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Technical Report 99

**THE EXPANSION OF KOA FOREST AFTER CATTLE
AND GOAT REMOVAL
HAWAII VOLCANOES NATIONAL PARK**

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ABSTRACT

Cattle (*Bos taurus*) were the most destructive agents of Hawaiian forests in the nineteenth century. Cattle continuously grazed in koa (*Acacia koa*) communities on Mauna Loa in Hawai'i Volcanoes National Park from the early 1800s to 1948. Park managers documented the deleterious impact of cattle grazing on koa regeneration in 1941 by establishing exclosures and vegetation plots. Prolific regeneration occurred with cattle exclusion. We relocated their exclosures in 1992-1994, re-photographed the stands from the same photopoints, counted koa and other trees by height and/or diameter classes, and determined cover of understory vegetation. We also located the exclosures on aerial photographs from 1954, 1965, 1977, 1986, and 1992. We found that koa has nearly disappeared from the adjacent ranch land where cattle grazing continued, whereas koa stands have expanded greatly by root suckering to form large stands of continuous forest in the Park. Koa stands expanded little in the 20 yrs following termination of grazing in 1948, probably because of the presence of stray cattle and building populations of feral goats (*Capra hircus*). By the mid-1970s stray cattle and feral goats were controlled and expansion of koa stands greatly accelerated. Koa forest canopy may become more open in the future. Dense mats of alien vegetation have developed in the koa understory and may be inhibiting koa regeneration, and a lethal vascular wilt disease has spread. We need to understand the current dynamics of koa forest that have developed in the absence of cattle and goats better before additional management of koa forests is undertaken.

INTRODUCTION

Domestic and feral cattle (*Bos taurus*) were the most destructive agents in Hawaiian ecosystems of the nineteenth century (Stone 1985). Cattle were introduced to Hawai'i in 1793 (Tomich 1986) and hunting or use was prohibited by the Hawaiian King Kamehameha. By the 1820s, cattle were very abundant, and by the mid-1800s their destructiveness was recognized (Hillebrand 1856). On the Island of Hawai'i cattle have altered most of the mountain parkland on the mid-elevation slopes of Mauna Kea and Mauna Loa between 1200 and 2000 m, a vegetation zone still heavily utilized for cattle ranching. Cattle were grazed in the mountain parkland of Hawai'i Volcanoes National Park (HAVO) starting in the early 1800s (Baldwin and Fagerlund 1943). Grazing continued after inclusion of the Mauna Loa Strip into the park in 1927 (Apple 1954) and was formally terminated in 1948, although small numbers of cattle remained until the early-1970s (Linda Pratt, pers. comm.).

In the 1930s, two prominent Hawai'i foresters, C.S. Judd and L.W. Bryan, observed that koa (*Acacia koa*) was not regenerating in the grazed mountain parkland of the park (Apple 1954). The Park Superintendent asked the territorial government to suspend grazing, but this request was denied. Consequently, Park Naturalist Gunnar Fagerlund and Civilian Conservation Corps Foreman Paul Baldwin undertook a study to document the effects of cattle grazing. Baldwin and Fagerlund established exclosure plots, 1935-1940, and prepared report of their findings (National Park Service 1941), which they subsequently published (Baldwin and Fagerlund 1943). The intent of their study was to determine if cattle grazing was detrimental to the primary purpose of the park as articulated in the park's enabling legislation which specifically protected "timber" or forest resources. If grazing were

detrimental, the Secretary of Interior was empowered to revoke grazing privileges on park land. Baldwin and Fagerlund (1943) concluded from their studies that cattle were detrimental to koa regeneration and the continued survival of koa forest on Mauna Loa.

Baldwin and Fagerlund (National Park Service 1941) documented the location of their exclosures and plots with photographs and detailed maps. We (McKinney and Markiewicz) were able to relocate their plots, the oldest set of permanent plots in the park. The purpose of this report is to describe changes in the cover, stand structure, and understory of the koa communities of the lower mountain parkland in the park following the removal not only of cattle and but also of feral goats (*Capra hircus*), controlled in the early 1970s. From this evaluation, we will make recommendations for additional research and management of koa communities in the park.

