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Stripping of *Acacia koa* Bark by Rats on Hawaii and Maui[1]

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ABSTRACT: Koa (*Acacia koa*) is the most valuable native timber species in Hawaii. Bark stripping of young trees by rats, a common but unstudied phenomenon, may affect survival, growth, and quality of koa. Up to 54% of the trees sampled in 4- to 6-year-old stands in the Laupahoehoe and Waiakea areas on Hawaii were wounded by rats; only 5% of trees sampled in a 1-year-old stand on Borge Ridge, Maui, were wounded. Wounds were generally long and narrow. Complete girdling was not observed, and direct mortality seemed low. However, indirect effects of damage—deformation of stems, infection by pathogens, and premature death—require further study. Because only young trees seem susceptible to bark stripping, rodent control may be desirable during the first 5 years of koa stand growth.

KOA (*Acacia koa*), A LEGUMINOUS TREE, is the most valuable native timber species in Hawaii (Whitesell 1964) and may play a major role in the nitrogen cycle of the koa–ʻōhiʻa (*Metrosideros polymorpha*) ecosystem. It is also an important habitat component for several native birds, including four endangered species, ʻakiapolaʻau (*Hemignathus wilsoni*), ʻakepa (*Loxops coccineus*), Hawaii creeper (*Loxops maculatus mana*), and Hawaiian crow (*Corvus tropicus*) (Scott et al., in press; Giffin et al., submitted). Bark stripping of young trees by rodents, probably the black rat (*Rattus rattus*) or the Polynesian rat (*Rattus exulans*) or both, may affect survival, growth, and quality of koa. But such damage is virtually undocumented, even though it is commonly observed (C. Wakida, H. Horiuchi, and E. Pung, pers. comm.).

This paper reports on the incidence of bark-stripping and the size, location, and severity of wounds in young koa stands in forests at Laupahoehoe and Waiakea, island of Hawaii, and Makawao, island of Maui. To aid interpretation of the data, it describes the structure of each stand in terms of koa diameter size class distribution and stem density. This information should prove useful to forest managers in establishing healthy koa stands.

STUDY AREAS

Laupahoehoe, Island of Hawaii

The Laupahoehoe study area lies on the northwest flank of Mauna Kea. The area includes forests disturbed by logging and road construction in an access corridor about 100 m wide, between 770 and 1330 m elevation. These activities began in 1969 at the lower forest reserve boundary and reached the 1330 m elevation in 1971. Koa stands developed in disturbed areas adjacent to the main road. Stand age was dated from the time of disturbance because koa seedlings typically emerge within 2 months of site disturbance (Whitesell 1964, Skolmen and Fujii 1980). When sampled, the koa stands ranged in age from 4 years at 1330 m elevation to 6 years at 770 m elevation.

Waiakea, Island of Hawaii

The study area in the Waiakea Forest Reserve is on the east flank of Mauna Loa,

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near the Flume Road at about 600 m elevation. The koa stands were about 6 to 8 years old when sampled except for stand 1 which was 11 years old. They developed on disturbed sites where conversion from native ʻōhiʻa–koa forest to introduced hardwoods failed.

Borge Ridge, Island of Maui

The Borge Ridge koa stand lies on the north flank of Haleakala between 1050 and 1160 m elevation within the Makawao Forest Reserve. A wildfire in 1961 destroyed the original ʻōhiʻa–koa forest. After site preparation—which included bulldozing and windrowing of remnant vegetation, and soil scarification in 1962—koa regenerated naturally in great numbers. The stand was about 1 year old when sampled by the Hawaii Division of Forestry (Korte 1963).

METHODS

Stand selection in the study areas on the island of Hawaii was arbitrary. In Laupahoehoe, we selected the first 10 large koa stands we encountered along the logging road. In Waiakea, we selected five stands located at about 1.3-km intervals along the Flume Road.

