

Effects of alien rodents on Hawaiian mesic forest

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Introduction

Four rodents were introduced to the Hawaiian Islands upon human settlement (*Rattus exulans* in 700 AD; *R. rattus*, *R. norvegicus*, and *Mus musculus* shortly after Captain Cook's arrival in 1778). Because the flora and fauna in Hawai`i did not evolve with any terrestrial mammals, there is strong potential for pronounced biotic change to result from the presence of alien rodents in Hawai`i. With such unique characteristics as arboreal and ground foraging, gnawing and destroying seeds, and high fecundity and population growth, rodents have the potential to alter Hawaiian ecosystems through their effects on plant recruitment.

My research is focused on completing the following: 1) Estimate rat densities, distribution, and habitat use, 2) Determine which fruits, seeds, and seedlings are vulnerable to rodents (particularly rats), and 3) Determine whether particular characteristics of fruits and seeds can predict vulnerability to rodents. Exploring these aspects will provide a better understanding of rodent biology in Hawai`i, and will assist in rodent control and Hawaiian natural resource management.

Methods

Study Site

This research occurs at three study sites in the Wai`anae Mountains, Oahu. Kahanahaiki (KHI) and Kaluaa at Honouliuli (HON) are the two sites that have been studied during this past year. Research at Makaha (MAK) will begin upon completion of the fence and ungulate extermination. All three sites are in mesic, montane forest at 500-660 m a.s.l., and all have a mixed flora that includes both native and alien plant species.

Density, Distribution, Habitat use

Distribution and abundance of rats at KHI and HON were assessed every two months from February-June 2007 using the mark-and-recapture technique (Seber 1982; Johnson 1994, Lindsay *et al.* 1999). Hagaruma live traps were set along transects at 25 m intervals. Four to six transects per site were established and each transect was approximately 50 m from adjacent transects. As a result, the total trapping area for KHI was 2.81 ha, whereas the trapping area for HON was 2.87 ha. A bi-monthly trapping event consisted of four consecutive trap nights where all 45 traps were opened. All traps were baited with fresh chunks of coconut and pre-baiting with shredded coconut took place 2-3 days prior to opening traps. Mice were also prevalent at both study sites, but because of the high abundance of rats captured at KHI there was insufficient time to process and tag all captured mice. Therefore, mice abundance and distribution was only determined for HON. On a single occasion, I attempted to use track tunnels to provide an index for rodent densities as the track tunnel could be compared to live-trap captures at KHI. This method will be improved and utilized in the future at KHI to assist with rodent estimates that do not require trapping or handling animals.

In order to estimate *R. rattus* home-range and habitat use at KHI, a subset of the captured rats were fitted with radio collars. Each radio collar was <4% of the animal's body weight (mean \pm SE collar mass: 3.86 ± 0.10 g). Radio telemetry provides a coarse-scale estimate of habitat use. Nighttime radio telemetry was conducted using the triangulation method (Lindsay *et al.* 1999). Finer scale habitat use was determined using two additional methods: 1) track tunnels were placed on the ground and in trees at KHI to compare activity levels in the two habitats, and 2) string bobbins were attached to the backs of rats (at KHI and HON) and mice (at HON only) to determine microhabitat use (see Hoare *et al.* 2007 for methods).

Rat Effects on Plants

Twelve stations (3 treatments x 4 replicates) for each species, each 10 m apart, were established along transects at KHI to determine the vulnerability of fruit and seeds to rodents. Each station was randomly assigned one of the following treatments: 1) no-vertebrate-access, which consists of a wire metal mesh (1.2 cm aperture) open-bottom square box (30 x 30 x 30 cm; length x width x height) that excludes all potential vertebrate seed predators and dispersers (*e.g.*, rodents, pigs, cats, birds, mongoose) and acts as the control to compare subsequent treatments, 2) small-vertebrate-access, which is the same dimensions as the no-vertebrate-access but four holes (one on each of the side-walls; 10 x 10 cm each) allow small vertebrates (such as rodents) to access the interior but excludes the entry of other large animals (*i.e.*, pigs and cats), and 3) open forest floor, where all vertebrates are able to freely access the station. Each mesh enclosure was pushed into the ground *ca.* 1 cm and held in place using 8 cm long turf staples. In order to determine if rats versus other similar-sized vertebrates (mice, mongoose, birds) enter the small vertebrate access treatment, and/or the open treatment, motion-sensing cameras (Bushnell Sentry 2.1 MB or Multrie) were placed at a subset of these treatment stations. Fruits of *Sapindus oahuensis* and *Pouteria sandwicensis* were collected from the study site, placed within each treatment, and removal was quantified over a 25 d period.

