

RODENT CONTROL DECREASES PREDATION ON ARTIFICIAL NESTS IN O‘AHU ‘ELEPAIO HABITAT

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Abstract.—The O‘ahu ‘Elepaio (*Chasiempis sandwichensis ibidis*) is an endangered monarch flycatcher endemic to the Hawaiian Island of O‘ahu. One of the main causes of the decline of this forest bird is low nest success. This study investigated whether introduced rodents might be important nest predators in ‘Elepaio habitat by conducting artificial nest experiments before and during a rodent control program. In each experiment, 20 artificial nests with two quail eggs each were placed on the ground and in trees, then checked at 5, 10, and 15 day intervals. The size, appearance, location, and odor of artificial nests were considered in order to make the experiment more realistic. Rodent control decreased predation on artificial tree and ground nests by 45% and 55%, respectively. Predation on ground nests was higher than predation on tree nests before rodent control, but afterwards predation was low on both ground and tree nests and did not differ between them. Survival of artificial tree nests after rodent control (80%, 0.985 daily) was similar to survival through incubation of ‘Elepaio nests (82%, 0.989 daily), indicating the artificial nests provided a realistic measure of predation on ‘Elepaio nests. Automatic cameras wired to nests documented the identity of the predator in 10 events; in every case it was a black rat (*Rattus rattus*). Black rats appear to be the primary nest predator in O‘ahu ‘Elepaio habitat, and rodent control is a valuable management technique that can be used to increase the reproductive success of ‘Elepaio.

CONTROL DE ROEDORES REDUCE LA DEPREDACIÓN EN NIDOS ARTIFICIALES EN EL HABITAT DE *CHASIEMPIS SANDWICHENSIS IBIDIS*

Sinopsis.—*Chasiempis sandwichensis ibidis* es un papamoscas en peligro de extinción, endémico de la isla O‘ahu de Hawaii. Una de las causas principales de la reducción poblacional de esta especie es el bajo éxito reproductivo. El estudio tuvo como objetivo investigar si los roedores introducidos eran depredadores importantes de los nidos del ave. Para determinar su efecto se condujo un experimento con nidos artificiales previo y posterior a un programa de control de roedores. En cada experimento, se colocaron 20 nidos artificiales con dos huevos de codorniz, en el suelo y en árboles y se cotejó su contenido a intervalos de 5, 10 y 15 días. El tamaño, apariencia, localización y olor de los nidos artificiales fue tomado en consideración para hacer un experimento lo más real posible. El control de roedores redujo la depredación en nidos artificiales de un 45% y 55% en nidos en el suelo y los árboles, respectivamente. Antes de efectuarse el control, la depredación de nidos en el suelo fue mayor que las de los nidos colocados en los árboles, pero luego del control de ratas, no hubo diferencia entre los niveles de depredación entre las localidades. La sobrevivencia de nidos en los árboles luego del control de roedores (80%, 0.985 diariamente) fue similar a la supervivencia durante el periodo de incubación (82%, 0.989 diariamente), lo que indica que los nidos artificiales proveen una medida real de la depredación de nidos en este papamoscas. Cámaras automáticas permitieron la identificación del depredador en 10 ocasiones, que en todos los casos resultó ser la rata negra (*Rattus rattus*). La rata negra parece ser el principal depredador de los nidos del ave, y el control de éstas parece ser una herramienta útil para incrementar el éxito reproductivo de la especie.

The ‘Elepaio (*Chasiempis sandwichensis*) is a territorial, non-migratory monarch flycatcher (Monarchidae) endemic to the Hawaiian Islands

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(VanderWerf 1998). 'Elepaio are fairly common and widely distributed on the islands of Kaua'i and Hawai'i (Scott et al. 1986), but on O'ahu they have seriously declined in the last few decades (Williams 1987; VanderWerf 1998). The O'ahu subspecies (*C. s. ibidis*) was recently listed as endangered under the federal Endangered Species Act (U.S. Fish and Wildlife Service 2000). The primary causes of its decline are habitat loss, high adult mortality from introduced diseases, and low reproductive success (VanderWerf 1998). Preliminary results from a study of 'Elepaio demography indicate that the rate of nest failure is high on O'ahu, possibly due to nest predation (E. VanderWerf, unpubl. data). Predatory birds are or were found on each of the Hawaiian islands, but the only terrestrial mammal native to Hawai'i is an insectivorous bat. Hawaiian birds are thus naive with respect to mammalian predators, and predation by introduced mammals, particularly the black rat (*Rattus rattus*), is suspected to be an important cause of the decline of many Hawaiian birds (Atkinson 1977; Scott et al. 1986; Amarasekare 1993).

