



Rat-Feeding Injury to Plants in Hawai'i

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Several species of rats attack important crops and native plants in Hawai'i. They cause feeding injury to roots, stem bark and pith, petioles, flowers, buds, fruits, pods, and seeds (Table 1). Depredations by the roof rat (*Rattus rattus*), the Polynesian rat (*Rattus exulans*), and the Norway rat (*Rattus norvegicus*) reduce income and increase overhead expenses for farms, orchards, and gardens. They cause considerable damage to landscapes and alter forested ecosystems.

Among important agricultural plants in Hawai'i, rats cause particularly acute economic damage to macadamia, sugarcane, citrus, banana, and avocado. They can severely injure many other plant species, such as palms and kava (*Piper methysticum*). Through predation and competition for food, rats also contribute to the decline and extinction of Hawaiian bird species.

Perhaps most importantly, rats vector several infectious human pathogens and parasites that cause debilitating diseases and maladies, such as rat lungworm. Therefore, suppressing outbreaks of rats becomes a primary concern for farms, households, and society in general. Here we describe the three rat species established in Hawai'i, along with their ecology and damage to natural and agroecosystems, and we suggest integrated management practices for their effective suppression.

Rats in Hawai'i

Polynesian Rat

Native to Southeast Asia, the Polynesian rat (*R. exulans*) occurs throughout the central and western Pacific. It has colonized most of the Pacific islands within 30° of the equator but is not yet present in the mainland United States (Tobin 1994). Also known as the Pacific rat, it came to Hawai'i in Polynesian canoes about 400 A.D. Comparatively small in size among rat species, the Polynesian rat weighs 56 to 85 g (2 to 3 oz.) and measures



The Polynesian rat (*Rattus exulans*) (photograph: D. Vietch).

10 to 13 cm (4 to 5 in) in length. The tail is as long as, or slightly longer than, the combined length of the head and body. Bristles along the tail form faint, narrow rings. The body color is cinnamon-brown to cinnamon-buff or grey. Stiff black guard hairs grow along the back and sides of the body. The underbelly color is grey or light buff. The Polynesian rat has a roundly pointed nose, short ears, and medium-sized eyes. The soles of the hind feet are darkly colored. Females have four pairs of nipples.

In Hawai'i, Polynesian rats primarily inhabit fields and are most commonly found below 2,500 feet (750 m) elevation (Tobin 1994). Their populations are largest on agricultural lands, including sugarcane (*Saccharum* spp.) and pineapple plantations (*Ananas comosus*) (Tobin 1994). They nest within burrows, gulches, rock piles, rock walls, wastelands, fields, and embankments. The Polynesian rat causes significant damage to sugarcane, pineapple, macadamia nuts (*Macadamia integrifolia*), coconuts (*Cocos nucifera*), coffee (*Coffea arabica*), and many other fruit and vegetable crops in Hawai'i (Brennan 1980).

The diet of Polynesian rats is diverse and includes broadleaf plants, grasses, fruits, seeds, and some animals and their eggs. They prefer fleshy fruits such as melastoma (*Melastoma malabathricum*), passion fruit (*Passiflora* spp.), guava (*Psidium* spp.), thimbleberry (*Rubus rosaefolius*), and popolo (*Solanum nodiflorum*) (Tobin 1994). Rats, needing more protein than plants can provide, also consume earthworms, spiders, amphipods (an order of crustaceans), insects, and the eggs and young of ground-nesting birds (Tobin 1994).

Norway Rat

The Norway rat (*R. norvegicus*), also known as the cellar rat, brown rat, wharf rat, and sewer rat, arrived in Hawai'i on European ships in the 18th century. The Norway rat is the largest of the rats found in Hawai'i, measuring 20 to 25.4 cm (8 to 10 in.) long and weighing 283 to 510 g (10 to 18 oz.). The Norway rat's stout tail is usually shorter than the length of the head and body combined. The Norway rat burrows in the soil to nest, or lives in rubbish piles or garbage dumps, or under walks and maritime docks (US Fish & Wildlife Service 2008). On farms, the Norway rat inhabits barns, granaries, livestock buildings, silos, and kennels (Timm 1994).

Norway rats are sexually prolific, as are the other rat species. Given sufficient food, shelter, and water, mother rats can birth from 8 to 12 offspring every 30 days. Young rats become sexually mature at 3 to 4 months of age (US Fish & Wildlife Service 2008) and can reproduce continuously until death. Therefore, a rat population can

theoretically increase from 1 to many millions within one year. Norway rat females may come into heat every 4 or 5 days, and they may mate within a day or two after a litter is born. The average female rat has 4 to 6 litters per year and may successfully wean 20 or more offspring annually (Timm 1994).