Results

Density, Distribution, Habitat use

During the February through May samplings, 103 rats were captured, marked, measured, and released at HON and KHI. Only two *R. exulans* were captured (both at KHI), as the remainder (98%) of the rats were *R. rattus*. The majority (*ca.* 60%) of the rats captured were males, and juvenile rats represented <13% of the rats captured at either site (Figure 1). There was a pronounced difference in rat captures between the two sites, as KHI had 2-4 times more individuals captured than HON (Figure 2). There appears to be slightly more rats captured at both sites during May than March (Figure 2). Rats were only active during the night, as no rats but several mice were captured on three occasions where traps were opened during the day at each site.

Ten *R. rattus* were radio-collared and tracked from February through June 2007 (Table 1). The locations of collared rats were taken both during the daytime (inactive period) and nighttime (active period) approximately once a week. The home-ranges of each of the 10 rats are still being analyzed; however, all collared rats have home-ranges <1 ha, and movement distances appear to be relatively close to den sites (range: 7-145 m; Table 1). Rat den sites were located both in the ground and in trees (live and dead). The most common trees for rat den sites were aliens (*Grevillea robusta*, *Psidium cattleianum*, *Aleurites moluccana*), although one female rat had a short-term (<1 week) den site in a cavity of the native *Santalum paniculatum*. All collared rats at KHI changed den sites multiple times (1-6 times) and only two rats returned to previously-used den sites after selecting a new den site. There were no occasions where two

collared rats shared the same den site; however, home-ranges commonly overlapped. Additionally, two collared females had their collars chewed off, presumably by a mate, suggesting social interactions among these feral rats. Four of the 10 rats suffered predation (Table 1), as rat collars were retrieved on the forest floor with only a rat stomach remaining or in one case only part of the pelt present. Stomachs from rats that were not collared were found on two occasions at KHI, suggesting that the collars did not cause the mortality of radio-collared rats. There are a suite of predators at KHI, as motion-sensing cameras revealed at least one feral cat and several mongooses at KHI. Barn owls, another potential predator of rats, have been observed on several occasions during nighttime radio telemetry and the remains of one dead rat (non-collared individual) was characteristic of barn owl predation (S. Mosher, personal communication).

Bobbins that were attached to rats provided up to 210 m/individ. of habitat use data. For all individuals with bobbins attached, rats did not travel further than 50 m from the trap site before the string ran out. There was not a clear partitioning of habitat for rats between the canopy and ground: rats that were caught on the ground used tree and ground habitat, and likewise, rats that were caught in the trees used both the tree and ground. Overall, rats appeared to use the ground habitat (79%) more than the trees (21%). When traveling above ground, rats were most often <1 m high, but in some cases they would climb to 12 m height. Bobbins were attached to mice that were caught on the ground at HON. Like the rats with bobbins attached, mice used both the canopy (up to 4.1 m) and the ground and traveled up to 55 m from the trap site while using up to 63 m of string.

Rat Effects on Plants

Both *Pouteria sandwicensis* and *Sapindus oahuensis* fruits were attractive to rats at KHI, as at least 25% of total fruit was removed after 5 d and 45% was removed after 25 d (Figure 3). Compared to the highly attractive *Pritchardia* fruits that were used in similar trials at Lyon Arboretum (wet forest), the two species used at KHI were removed less rapidly (Figure 3). All four species are relatively large-fruited Hawaiian natives (Table 2). Removal of *P. sandwicensis* was terminated after 25 d due to fruit rot. For both species of *Pritchardia*, and for *P. sandwicensis*, there was no difference ($P > 0.05$) in fruit removal between small-vertebrate-access treatments and open sites. However, *S. oahuensis* tended to have a higher fruit removal rate from small-vertebrate-access treatments than open sites. Therefore, at least in some cases, the wire mesh used for the enclosure treatments may act as an attractant to seed predators. Future trials will use a fourth treatment to test for cage effects. In all cases for these trials, the fruit remained in the no-vertebrate-access treatment. Motion sensing cameras did not capture any animals removing fruits at KHI during the trials.

