Recovery of Goat-Damaged Vegetation in an Insular Tropical Montane Forest[1]

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ABSTRACT

The feral goat (*Capra hircus*) is an alien herbivore that has wreaked havoc in island ecosystems, including the dry, rugged, and relatively inaccessible montane koa parkland on the islands of Maui and Hawai'i. The objective of the present work was to evaluate the ability of koa parkland on Maui to recover naturally from browsing damage if goats are eliminated. We studied recovery over 7 years by periodically determining percent ground cover, species composition, and woody plant abundance inside and outside a goat exclosure. Initially, plant cover did not differ inside and outside the exclosure; but, after 3 years, plant cover inside was almost twice that outside. Molassesgrass (*Melinis minutiflora*), an introduced mat-forming species, spread rapidly inside the exclosure and showed no sign of dying out or retreating. Goats exert some control over this species. After 7 years, tree regeneration has occurred only inside the exclosure except for koa (*Acacia koa*) regeneration, which also occurred outside the exclosure. Heights of koa seedlings indicated that those outside represented recent germinants only, while those inside represented older individuals as well as recent germinants. The results indicated that the aging koa overstory could be replaced by koa regeneration if goats were eliminated and that some native species (*Dodonaea, Styphelia, Coprosma*) could at least partially recover. Once established, some introduced species (*e.g., Melinis minutiflora*), are favored by elimination of goats and may severely inhibit recovery of native species.

Feral animals introduced into insular environments become ecologically dominant and have extensive adverse effects on native biota (Coblentz 1978). And tropical oceanic islands have not been immune to the assaults of alien herbivores. Examples of wholesale destruction of vegetation by ungulates include islands in the Marquesas (Adamson 1936, Holyoak 1973, Thibault 1973), the Galapagos (Hamann 1975, 1979), and the Hawaiian Archipelago (Mueller-Dombois 1979, Katahira 1980, Scowcroft and Giffin 1983).

Alien ungulates, goats among them, were introduced into Hawai'i[2] about 1780 A.D. Goats (*Capra hircus*) became established in the wild, and by the 1850's feral populations were large (Tomich 1969). The adverse impact of feral goats on Hawaiian forests has concerned managers and ecologists (Tomich 1969, Yocom 1967, Spatz and Mueller-Dombois 1973, Reeser 1976). Kramer (1971) considered the feral goat the most destructive ungulate introduced to the islands. Control efforts, which began about 1910 (Tomich 1969), proved effective where rigorously applied, a situation illustrated by the fencing and goat eradication program conducted in Hawai'i Volcanoes National Park. Feral goats are still a problem in some areas on Hawai'i, Kaua'i, Maui, Moloka'i, and Kaho'olawe. We studied one of the problem areas on Maui, where the native forest of koa (*Acacia koa*) appears to be decadent due to many years with little or no tree recruitment.

This paper reports a study of changes in ground cover, understory species composition, and regeneration of tree species in an area where goat browsing was eliminated for 7 years. It also compares that area with an adjacent area in which goat browsing continued.

STUDY AREA

A goat exclosure was erected in July 1976, at Healani on the south flank of Haleakala near Kaupo Gap, at an elevation of 1220 m. The exclosure lies within the Kipahulu Forest Reserve, owned and managed by the State of Hawai'i. The site was selected by consensus of knowledgeable scientists and land managers as representative of the surrounding goat-damaged montane parkland ecosystem.

The exclosure is rectangular, 30.5 × 61.0 m, and oriented with its long axis parallel to the 15° south-facing slope. The fence, designed to exclude feral goats and feral pigs, was made from 1.2-m high hog wire buried 15 cm in the soil and topped with a strand of barbed wire. The fence excluded pigs and goats successfully for about 6 yr. But in 1982, a large koa limb fell onto the fence, creating

[1] Received 10 May 1985, revision accepted 24 March 1986.

[2] Diacritical apostrophes indicate glottal stops in Hawaiian words.

a ramp into the exclosure. Goats got in and damaged tree regeneration. In 1983, recent browsing by goats was not evident, and none were in the exclosure.

VEGETATION.—The forest overstory is dominated by koa, which generally does not exceed 18 m in height. 'Ohi'a-lehua (*Metrosideros polymorpha*) is also a component of the overstory, but individuals are widely scattered and of small stature. Understory tree species growing in the area include kolea (*Myrsine lessertiana*), naio (*Myoporum sandwicensis*), 'a'ali'i (*Dodonaea eriocarpa*), and pilo (*Coprosma stephanocarpa*). The understory trees are typically less than 5 m tall. All tree species in the area are native.