During May and June 1975, we established 6-m wide transects through the center of each sample stand, adding segments to the right or left of the original transect as needed to tally 100 koa trees. For each tree with a diameter of at least 1.3 cm at 0.3 m above the ground, we measured and recorded (1) stem diameter class, each 2.5 cm wide, (2) relative age of wounds, (3) maximum wound length and width, and (4) maximum height of wound above the ground as measured from the top of the wound. We defined new wounds (presumed to be less than 1 year old) as those without callus formation (Figure 1).

For each stand, the median rather than the mean was calculated for stem diameter and wound length, width, and height above the ground. We chose this statistic because our data were recorded as class values instead of exact measurements and because stem diameter distributions were not normal, but skewed. The median described these distributions such that half of the area lay to its right and left.

The Borge Ridge stand was sampled using 4-m^2 quadrats in November 1963, when the trees were about 1 year old. Twenty-two starting points were marked at 90-m intervals along the access road. From each point, a random distance was paced off along a compass line perpendicular to the road and the quadrat established. The 22 sample quadrats represented about 0.06% of the stand. The data collected included stem diameter at ground level, a subjective classification of the severity of wounding (i.e., dead due to girdling, wounded extensively with little chance of surviving, slightly damaged, and unwounded), relative proximity of debris piles, and relative amount of blackberry.

We assumed that all wounds in the study areas were made by rodents, probably the black or roof rat. This assumption seems reasonable in light of the nature, size, and position of the wounds and the absence of other animals capable of inflicting such damage. The black rat has been observed feeding on bark of another endemic tree, *Hibiscadelphus giffardianus*, in some cases girdling main branches (Baker and Allen 1978). In native rain forests, the black rat is the predominant rodent (Mueller-Dombois, Bridges, and Carson 1981). The Polynesian rat, however, also occupies native rain forests to about 900 m (Tomich 1969). Both rats can climb trees.

RESULTS

Laupahoehoe

STAND STRUCTURE: Stand densities ranged from about 850 to nearly 5000 stems ha^{-1} (Table 1). Density, probably a reflection of stand age, tended to increase with elevation. The lowest, least dense stand was about 6 years old, while the highest, most dense stand was about 4 years old. Stem diameter in the stands tended to decrease with increasing elevation as a function of lower stand age and growth rates. The diameter class distribu-