Discussion

Density, Distribution, Habitat use

Rats are prevalent throughout both study sites, and *R. rattus* is the dominant rat species. Although *R. rattus* are commonly diurnally active on some islands in the Pacific, there were not any rats captured at KHI or HON when traps were open during the day. This is probably due to densities at my sites not reaching those on small islands that cause greater competition and a survival need to be active both diurnally and nocturnally. Densities of *R. rattus* at HON and KHI were similar to those sampled at lower elevation sites on Oahu from 1968-1970 (Tamarin & Malecha 1972). There is not a clear explanation for the 2-4 times greater density at KHI when compared to HON, although environmental conditions and variation in predator and/or food resources are possible explanations. The KHI rat densities (30 *R. rattus*/100 trap nights) are

similar to those reported for Paradise Park in Manoa Valley (24 *R. rattus*/100 trap nights; Tamarin & Malecha 1972). Although the HON site appears unreasonably low when compared to KHI (8 *R. rattus*/100 trap nights), it is nearly identical to the average densities of four of the five sites sampled across various wet-dry habitats on Oahu (ca. 8 *R. rattus*/100 trap nights; Tamarin & Malecha 1972). The densities of *R. rattus* at Hakalau Forest National Wildlife Refuge (11-25 *R. rattus*/100 trap nights; Lindsay *et al.* 1999) were also within the range of those reported in my study, yet the abundance of juvenile *R. rattus* (<13%) at my study sites is half that reported at Hakalau (26%; Lindsay *et al.* 1999). However, the highest proportion of juveniles at Hakalau was found during September-November, so it is possible that recruitment may be more similar when I sample these months at my sites. Both HON and KHI appear to exhibit a slight increase in rat densities in May compared to March, and such information can be useful for focusing rat control strategies when a year-long data set is completed.

Habitat use patterns for *R. rattus* at my study sites do not match those reported in Lindsay *et al.* (1999). Home-range estimates in my study are <1 ha, whereas those reported for *R. rattus* at Hakalau average 3.6 ha. Because the densities of rats are similar between my study and that of Lindsay *et al.* (1999), the greater area used by *R. rattus* at Hakalau compared to those at my sites may be a result of fewer food resources at Hakalau. Den sites were also different between the two studies as all *R. rattus* den sites at Hakalau were only in trees above ground, whereas den sites at KHI were both in the ground and in the trees. Comparison of the habitat use data between these two studies also suggests that *R. rattus* at HON and KHI do not use trees as much as *R. rattus* in the wetter, higher elevation forest of Hakalau. With surprisingly high predation rates at KHI (40% mortality during 4 months of sampling), it is surprising that rats do not use the canopy more than the ground.

Rat Effects on Plants

Rats removed fruits of all four plant species (Table 2, Figure 3). Only rats were photographed removing fruit of *Pritchardia*; however, cameras were not triggered when *Pouteria* and *Sapindus* were removed at stations in KHI. This may be a result of fewer cameras deployed during the trial period at KHI. At least 25% were removed within 7 days and three of the four species had over 60% fruit removed during the study. More species with a wider range of fruit and seed traits will be tested to determine which qualities are most attractive to rats. A better understanding of seed fates will help uncover specific impacts of rats as seed predators and/or seed dispersers. These current findings show that we cannot ignore alien rats in island ecosystems as they have the potential to alter plant composition through their effects on fruits and seeds.

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Goals for the next year:

- Begin analyzing rat diets: stomach contents and possibly stable isotope analysis from snap trapped rats. Analyze droppings for seed content.
- Continue to estimate rat abundance bimonthly at HON and KHI. Add MAK when pig free.
- Periodically use track tunnels at each site in attempt to associate live-trap densities with track tunnel activity.
- Continue field diaspore trials using exclosures and motion-sensing cameras at HON and KHI.
- Measure fruit/seed rain at KHI for 1 year.
- Set up plots to measure and permanently tag all plants >1 cm at all three sites.
- Begin captive feeding trials with rodents at Lyon Arboretum. I recently built a housing facility (see Figure 4) and received approval to conduct these trials during the next year.
- Take comprehensive exams.
- Submit *Pritchardia* manuscript, and begin preparing habitat-use manuscript.

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Table 1. *R. rattus* individuals with radio collars attached and tracked at Kahanahaiki during February to June, 2007.