Unlike the trees, relatively few of the shrubs and herbaceous species are native. The more conspicuous native species are *Deschampsia australis*, a grass, pukiawe (*Styphelia tameiameiae*) and naupaka (*Scaevola chamissoniana*), both shrubs, and maile (*Alyxia olivaeformis*), a vine. Native shrubs and herbaceous plants are scarce throughout the parkland ecosystem.

CLIMATE.—The median annual rainfall for the study area is about 2500 mm (State of Hawaii 1982). Nearly two-thirds of it falls during November through March. Temperatures during summer probably range from daytime highs near 30°C to nighttime lows near 10°C.

GOAT POPULATIONS.—Goats have not been censused in the vicinity of the exclosure. Nevertheless, wildlife biologists believe that a herd of 30 to 40 goats used the area in the mid to late 1970's (M. Ueoka, pers. comm.). At least 25 goats were seen near the exclosure in January 1981 (L. Loope, pers. comm.).

Hunters have reported a general downward trend in population size since about 1970. If this trend is true, the most likely cause was sustained heavy hunting promoted by local ranches and hunting clubs. Hunter success was so poor in1983 that the ranch controlling access to the forest closed the road so the goat population could build up again.

METHODS

HERBACEOUS LAYER VEGETATION.—We estimated percent live cover and relative species cover for herbaceous plants, tree seedlings, and shrubs using the point-intercept method (Mueller-Dombois and Ellenberg 1974). Four uniformly spaced transects, each 43 m long, were laid out within the exclosure, parallel to its long axis. Fifteen sample points spaced 3 m apart were marked along each transect; each sample point was a sampling unit.

A frame with 10 pointed brass rods was positioned at each sample point and the rods were lowered one at a time. Pin tip contacts with living plant tissue were recorded by species in order of contact. Only the first hit per species was recorded. Contacts with dead plant parts attached to a living plant were not recorded.

Percent live ground cover was estimated as the proportion of pins per sample point contacting live herbaceous layer vegetation. Relative species cover was estimated for each sample point as the number of live contacts for a given species divided by the total live contacts for all species.

A comparably sized area was delineated adjacent to and separate from the exclosure to serve as an unfenced control. Point-intercept data were collected in like manner as inside the exclosure. Both areas were sampled in August 1976, October 1977, September 1978, and October 1979. The same points were sampled each time.

TREE AND SHRUB REGENERATION.—Tree regeneration was assessed only in August 1983, 7 years after the exclosure was built. We measured total height and stem diameter at breast height (1.4 m above the ground) for all trees inside and outside the exclosure. Separate categories were kept for trees already established when the exclosure was built and trees that established after that time. We also noted whether browsing damage was evident and whether flowering or fruiting was occurring.

Not all trees were tall enough to have a diameter at breast height. In those cases we measured only total height and noted whether browsing damage was evident. Where they could be distinguished, we recorded seedlings and root sprouts separately.

Height and damage data were also collected for the shrubs lantana (*Lantana camara*) and pukiawe.

ANALYSIS.—Several hypotheses about herbaceous layer vegetation were tested: live cover inside the exclosure did not differ significantly from that outside at any time; year-to-year changes in live cover inside the exclosure did not differ significantly from the associated year-to-year changes outside; live molassesgrass cover did not change significantly from year to year inside or outside the exclosure; and significant changes in live cover of molassesgrass (*Melinis minutiflora*) were not accompanied by significant changes in live cover of velvetgrass (*Holcus lanatus*), natal redtop (*Rhynchelytrum repens*), or broad-leaved carpetgrass (*Axonopus compressus*).

These hypotheses were evaluated with one of two statistical procedures: comparison of two sample means with unpaired observations and equal variances, or comparison with paired observations (Steel and Torrie 1980). Multiple pairwise comparisons among means were made using the Bonferroni t-statistic (Bailey 1977) in the calculations instead of the student t-statistic (Miller 1981). Overall significance level did not exceed 0.05 for each set of comparisons.