STUDY AREA

The study area is an approximately 100 ha area located between 1325-1375 m elevation, west of the Mauna Loa Road and including the portion of Kapapala Ranch adjacent to HAVO on the Island of Hawai'i (19° 27' N, 155° 20' W) (Fig. 1) This area is representative of the lower mountain parkland between approximately 1250-1400 m elevation in the Mauna Loa Strip section of the park. The plots are located on pahoehoe flows >4,000 years old (Lockwood, 1987). Soils are derived from volcanic ash and average 25-75 cm in depth, forming a sandy loam inceptisol with a small percentage of stones and considerable decayed litter (US Department of Agriculture 1973). The study area lies above the wet forest belt because of a persistent temperature inversion associated with trade wind weather. The mean average rainfall is approximately 1400 mm with a

distinct summer dry period (Bridges and Carey 1973).

The current vegetation of the study area is nearly continuous open to closed koa forest with an alien grass understory, interspersed with scattered alien grasslands and shrublands. The historical vegetation prior to the introduction of cattle is not known with certainty. Based on a generalized description of the vegetation of Kapapala Ranch from Menzies in the late 1700s, Robyns and Lamb (1939) speculated that the original vegetation was mountain parkland, consisting of small stands of koa forest interspersed with grasslands. Baldwin and Fagerlund (1943) found a similar vegetation type in the 1930s, with small closed stands of koa and grasslands with older scattered koa trees growing within a grassland. Dead or dying koa trees were abundant in the grassland, suggesting that the koa forest was formerly more extensive.

Koa reproduces almost entirely by root suckers in the Mauna Loa Strip and drier areas of the mountain parkland (Spatz and Mueller-Dombois 1973). Stands will expand by proliferation of fast-growing root suckers on the periphery of a nucleus of mature trees (Spatz and Mueller-Dombois 1973, National Park Service 1941).

METHODS

The six plots established by Baldwin and Fagerlund in 1935 and 1940 were located at approximately 1400 m elevation within a 1 km radius of a common center. One plot in each pair was selected in a "senile or decadent" stand, i.e., a stand with large, older senescent trees; the paired plot was located in a "healthy and vigorous" stand, i.e., a stand with predominantly younger trees. Cattle were excluded from one pair of plots for six months (1940-1941) (Plots 5 and 8, Fig. 2); cattle were excluded from a second pair of plots for six years

(1935-1941) (Plots 1 and 2); grazing continued in the third pair located on Kapapala Ranch land adjacent to the park (Plots 7 and 9). This area has probably been grazed by cattle since at least the 1820s (Baldwin and Fagerlund 1943), and continues to be grazed today. Measurements were not taken prior to construction of the exclosures; all plots were evaluated in 1941.

We relocated Baldwin and Fagerlund's plots and 0.1 ac (0.04 ha) subplots by measuring from known landmarks and by finding signature trees present in the 1941 photographs. Vestiges of old fence lines, recollections of individuals familiar with the exclosures, and comparison of old and recent aerial photographs were additional aids in relocating the plots (Fig. 2). A detailed description of plot locations is provided for relocation purposes (Appendix 1).

Photographs were taken of each subplot from the original photopoints. Koa suckers <30 inches (76 cm) tall were counted, and the diameter of all koa stems >4.5 feet (1.4 m) tall was determined at breast height. The cover of understory vegetation in each subplot was determined by point-intercept method using a point frame along five equally spaced transects per subplot. Field work was conducted from 1992-1994, with all results reported as of 1994.

Aerial photographs of the study area from 1954, 1965, 1977, 1986, and 1992 were compared. Only photographs with the study area located near the center were used in order to minimize distortion. The scale of aerial photographs and plot outlines were standardized.

RESULTS

Forest Stand Structure

Six months after cattle were removed, Baldwin and Fagerlund (1943) found an abundance of young root suckers (<75 cm tall), an immediate response to the relaxation of grazing pressure (Plots 5 and 8) (Tables 1 and 2). Six years after cattle exclusion, they found few root suckers but a dense cohort of poles 3-4 m tall and 7-8 cm in diameter (dbh) (Plots 1 and 2). They found no koa regeneration in Plots 7 and 9, located immediately outside HAVO on adjoining ranch land, except for very short root sprouts along one root.

Koa continued to regenerate in all plots (exclosures) in the park established by Baldwin and Fagerlund (1943) (Plots 1, 2, 5, and 8) since the removal of cattle and goats. This is demonstrated by an average 4-fold increase in density of mature trees (>15 cm dbh) (Table 1) and the presence of sprouts and saplings (0-5 cm dbh) and poles (5-15 cm dbh) in some plots (Table 2).