Rat #	Sex	Den site	Max Den distance from trap	Tracking duration	Currently tracking	Reason dis-continued
.111	Male	Tree	81 m	62 days	No	Battery died
.1717	Male	Tree	89 m	65 days	No	Battery died
.212	Male	Ground	22 m	164 days	Yes	-
.0524	Male	Tree	38 m	60 days	No	Killed/ predation
.152	Female	Ground & Tree	7 m	50 days	No	Killed/ predation
.191	Female	Ground	145 m	40 days	No	Collar malfunction
.013	Female	Ground & Tree	31 m	78 days	Yes	-
.032	Female	Ground	20 m	8 days	No	Collar malfunction
.1324	Female	Ground & Tree	26 m	34 days	No	Killed/ predation
.0725	Female	Ground	39 m	14 days	No	Killed/ predation

Table 2. Fruit characteristics of the four native Hawaiian species used in the field trials (Mean \pm SE; N = 4-20).

Species	Family	Mass (g) (fresh)	Length (cm)	Width (cm)	% water content
<i>Pouteria sandwicensis</i>	Sapotaceae	16.05 \pm 1.91	3.42 \pm 0.09	2.63 \pm 0.09	62.48 \pm 1.07
<i>Pritchardia affinis</i>	Arecaceae	6.15 \pm 0.32	2.48 \pm 0.04	2.15 \pm 0.04	25.65 \pm 0.91
<i>Pritchardia hillebrandii</i>	Arecaceae	2.50 \pm 0.09	1.72 \pm 0.02	1.69 \pm 0.03	26.69 \pm 0.79
<i>Sapindus oahuensis</i>	Sapindaceae	5.42 \pm 0.44	2.90 \pm 0.10	2.31 \pm 0.08	28.90 \pm 3.29

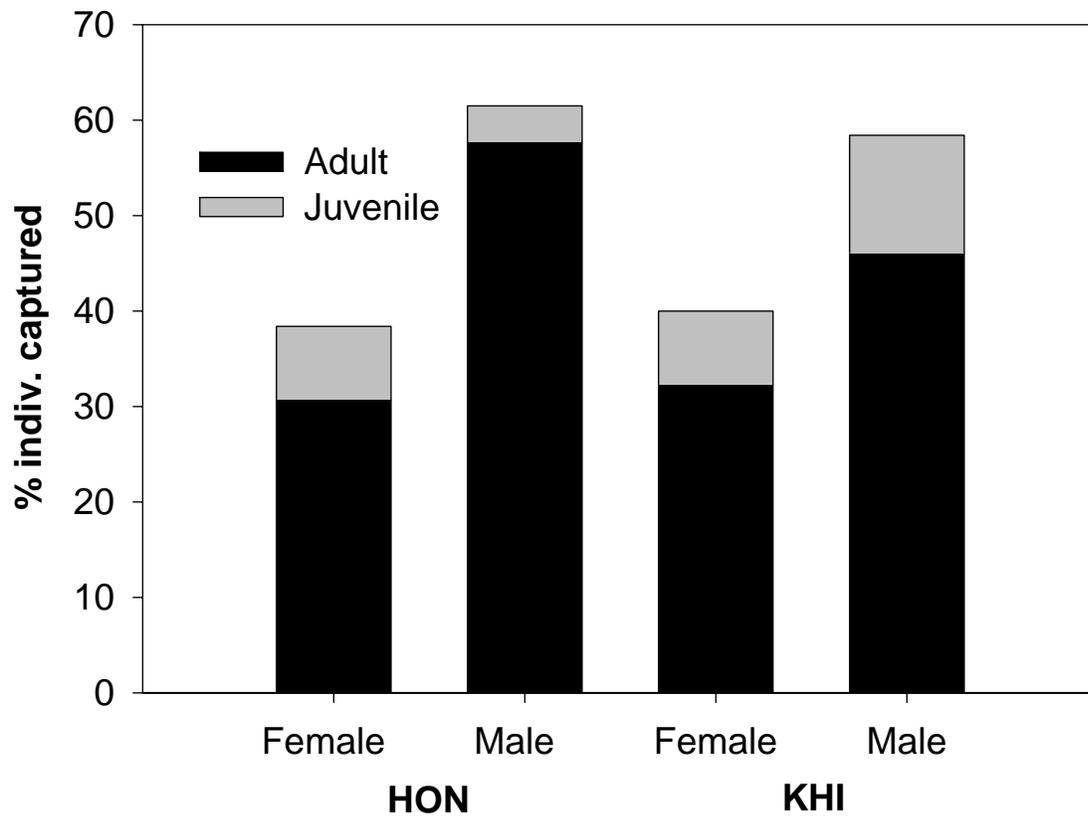


Figure 1. Proportion of adult and juvenile rats (*R. rattus*) captured at Honouliuli (HON) and Kahanhaiki (KHI) from February through April, 2007.