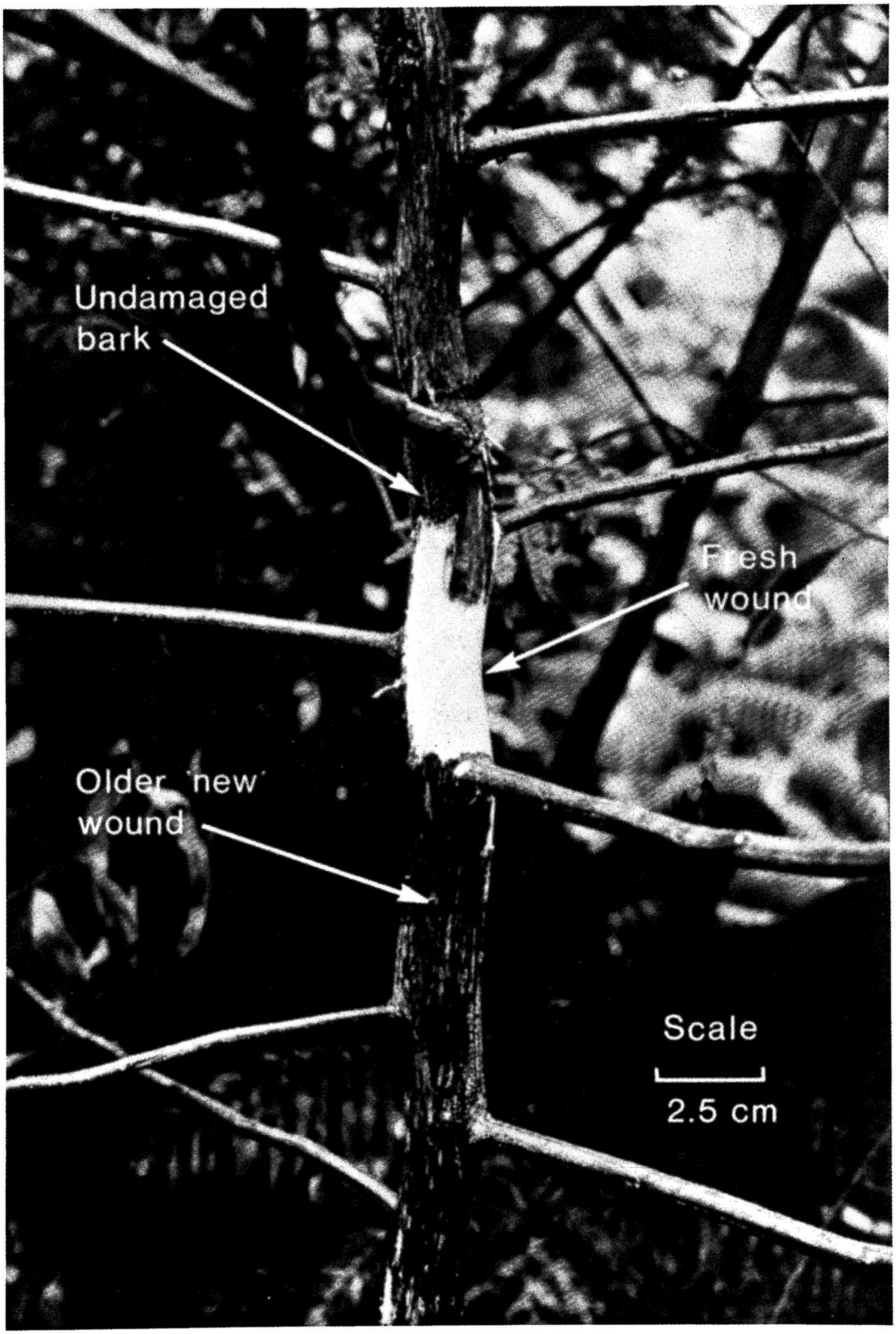

FIGURE 1. Many *Acacia koa* bark wounds were located well above the ground and were probably inflicted by the black or roof rat (*Rattus rattus*) as indicated by incisor tooth marks. Partial girdling as shown here was more common than complete girdling. Fresh and older new wounds are visible.

TABLE 1

TREE DENSITY AND MEDIAN DIAMETER, MEDIAN DIMENSIONS OF WOUNDS MADE BY RATS, AND PERCENTAGE OF *Acacia koa* WOUNDED IN STANDS ALONG AN ELEVATION GRADIENT, LAUPAHOEHOE, HILO FOREST RESERVE, ISLAND OF HAWAII*

ELEVATION (m)	DENSITY† (trees ha^{-1})	STEM DIAMETER† (cm)	TREES WOUNDED† (%)	WOUNDS (cm): LARGEST DIMENSIONS: LENGTH‡	WIDTH‡	HIGHEST POINT ON TREE‡
1,330	4,990	5.6(2.0)	53	15.0(7.5)	2.4(1.2)	275.3(84.2)
1,260	2,200	5.1(2.6)	19	14.0(7.0)	2.1(1.1)	50.7(48.1)
1,110	3,340	7.0(2.9)	48	29.0(20.7)	3.5(1.6)	297.6(53.0)
1,090	1,660	7.2(2.6)	35	17.3(8.6)	2.3(1.1)	214.5(92.5)
980	2,200	8.3(3.4)	44	23.4(14.7)	4.5(1.6)	250.6(67.5)
920	2,840	6.4(2.4)	32	15.2(7.6)	2.7(1.5)	243.2(169.7)
890	820	10.5(4.0)	15	15.5(7.7)	2.6(1.3)	65.4(140.3)
840	940	10.9(3.8)	30	13.7(6.9)	2.7(1.4)	45.3(29.6)
810	890	9.7(3.1)	13	13.2(6.7)	2.5(1.2)	43.8(33.0)
770	840	13.4(5.1)	9	17.0(8.6)	2.8(1.5)	20.0(13.3)
All	1,430	7.8(2.8)	30	17.3(8.6)	2.8(1.5)	179.1(125.8)

* Values in parentheses are semi-interquartile ranges, a measure of attribute variability, defined as $(Q_3-Q_1)/2$, in which Q_3 is the value of the 75th percentile and Q_1 is the value of the 25th percentile.
†Based on 100 sample trees per stand.
‡N = the value shown in the column titled TREES WOUNDED.