Nest predation is one of the most important factors shaping the life histories of birds, and it can influence the abundance and distribution of bird species (Martin 1988, 1995). Predation on wild bird nests can be very difficult to study, however, and an increasingly popular method of investigating nest predation is through the use of artificial nests (reviewed in Major and Kendal 1996). Studies that use artificial nests have the advantages of potentially large sample sizes, adjusting for confounding factors such as nest height, location, and density, and less time required to place artificial nests than to find real nests. However, the use of artificial nests has been criticized recently on several grounds, most importantly because the rates of predation on artificial and real nests may not be the same. Artificial nests lack incubating adults, begging nestlings, and fecal material, and therefore may provide fewer visual and olfactory cues to predators, making predation less likely (Petit et al. 1989; Haskell 1994). In contrast, predation on artificial nests may be higher if they are more conspicuous than real nests or if incubating adults are able to drive off predators (Wilson et al. 1998; King et al. 1999). Predation on real and artificial nests was similar in one previous study (Yahner and DeLong 1992), but in others predation was higher on artificial nests (Storass 1988; Reitsma et al. 1990; Wilson et al. 1998; King et al. 1999). The use of Japanese Quail (*Coturnix japonica*) eggs in artificial nests has also been criticized because they may be too large for some predators to break, possibly resulting in erroneously low estimates of predation (e.g., Roper 1992; Haskell 1995; DeGraaf and Maier 1996; but see Craig 1998). Despite these criticisms, if artificial nests are made as similar as possible to real nests, artificial nests are still a useful tool for examining relative predation rates in different areas or at different seasons, or for measuring a treatment effect (Major and Kendal 1996).

The goal of this study was to determine whether control of introduced rodents was effective at decreasing predation on artificial O'ahu 'Elepaio nests. I concurrently monitored success of real 'Elepaio nests, but the

larger sample size of artificial nests made it possible to more quickly address the efficacy of the rodent control program. I used automatic cameras to document the identity of nest predators to ensure that predator control efforts were focused on the appropriate species.

METHODS

This study was conducted at 100–200 m elevation in the Honolulu Watershed Forest Reserve, near the center of the largest remaining 'Elepaio population on O'ahu (E. VanderWerf, unpubl. data). The area is mesic forest composed largely of introduced plants species, including guava (*Psidium guajava*), strawberry guava (*Psidium cattleianum*), mango (*Mangifera indica*), kukui or candlenut (*Aleurites moluccana*), christmasberry (*Schinus terebinthifolius*), and coffee (*Coffea arabica*), with smaller numbers of native plants such as papala kepau (*Pisonia umbellifera*), koa (*Acacia koa*), mamaki (*Pipturus albidus*), and lama (*Diospyros sandwicensis*). For a more detailed description of the habitat see VanderWerf et al. (1997).

A rodent control program was conducted in the study area from 26 January–28 June 1998 in collaboration with the Hawaii State Division of Forestry and Wildlife. Rodents were controlled in an area of approximately 15 ha using a total of 23 snap traps and 18 bait stations containing 0.005% diphacinone rodenticide bait blocks with molasses/peanut butter flavorizer (J.T. Eaton, Twinsburg, Ohio). This area encompassed the territories of 10 pairs of 'Elepaio that were color-banded as part of a demographic study. Traps and bait stations were checked and rebaited twice weekly for the first 4 wks when the capture rate and take of bait were high, then weekly for the rest of the study period. In an effort to maximize the efficacy of control efforts, traps that did not catch any rats and stations from which no bait was taken were moved to new locations during the control program. All baiting procedures were conducted in compliance with U.S. Environmental Protection Agency registration no. 56-42 and special local need no. HI-940001, and with regulations of the Hawaii State Department of Agriculture.