TABLE 1. *Average live herbaceous layer cover[a] inside and outside the Healani goat exclosure by year. Standard errors of the mean are in parentheses.*

Year	Percent live cover	
	Inside	Outside
1976	37.3a (3.1)	41.8a (3.7)
1977	63.5b (4.7)	54.7b (3.9)
1978	71.3b (3.9)	62.7b (3.6)
1979	71.8b (4.2)	38.5a (3.0)

[a] Values in the same column followed by the same letter do not differ significantly ($P > 0.05$).

Tests were performed using untransformed and transformed data (arcsin$\sqrt{x}$). Because results of each set of multiple pairwise comparisons were the same in both cases, summary statistics presented herein are based on untransformed data. Tree and shrub data were not statistically analyzed because differences inside and outside the exclosure were obvious.

RESULTS AND DISCUSSION

When built in 1976, the exclosure contained 19 different plant species including five endemic trees (koa, 'ohi'a-lehua, 'a'ali'i, kolea, and naio), and indigenous shrub (pukiawe), an endemic grass (*Deschampsia australis*), and three indigenous ferns (*Dryopteris glabra, Pleopeltis thunbergiana,* and *Pteridium aquilinum*). During the succeeding 7 yr, only five new species invaded the exclosure. The new species included pilo, an endemic tree represented by three individuals; *Carex wahuensis,* an endemic sedge; and three alien grass or sedge species-ricegrass (*Paspalum orbiculare*), smutgrass (*Sporobolus capensis*), and kyllinga (*Cyperus brevifolius*). All of the species present when the exposure was built were still present 7 yr later.

A complete species list was unavailable for the unfenced study area in 1976. In 1983, 15 species were listed outside including three endemic trees (koa, 'ohi'a-lehua, and 'a'ali'i), two indigenous ferns (*Pleopeltis thunbergiana* and *Pteridium aquilinum*), and an endemic grass (*Deschampsia australis*). All species found in the unfenced study area in 1983 also were found inside the exclosure. The endemic fern *Dryopteris glabra* which was observed in 1976 in the unfenced area had disappeared by 1983. The reduced number of species outside (15) relative to inside the exclosure (24) may be due to suppression by goat browsing. Such a conclusion is tentative because we lack an initial species list for the unfenced area and because other factors could account for the lack of certain species, *e.g.*, no dispersal of heavy seeded species into the area.

HERBACEOUS LAYER VEGETATION

LIVE COVER.—Live cover inside the exclosure increased yearly from 1976 to 1979 (Table 1). However, only the 1976–77 increase was statistically significant. That year live cover almost doubled from 37 to 63 percent.

Live cover outside the exclosure increased the first 2 yr of the study (Table 1). The first year's increase was statistically significant; the second year's increase was not significant. The third year (1978–79) live cover decreased sharply to its initial level. The decrease may have been due to increased goat browsing pressure, although we have no independent evidence of it.

Total rainfall recorded at nearby Panileihulu during the 4 months before the 1979 measurement (390 mm) was similar to totals for 1977 (220 mm) and 1978 (425 mm). Because rainfall was not exceptionally low in 1979 and because live cover was stable inside the exclosure in 1979, we believe weather was not a factor contributing to decreased live cover outside the exclosure.

Yearly comparisons of live cover inside with that outside indicated a significant difference for 1979 only. Therefore, we rejected our first hypothesis that live cover did not differ between fenced and unfenced areas at any time during the study.

Year-to-year change in live cover inside was significantly different from that outside only during 1978–79. That year live cover increased only slightly inside and decreased about 24 percent outside (*cf.* Table 1). Thus, we rejected our second hypothesis of no difference in year-to-year changes in live cover inside versus outside.

RELATIVE SPECIES COVER.—Grasses were the predominant cover vegetation in the herbaceous layer for all years. They accounted for 76 to 85 percent of the live vegetation inside the exclosure and for 77 to 89 percent outside. Forb, fern, shrub, and tree species—in decreasing order—made up the rest of the live vegetation.

