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Effects of *Rattus* spp. Control Measures and Nesting Substrate on Nest Depredation, East Maui, Hawaii

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ABSTRACT: We monitored natural and artificial nests during a two-part study on East Maui, Hawaii, designed to examine factors influencing nest depredation by black and Polynesian rats. The first half of the study examined the effects of rat control on nest depredation within portions of the Hanawi Natural Area Reserve. Rat density monitoring indicated control efforts had significantly reduced black rat captures in treatment areas, but no differences in survival of artificial or natural nests between treatment and control areas were observed. The second half of the study examined the effect of nesting substrate on nest depredation in the Makawao Forest Reserve during June 2003 and June 2004. We chose fruiting and non-fruiting nest substrates for artificial nests in two habitat types, native ohia/koa forest and an adjoining forest dominated by non-native tropical ash. Results from snap trapping showed that the relative density of black rats was significantly higher in the ohia/koa forest than the tropical ash forest, but plots with more rat captures did not always have higher rates of nest depredation as predicted. Our findings suggest that there is a large degree of variability in nest depredation by *Rattus* spp., but that rat density, forest type, and nest substrate influence nest depredation rates.

KEY WORDS: artificial nests, black rat, Hawaii, honeycreeper, nest depredation, Polynesian rat, *Rattus exulans*, *Rattus rattus*, rodent control

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INTRODUCTION

Introduced rat species are considered to be an important limiting factor in the decline of native birds in the Hawaiian Islands (Atkinson 1977, VanderWerf 2009). Periodic population irruptions of *Rattus* spp. can have a devastating impact on endemic bird species in a very short time (Bell 1978). Both *Rattus rattus* and *Rattus exulans* are known to take eggs, chicks, and adults of many bird species, and *R. rattus* has been specifically implicated in the rapid extinction of Hawaiian bird species (Atkinson 1977). However, recent studies have had conflicting results on the role of rat predation in limiting Hawaiian bird species. Data for the Puaiohi (*Myadestes palmeri*) shows that in 1998 and 1999, 14%, and 22% of nests, respectively, failed due to confirmed rat predation, including three females taken on their nests (USFWS 2003). *R. rattus* was implicated as the primary predator limiting O'ahu 'Elepaio (*Chasiempis sandwichensis gayi*) (VanderWerf 2009). Conversely, little evidence was found implicating *Rattus* spp. in the low reproductive success of the palila (*Loxioides bailleui*), an endangered Hawaiian honeycreeper on the island of Hawaii (Amarasekare 1993). For native bird species already reduced to low numbers, even the incidental predation of nests or adults can be devastating. Rodent control measures in Hawaii have been shown to reduce the level of predation on artificial and natural nests (VanderWerf 2009), but these measures are costly and labor intensive, limiting their scale and use.

Nest substrate has also been shown to influence nest predation rates, and nests in exotic nest substrates can have higher nest predation rates than those in native substrates (Schmidt and Whelan 1999, Borgmann and Rodewald 2004). The use of exotic fruit and nut-producing tree species as nesting substrates by Oahu 'Elepaio has been identified as one of the factors

contributing to high rates of nest depredations by *R. rattus* (VanderWerf 2009). Both *R. rattus* and *R. exulans* consume large quantities of plant materials, and the availability of fruit within a nest tree may influence foraging decisions by rats and subsequent nest depredations. Better insight on how rodent control and nest substrate affect nest depredation rates can help resource managers decide when and where to apply rodent control programs, and information supporting the need for rodent control programs can justify the expenditure of political and financial capital.