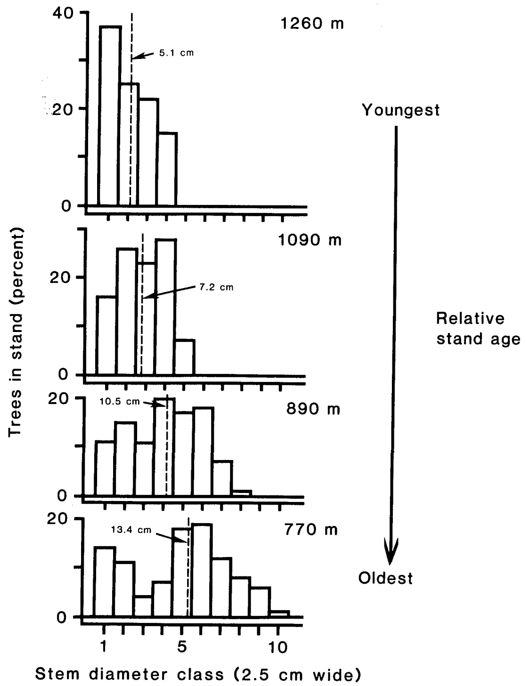

FIGURE 2. Diameter class distributions for four of the ten young stands of *Acacia koa* located along an elevation gradient in the Laupahoehoe section of the Hilo Forest Reserve, island of Hawaii. Dashed vertical lines denote the median stem diameters in the stands.

tions (Figure 2) indicated that the decrease in stem diameter was probably due to the progressively younger age of stands at higher elevations.

WOUND INCIDENCE AND SEVERITY: The proportion of rat-damaged trees generally increased with elevation, and thus with decreasing age. About 53% of the saplings in the highest stand were damaged, while less than 10% in the lowest stand were damaged.

New wounds were found in only 4 of the 10 stands. They were most common in the uppermost (youngest) stand where 25% of the damaged trees had new wounds. Less than 7% of the wounded trees in the other three stands had new wounds. The four lowest (oldest) stands showed no evidence of recent bark stripping.

Wounds were generally long and narrow (Table 1) indicating that the bark was loosened at the top and peeled down rather than gnawed off. The largest wound exposed 700 cm^2 of cambial tissue, but this was unusual. About 66% of the wounds were smaller than 10 cm^2 and only 10% were larger than 30 cm^2. We observed complete girdling of some

TABLE 2

TREE DENSITY AND MEDIAN DIAMETER, MEDIAN DIMENSIONS OF WOUNDS MADE BY RATS, AND PERCENTAGE OF *Acacia koa* WOUNDED IN STANDS ALONG A 600-M CONTOUR, WAIAKEA FOREST RESERVE, ISLAND OF HAWAII*

				WOUNDS (cm)		
				LARGEST DIMENSIONS		
STAND	DENSITY† (trees ha^{-1})	STEM DIAMETER† (cm)	TREES WOUNDED† (%)	LENGTH‡	WIDTH‡	HIGHEST POINT ON TREE‡
1	2,270	3.6(2.5)	17	13.3(6.3)	3.2(1.8)	64.8(28.4)
2	1,330	5.4(3.4)	12	26.6(16.2)	4.6(1.5)	141.0(57.1)
3	2,130	5.5(2.8)	11	18.3(11.9)	3.0(1.9)	87.0(42.1)
4	1,330	6.0(2.5)	34	15.1(7.5)	2.8(1.5)	59.3(32.1)
5	1,090	5.9(3.7)	54	18.0(9.3)	3.3(1.6)	382.3(188.9)
All	1,500	5.7(3.1)	26	16.9(8.4)	3.2(1.7)	121.0(135.7)