Stand structure varied among the four park plots in 1994. Plots 1 and 2, fenced in 1935, had an abundance of saplings and poles in 1941 due to six years of cattle exclusion (Table 1). By 1994 Plot 1 was an all-aged stand, with all size classes represented (Table 2) (Figs. 3 and 4). Small root suckers and saplings were abundant in 1992 only in Plot 1. The density of mature trees (>15 cm dbh) increased more than 10-fold (Table 1). Outside the subplots there were large gaps with little regeneration around senescent and dead koa. Plot 2 differed from Plot 1 in having few sprouts, saplings, and small poles and few very large trees (Figs. 5 and 6). The density of mature trees doubled from 1941-1992, notwithstanding that nearly 40% of the standing trees in the subplots, many of which were >15 cm dbh, were dead in 1994.

Grazing was temporarily stopped in Plots 5 and 8 in 1940-1942. It resumed in 1942 and was terminated in 1948. Both plots had an abundance of root sprouts in 1941, six months after grazing ended for the first time (Table 1). By 1994 Plot 5 was a lightly stocked, mostly open stand with small stands of sprouts, saplings, poles and smaller mature trees interspersed among gaps with large senescent or dead koa with little regeneration around them (Figs. 7 and 8).

Plot 8 was more of an even-aged stand than the other plots, with most trees in the pole stage or small mature trees <30 cm dbh (Tables 1 and 2). There were no large senescent trees and virtually no small root sprouts and saplings (Figs. 9 and 10).

In 1994 there was no koa regeneration in either of the continuously grazed plots on Kapapala Ranch (Tables 1 and 2). Plot 7 had a few large, older trees (Figs. 11 and 12); Plot 9 had no trees (Figs. 13 and 14). Some of the larger trees were killed in 1975 by the Six Tanks Fire. This fire originated in Keauhou Ranch, carried through the park north of the plots, and burned Plots 7 and 9 in Kapapala Ranch.

Although `ohi`a (*Metrosideros polymorpha*) is not an overstory component of the koa forests in the study area, very scattered individuals have become established beneath the koa canopy in HAVO (Fig. 15). `Ohi`a is generally an early successional dominant at lower elevations of the Mauna Loa Strip, invading lava flows and is replaced by koa over time. We found 15 `ohi`a/ha in Plot 2, 7 `ohi`a/ha in Plots 1 and 8, and 0.1 `ohi`a/ha in Plot 5. Sizes varied from seedlings to trees 15 cm dbh. All `ohi`a were growing on nurse logs and their crowns were located beneath the koa canopy (Fig. 15).

Aerial Photographs

Aerial photos of the study area from 1954 confirm Baldwin and Fagerlund's (1943) description of Mauna Loa as largely a koa savanna, interspersed with scattered stands of koa and shrublands (Fig. 16). The perimeters of Plots 1 and 2 had angular outlines, following the enclosure fence line. Only a few trees were apparent in Plot 9, characterized by Baldwin and Fagerlund (1943) as decadent. Plot 7 is partly forested.

Expansion of koa in the park was noticeable by 1965 (Fig. 16). Expansion is indicated by the loss of the angular edges of the plots characteristic of the 1954 aerial photo. Expansion of koa groves was especially noticeable on the east edge of Plot 1. Koa stands north of Plots 1 and 5 had filled in conspicuously, and disjunct lines of trees can also be seen along the east edges of Plots 1 and 2. Koa in the ranch land (Plots 7 and 9) changed little in this period.

The koa stands in the park expanded rapidly between 1965 and 1977 (Fig. 16). This was particularly evident by new, closed canopy forest north, east, and south of Plots 1 and 2. Most of the koa in the ranch land were killed by fire in 1975. Koa expanded rapidly between 1977 and 1986 throughout the study area (Figs. 16-17). Regeneration was not evident in plots in adjacent ranch land because of combined effects of fire followed by continued cattle grazing. By 1992, the study area inside the park was largely continuous koa forest, except for small scattered grasslands and shrublands (Fig. 17).