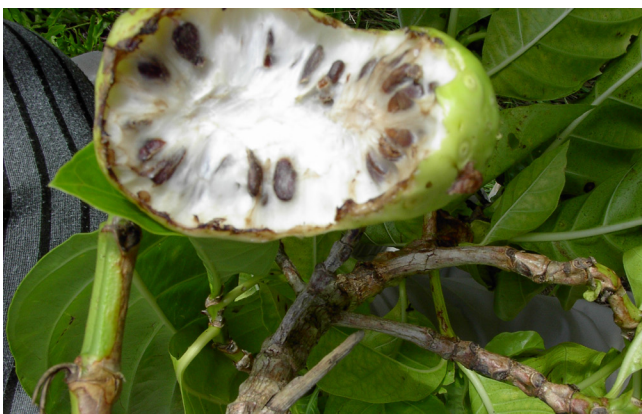
Roof Rat

The roof rat (*R. rattus*) is a medium- to large-sized rat. The body measures 13 to 18 cm (5 to 7 in.) in length and has a slender tail that is longer than the head and body lengths combined. The body color of the roof rat varies from grey to jet-black. The underside is grey, grey-white, or white. The nose is sharply pointed. The face has large eyes, with large, thin ears. Adult females have five pairs of nipples (Brennan 1980).

This pest is an expert climber and can scale stems, trees, wires, and fences readily. Among agricultural plantings, the roof rat prefers sugarcane fields, macadamia nut orchards, coffee and papaya farms, and banana plantations. It has also caused extensive damage to some endemic plants within native Hawaiian ecosystems. The roof rat nests in attics of buildings, trees, banana bunches, and the abandoned burrows of Norway rats (Brennan 1980).

Symptoms of Rat Feeding and Chewing Injury

Rats are omnivorous and eat almost any type of food, from plants to animals. Among agricultural plants and commodities, rats consume a wide variety of fruits, nuts,



Rat-chewing injury to a fruit of noni (*Morinda citrifolia*). These pests are voracious eaters.



Rat claw damage to fruits of mai'a 'ele'ele (photograph: Angela Kay Kepler).

and plant tissues for sugars, proteins or amino acids, vitamins, and minerals.

Rats require 15 to 30 ml (½ to 1 oz.) of water daily when they feed on dry foods but drink less when consuming moist foods (Timm 1994). They must drink water at least once every 2 days and must eat food at least once every 4 days (Brennan 1980).

Rats have preferred sources of water and food. However, when these sources become less plentiful or unavailable, or during adverse weather events, rats shift their depredation to other targets, sometimes with devastating consequences to agroecosystems. To obtain water during dry periods, rats may chew holes in drip irrigation lines or gnaw on plant stems, pith, and bark. During such periods of drought, rats seek water from the stems and petioles of succulent plants. The pith and cambium of young coffee stems, for instance, contain water and nutrients preferred by roof rats. Rats may descend upon coffee verticals from overhanging tree branches that come in contact with the plant. During periods of rainy weather or flooding, rats are driven into the foliage of trees to nest and feed. Therefore, feeding injury to some plant species is weather dependent and typically varies with time and circumstance. For example, during rainy weather, rats often seek shelter in banana bunches, where they nest and feed on banana fruits.

Feeding injuries caused by roof rats, Norway rats, and Polynesian rats are similar in appearance, ranging from barely perceptible nicks in epidermal tissues and

fruit rinds to distinct, well-defined, canoe-shaped cavities (Tobin 1994). The most diagnostic sign of rat feeding is parallel, narrow rodent teeth marks in plant tissues caused by gnawing or scraping. Much of the feeding injury within the canopies of trees and palms is due to roof rats, which are expert scalers and nimble climbers.

Signs and Diagnosis

One or more of the following common signs can help determine the presence of rats:

- Rat feces, soft in texture when fresh, occurs along runways, near shelters, and at feeding sites. The droppings may measure up to ¾ inch (2 cm) long and ¼ inch (0.6 cm) in diameter (Timm 1994).
- Small chips from the food source may be present on the ground where rats feed.
- Rat damage can be readily distinguished from that of feral pigs (*Sus scrofa*); pigs chew on entire stalks, shredding them and trampling vegetation, whereas rats cause more localized and discrete injuries (Tobin 1994).
- Rat feet and tail marks occur as tracks along rat pathways in dust or mud. Such evidence of rats may be collected by scattering flour over a pathway and inspecting it in the morning (Timm 1994). Rat claw marks may appear on soft plant tissues, such as the skins of ripe bananas.
- Rat urine, either wet or dry, fluoresces under ultraviolet light. The urine stains are visible along pathways



Rat-chewing injury to a stem of Hawaiian 'awa (kava, *Piper methysticum*). Feeding injuries caused by roof rats, Norway rats, and Polynesian rats are very similar, ranging from barely perceptible nicks in epidermal tissues or rinds to neatly chiseled canoe-shaped cavities.



