Impact of Feral Herbivores on Mamane Forests of Mauna Kea, Hawaii: Bark Stripping and Diameter Class Structure

PAUL G. SCOWCROFT AND HOWARD F. SAKAI

Abstract

Management of feral and Mouflon sheep and feral goats within the Mauna Kea Forest Reserve/Game Management area has been criticized as inadequate to prevent the adverse environmental impact which these introduced herbivores have on native components of the scrub forest ecosystem. This study determined the intensity of bark stripping of mamane *(Sophora chrysophylla)*, a small endemic leguminous tree, by these animals and assessed the impact of their browsing on the size class structure of mamane stands. In all but one of the 4 areas sampled, a high proportion of mamane trees bore bark stripping wounds. Differences in the amount of stripping between elevations in a given area, and between areas, were attributed to differences in browsing pressure, which in turn was dependent on the frequency of human disturbance and the behavioral traits of the herbivores. Tree size class distributions revealed that browsing has suppressed mamane reproduction in some areas. Suppression appeared to be the greatest in the most heavily browsed areas.

Mamane *(Sophora chrysophylla)*, an endemic leguminous tree (<12 m tall), is a principal component of the scrub forest ecosystems found on Mauna Kea, on the island of Hawaii, at 1800 to 2900 m (6000 to 9500 ft) elevation. The species plays a vital role in the survival of the Palila *(Psittirostra bailleui)*, an endangered endemic bird found only in the scrub forests on Mauna Kea. The Palila depends on mamane for food, shelter, and nest sites (Berger et al. 1977). To the best of our knowledge the species could not survive without mamane.

Mamane is also a preferred browse species for three introduced herbivores (Griffin 1976): feral sheep *(Ovis aries)*, feral goats *(Capra hircus)*, and Mouflon sheep *(Ovis musimons)*. These animals not only eat shoots, leaves, and flowers, but bark as well, particularly the thin bark of young trees. Such wounds increase the likelihood of invasion by harmful insects and disease organisms that could kill trees or reduce their vigor.

Bark stripping by deer is a recognized problem in the forests of Europe, England, and parts of North America (Chard 1970, Murie 1951, Szczerbinski 1966, Ueckermann 1960). McIntyre (1972), summarizing the more plausible hypotheses to explain why animals strip bark, included these:

a. Bark is high in lignin, a good source of necessary roughage.
b. Fresh bark, during droughts, can be a source of moisture.
c. Interaction of animal density and habitat quality is such that as animal density increases or habitat quality decreases, barkstripping increases.

Any or all of these reasons may apply to bark stripping on Mauna Kea.

This study was conducted to determine the intensity of bark stripping of mamane within the Mauna Kea Forest Reserve/Game Management Area and to describe the diameter class structure of mamane in areas sampled.

Authors are research forester and wildlife biologist, Pacific Southwest Forest and Range Experiment Station, USDA, Forest Service, stationed at Honolulu, Hawaii.
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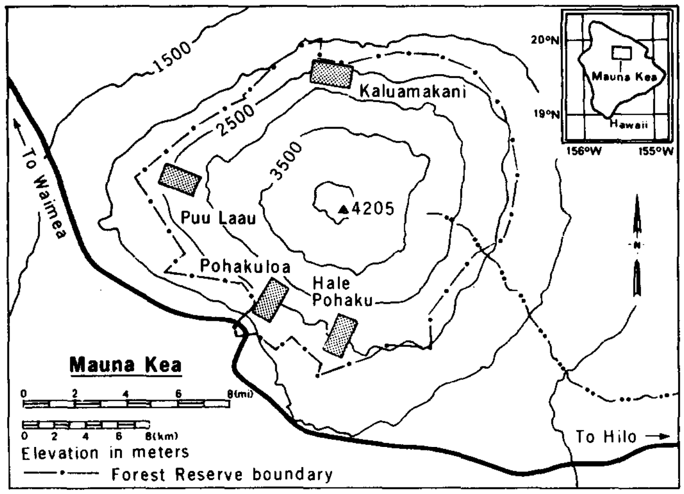

Fig. 1. *Location of the four sampling areas within the Mauna Kea Forest Reserve/Game Management Area, Island of Hawaii.*

Study Areas

Four study areas (Fig. 1) were selected: Puu Laau, Kaluamakani, Hale Pohaku, and Pohakuloa. Browsing pressures differed among these areas, as did the vegetation.