Monitoring natural nests in the wild provides the most useful information on nest depredation, but there are issues with this method. Difficulty in finding nests, obtaining sufficient sample sizes, controlling confounding factors, and making observations without affecting the outcome of the nest are just a few of the potential problems. Artificial nests are a convenient way of studying nest predation without some of the difficulties associated with natural nests. These studies have been widely criticized (King et al. 1999, Haskell 1995), and the major concern is that artificial nests do not actually reflect the rates of predation on natural nests. In a review of artificial nest studies (Major and Kendall 1996), several reasons were given for why artificial nests may not accurately reflect natural nests. The most crucial of these was the olfactory and visual cues predators might use in locating nests. Artificial nests lacking cues might produce predation rates lower than actual rates of predation. Additional cues provided by the researchers themselves could increase rates of predation. The use of Japanese quail eggs has also been criticized because some predators may not be able to predate these large eggs (Haskell 1995). The most effective way to account for the possibility of artificial nests not accurately reflecting predation rates is to monitor natural nests at the same time

as the artificial nests. Even a small sample of natural nests is useful in validating the results of the artificial nests. In this study, we were only concerned with predation caused by *R. rattus* and *R. exulans*, and they have been shown to effectively predate Japanese quail eggs in artificial nests in Hawaii (Amarasekare 1993, VanderWerf 2001). Feral cats (*Felis catus*) and small Indian mongooses (*Herpestes auropunctatus*) in our study sites occur at low densities (Maui Forest Bird Recovery Project, Makawao, HI, unpubl. data) and as a result, are probably responsible for comparatively few predations. Mongooses have limited arboreal ability, further reducing their contribution to nest predation of forest birds nesting in trees (Tomich 1986). House mice (*Mus musculus*) are found in these forests and could predate passerine eggs, but they appear to be limited to foraging on the ground in Hawaii (Amarasekare 1993).

This paper documents a two-part study conducted on East Maui between January 2003 and June 2004. The first part of the study attempted to determine the effects of ongoing rodent control in the Hanawi Natural Area Reserve (NAR) on nest depredation. These rodent control efforts have been shown to effectively reduce *R. rattus* (Malcolm et al. 2008), but the effects of rodent control efforts on reducing nest depredation within these areas is unknown. Artificial nests were used to provide a large sample size, while monitoring natural nests allowed us to compare rates of predation between natural and artificial nests. The second part of the study examined the effects of three different nesting substrates, ohia (*Metrosideros polymorpha*), fruiting olapa (*Cheirodendron trigynum*), and non-fruiting olapa, to examine on nest predation. Artificial nests were again used to provide a large sample size and allow us to manipulate nest substrate species and nest tree fruiting condition. We chose two plots to compare native and non-native forest types. Snap trapping in each plot following the nest studies allowed us to compare relative densities of rats between plots.

STUDY AREAS

Effects of Predator Control

This part of the study was conducted within the Hanawi NAR, located on the eastern portion of contiguous forest found on East Maui, Hawaii. Hanawi NAR encompasses 4,000 ha and habitats ranging from alpine grassland to lowland tropical rainforest (for detailed habitat descriptions see Mountainspring 1987). This area has a high diversity of native flora and fauna and is designated by the American Bird Conservancy as an Important Bird Area (American Bird Conservancy 2003). This work was carried out in the fenced portion of the reserve found above 1,500 meters in elevation.

Effects of Nesting Substrate

The Makawao Forest Reserve is part of the western-most portion of contiguous forest found on East Maui, Hawaii. The reserve ranges in elevation from 600 to 1,440 meters in elevation and encompasses 900 ha. It consists of both native and non-native forests and has a wide range of both native and alien plant and animal species. The area is managed for hunting, but no other direct management activities are aimed at reducing or

eliminating introduced mammalian predators. The two study plots were placed in the upper portions of the reserve between 1,260 and 1,320 meters in elevation. The native plot had a mixed canopy of ohia and koa, with a mixture of native and non-native species in the understory. The tropical ash plot was a forest patch primarily consisting of tropical ash, with a few native species in the canopy and a very sparse understory. These two plots were approximately 500 m apart.