Rat-chewing injury to an 'Okinawan' purple sweetpotato. The long, scraping teeth marks typify rodent feeding injury and are a diagnostic symptom.



Left: Rats feed on the pith of plant stems to obtain sugar and moisture. **Middle:** Rats often feed on the petioles of palm species, such as this Manila palm, often killing the leaves and causing them to drop to the ground. **Right:** Rat-chewing injury to ripe Hawaiian apple bananas ('Santa Catarina', dwarf Brazilian). Rat damage may coincide with damage by birds such as mynahs, as depicted here. However, rat injury may be diagnosed by the long, scraping claw marks made by grasping rats that are visible on the banana fruit skins. Another way to identify rat damage is to smell for the aroma of their urine, as these pests tend to urinate where they feed.

or in feeding areas (Timm 1994). A strong odor of rat urine is present in nests and feeding areas.

- Runs or rat burrows are commonly found adjacent to walls, along fences, next to buildings, or under bushes and debris. Rats habitually use the same routes for their travel. Smudges made by rat bodies may mark these routes (Timm 1994).
- Damaged plant materials usually have the gnawing injury characteristic of rodent teeth (see the photographs in this article). Gnawing marks and accumulated debris also occur on and around surfaces infested by rats (Timm 1994).
- Rats make characteristic sounds associated with gnawing, climbing, clawing, and combat (Timm 1994).
- Fallen green palm fronds may show chewing injury on the petioles at the point of detachment.
- Partially detached, severed, or collapsed stems on plants such as coffee show gnawing injury.
- Nests are present and may be visible, as often seen in banana bunches.
- Holes chewed by thirsty rats are present in drip irrigation tubes, or holes may be chewed in polyethylene sleeves covering banana bunches by rats seeking food and shelter.

Injuries made by other pests may resemble those caused by rats. Mice cause similar feeding injuries, but their tooth marks are smaller and narrower. Although bird-feeding injury resembles that of rats on soft fruits such as banana or papaya, the beaks of birds make narrow probing holes in fruits, unlike the gnawing produced by rats' teeth. Birds with diurnal habits may also be seen feeding on fruits during daylight hours.

Management

Rats are an exotic, invasive species in Hawai'i, so they are not protected by law. They may be controlled by any method consistent with state and federal laws and regulations (Tobin 1994). Please refer to articles cited in the References section of this paper for comprehensive discussions of rat management (e.g., for Norway rats, refer to Timm 1994).

General Considerations

- Because rats are such prolific breeders, their populations can rise rapidly and reach very high numbers. The best approach for farmers is to implement management practices before rat populations are large enough to cause significant economic losses (Economic Injury Level).



Rat-chewing injury to vertical coffee stems. This type of damage is common when coffee is planted near forest trees.

- The goal should be to reduce rat populations to levels that cause minimal or tolerable levels of crop damage and economic loss, rather than to eradicate the rats. Eradication is usually not cost effective, nor is it even possible in most circumstances.
- Management efforts must be consistent over a long period (perhaps many months) to be successful.
- In rodent management, there are many tools from which to choose. These methods include biological controls, poison bait stations, rat snap traps, electronic traps, live traps, glue traps, and outdoor repellent granules. The integration of cultural management practices with these tools usually gives a more effective suppression of rats than applying them individually.

Cultural Practices

- Remove rats' access to food, water, and shelter. Thirsty or hungry rats become desperate and are therefore easier to manage because they become



Rat nest made from detritus in bunch of bananas (photograph: Angela Kay Kepler).

- less wary (Brennan 1980). Remove all off-grade crops from fields after harvest, such as unwanted sweetpotatoes. Practice strict sanitation around fruit trees, picking up the ripe fallen fruits daily. Do not throw ripe fruits onto open compost piles, as this will attract foraging rats.
- Limit rats' access to a crop. Install electric fences and physical barriers to exclude rats from high-value farm plots. Such barriers, although expensive, may be necessary to protect endangered plants.
- Shorten cropping cycles where possible (i.e., for sugarcane) to reduce damage.
- Synchronize planting and harvesting of adjacent fields to reduce movement of rats from recently harvested fields into younger fields.
- Modify or eliminate non-crop vegetation adjacent to fields to help reduce invasion from surrounding areas. Cattle grazing or commercial production of trees for energy or timber might reduce the vegetative understory in such areas (Tobin 1994).