The Puu Laau area, on the west side of the mountain, has open stands of pure mamane, ranging from 2 to 12 m (6 to 40 ft) tall. At lower elevations, the relatively dense ground cover consists primarily of introduced grasses, including Kentucky bluegrass *(Poa pratensis)*, Yorkshire fog *(Holcus lanatus)*, and sweet vernal-grass *(Anthoxanthum odoratum)*. These species gradually become less common with increasing elevation, giving way to native grasses, principally *Trisetum glomeratum* and *Agrostis sandwicense*. The soil is medial over cindery, isomesic, typic vitrandept (Soil Conserv. Serv. 1973, 1975). Permeability is rapid and runoff slow. Rainfall averages 508 mm (20 inches) per year (State of Hawaii 1970). Daytime temperatures rarely exceed 24° C (75° F).

In the Kaluamakani area, on the north side of the mountain, mamane is the only tree species. Grasses are less abundant than at Puu Laau, and pukiawe bushes *(Styphelia tameiameiae)* are common in the understory. Climatic and edaphic features are similar to those at Puu Laau.

The Hale Pohaku area is adjacent to the paved Mauna Kea summit road on the south side of the mountain. Again, mamane is the only tree species in the area, and grows to an average canopy height of about 5 m (15 ft). The understory is composed mostly of bunch grasses such as *Danthonia pilosa* and *Deschampsia australis,* and the shrub, *Chenopodium* spp. A large part of the area is cinder land with very little soil development; soil in the rest of the area is similar to that of the Puu Laau and Kaluamakani areas. Rainfall is slightly greater than in the above areas—about 760 mm (30 inches) annually.

The Pohakuloa area is on the south-facing slopes above Pohakuloa State Park. The area is roadless, and access on foot is made difficult by the dense stands of mamane and naio *(Myoporum sandwicense),* the steep slopes, and the high altitude. Naio is very abundant below 2600 m (8500 ft) elevation, but absent at tree line. Average tree height is about 5 m (15 ft). The soils and climate are the same as those at Puu Laau.

Browsing pressures vary between and within these areas. Within each area, browsing is generally lightest in the lowest portions and heaviest in the uppermost portions. Between areas, differences depend primarily on the number of sheep present. Census and home range data indicate that 0.20 sheep/ha used the Puu Laau area in 1975; 0.12/ha, the Kaluamakani area; 0.11/ha, the Hale Pohaku area; and 0.09/ha, the Pohakuloa area. Comparable estimates for 1955 placed sheep populations in these areas at 0.08, 0.06, 0.14 and 0.08 animals/ha (data from Hawaii Division of Forestry and Wildlife, Honolulu).

Methods

Each study area was sampled along five strip transects laid out along contours separated by 90 meters (300 ft) elevation, with the first at 2440 m (8000 ft) elevation. Starting points for each set of 5 transects were along a base line perpendicular to the general contour. Transects in the Pohakuloa area were established at 150-m (500-ft) contour intervals, with the lowest at 2195 m (7200 ft) elevation. Transects were 6 m (20 ft) wide except in the Pohakuloa area, where low mamane tree density made a 9-m (30-ft) width desirable. Transects varied in length, each being only long enough to include 100 trees. The longest transect was 1140 m (3735 ft); the shortest, 265 m (870 ft). Each transect represented less than 0.2% of the area being sampled.

Information was recorded for each tree within a transect with a diameter of at least 1.3 cm (0.5 inch), at 0.3 m (1 ft) above the ground, as follows: stem diameter class, each 2.5 cm (1 inch) wide, stem form (single or multiple stemmed), number of stems wounded, relative age of wounds, maximum wound length and width, maximum height of wound above the ground, and extent of multiple wounding of individual stems. New wounds were those that showed no sign of callus formation and were thus assumed to be less than 1 year old. Callused wounds were classified as old. Trees with both old and new wounds were recorded as a separate category. Data were collected during July and August 1975.