METHODS

Effects of Predator Control

Rodent control efforts within Hanawi NAR are described at length in Malcolm et al. (2008). Rodent control took place in three areas (HR1, HR2, and HR3) of approximately 40 hectares in size within the reserve, beginning in 1998. These efforts used a combination of ground-based rodenticide (0.005% diphacinone) and snap trapping to reduce rodent density. Bait stations were placed along transects with stations approximately 50 m apart. In addition to rodenticide, Victor™ snap traps were used along bait station transects at varying intervals to provide additional rodent control. Bait stations and snap traps were rebaited and replaced as necessary every 3 months. We used two of these three treatment areas (HR2 and HR3) as our treatment areas for the artificial nest experiment. Two external reference areas (X1 and X2) were positioned in similar habitat to measure nest depredation in unmanaged rodent populations.

Prior to use, the artificial nests were placed in field acclimation cages with either native Hawaii amakihi (*Hemignathus virens*) or non-native Japanese white-eye (*Zosterops japonicus*) in an attempt to condition the nests to provide olfactory clues that rats may use in locating natural nests. Forty nests were conditioned with Hawaii amakihi, and 40 were conditioned with Japanese white-eyes. The field cages were cloth-sided and 1 × 1 × 2 ft (30 × 30 × 61 cm) in dimension, which kept the birds in close proximity to the nests. The birds were held in field cages with the nests for 5 days, and then released. All birds were released unharmed. After conditioning and until placement in ohia, artificial nests were only handled while wearing gloves, to avoid contamination with human scent.

During April 4 - 18, 2003, in each of the four plots 20 artificial nests were placed in ohia, which was the primary nesting substrate used by native birds at the site. We systematically selected the first 20 stations in the existing 25 station snap-trapping grid and used the nearest ohia to each station for nest placement. Aluminum extension ladders allowed us to place the nests at realistic heights (2 - 5 m) with minimal disturbance to the vegetation. Nests were attached to the trees with thin wire, and each nest received one Japanese quail egg. On alternate days, the nests were inspected with a mirror pole to determine if predation had occurred. Nests were considered depredated if the eggs were missing, chewed, or broken. The artificial nests were left in place for 14 days to simulate an average incubation period for the Hawaii amakihi (van Riper 1987).

Between February and April 2003, systematic searches for natural nests were conducted in the treatment

and reference areas. Searchers used an existing system of trails to search for nests, and logged approximately 1,200 hours searching for or monitoring nests. When a nest was found, it was flagged from a spot located at least 25 m away along the trail that would allow observation without disturbing the nest. Once a nest was located and confirmed as active, an observer would return and monitor the nest using binoculars or a spotting scope every 1 - 3 days. Observation periods varied in length, but generally lasted for either 1 hour or until definite confirmation of nest stage could be recorded, whichever came first. Observers took notes on behaviors of parents, recorded color band combinations where adults were banded, and counted the number of chicks when possible. Nests were considered to have failed if adults abandoned nests after incubation had begun and before a chick was fledged.

Effects of Nesting Substrate

Nests from the rodent control study were reused for the nesting substrate study. At the conclusion of the first study, the nests were rinsed, dried, and stored together for 20 days in an attempt to negate the effects of prior conditioning. During this time, nests were handled directly by researchers and no attempt was made to reduce contamination by human scent. In both plots, 10 nests containing 1 Japanese quail egg were placed in ohia, fruiting olapa, and non-fruiting olapa trees, on June 4 - 18, 2003 and June 1 - 14, 2004. Artificial nests were in trees 10 to 15 m apart and were placed between 2 and 3 m aboveground in the tree. The artificial nests were left in each tree for 14 days to simulate an average incubation period for the Hawaii amakihi (van Riper 1987) and were monitored every 2 - 3 days to record predation. Nests were considered depredated if the eggs were broken, chewed, or missing. When possible, the remains of the egg were located and examined to attempt identification of the nest predator.

