion of carcasses surviving at days 10 (S = 80%), 20 (S = 80%), 45 (S = 73%), 90 (S = 67%), 130 (S = 63%). The dashed line shows survival estimated from a Cox proportional hazard regression analysis.

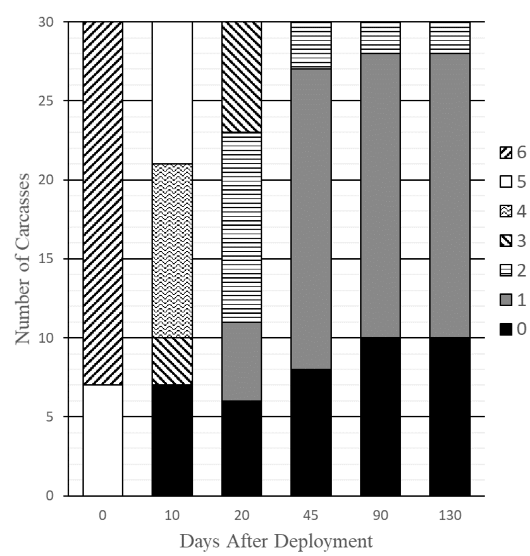

Figure 2. Body conditions of carcasses (n = 30) across survey period.

DISCUSSION

A common goal for natural resource managers in island ecosystems is to trap invasive rodents for the protection of native and endangered species (Capizzi et al. 2014). As the self-resetting Goodnature A24 traps grow in popularity, it is important to understand the risks that rat traps pose to non-target species such as native birds, and it is equally important to be able to successfully judge the frequency that non-target kills occur, especially since A24s are visited less frequently than snap-traps. In New Zealand (Gillies et al. 2014), and at our study site in Kauai, a small number of birds have been killed by the A24 rat traps, as indicated by carcasses found under the traps (Gillies et al. 2014, KFBRP unpubl. data). Our results show we are highly likely (67% chance) to detect a non-target kill in a Hawaiian rainforest that is managed for ungulates and rodents. Thus, our study shows if the A24 traps deployed at our site are killing large numbers of birds, then it is likely that we would have detected more bird carcasses at the four-month trap servicing intervals than we have to date.

The sooner a trap is visited, the greater the probability of detecting (bird) carcasses. If a bird or other non-target species is killed 45 days before an A24 is visited, our model predicts 75% (SE = 11%) probability that the carcass would be detected. Rigorous searching (approximately 30-120 seconds) produced two more carcasses that were buried by leaf litter and considered undetectable by trap protocol-determined searching (≤10 seconds) at 130 days. If an area is high-risk of bycatch or in early days of a trapping program, traps could be visited more frequently to monitor carcass type and search effort increased, yet still at intervals suitable for the environment and logistical management. Therefore, A24s still remain less labor intensive, and require fewer visits than snap-trap grids while remaining efficacious.

Scavenging of carcasses by vertebrates accounted for fewer disappearances than we expected. Vertebrate scavenging was indicated at most for five carcasses, which all were absent at the 10-day check. One carcass was taken (likely by a rat) into a nearby root system, and four other carcasses were not located with no or little evidence such as feathers left behind. These incidences could be attributed to cats or rats. A sixth carcass was absent at the 10-day check, but not attributed to scavengers. It was placed in the gulch it is likely that it washed away after heavy rains caused the stream to raise considerably, as indicated by debris at the station. Further monitoring of carcasses with cameras would identify the scavenger community of the specific management areas.

The study site is enclosed by an ungulate-proof fence, so the local scavenger community does not contain pigs or goats. Unlike other Hawaiian Islands, Kauai is not plagued by mongoose, which is the dominant scavenger across multiple environments on the Island of Hawaii (Abernethy et al. 2016). Abernethy et al. (2016) used multiple species of carcasses and observed the animal scavengers over a six-day period at sites not managed for invasive vertebrate species. In accordance with our findings, the days after carcasses were first deployed were an active time for scavengers: 55% were at least partially scavenged by vertebrates within that time period (Abernethy et al. 2016). In the rainforest site on Hawaii Island, Abernethy et al. (2016) discovered that rodents were the most abundant scavenger, but mongoose removed more total carcasses. Because our A24 trapping activities have suppressed relative rodent abundance more than four-fold at our site since 2015 (compared to reference untrapped areas; KFBRP unpubl. data), we may have reduced rodent scavenging activity and increased carcass survival compared to areas not managed for rodents.

Abernethy et al. (2016) did not leave carcasses out for as long as needed for the purpose of our study, and they did not document a body condition scale such as we did in our study. However, they noted that the carcasses in the rainforest site still had intact flesh available to vertebrate and invertebrate scavengers after six days; in contrast no flesh remained on the carcasses at their lava and scrub sites due to invertebrate scavenging (Abernethy et al. 2016). Our study shows that flesh and soft tissue remains on most carcasses up until 20 days, and after 45 days cartilage and small, dried pieces of skin can remain until 130 days. The greater persistence of soft tissue on the carcasses in the rainforest setting may signify different or reduced invertebrate populations in rainforest environments compared to drier environments.

To have a more comprehensive understanding of small animal decay in rainforest sites managed for rodents, a future study should include rodent carcasses, increase the number of carcasses, and expand to an unfenced site. This study was hindered by malfunctioning trail cameras that were unable to capture scavengers interacting with carcasses. With functioning cameras, monitoring of these carcasses could be valuable to identify the scavenger community at different management sites on Kauai, and reveal how long carcasses are attractive to scavengers. The addition of rodent carcasses would allow comparison of bird and rodent decay rates and show if scavengers prefer a taxon. Collectively, this information could help management organizations estimate the actual number of trap kills vs. the number of carcasses found and estimate bycatch of non-target species, especially if uncommon.

Our study indicates that birds killed as bycatch by traps in a rainforest environment that is managed for ungulates and rodents would likely be found up to four months later, and prominent evidence of feathers and bones would remain for at least 130 days. This detection period falls within both snap-trap and A24 trap servicing in most situations in Hawaii (e.g., Shiels et al. 2007, Pender et al. 2013, Shiels et al. 2019). Thus, it seems that such bycatch is relatively uncommon. Suppression of rodent scavengers and shortened intervals between trap servicing would further increase the likelihood of detecting and identifying non-target animals. Further investigation of rodent decay in management areas could help organizations better quantify and monitor kill rates to improve efficacy of trapping efforts and avert non-target mortality.

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