When the exclosure was built in 1976, differences in relative species cover inside and outside the exclosure were less than 2 percent for every species except broad-leaved carpetgrass, velvetgrass, molassesgrass, natal redtop, and gosmore (Table 2). Velvetgrass accounted for a greater proportion of the live plant cover outside than inside the exclosure. More molassesgrass and natal redtop were found inside than were found outside the exclosure, but differences were not statistically significant. During each of the ensuing 3 yr, the differences between relative cover inside and outside the exclosure were generally less than 4 percent for most species (Table 2). Broad-leaved carpetgrass, vel-

TABLE 2. *Relative percent species cover of live herbaceous layer vegetation inside and outside the Healani goat exclosure, 1976–1979. Standard errors of the mean are in parentheses.*

Species: Scientific name	Species: Common name	1976 Inside	1976 Outside	1977 Inside	1977 Outside	1978 Inside	1978 Outside	1979 Inside	1979 Outside
Grasses and sedges:									
Axonopus compressus	Broad-leaved carpetgrass	32.4 (6.0)	22.0 (4.6)	25.6 (4.9)	18.5 (3.9)	17.1 (3.8)	25.8 (4.3)	14.5 (3.7)	27.3 (4.8)
Cyperus brevifolius	Kyllinga	—	—	0.2 (0.2)	—	—	—	—	—
Deschampsia australis	—	—	—	0.9 (0.9)	—	—	—	—	—
Holcus lanatus	Velvet grass	4.7 (1.5)	37.9 (5.1)	8.3 (2.3)	24.1 (4.2)	7.3 (2.5)	16.6 (2.9)	3.7 (1.2)	16.0 (3.9)
Melinis minutiflora	Molassesgrass	21.4 (5.5)	7.9 (3.1)	32.2 (5.9)	16.9 (4.4)	44.9 (6.3)	15.5 (4.4)	57.1 (6.1)	24.0 (5.6)
Rhynchelytrum repens	Natal redtop	17.5 (4.9)	8.9 (3.1)	16.6 (4.1)	25.2 (4.7)	15.5 (3.8)	29.9 (4.7)	8.7 (2.5)	21.7 (4.7)
Sporobolus capensis	Smutgrass	—	0.4 (0.4)	0.2 (0.2)	1.0 (0.6)	—	—	—	0.3 (0.3)
Forbs:									
Bidens pilosa	Beggar's tick	1.1 (0.8)	1.9 (1.9)	3.3 (2.0)	2.5 (1.0)	0.6 (0.4)	2.0 (1.1)	—	0.7 (0.7)
Hypochoeris radicata	Gosmore	12.8 (3.9)	17.6 (4.0)	6.5 (2.8)	8.1 (2.4)	9.2 (3.0)	7.4 (1.8)	5.3 (2.6)	7.1 (2.7)
Ferns:									
Dryopteris glabra (E)[a]	Kilau	2.8 (2.1)	0.6 (0.6)	0.2 (0.2)	—	1.8 (1.3)	0.9 (0.9)	2.2 (1.8)	—
Pteridium aquilinum (I)[a]	Bracken	2.9 (2.0)	2.4 (2.0)	4.0 (2.1)	2.8 (1.7)	1.7 (1.0)	0.8 (0.4)	3.7 (1.5)	1.8 (1.8)
Shrubs:									
Rubus rosaefolius	Thimbleberry	1.9 (1.9)	0.4 (0.4)	—	0.6 (0.6)	—	0.7 (0.7)	—	1.1 (1.1)
Trees:									
Acacia koa (E)[a]	Koa	1.9 (1.9)	—	2.0 (1.8)	0.3 (0.3)	0.2 (0.2)	0.4 (0.4)	—	—
Coprosma stephanocarpa (E)[a]	Pilo	0.6 (0.6)	—	—	—	—	—	—	—
Dodonaea eriocarpa (E)[a]	'A'ali'i	—	—	—	—	1.7 (1.7)	—	4.8 (2.6)	—

[a] E = endemic species; I = indigenous species; all others are alien species.

vetgrass, molassesgrass, and natal redtop were again exceptions.

Molassesgrass was the most aggressive herbaceous layer species in the absence of browsing pressure. At time of fencing, only 12 out of 60 sample points had molassesgrass and only one of those had all 10 pins make contact (Fig. 1A). Spread during succeeding years was rapid; by 1979 over one-half of the sample points had molassesgrass, and all but five of these had 10 pins make contact.

Relative cover of molassesgrass consistently increased from year to year inside the exclosure (Table 2). Its expansion had not stopped when last measured in 1979. Multiple pairwise comparisons revealed the following differences in relative cover of molassesgrass among years:

1976 1977 1978 1979

Based on these results we rejected the third hypothesis of no yearly difference in live cover of molassesgrass inside the exclosure.