The stand structure of Plots 1, 2, and 5 appeared to have changed little from 1954 to 1992 (Figs. 16-17). Plots 1 and 5 remained all-aged stands with small gaps around older, open-form, senescent or dead trees; Plot 2 was relatively closed and even-aged, with some areas of all aged structure. The stand structure of Plot 8 changed

noticeably from 1954-1992. In 1954, Plot 8 was mostly savanna, with some areas of open forest; it was closed, mostly even-aged forest in 1992. The perimeters of the Plots 1 and 2 can be distinguished from 1977-1992 because of differences in stand structure within Plots 1 and 2 and the expanding koa forest on their south, north, and east margins.

Understory

Baldwin and Fagerlund (1943) estimated the cover of understory species for the 18 subplots in 1941, reporting their data only in summary fashion. The principal understory plants were dallis grass (*Paspalum dilatatum*) (25%), velvet grass (*Holcus lanatus*) (20%), Bermuda grass (*Cynodon dactylon*) (10%), thimbleberry (*Rubus rosifolius*) (9%), orchard grass (*Dactylis glomerata*) (7%), and *Deschampsia nubigena* (7%), the most abundant grass in open areas (National Park Service 1941).

Understory vegetation has changed dramatically since 1941 and also differed greatly in 1994 between grazed and ungrazed plots (Table 3). In 1994 the most abundant understory plants in the grazed ranch land (Plots 7 and 9) were Kikuyu grass (*Pennisetum clandestinum*) (60%), dropseed (*Sporobolus africanus*) (20%), white clover (*Trifolium repens*) (9%), and dallis grass (4%), all alien species. (Table 3). The most abundant understory plants in the park plots (Plots 1, 2, 5, and 8) were meadow ricegrass (*Ehrharta stipoides*) (42%), dallis grass (16%), kilau or bracken fern (*Pteridium aquilinum*) (10%), Kikuyu grass (9%), 'emoloa (*Eragrostis variabilis*) (5%), orchard grass (3%), and blackberry (*Rubus argutus*) (3%). 'Emoloa and kilau are native species; the others are alien.

Cover varied greatly by plot in the park. The understories of the adjacent Plots 1 and 5 were dominated by meadow ricegrass. The understories of the adjacent

Plots 2 and 8 were dominated by dallis grass, `emoloa, Kikuyu grass and blackberry. Aside from `emoloa, not apparently a widespread species in 1941, and now locally abundant, native herbaceous understory plants are also very rare. *Deschampsia*, relatively common in 1941 has essentially disappeared, present only in one plot on a nurse log. Scattered tree fern (*Cibotium glaucum*), wood fern (*Dryopteris spp.*) and palapalai fern (*Microlepia strigosa*) occur, always on nurse logs.

DISCUSSION

Cattle grazing has nearly eliminated koa from the Kapapala Ranch adjacent to the Park, as predicted by Baldwin and Fagerlund (1943). Continued grazing may eventually result in the complete loss of koa from grazed lands in Kapapala Ranch near the park.

Wildfire, followed by cattle grazing, hastened the decline of koa in Kapapala Ranch. Fire killed mature koa in the ranch plots, with only a few individuals surviving the 1975 Six Tanks Fire. The resumption of cattle grazing after the fire prevented koa regeneration by root suckers, which would have followed fire in the absence of grazers. In the park, koa regenerated prolifically by root suckers after the Six Tanks Fire (Parman 1976). This fire was not a factor in the recovery of koa in the plots in the park because it did not burn this area.

Removal not only of cattle but also of feral goats was important in permitting the expansion of koa stands. Feral goats (*Capra hircus*) have probably been present in the Mauna Loa Strip for nearly 200 years although their population levels may have been low in areas in which cattle grazing was intensive (Baldwin and Fagerlund 1943). Goat populations built up in the 1950s and 1960s following the termination of cattle grazing rights (Baker and Reeser

1972). Goats were almost completely suppressing koa regeneration by the late 1960s in a site at 1900 m in Mauna Loa Strip (Spatz and Mueller-Dombois 1973). Removal of goats in an experimental enclosure allowed the proliferation of root suckers. Goat populations were sharply reduced on the Mauna Loa Strip in the mid-1970's and finally eradicated by 1985 (Larry Katahira, pers. comm.).