Snap Trapping

Snap trapping was conducted following artificial nest exposure periods during both parts of the study to obtain relative density measurements of rat populations within each plot. Rats were trapped by using a 5 × 5-m grid of Victor™ snap traps placed on the ground 25 m apart. Plastic covers were used to protect the trap and bait from weather and to reduce the risk of capturing non-target species. Snap traps were pre-baited for 3 nights with coconut chunks and then re-baited with coconut, set, and checked for 6 nights. Trapping was conducted in Hanawi NAR during May 4 - 15, 2003, and was conducted in Makawao Forest Reserve during June 18 - 27, 2003 and July 13 - 22, 2004.

RESULTS

Effects of Predator Control

All 80 artificial nests survived the 14-day exposure period intact. We found and monitored 25 active native bird nests during this part of the study, 3 of which failed. All 25 nests were in ohia; 20 were within the T1 treatment area, and 5 were in the X1 external reference area. None of the 5 natural nests found in the control area failed. During the incubation period of natural nests, the

daily survival rate was 98% ($n = 15$). The daily survival rate for the nestling period was 100% ($n = 22$). The daily survival rate for incubation and brood rearing combined was 99% ($n = 25$). In the two treatment areas, *R. rattus* captures were 0 rats per 100 trap-nights and *R. exulans* captures averaged 0.90 rats per 100 trap-nights. In the two external reference areas, *R. rattus* captures averaged 6.69 rats per 100 trap-nights and *R. exulans* captures averaged 3.18 rats per 100 trap-nights.

Effects of Nesting Substrate

During 2003, all 30 nests survived the exposure period in the ohia/koa plot. In the tropical ash plot, all 10 nests in ohia survived, but 2 nests in non-fruiting olapa and 5 nests in fruiting olapa were depredated. During 2004, 8 nests in ohia, 9 nests in non-fruiting olapa and all 10 nests in fruiting olapa were depredated in the ohia/koa plot. In the tropical ash plot, 1 nest in ohia, 2 nests in non-fruiting olapa, and 2 nests in fruiting olapa were depredated. Daily survival rates were significantly different for each substrate in the ohia/koa forest between 2003 and 2004, but remained similar between years in the tropical ash forest (Figure 1). During 2003, *R. rattus* capture rates in the ohia/koa plot were 19.7 rats per 100 trap-nights and 8.7 rats per 100 trap-nights in the tropical ash plot. Only *R. rattus* was captured in 2003. During 2004, capture rates for *R. rattus* in the ohia/koa were 19.9 rats per 100 trap-nights and 11.7 rats per 100 trap-nights in the tropical ash plot. Capture rates for *R. exulans* during 2004 were 0.75 rats per 100 trap-nights in the native plot and 0.73 rats per 100 trap-nights in the tropical ash plot.

DISCUSSION

During our study on the effects of predator control, none of the 80 nests were depredated. Natural nests monitored at the same time also had low rates of failure (12%, $n = 25$). At least one of the natural nests is presumed to have failed due to weather, while the reason for the other two failures could not be determined. The artificial nests and natural nests had similar rates of survival, and the artificial nests appear to have produced valid representa-

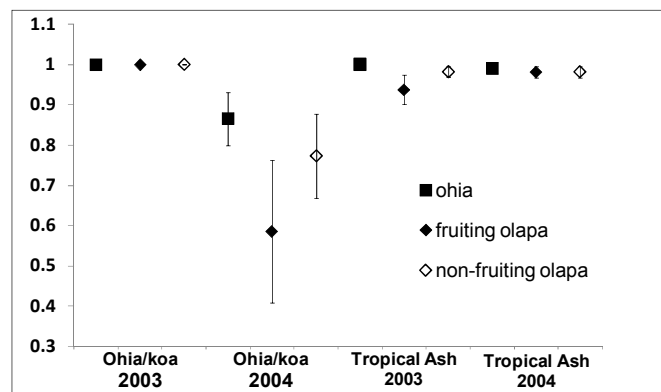


Figure 1. Average daily survival rates and 95% confidence intervals for artificial nests in (■) ohia, (◆) fruiting olapa, and (◇) non-fruiting olapa in native ohia/koa forest and non-native tropical ash forest in the Makawao Forest Reserve on Maui, Hawaii, USA during 2003 and 2004.