Expansion of molassesgrass inside the exclosure occurred at the expense of broad-leaved carpetgrass (Fig. 2). Relative cover of the latter was significantly less in 1979 than in 1976. Decreases in relative cover of natal redtop

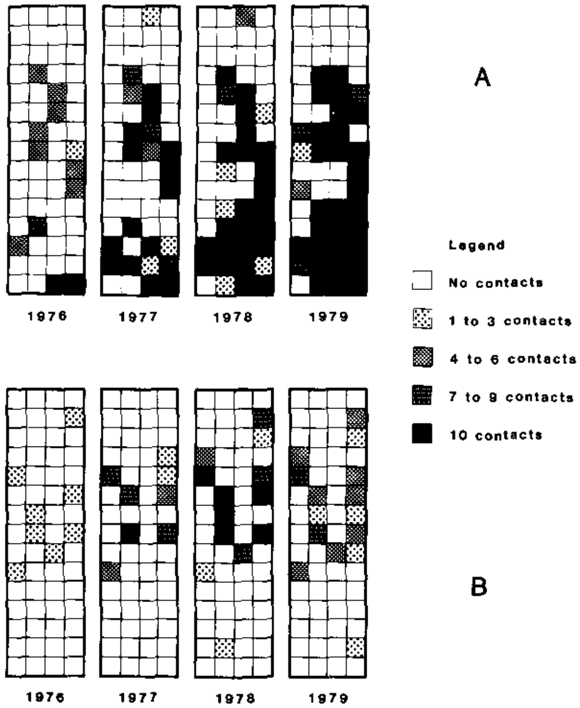

FIGURE 1. Spread of molassesgrass (*Melinis minutiflora*) from 1976 to 1979, inside (A) and outside (B) the Healani exclosure. Each cell represents a sampling point where 10 pins were lowered.

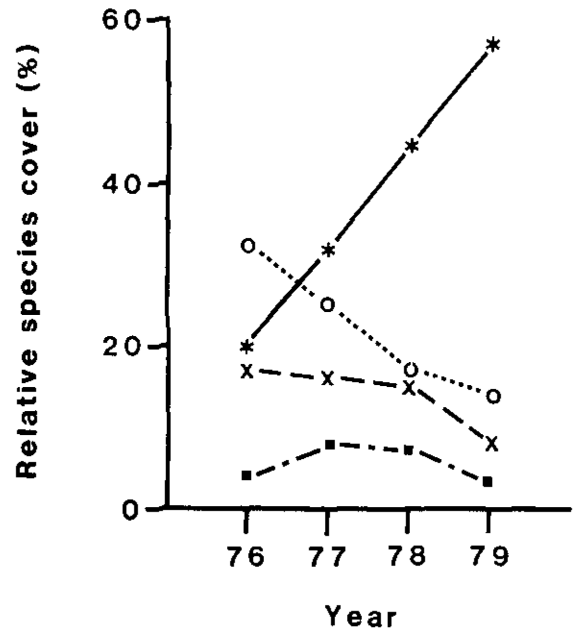

FIGURE 2. Change in relative species cover of *Melinus minutiflora* (•——•), *Axonopus compressus* (o----o), *Rhynchelytrum repens* (x———x), and *Holcus lanatus* (■-·-·■) inside the Healani goat exclosure.

and velvet grass also occurred, but the decreases were not statistically significant. Thus, we rejected the fourth hypothesis and concluded that molassesgrass was able to outcompete broad-leaved carpetgrass.

Outside the exclosure, molassesgrass also expanded (Fig. 1B), but the expansion was less pronounced than inside. Differences in relative cover among years were not statistically significant. No consistent trend in relative cover of other grasses accompanied the increases in molassesgrass.

In 1976 and 1977, relative molassesgrass cover inside was not statistically greater than outside the exclosure. But in 1978 and again in 1979, relative molassesgrass cover inside significantly exceeded that outside—44.9 vs 15.5 percent and 57.1 vs 24.0 percent, respectively.

TREE AND SHRUB REGENERATION

The seed-bearing trees and shrubs present at study establishment provide a basis for evaluating natural woody regeneration observed 7 yr later. Four tree and two shrub species occurred inside the exclosure. The trees included eight koa (80.8 cm average diameter at breast height), two ohia (18.0 cm dbh), one naio (19.3 cm dbh), and four kolea (22.9 cm dbh). The shrubs were a lantana 79 cm tall and a pukiawe 56 cm tall. In the unfenced study area two tree species occurred: seven koa (100.3 cm dbh) and two 'ohi'a-lehua (100.3 cm dbh). No shrub species occurred in the unfenced area.