* Values in parentheses are semi-interquartile ranges, a measure of attribute variability, defined as $(Q_3-Q_1)/2$, in which Q_3 is the value of the 75th percentile and Q_1 is the value of the 25th percentile.
† Based on 100 sample trees per stand.
‡ N = the value shown in the column titled TREES WOUNDED.

terminal shoots and lateral branches, but not on the sample trees.

Wounding was observed as high as 10 m. The median height of wounding ranged from a low of 20 cm in the lowest stand to a high of 275 cm in the highest stand (Table 1). Damage also occurred when rats climbed high onto the terminal shoot and their weight caused the terminal to break. Such damage was observed in several saplings in the upper-elevation stands, but not among the sample trees.

Waiakea

STAND STRUCTURE: Stand densities were higher and less variable in Waiakea than in Laupahoehoe (Table 2). They ranged from 1100 stems ha^{-1} in one of the 6-year-old stands (#5) to 2300 stems ha^{-1} in the 11-year-old stand (#1).

Median stem diameter for all 500 sample trees was 5.7 cm, and that for individual stands varied from 3.6 to 6.0 cm (Table 2). These values were generally smaller than those for Laupahoehoe, even though the Waiakea stands were up to 5 years older. The shape of the diameter class distributions for the Waiakea stands were similar to those of the 1330-m elevation stand in Laupahoehoe, but up to nine diameter classes were represented in Waiakea as opposed to four in Laupahoehoe.

WOUND INCIDENCE AND SEVERITY: About 26% of the 500 sample trees had bark stripping wounds. The proportion of wounded trees varied among stands from 11 to 54% (Table 2), a range almost identical to that observed in Laupahoehoe (9 to 53%). Only one tree in a 6-year-old stand had been recently wounded; no fresh damage was seen in 7-, 8-, and 11-year-old stands.

The size of wounds in the Waiakea stands was similar to those in Laupahoehoe (Table 2). About 60% of the wounds were smaller than 10 cm^2 and about 10% were greater than 30 cm^2. The largest wound was 66 cm^2. No evidence of complete girdling was found.

Damage occurred as high as 10 m above the ground, as at Laupahoehoe. Such high wounding was confined to stand 5 where 23 of the 54 damaged trees had wounds more than 5 m above the ground. Of those 23 trees, 18 grew in close proximity to each other.

Borge Ridge

STAND STRUCTURE: The Borge Ridge stand was much denser than those on the island of Hawaii, with more than 41,000 trees ha^{-1}. The trees were also smaller—none had a diameter greater than 5.4 cm (Figure 3). More than 90% were less than 2.6 cm in diameter. The median stem diameter at ground level was 1.4 cm with a semi-interquartile range of 0.6