Two artificial nest experiments were conducted in conjunction with the rodent control program; one from 7–22 January 1998, before rodent control efforts began and just before the 'Elepaio nesting season, and another from 30 May–14 June 1998, 4 mo after rodent control began (26 January) and near the end of the 'Elepaio nesting season. Each experiment used 40 artificial nests made from wicker baskets lined with Spanish moss, and each nest contained two Japanese Quail eggs. Twenty of the nests were placed on the ground, and 20 were placed in trees at an average (\pm SD) height of 4.23 ± 0.87 m. Two pairs of nests, each consisting of one ground nest and one tree nest, were placed in each of 10 'Elepaio territories. Ground and tree nests in each pair were separated by an average (\pm SD) of 16.0 ± 1.2 m, and pairs of nests were > 23 m apart, and usually > 50 m apart. Nests were checked after 5, 10, and 15 days, using a mirror-pole in the case of tree nests. Nests were counted as depredated if the

eggs were gone, broken, moved from the nest, or had scratches or tooth marks. Artificial nests were placed in similar locations in both experiments, either at the same height in the same tree or within 1 m of the previous ground nest location. Although 'Elepaio do not nest on the ground, artificial nests were placed on the ground to monitor the potential effect of rodent control on ground-nesting species. Efficacy of the rodent control program was judged by comparing the number of artificial nests depredated before and during rodent control at 5, 10, and 15 day intervals using χ^2 tests.

Predation rates on artificial nests are known or suspected to be affected by many factors, including appearance, location, odor, density of nests, size, type and color of eggs used, and length of exposure (Martin 1987; Yahner and Cypher 1987; Whelan et al. 1994; Yahner and Mahan 1996; Bayne and Hobson 1999; DeGraaf et al. 1999; Lindell 2000), and each of these factors was considered in order to make this experiment more realistic. Dimensions and color of the baskets used (7.5 cm in diameter by 5.0 cm tall; dark brown) were similar to those of real 'Elepaio nests (7.2 cm by 7.8 cm; Conant 1977). Of the 20 artificial nests in trees, 55% were placed in guava, 35% in mango, and 5% each in christmasberry and papala kepau, and these proportions were similar to actual tree species used by 'Elepaio in the same area (55%, 39%, 4%, and 2%, respectively; E. VanderWerf, unpubl. data). Although the average (\pm SD) height of artificial nests (4.23 ± 0.87 m) was lower than that of 'Elepaio nests (9.5 ± 3.8 m, $n = 89$, E. VanderWerf, unpubl. data) due to practical limitations, nests were placed in realistic positions within the tree, and the height of all artificial nests was within the range of heights at which 'Elepaio nests have been found (1.5–19.0 m). Whether artificial nests provided a realistic measure of predation was tested by comparing the numbers of artificial tree nests and real 'Elepaio nests that were depredated and that survived using a χ^2 test.

Prior to being placed in the field, the wicker baskets and nest lining material (Spanish moss) were taken to the Honolulu Zoo and placed in an aviary for one week with several species of Estrildid finches, which roosted in the baskets and began to use them for nesting. I hoped that contact with birds and their feces would impart an odor to the nests that would provide realistic cues for olfactorily-searching predators, such as rats.

Because there were four artificial nests per 'Elepaio territory, the density of artificial nests was four times higher than that of natural 'Elepaio nests, but several other bird species that are more abundant than 'Elepaio, including Japanese White-eyes (*Zosterops japonicus*), Red-billed Leiothrix (*Leiothrix lutea*), Red-vented Bulbuls (*Pycnonotus cafer*) and Red-whiskered Bulbuls (*P. jocosus*), were nesting in the area at the same time, so the density of artificial nests was low compared to the density of nests of all bird species combined. Nests were exposed for 15 d because this is similar to the incubation period in 'Elepaio (18 d; VanderWerf

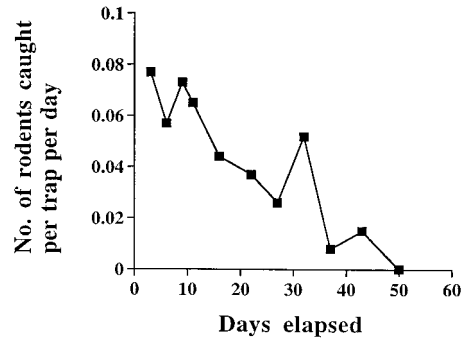


FIGURE 1. Number of rodents captured per trap ($n = 23$) per day in Pia Valley, Oahu. Day zero was 26 January 1998.