Seven years after establishment, tree and shrub regeneration occurred only inside the exclosure *i.e.*, their canopies were beyond the reach of goats, and their stems were too large to be pushed over. In addition to 11 established koa, which averaged 6.3 (±1.5 SD) m tall and 11.7 (±2.7 SD) cm dbh, the exclosure contained 10 established 'a'ali'i trees which averaged 4.5 (±1.2 SD) m tall and 6.1 (±2.1 SD) cm dbh.

Most of the regenerated trees and shrubs inside the exclosure and all those regenerated outside were too short to have measurable diameter at breast height and were not considered established. Included in this category were four tree species and two shrub species (Table 3). All six species were reproducing inside the exclosure; outside only koa was reproducing. Thirty-four koa seedlings averaging 4.9 cm tall and one koa root sprout, 5.1 cm tall, were found outside. These heights are markedly shorter than for koa regenerated inside. Further evidence of the disparity between the two populations is apparent in their height class distributions (Fig. 3).

The lack of tree and shrub regeneration outside (except for koa) may be due to the combined effects of goat browsing and rate of input of viable seed. We suggest that few seeds dispersed into the unfenced area. For in-

TABLE 3. *Abundance and average height of trees and shrubs, less than 1.4 m tall, recruited inside the Healani exclosure and measured August 1983. Standard deviations are in parentheses.*

Species	Inside	
	Number	Height (cm)
Koa (seedling)	28	26.0 (18.2)
Koa (root sprout)	6	73.7 (30.5)
Pilo	3	35.6 (37.6)
'A'ali'i	50	37.6 (17.9)
Lantana	1	38.1 (—)
Kolea	240	9.7 (9.1)
Pukiawe	4	41.3 (18.1)

stance, pilo, kolea, and pukiawe have heavy fruits which drop close to the parent and are not dispersed by animals. The probability that such seeds could arrive in the unfenced study area seems low considering that no parent trees occurred there. Seedlings produced by the few seeds that might have reached the unprotected study area were probably eaten by goats.

If goats ate the tree and shrub seedlings outside the exclosure, why was koa regeneration as abundant there as inside the exclosure, 35 and 34 plants, respectively? We suspect that goats had not visited the area for a month or more and during their absence conditions favored seedling development. Existing koa trees inside and outside the exclosure bore seed throughout this study; however, generation of koa does not depend on annual seed rain, because koa seeds remain viable in the soil for years (Whitesell 1964). Conceivably, a decrease in browsing when conditions favored koa seed germination could have resulted in the crop of young seedlings we observed. Hunters reported that the goat population in the area was down in 1983, and during the month before our measurements the site received over 250 mm of rain. The seedling crop outside, which averaged only 4.9 cm tall, could have sprung up during this wetter-than-normal month.

We observed mortality of koa and 'a'ali'i regeneration in 1983. We counted one dead koa and 22 dead 'a'ali'i inside the exclosure. None of these had reached the size where they would be considered established. We could not determine if these trees had been weakened or killed by the goats that got into the exclosure in 1982.

Some goat damage to tree regeneration inside was evident in 1983. Eight of the 11 established koa trees, but none of the established 'a'ali'i trees, had bark stripping wounds. Among the short stature, unestablished woody regeneration, 33 of the 49 'a'ali'i, all three pilo, one of the four pukiawe, 10 of the 28 koa seedlings, and five of the 240 kolea had been browsed. The established koa and 'a'ali'i inside the exclosure appeared to be vigorous. Five of the koa and five of the 'a'ali'i trees were already