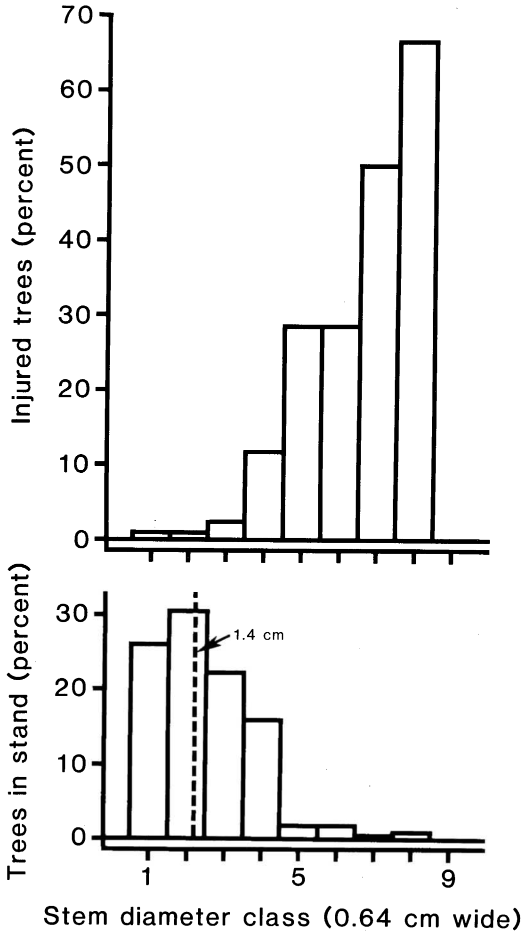

FIGURE 3. Diameter class distribution of *Acacia koa* in the Borge Ridge stand, island of Maui, and the percentage of trees wounded by rats in each class. The median stem diameter at ground level is denoted by the dashed line.

cm. This was considerably smaller than the median diameters of koa stands on Hawaii, and undoubtedly reflected the youthfulness of this stand, about 1 year.

WOUND INCIDENCE AND SEVERITY: Rats had gnawed on the bark of only 5% of the 369 sample koa trees. In contrast, the smallest proportion of rodent-damaged trees on Hawaii was 9%, and in several stands more than 33% of the trees were wounded.

All wounds were new, in this case, probably less than 2 months old. Trees in all diameter classes were wounded (Figure 3). The proportion of injured trees in each diameter class increased from 1% for the smallest class to 67% for the largest class. Greater damage to larger reproduction may be an artifact of small sample sizes in the larger classes.

Of the 22 sample plots, 7 contained rodent-damaged trees. Six of these supported dense stands of blackberry, or were near brush piles. None of the plots without damaged trees had blackberry or were near a brush pile.

No further wounding occurred after the first year of stand development.

SUMMARY AND RECOMMENDATIONS

The preceding results can be summarized as follows:

At Laupahoehoe, younger (high elevation) stands showed greater damage than did older (low elevation) stands, and the incidence of fresh wounds was greatest in the youngest stand and absent in the oldest stands;
At Waiakea, only one 6-year-old tree had fresh damage, and no fresh damage was seen on 7-, 8-, and 11-year-old trees;
At Borge Ridge, rats damaged trees when the stand was 1 year old, but not after that;
Few trees were killed outright by girdling.

Thus, it seemed that bark stripping of koa by rats was a transitory phenomenon affecting stands generally less than 6 years old.

We could offer several reasons why younger stands in Waiakea and Laupahoehoe tended to show more damage than did older stands. But, because we lack data on size and fluctuation of rat populations and on the effect of stripping on tree mortality, our explanations would be speculative or incorrect. Conceivably, the younger stands suffered greater damage by chance and independent of man's activities. By coincidence they may have been in areas undergoing a cyclic increase in rat abundance. Nevertheless, we believe the data justify the premise that wounding is transitory and confined to stands less than 6 years old.

The following set of multiple working hypotheses is based on the premise above.

I. Rat populations increase after harvesting or clearing of koa forest because cover, nest sites, and food are temporarily more abundant. Within 6 years of disturbance, rat populations decrease to a steady state as structural changes make the habitat less favorable. Partial control of the population buildup can be achieved by disposing of slash.

II. The intensity of fresh stripping of koa bark is a function of rat density, abundance of other foods, and bark palatability, and closely follows the trend of the rat population. Fresh wounding peaks the 2nd or 3rd year after disturbance and ceases about the 6th year.

III. As trees age, their bark becomes less palatable due to changes in texture and nutrient composition. As a result, fresh wounding is observed less and less as stands mature, even when rat density stays high.

IV. The proportion of trees with visible wounds decreases over time because (1) fresh wounding peaks about 2 to 3 years after disturbance and then declines, (2) mortality is greater among damaged trees, and (3) wound closure is rapid.

Until these hypotheses are tested, we recommend that managers consider rodent control for the first 5 years of koa stand development, especially in areas where a mature native forest is harvested as part of a koa regeneration plan.

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