The proportion of bark-stripped trees, the proportion of injured stems with multiple wounds and the diameter of new vs old wounded trees were the only data subjected to statistical analysis. To determine if location and elevation interacted to affect stripping, multiway contingency table analysis (Chi square), log-linear model, was used (Everitt 1977; Dixon and Brown 1979). Differences in stripping between elevations at each location were examined using Sokal and Rohlf's (1969) procedure for determining the equality of two percentages. To compare differences in stripping among locations for each elevation, we interpolated percent values at Pohakuloa for the 2440-, 2530-, 2620- and 2710-m transects, and took into account the variance of the interpolations. This was necessary because the transects at Pohakuloa were laid out at elevations different from the other locations. The same procedures were used to examine the effect of location and elevation on the proportion of stems with multiple wounds. All hypothesis testing was done at a significance level less than or equal to 0.01 unless otherwise stated.

Stem diameter class distributions were constructed for each transect to assess the effect of browsing on stand structure qualitatively. Each class was 2.5 cm wide.

Table 1. Proportion[1] of mamane trees with bark stripping wounds by study area and elevational transect.

	Percent of trees by elevation (m)				
Site	2440	2530	2600	2710	2800
Puu Laau	53 a	72 a	73 a	92 b	98 b
Kaluamakani	71 a	89 b	92 b	90 b	89 b
Hale Pohaku	16 a	12 a	7 a	63 b	21 a
Pohakuloa[2]	55 a	89 b	98 bc	96 bc	100 c

[1]Within a row, values followed by the same letter do not differ significantly ($p<0.01$).
[2]Elevations at Pohakuloa were 2200, 2350, 2500, 2650, and 2800 m.

Results and Discussion

Bark-stripping Wounds

Wounds were generally long and narrow. The average maximum length varied from 18 to 66 cm (7 to 26 in) and the width from 2.5 to 10 cm (1 to 4 in). None of the wounds completely girdled a stem. In the Kalumakani and Pohakuloa areas, wounds tended to be larger than those elsewhere. The shape of the wounds and scarcity of tooth marks on the exposed wood of young trees suggested that sheep peel off a long strip rather than gnaw it off; remnants of stripped bark were found hanging from the young trees. In contrast, on older trees, gnawing was evident and the wounds were localized within the gnawing area. The maximum height of the upper end of any wound was 175 cm (69 in) above the ground. The average maximum height above ground varied from 60 to 105 cm (23 to 40 in).

The location and elevation of the site significantly affected the amount of bark stripping. But the location-elevation interaction was also significant; that is, the effect of elevation on stripping differed from location to location. At each site, wounded trees tended to be less common at the lowest elevation than at higher elevations (Table 1). Hale Pohaku was an exception.

Differences in stripping between sites for each elevation showed

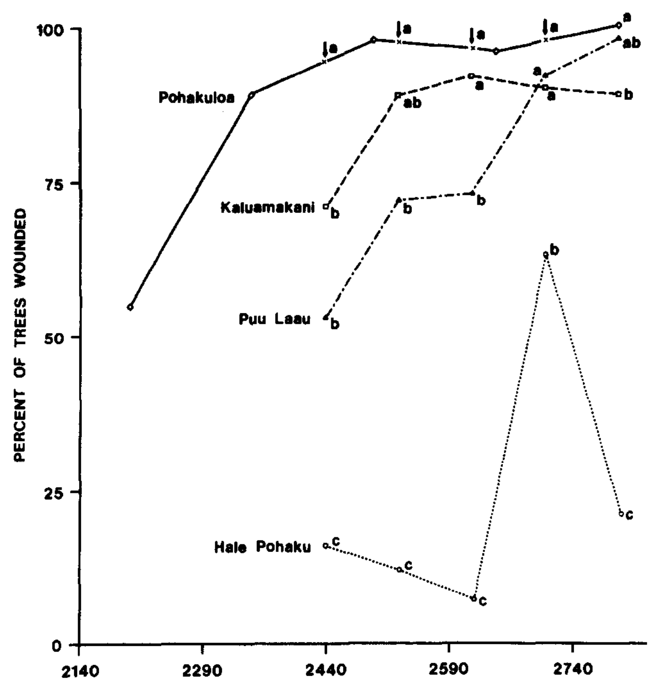

Fig. 2. *Comparison of percent wounded mamane trees among sampling areas for each elevational transect. Stripping percentages for a given elevation that are followed by the same letter are not significantly different from each other (p≤0.01). Values for Pohakuloa designated by an 'X' were interpolated from the original data.*