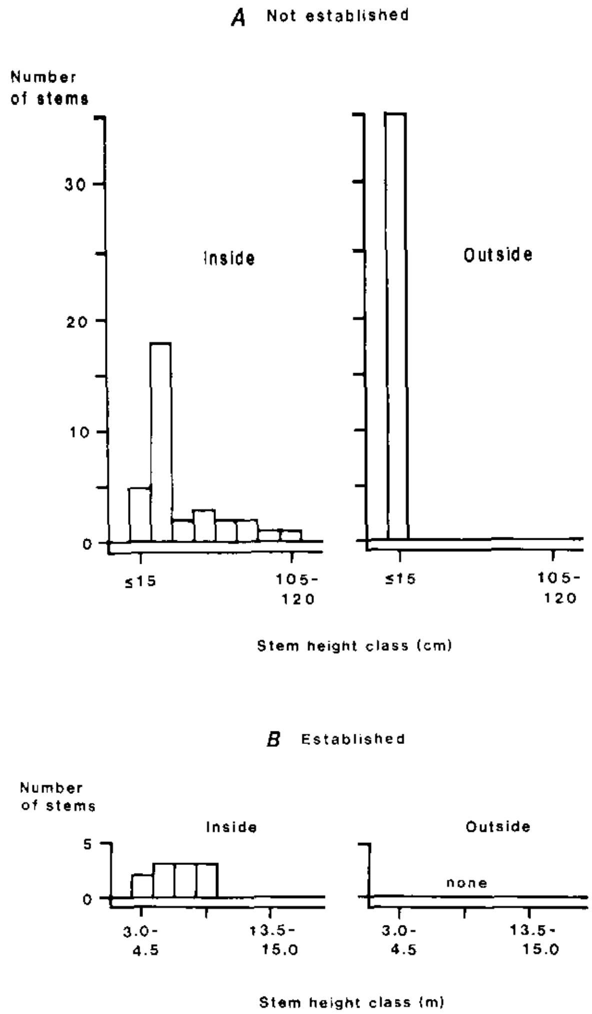

FIGURE 3. Height class distributions of non-established (A) and established (B) koa (*Acacia koa*) regeneration inside and outside the Healani goat exclosure 7 years after fencing. Established regeneration are individuals with canopies out of reach of goats and with stems stout enough to resist being pushed over.

flowering and bearing seed. The maximum age for these trees was 7 years. Outside the exclosure none of the koa seedlings had been browsed. This also indicated that the seedlings were recent emergents that had grown since goats had last browsed the site.

CONCLUSIONS

Feral goats contributed to the lack of tree and shrub regeneration at our study site. When these animals were excluded, regeneration of koa and other tree and shrub species occurred. In a different montane koa parkland on the Island of Hawai'i, Spatz and Mueller-Dombois (1973) found that goat feeding also interfered with reproduction of koa. Koa reproduction there was primarily by root suckers, and goats not only ate the shoots, but their activity also stimulated suckering which created unnaturally dense stands when released from browsing. We saw no evidence of increased suckering in our unfenced study area, nor had we expected an increase. Unlike the parkland ecosystem studied by Spatz and Mueller-Dombois (1973), koa stands in the Maui parkland appear to reproduce exclusively from seed. Root sprouts are transitory.

The understory vegetation at Healani also responded to release from browsing pressure. In particular, molassesgrass expanded and crowded out other grasses because of its ability to form thick, dense mats. Mueller-Dombois and Spatz (1975) observed a steep first-year rise in cover of molassesgrass in a goat-browsed coastal perennial grassland on the Island of Hawai'i. In contrast with its behavior at Healani, molassesgrass cover did not increase further in succeeding years (Mueller-Dombois 1979, 1981). Factors other than goat browsing were limiting spread.

Unlike the response at Healani, Mueller-Dombois and Spatz (1975) found that natal redtop spread rapidly the first year of their study. In subsequent years cover of natal redtop and molassesgrass remained stable at about 25 percent. Apparently, interspecific competition among perennial grasses was not as severe in the coastal grasslands as it was in Maui's montane koa parkland.

We believe molassesgrass is capable of interfering with regeneration of woody species that try to get started after the grass becomes dominant. Once established, molassesgrass will probably dominate understory vegetation until, and if, the developing tree canopy closes sufficiently to kill this shade-intolerant ground cover.

Long-term monitoring of the exclosure is planned to study successional changes during vegetation recovery. Particularly interesting is the interaction between native and alien species as the overstory develops. We hypothesize that alien understory species will remain viable components of the recovering vegetation and that invasion by native species will occur, but at a rate governed partly by competition with aliens and partly by rate of input of seed.

We studied only one site and, thus, have no measure of the variability of the forest or recovery. For this reason, we have not extrapolated our results. Additional exclosures of the size used in the present study would enable us to assess variability and to make legitimate inferences about recovery of the forest as a whole.

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