Contrary to expectation, the aerial photographs indicate that there was little or no expansion of koa groves by 1954, in spite of termination of cattle grazing rights in 1948 and the rapid regeneration of koa that occurs after cattle exclusion. The angular outline of the fenced plots (Plots 1 and 2, Fig. 16) probably resulted from the proliferation of koa root sprouts within the enclosure up to the fencelines, and the absence of koa regeneration outside the plot. The failure of koa groves to expand by 1954 may reflect the continued presence of stray cattle from the ranch, habituated to use of the site (Superintendent's Report, 1948; Gordon Cran, pers. comm.) and/or increasing goat populations documented by observers at the time (Baker and Reeser 1972, Spatz and Mueller-Dombois 1973).

The aerial photographs indicate that koa groves in the study area began to expand between 1954 and 1965, a trend observed in koa stands in other parts of the Mauna Loa Strip. Koa stands expanded 0.5-2.5 m/yr between 1954 and 1965 in other parts of the Mauna Loa Strip (Mueller-Dombois 1967), and koa forest contiguous to the study site expanded from 4.4% to 10.3% of aerial cover from 1956 to 1965 (Cuddihy 1984). The investigators inferred that cattle removal permitted these modest expansions since they occurred in spite of intense goat browsing from an expanding goat population.

Rapid expansion of koa forest occurred largely after removal of the last stray cattle and after goat control, both

Katahira, pers. comm., Linda Pratt, pers. comm.). Rapid expansion of koa forests started sometime in the period from 1965-1977, as indicated by the 1977 aerial photographs. Expansion occurred very rapidly from 1977-1986, with the development of nearly continuous forest from 1977-1986.

We cannot evaluate the relative importance of cattle and goat control in the study area because of the complex history of ungulate control. After termination of cattle grazing rights, both cattle and goats may have limited koa stand expansion. We also know that koa stands coalesced into forest after 1977, after both cattle and goats were removed.

Control of feral pigs (*Sus scrofa*) in the mid-1980s may have contributed to the expansion of koa to some degree. Pigs are known to eat koa seeds (Katahira *et al.* 1993) and koa seedlings (Mueller-Dombois 1981 (a)), and they also eat and uproot root suckers. However, it is not possible to separate the possible effects of feral pig removal on koa populations from those of feral cattle and goat removal.

The koa forests of the study area may now be more extensive than those of pre-cattle days, thought to have been a mosaic of small koa stands and grasslands (Robyns and Lamb 1949). Spatz and Mueller-Dombois (1973) believed that stocking levels of koa stands after the removal of feral goats were unnaturally high due to browsing and trampling damage which stimulated high levels of root sprouting.

Although koa stands expanded rapidly and now form nearly continuous forest in the study area, koa regeneration may decline and koa forest structure may become more open in the future, beyond what is expected by self-thinning in densely stocked koa stands resulting from a proliferation of root sprouts. This

possibility is suggested by the paucity of koa regeneration in the dense mats of alien grasses and stands of blackberry that have formed beneath the koa canopy and which persist in gaps. Root suckers, the only form of koa regeneration observed in the plots, are now found only on nurse logs, even in large forest gaps. Almost always the nurse logs are well-rotted and penetrated by koa roots which give rise to root suckers. We did not expect to find much sprout or seedling recruitment in young, closed koa forest that has developed recently, e.g. most of Plots 2 and 8. Koa sprouts may require greater levels of light and higher temperatures found typically in forest gaps, as Spatz (1973) found for koa seedlings. However, we expected to find koa regeneration in gaps around senescent or dead trees. The paucity of regeneration in gaps may be due to dense mats of alien vegetation that formed in the understory prior to gap formation. Spatz (1973) found little root suckering of koa in a savanna study site with a dense grass sward unless the sward was artificially removed.

The most important alien understory grasses are now meadow ricegrass, dallis grass, and Kikuyu grass. Meadow ricegrass was apparently an uncommon plant in the Park prior to cattle removal (Fagerlund and Mitchell, 1944; Fagerlund 1947), but was abundant by 1972 (Linda Pratt, pers. comm.). It is probably now the most abundant species in the understory of koa forests in lower and mid-elevations on the Mauna Loa Strip and forms a dense mat 0.5-0.75 m tall with a persistent litter layer. It dominates the understory in Plots 1 and 5. It appears that meadow ricegrass invades after koa stands develop; it is nearly absent from grasslands and shrublands in the early stages of koa invasion. Dallis grass and Kikuyu grass also form locally dense, single species swards in the understory and are abundant in Plots 2 and 8. Alien blackberry was also not important prior to cattle removal; it is now locally abundant. Dense stands of blackberry appear to nearly

preclude native tree regeneration, including seedling/sapling recruitment of koa (Tunison *et al.*, in prep.).