that Hale Pohaku contained significantly fewer wounded trees than the other sites (Fig. 2). Differences between Puu Laau and Kaluamakani were not significant except at 2620 m (8600 ft) elevation where fewer wounded trees were found at Puu Laau. Stripping was consistently more common in the Pohakuloa area than elsewhere, although the differences were not always significant.

Differences in the proportion of wounded trees between areas and between elevations within an area can be explained largely by differences in intensity of browsing pressure as affected by frequency of human disturbance; the more frequent the disturbance, the lower the browsing pressure and incidence of bark stripping.

Wounding was least common in the Hale Pohaku area, where the starting points for all 5 transects lay within 0.6 km (0.4 mile) of the heavily used Mauna Kea summit access road. Daily traffic along the road, and frequent use of several tributary jeep trails by hunters and other recreationists, undoubtedly limit sheep browsing. The 2710-m (8900-ft) transect lies behind several large cinder cones, which shield it from daily human disturbance, and trees along the transect showed evidence of recent browsing not seen on the other 4.

In other areas, human disturbance also appears to be a factor. The only hunter-access jeep trail circling most of Mauna Kea lies near the 2440 m transect in the Kaluamakani area. Although traffic is largely seasonal, and not heavy even then, there is apparently enough disturbance or hunting pressure to reduce sheep usage. At Pohakuloa, State park and military training camp facilities are located at 1980 m (6500 ft) elevation, below the lowest sample transect. Both are operated year-round and hikers can easily reach the 2200-m transect, but dense vegetation after that, forms a barrier. No other roads or trails gave access to either Kaluamakani or Pohakuloa, and except for an occasional hunter (during a 2-month season), no one was likely to disturb sheep in the upper forest.

On the rough jeep trails in the Puu Laau area, traffic is moderately heavy, but still less than along the paved summit road at Hale Pohaku. All 5 transects lay adjacent to the main jeep trail. Human disturbance along these access corridor seems to decrease with elevation.

Table 2. Proportion of wounded mamane trees[1] with a preponderance of multiple-wound stems by study area and elevational transect.

	Percent of trees by elevation (m)				
Site	2440	2530	2620	2710	2800
Puu Laau	53 a	51 a	41 a	43 a	74 b
Kaluamakani	54 a	66 ab	82 bc	93 c	93 c
Hale Pohaku	25 a	25 a	43 a	29 a	24 a
Pohakuloa[2]	45 a	53 a	60 ab	80 bc	86 c

[1]Within a row, values followed by the same letter are not significantly different ($p<0.05$).
[2]Elevations at Pohakuloa were 2200, 2350, 2500, 2650, and 2800 m.

Sheep, which are more abundant here than elsewhere on the mountain, normally follow a pattern that helps to explain the increased wounding with increased elevation. They move downhill from their bedding grounds above tree-line to their feeding area, which may be as low as 2300 m elevation. The sheep always pass through the tree-line zone on their way down, thus causing greatest damage by virtue of most frequent usage. Use and, hence, damage declines in progressively lower areas because sheep do not always move downhill the same distance.

New wounds were found on only 4% of the 2,000 trees examined. It is not known if this figure changes significantly from year to year. Within the Puu Laau, Kaluamakani, and Pohakuloa areas, new wounds were most common near tree line along the 2800-m (9200-ft) transect. The only new wounds observed in the Hale Pohaku area, were along the 2620-m transect.