- Set mechanical or electrical traps, or both. Polynesian rats, for example, can be easily captured with coconut bait and standard snap traps, modified Japanese wire-cage live traps, or other appropriate traps. However, trapping on farms or in fields is labor intensive and may not sufficiently reduce rat populations nor minimize damage.
- Place baits and bait stations near, but not on, rat runways. Rats will quickly find the baits and, after a short period of avoidance, will cautiously investigate them. Baited but unset traps will aid in overcoming the rats' fear of traps; expanded-trigger traps set directly on travel routes may immediately catch rats (Timm 1994).
- Shooting is not a practical form of rat population control, though rats can be killed in this manner.
- Trim overhanging trees away from coffee plants for management of roof rats, as these pests climb from tree to tree. When planting coffee next to a forest, eliminate any touching branches that extend from forest trees to coffee trees.
- Use natural predators of rats, such as cats, small dogs, the Indian mongoose (*Herpestes auro-punctatus*), barn owls (*Tyto alba*), and the native short-eared owl (*Asio flammeus*). Sometimes having resident cats on a farm can eliminate or reduce rat damage to acceptable levels.
- Cut off all manila palm inflorescences before they ripen.
- Install rat guards on the branches of endangered trees to prevent rats from gnawing and girdling them.
- Destroy unwanted, volunteer, or wild plants that may serve as food sources, nesting sites, or both.
- Perforated polyethylene sleeves placed over developing banana bunches can discourage rats.

Rodenticides

Rodenticides are the most effective means of controlling rodent populations. However, poisons that are highly toxic to rats may be dangerous to humans and domestic animals. Therefore, strict safety precautions should be used in the preparation, broadcasting or placement, and disposal of rodenticides. Rats behave cautiously toward unfamiliar food or baits, making killing with poison bait difficult to achieve in some cases.

Due to the new rodenticide laws that took effect in June of 2011 (EPA 2011), many rodenticides are no longer available to the general public for residential use, and some forms of rat and mouse baits are no longer on the market. Small quantities of rodent baits will be sold only in approved, tamper-resistant bait stations. Rodenticides containing brodifacoum, bromadiolone, difethialone, and difenacoum are still available for use in agricultural settings. However, bait stations are required for all outdoor,



Left and middle: Rat-chewing injury to unripe banana fruits. Such damaged bunches must be discarded. Right: Damage by rats to a bunch of bananas can occur rapidly and extensively as fruits ripen (photograph: Angela Kay Kepler).

aboveground uses to minimize exposure for children, pets, and wildlife. Always read the pesticide label to determine if the law allows you to use the product on your host plant or crop or in your fields.

Rat Management Considerations for Specific Farms or Ecosystems

Management practices for rats may vary according to the type of farm, plantation, or ecosystem and the type of crop or plant grown. Here we provide some information for specific cases. Consider using a combination of general and cultural methods for effective rat control, along with a rodenticide if necessary.

Banana Plantations

Rat control is needed in fields and in packing sheds. Rat damage to banana bunches occurs commonly during very rainy weather, when rats move from ground-based feeding and nesting to foliar feeding and nesting. An integrated program using cultural practices, cats, and rodenticides is most effective. For example, use a product such as d-CON[®] inside the banana fruit packing shed and bait blocks in containers within fields. Place one bait station near the rat-damaged plant. Large-scale banana plantations in Hawai'i cover bunches with perforated polyethylene sleeves, tied at both ends, to protect bunches from parasites and rats. Although the sleeves restrict rat

access to fruits, they do not prevent determined rats, which can easily chew a hole through the thin polyethylene. One or more cats living on a plantation can be very effective at suppressing rats.

Macadamia Nut

Where possible, destroy nests within macadamia trees. Pick up fallen nuts promptly.

Coffee

Select a site that is not adjacent to a forest. If planting next to a forest, create a tree-free buffer zone between the forest and the farm.

Palms (Residential and Farms)

Install metallic rat guards on the stems of susceptible palms to prevent their ascent into the foliage. Remove fruits, inflorescences, and dead leaves to reduce feeding and nesting. Place traps or bait stations near the base of susceptible palms.

Sugarcane

Zinc phosphide (e.g., ZP[®] Rodent Bait AG; Prozap Zinc Phosphide Oat Bait) is the only toxicant registered in the United States for rat control in sugarcane. Rodenticides containing zinc phosphide are restricted-use products due to their toxicity to non-target species. Restricted-



Left: Rat-chewing injury to palm leaf midrib (photograph: Timothy Pickering). Middle: Severed palm petioles due to rat-feeding injury. The foliage of such palms also makes good nesting areas for rats. Right: Rats can sever the petioles of *Cycas circinalis* (Queen sago palm) leaves while feeding on their pithy tissues (photograph: Timothy Pickering).