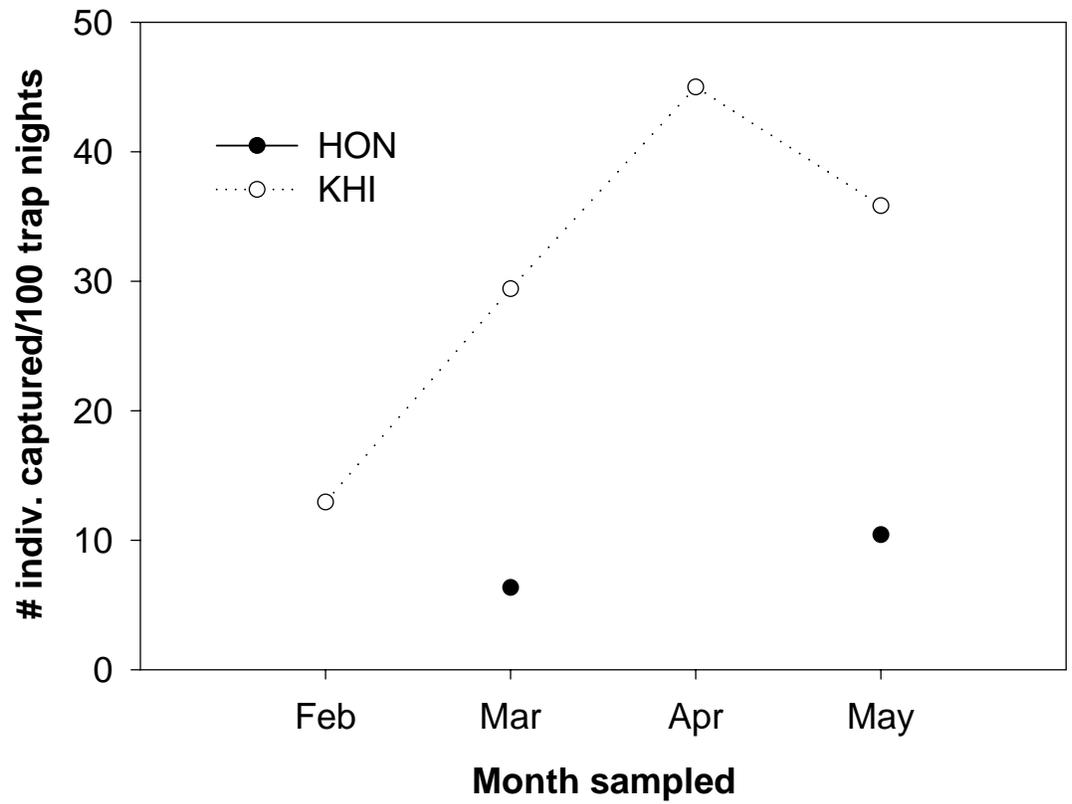


Figure 2. Capture rates (# indiv./100 trap nights) for *R. rattus* at HON and KHI during 2007.



Figure 3. Total fruit removal from the forest floor of four native Hawaiian species (*Pouteria sandwicensis*, *Pritchardia affinis*, *Pritchardia hillebrandii*, *Sapindus oahuensis*). Trials for both species of *Pritchardia* were conducted in wet forest at Lyon arboretum, whereas trials for *Pouteria* and *Sapindus* were conducted in mesic forest at Kahanahaiki.

Figure 4. Relevant photographs and descriptions from field and laboratory.

Rodent Capture and Processing at Field Site



(Left) Photo of feral black rat (*Rattus rattus*) at field site. (Right) Anesthetizing procedure: a rodent trapped in a live-trap is placed in a large ziplock bag with a cotton ball containing isoflurane. The condition of the rodent can be easily monitored through the clear bag. This procedure allows for easy transfer to suspended rodent cages.

Laboratory Facilities – Lyon Arboretum Rodent Housing Facilities (LARHF)



Upper: (Left) Workshed at Lyon Arboretum. Notice padlocked door & screen-covered windows to allow airflow. Water spigot is on the far right side of this building. (Middle) Plastic partition that separates Lyon employee workspace from the rodent-housing facilities (located on the far side of the partition). (Right) Rodent-housing facility. Partition lets some ambient light penetrate.

Lower: (Left) Rodent hanging cages and plastic shelving. All wall-space is lined with black plastic. Notice the floor is gravel beneath the cages. (Middle) Close-up of cage showing removable pan for rodent waste collection and the cage's suspended flooring. (Right) Supplemental lighting and a fan to cool temperature (thermometer not shown) in the rodent-housing facility.