tions of natural nests. The low rates of predation were unexpected. In areas with predator control we had correspondingly low rat capture rates, but capture rates were much higher in areas without predator control. Ohia was the only nest substrate for both artificial and natural nests for this study, and it produces tiny wind-borne seeds. Olapa and three shrub species, kanawao (*Broussaisia arguta*), ohelo (*Vaccinium calycinum*), and akala (*Rubus hawaiiensis*), were fruiting during this study, and rats may have been selectively foraging in these species to exploit available food resources, and thus infrequently encountering the artificial and natural nests.

In examining nesting substrate, higher relative rat densities did not always result in higher rates of predation, but artificial nests in fruiting olapa always had higher rates of depredation in plots where depredation occurred. During our study, olapa was the only fruit available in abundance in the tropical ash plot, whereas olapa, *Clermontia* spp., kanawao, and akala were fruiting in the native plot. Predation rates appeared to remain constant in the tropical ash plots across years, but there were significant differences in nest depredation rates between years in the ohia/koa plot. Changes in rat density or nesting substrate do not seem to account for these differences, and these results may be due to our small samples sizes.

Two previous artificial nest predation studies in Hawaii have had conflicting results regarding the extent of rat predation on nests. Both studies identified *R. rattus* as the primary predator and used a combination of natural and artificial nests to determine predation rates. VanderWerf (2001) examined the effects of rodent control on nest predation in O'ahu 'Elepaio habitat. He found that a combination of snap trapping and rodenticide reduced predation rates on artificial nests in trees by 45%, and that it increased 'Elepaio reproduction by 112%, and female 'Elepaio survival by 66% (VanderWerf 2001). During a nest survival study of palila on the island of Hawaii, Amarasekare (1993) found that *R. rattus* was responsible for all depredations on artificial nests but overall predation rates were extremely low ($4\% \pm 1\%$, $n = 500$). These rates were comparable for rates observed for actual palila nests from 1988 to 1990 (6%, U.S. Fish and Wildlife Service, unpubl. data).

R. rattus shows a high degree of stereotypy in foraging (Clark 1982). They may key in on certain foraging substrates seasonally and exclude others, based on food availability in that particular substrate. Rats are less likely to come into contact with nests in ohia if they do not spend as much time foraging in ohia compared to other substrates. Ohia is a large, flowering canopy species that produces tiny wind-dispersed seeds. Rats may not be as attracted to it as a foraging substrate as they are to other trees, such as olapa, guava, or mango, which all produce fleshy fruit. Nesting substrate and fruit availability might explain the differences in the rates of predation reported by VanderWerf (2001) and Amarasekare (1993). In VanderWerf's study of O'ahu 'Elepaio, nests were primarily in non-native guava (*Psidium guajava*), and mango (*Mangifera indica*) (VanderWerf 2001). Both of these species produce large amounts of fruit that would attract rats into the tree in

search of food. In contrast to this, the majority of nests in Amarasekare's study were in mamane (*Sophora chrysophylla*), which is not a preferred food for *R. rattus* (Amarasekare 1993). Naio (*Myoporum sandwicense*) was a second nest substrate species used in this study, and it produces a fruit that is a food preferred by rats. When the artificial nests in naio and mamane are compared separately, predation rates were 22% in naio and 0% in mamane. In addition, the same study reported higher levels of predation during months of high fruit production, which the rats exploit by increasing arboreal activity (Amarasekare 1993).

Our results and these previous studies indicate that nesting substrate and fruit availability influence nest predation by rats. In Hawaii, more work needs to be done on how, where, and when rats depredate nests and compete with native birds. The relatively low rates of predation we found in ohia does not change the fact that many of Hawaii's forest bird species are in critically low numbers, and any predation by rats on nests or adults could further imperil the species.

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