1998), and similar to the time used in many previous artificial nests experiments (Major and Kendal 1996).

Whether quail eggs were of an appropriate size to test predation by rats was determined by comparing the width of quail eggs to the jaw gapes of rat species found in the area. The tooth-tip to tooth-tip gapes of rat jaws were measured following the methods of Haskell (1995), in which the coronoid process of the mandible was articulated with the skull, and the jaw was opened as far as possible, until the angular process of the mandible was stopped by the auditory bulla.

In order to document the identity of nest predators, two automatically triggered camera systems were constructed by wiring cameras to artificial nests. Wires were soldered to the camera shutter and flash contacts, then connected to a small lever switch to create a circuit. The lever switch was positioned in the bottom of the nest, and a quail egg was placed on top of the lever to hold it down. If the egg was moved, the lever switch was released, completing the circuit and activating the camera and flash. Photographs were stamped by the camera with the time and date when each was taken. Cameras were deployed at tree nests in 12 locations from 14 January–22 February and in 6 locations from 30 May–14 June. Cameras were moved to a new location if the eggs were depredated or after 10 d of exposure without predation.

RESULTS

The rodent control program appeared to decrease the abundance of rats in the study area. Capture rate of rats in snap traps and take of bait from stations were high at first, but declined rapidly and remained low for most of the study period (Figs. 1, 2). A total of 40 rodents were caught in snap traps, including 17 black rats, 2 Norway rats (*Rattus norvegicus*), 2 Polynesian rats (*Rattus exulans*), 5 house mice (*Mus musculus*), and 14 that could not be identified to species. A total of 980 blocks (55.7 kg) of bait containing 2.78 g of diphacinone (0.005% by weight) were taken during the control program.

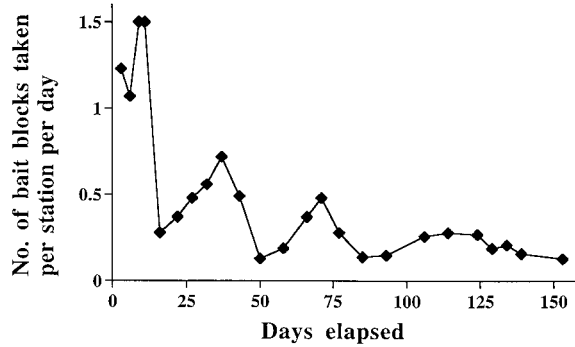


FIGURE 2. Number of bait blocks containing 0.005% diphacinone taken from bait stations ($n = 18$) in Pia Valley, Oahu. Day 0 was 26 January 1998.

A sample of 20 quail eggs used in the experiment averaged (\pm SD) 30.2 ± 1.9 mm in length and 23.7 ± 1.3 mm in maximum width. The average (\pm SD) jaw gapes of 10 museum specimens collected in Hawaii were 20.7 ± 1.3 mm for black rats, 21.7 ± 1.3 mm for Norway rats, and 16.2 ± 1.0 mm for Polynesian rats.

Rodent removal reduced predation on artificial tree nests and ground nests by 45% and 55%, respectively (Fig. 3). Predation on tree nests was lower during rodent control at 5, 10, and 15 d intervals ($\chi^2 = 3.58, 7.62,$ and $8.29, P = 0.059, 0.006,$ and $0.004,$ respectively). Likewise, predation on ground nests was lower during rodent control at 5, 10, and 15 d intervals ($\chi^2 = 12.13, 14.55,$ and $12.38, P = 0.001, < 0.001,$ and $< 0.001,$ respectively). The survival rate of artificial nests in trees (80% over 15 d, daily survival probability = 0.985) did not differ from the survival rate through incubation of 'Elepaio nests in the study area during rodent