Table 1. Examples of important crops and plants attacked by rats in Hawai'i and the typical economic damages.¹

Crop or Plant Attacked	Damages
Macadamia	Nuts chewed (5–10% crop damage annually in Hawai'i (Smythe 1964)
Vegetables, fruits	Vegetables and fruits chewed and consumed
Coffee, sugarcane, kava, <i>Dubautia arborea</i> , kiawe	Stems severed; stem bark on branch tips chewed and stripped
Palms: Manila, coconut, Queen sago, <i>Dioon spinulosum</i> (gum palm, giant dioon, a cycad), <i>Pritchardia</i> spp.	Petioles and/or buds chewed and severed; stem pith consumed
Pineapple, papaya, banana, guava, melastoma (<i>Melastoma malabathricum</i>), thimbleberry (<i>Rubus rosaefolius</i>), popolo (<i>Solanum nodiflorum</i>), passion fruit, noni, citrus, avocado	Fleshy tropical fruits chewed and consumed
Sweetpotato, <i>Sanicula sandwicensis</i>	Roots chewed and consumed
Naupaka (<i>Scaveola taccada</i>)	Succulent lateral buds chewed and consumed
<i>Cyanea</i> , <i>Clermontia</i>	Stem bark gnawed, chewed, and stripped, sometimes killing plants
<i>Pritchardia</i> , sandalwood, <i>Melicope ovalis</i>	Seeds consumed or chewed open
Gardenia, allectryon	Fruits consumed
<i>Hibiscadelphus giffardianus</i> (hau kuahiwi), <i>Hibiscadelphus hualalaiensis</i>	Bark gnawed and consumed; branches girdled and killed; flowers destroyed to obtain nectar and pollen; buds chewed and destroyed; seeds and pods chewed and destroyed

¹Damage can be pre- or post-harvest and occur on ripe or unripe materials, in trees and shrubs, on the ground, and in packing-houses and processing facilities. Because rats are omnivorous, many other plants or crops may be attacked. Indirect damages may also occur, such as souring of sugarcane. Damage can vary by season and between geographic locations based on the availability of other food sources, such as tree snails, birds and their eggs, etc.

use products can only be purchased and applied by a state-certified pesticide applicator or someone under their direct supervision. Baits are either formulated as pellets or sold mixed with oats and usually are broadcast at the rate of 5 pounds per acre (5.6 kg/ha). A maximum of four applications and 20 pounds per acre (22.4 kg/ha) may be applied per crop cycle. Zinc phosphide baits in Hawai'i are most effective against Polynesian rats and least effective against Norway rats. Because the relative abundance of the two species varies substantially from field to field and may shift as the crop matures, the efficacy of zinc phosphide baits also varies. If Norway rat populations increase during the second year of the crop cycle, zinc phosphide baits become progressively less effective (Tobin 1994).

Native Ecosystems

After their introduction, rats colonized most native ecosystems in Hawai'i, including dry forests, the wettest high-rainfall forests, and high-elevation shrub lands. It is likely that rats migrated into adjacent native plant communities from abandoned sugarcane plantations. Roof rats have caused considerable damage to native trees, contributing to their endangerment or extinction (Baker and Allen 1978). For example, roof rats feed on the bark, buds, flowers, seeds, and pods of *Hibiscadelphus giffardianus* (hau kuahiwi) and *Hibiscadelphus hualalaiensis* (Hualālai hau kuahiwi), causing the death of limbs by girdling and the complete destruction of most flowers and seeds. Although rat guards and snap traps can provide some protection, the most effective management



Rat-feeding injury to a bunch of wild iholena kápua (photograph: Angela Kay Kepler).



Rat-chewing injury to bark and stem of *Dubautia arborea*. Rats can place plants in natural ecosystems at great risk (photograph: Charles Lamoreux).

practice is an effective rat poison (Baker and Allen 1978). *Melicope ovalis* (wild pelea or Hana melicope) is also highly vulnerable to seed predation by rats. For these and other affected native Hawaiian plant species, plans to conserve them must consider rats as major threats and management of rats as a central priority.

Acknowledgements

The author thanks Fred Brooks and Barry Brennan of UH-CTAHR for their thoughtful reviews of this manuscript, as well as Hank Oppenheimer, Forest Starr, Glenn Teves, and Michael Thomas of the University of Hawai'i at Mānoa for information.

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