Until this study was made, we suspected that stripping was confined to small diameter trees; that is, <13 cm (5 inches)—those that had relatively thin, smooth bark. The study data indicated, however, that large trees with thick rough bark are also susceptible to stripping, probably by Mouflon sheep, because they are more abundant in the areas where we observed such damage. At Kaluamakani, the average diameter class of trees with new wounds ranged from 25 cm (9.8 in) at 2800 m to 30 cm (11.6 in) at 2710 m. Newly wounded trees in the Puu Laau, Hale Pohaku, and lower Pohakuloa areas had much smaller diameters averaging 2.5 to 10

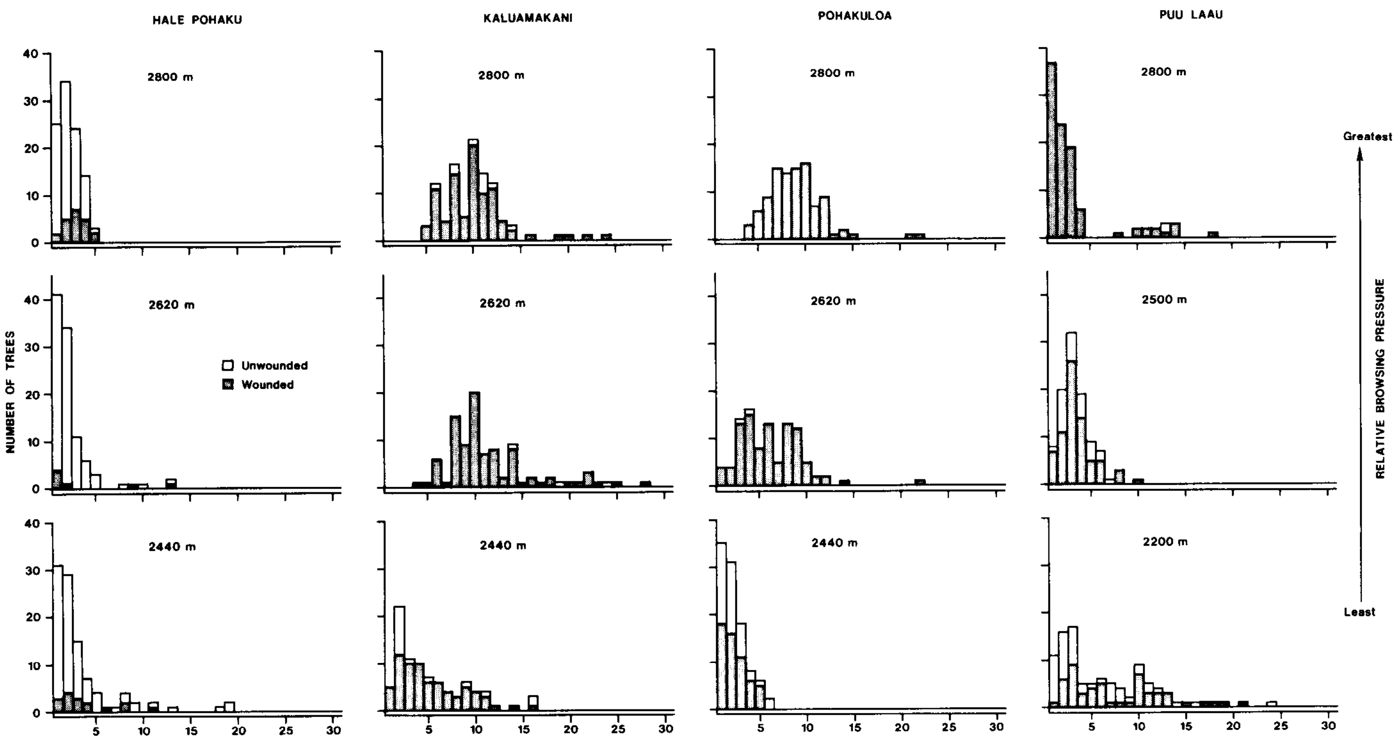

Fig. 3. *Number of manane trees within each 2.5-cm (1-in) diameter class for the lower, middle, and upper elevational transects in each sample area. Number of trees with bark stripping wounds are shown (shaded portion) for each diameter class.*

cm. Along the 2800-m transect at Pohakuloa, the average diameter of newly wounded trees was 22.4 cm (8.8 in).

Differences in diameter between trees with new wounds and trees with old wounds were not significant (t-test, $p=0.05$); trees within each transect were compared.

Many stems had multiple wounds (Table 2). The greatest amount of multiple wounding occurred near tree line in 3 of the 4 areas. In the Hale Pohaku area, trees along the 2620-m transect showed the most multiple wounding. Multiple new wounds were not observed.