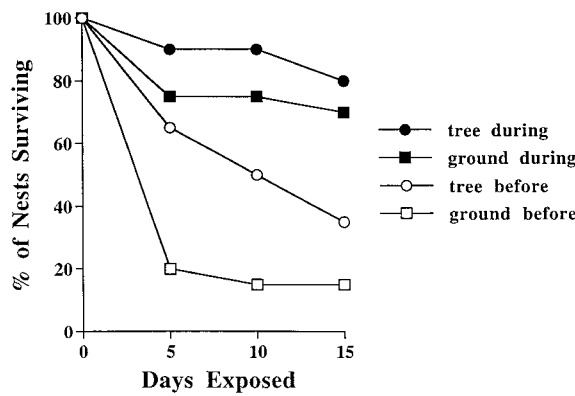


FIGURE 3. Percent survival over time of artificial nests with quail eggs placed on the ground and in trees, before and during rodent control in Pia Valley, Oahu.

control (82% over 18 days, daily survival probability = 0.989, $n = 22$, $\chi^2 = 0.022$, $P = 0.88$; E. VanderWerf, unpubl. data).

Before rodent control, predation was higher on ground nests than on tree nests at 5 and 10 d (Fig. 3; $\chi^2 = 8.29$ and 5.58 , $P = 0.004$ and 0.018 , respectively), but after 15 d the difference was no longer significant ($\chi^2 = 2.13$, $P = 0.14$). Ground nests were depredated more rapidly than tree nests, but most tree nests were depredated eventually. After rodent control predation was low on both ground and tree nests, and did not differ between these two groups at 5, 10, or 15 d intervals ($\chi^2 = 1.56$, 1.56 , and 0.53 , $P = 0.21$, 0.21 , and 0.47 , respectively).

There was no difference in mean (\pm SE) height of tree nests that were depredated and those that were not depredated, either before rat removal (4.26 ± 0.23 m vs. 4.18 ± 0.39 m, respectively; Mann-Whitney U -test = 136, $P = 0.86$) or after rat removal (3.89 ± 0.14 m vs. 4.02 ± 0.24 m, respectively; Mann-Whitney U -test = 28, $P = 0.20$).

Of the 80 eggs in the 40 nests that were depredated in both experiments, 35% were completely removed, 25% were broken and had tooth or chew marks, 15% were broken but had no marks, and 25% were not broken but had scratches or tooth marks. The number of eggs in each of these four categories did not differ between tree and ground nests ($\chi^2 = 2.10$, $P = 0.55$), or before versus after rat removal ($\chi^2 = 3.94$, $P = 0.27$). Of the 20 sets of eggs with tooth marks, 15 had paired tooth marks separated by a distance similar to that between rat incisors, two had very small, closely-spaced paired marks indicative of mouse incisors, and three sets on the ground had large chewing marks, such as might be caused by a larger predator like a small Indian mongoose (*Herpestes auro-punctatus*) or feral cat (*Felis catus*).

Cameras wired to artificial tree nests documented 10 predation events in 12 locations before rodent control; in every case the predator was a black rat. One photograph showed a black rat with a quail egg in its mouth, demonstrating that black rats prey on eggs and that quail eggs are not too large for rats to carry. Nests were depredated by rats rapidly and at night; 9 of 10 predation events took place on the first night the nest was placed in the field, the other occurred after 5 d. Eight of 10 photographs were taken between 1854 and 2347 h, the others at 0139 and 0506 h. In two of the 10 cases where photographs showed that a rat had visited the nest, the egg was not harmed, and there was no evidence that the nest had been disturbed, perhaps because the rat was scared off by the flash. Later in the season during rodent control, none of six nests with cameras were disturbed, so no predation events were documented, presumably because relatively few rodents were left in the area.

DISCUSSION

Artificial nest experiments demonstrated that a rodent control program was effective at decreasing nest predation in O'ahu 'Elepaio habitat. Predation rates on artificial nests placed in trees and on the ground were 45% lower and 55% lower, respectively, during rodent control than before

rodent control. Moreover, the survival rate of artificial tree nests was similar to that of natural 'Elepaio nests in the study area, indicating the artificial nests provided a realistic measure of predation on 'Elepaio nests. Control of introduced rodents appears to be an effective management technique for increasing the reproductive success of 'Elepaio, but monitoring of 'Elepaio nests should continue to verify these results. In a similar study, Robertson et al. (1994) found that control of Polynesian rats lead to a dramatic increase in nest success and population size of the Rarotonga Monarch or Kakerori (*Pomarea dimidiata*) in the Cook Islands.

Photographs taken by automatic cameras identified black rats as the main predator at artificial nests, which was not surprising. Black rats are known to be arboreal and are thought to be serious predators on the nests of many Hawaiian birds (Atkinson 1977; Amarasekare 1993). Smaller numbers of Polynesian rats, Norway rats, and house mice were also caught in snap traps, but all 10 photographs showed black rats taking quail eggs, indicating these other rodents are less serious nest predators in O'ahu 'Elepaio habitat than are black rats.

Rats were quite capable of preying on quail eggs even though the jaw gapes of all three rat species were smaller than the maximum width of quail eggs used in this study. Many broken eggs had paired tooth marks of a size indicative of rat incisors, and a black rat was photographed with an egg in its mouth, demonstrating that rats can carry eggs larger than their gape. Similarly, Craig (1998) found that least chipmunks (*Tamias minimus*) with a jaw gape of only 16.0 mm were capable of breaking quail eggs by biting them at the small end while using the side of the nest for leverage. Two eggs had small tooth marks indicative of mouse incisors, but were not broken, suggesting very small predators like mice might be unable to break quail eggs. These cases were counted as predation events even though the egg was not broken because 'Elepaio eggs (mean length \times width = 19.8 \times 15.2 mm; VanderWerf 1998) are smaller than quail eggs and smaller predators probably would be able to break them. Three eggs were found with large chewing marks suggestive of cats or mongooses, all from ground nests. Most 'Elepaio nests are built on thin branches 1–2 cm in diameter (VanderWerf 1998), where they probably are not accessible to large predators like cats or mongooses.

Previous studies have shown that olfactory cues can affect predation rates on artificial nests (Whelan et al. 1994) and on natural bird nests (Petit et al. 1989). Predators may even use human scent trails left by researchers to locate artificial nests, and some studies have attempted to reduce this potential bias by removing human scent from eggs and nests or by masking human scent with other scents (Whelan et al. 1994; Major and Kendal 1996). Several studies have used bird nests from previous years to increase visual realism (e.g., Martin 1987), but no previous studies have attempted to provide realistic olfactory cues. In areas where most predators are diurnal and locate nests visually the lack of natural olfactory cues and presence of human scent may not be important, but in areas where the primary nest predators are nocturnal and locate nests by ol-

faction, like rats, the potential biases of olfactory cues should be considered (Whelan et al. 1994). If an attempt is made to reduce the bias from human scent by masking it with another scent, the masking agent might as well provide a natural cue that predators would associate with bird nests. The realism and validity of artificial nest experiments may be improved by exposing nest materials to birds before they are placed in the field, as was done in this study.

Predation pressure in O'ahu 'Elepaio habitat prior to rodent control was high. Ninety percent of predation events documented by automatic cameras occurred on the first day of exposure, and the majority of both tree and ground nests were depredated. It seems unlikely that 'Elepaio populations are sustainable with such a high rate of nest failure. Predation by introduced mammals likely was an important factor in the extinction of many Hawaiian birds, especially ground-nesting species (Olson and James 1982), and predation is thought to currently limit populations of several endangered species, including the Nene or Hawaiian Goose (*Branta sandvicensis*; Stone et al. 1994), the Hawaiian Dark-rumped Petrel (*Pterodroma phaeopygia*; Pratt 1994), Newell's Shearwater (*Puffinus auricularis newelli*; Pratt 1994), and several species of endangered water birds (U.S. Fish and Wildlife Service 1999). Birds on oceanic islands like Hawai'i that originally had no mammalian predators may be especially vulnerable to predation by introduced species, and predator control may be necessary for the long-term conservation of many of these species.

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