Bark stripping occurred in most of the stem diameter classes sampled (Fig. 3). With larger sample sizes, we believe wounds would have been encountered on trees of all represented diameter classes.

Diameter-Class-Index of Survival

The diameter class distributions (Fig. 3) reveal another aspect of the adverse effect of feral sheep on the forest—suppression of mamane regeneration.

We believe that before herbivores were introduced, the mamane forest was a self-perpetuating uneven-aged forest at all elevations. The diameter class distribution of such a forest would be maintained over time, at least as long as no major catastrophe occurred. The shape of the diameter class distribution for the balanced uneven-aged forest would be a reverse J, with the greatest number of trees in the smallest diameter classes (Smith 1962). Departures from the expected would presumably indicate disturbances of one or more phases of forest development. With these points in mind, we examined the diameter class distributions for each transect in our study.

Of the 4 areas, Hale Pohaku best fit the expected diameter distribution, but even there deviations were evident. The presence of trees in diameter classes greater than the 15th (38 cm) within the 2440- and 2530-m transects suggested that the stands went through a period when regeneration was suppressed. More recent suppression was indicated for the 2710- and 2800-m transects, which contained fewer trees in the 1st class than in the 2nd class. Trees with diameters greater than 13 cm (5 in) became less common with increasing elevation, suggesting that the stands are of more recent origin at higher elevations. However, because the transects varied in length, the decrease in large diameter trees may be an artifact.

Several deductions can be made from the diameter distributions for the Puu Laau area. For the 3 lower transects (and to a lesser extent the 2710-m transect), the 1st and 2nd (2.5- and 5.0-cm) diameter classes contain fewer trees than one would expect in a self-maintaining stand. Suppression of mamane reproduction by sheep is one possible cause for the low numbers. Another factor probably limiting regeneration is competition with dense stands of grasses, mostly non-native species.

The distribution for 2800-m at Puu Laau suggests that two stands are represented. The larger (older) trees are remnants of the forest existing when sheep first began to affect the forest adversely, perhaps in the middle to late 1800's. These trees would have been small in diameter then. Between that time and the 1940's, sheep suppressed most of the mamane reproduction. Effective sheep control beginning in 1937 permitted the new establishment of mamane regeneration, most of it in the late 1940's and early 1950's when the sheep populations were in the low hundreds. Examination of aerial photographs for 1954, 1965, and 1975 support this chronology (Scowcroft 1977).

The drawn-out "tails" of the 2440- and 2530-m distributions at Puu Laau may indicate that there was a period when regeneration was also suppressed. Game managers familiar with these areas in the 1930's and 1940's state that it was; understory vegetation of any kind was either nonexistent or so heavily browsed that it gave the impression of only bare ground. The forest was composed of large trees and bare ground.

The most important feature of the diameter distributions for the Kaluamakani and Pohakuloa areas was the lack or scarcity of trees in the lower diameter classes at all but lower elevations. At noted before, human disturbance in these areas was greatest at the lowest elevations, resulting in reduced sheep browsing and increased mamane reproduction. Distributions for the 2440-m transect at Kaluamakani and the 2530-m transect at Pohakuloa had the general form of a balanced distribution for an uneven-aged stand. At higher elevations the distributions indicated that sprout and seedling regeneration have been suppressed, completely so near tree line. Sheep and goats were undoubtedly responsible.

Conclusion

Disruption of forest structure is a likely outcome of introducing large herbivores into island ecosystems. In continental forests, native herbivores like deer can also suppress tree regeneration (i.e., Marquis 1974). But the outcome of grazing and browsing will probably be more harmful in island ecosystems where animals often find favorable habitats and where native plants lack defensive mechanisms (Mueller-Dombois 1981). Where the destructive activities of large herbivores are augmented by man, i.e., by forest cutting, vegetation type conversions accompanied by depletion or extinction of native plant and animal populations may occur. In the present case, feral sheep and goats suppress mamane regeneration in some areas of the Mauna Kea Forest Reserve, thus altering the forest structure. Prolonged suppression could further endangering the Palila by reducing the size of the forest.

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