Even though there appears to be little koa recruitment in forest gaps, koa root suckers continue to invade the remnant grasslands and shrublands in the study area. Koa root suckers penetrate a largely different suite of grasses and shrubs in the grassland and shrublands than in the gaps. Species in grasslands and shrublands include broomsedge (*Andropogon virginicus*), sweet vernal grass (*Anthoxanthum odoratum*), beardgrass (*Schizachyrium condensatum*), velvet grass (*Holcus lanatus*), *Deschampsia*, and 'emoloa, along with the native shrubs pukiawe (*Styphelia tameiameia*) and 'a'ali'i (*Dodonaea viscosa*). Forest gaps support a suite of grasses typical of the koa understory, especially meadow ricegrass. Patterns of koa recruitment in gaps may change as large dead limbs begin to decompose and lie against the soil surface. Most koa sprouts are found on well-rotted nurse logs, and many dead koa limbs in gaps are now elevated and not decaying rapidly.

Forest cover may also be affected by an unexplained dieback of koa, which may be spreading. There is an approximately 100 m diameter dieback center on the western edge of Plot 1. Similar smaller dieback centers are found in Plot 2 and elsewhere in the Mauna Loa Strip in koa forest. Dieback centers differ from open gaps around dead or senescent large koa in that there is mortality of all size classes of koa. Essentially all koa are dead in the center of the dieback area. Away from the center, there are fewer dead trees. On the periphery of the dieback centers, most trees are living but have some dead branches. Gardner (1980) believes that an internally seed-borne pathogenic fungus (*Fusarium oxysporum* f. sp. *koae* f. sp. nov.), which causes a vascular wilt disease of koa seedlings under greenhouse

conditions, might be a factor in mortality of older koa, possibly along with other pathogens.

CONCLUSIONS AND RECOMMENDATIONS

Park ungulate control programs have stimulated the rapid expansion of koa forest in the Park and prevented the near demise of koa communities that has occurred on adjacent ranch land. However, forest development and removal of grazers may have resulted in changes in stand structure and understory vegetation that now inhibit the regeneration of koa within koa stands. We cannot predict the future structure of the koa forest with existing data. Therefore, we make the following recommendations:

1. Continue exclusion of feral ungulates and scouting for alien plants that may spread into the Mauna Loa Strip, e.g., faya tree (*Myrica faya*).
2. Study the dynamics of koa stands on Mauna Loa, especially the effects of understory vegetation on koa regeneration, and regeneration in gaps. We also need to understand the dynamics of koa forest after fire, probably an inherent ecological factor of this environment (Mueller-Dombois, 1981 (b)).
3. Investigate koa dieback or wilt. Dieback appears to be increasing on Mauna Loa and may become an important factor determining koa stand structure in the future.
4. Undertake experimental restoration of the native understory. Some components of a native understory are present. Native ferns occur on nurse logs and the native grass 'emoloa is locally common. Control of alien grasses and blackberry may allow the spread of these plants.

Before we can manage koa forest on a greater scale, we first need to understand the dynamics of the koa forests that have developed in the absence of cattle and goats, particularly the effects of alien understory on koa regeneration.

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LITERATURE CITED

- Apple, R.A. 1954. The history of land acquisition for Hawai'i National Park to December 31, 1950. M.A. Thesis. University of Hawai'i, Honolulu. 158 pp.
- Baldwin, P.H. and G.O. Fagerlund. 1943. The effect of cattle grazing on koa reproduction in Hawai'i National Park. *Ecology* 24:118-122.
- Baker, J.K. and D.W. Reeser. 1972. Goat management problems in Hawai'i Volcanoes National Park: A history, analysis, and management plan. Natural Resources Report No. 2. USDI, Natl. Park. Serv. 22 pp.
- Bridges, K.W. and G.V. Carey. 1973. The climate of the IBP sites on Mauna Loa. Technical Report No. 22. U.S. International Biological Program.
- Cuddihy, L.J. 1984. The effects of cattle grazing on the mountain parkland ecosystem, Mauna Loa, Hawai'i. Tech. Report 51. Coop. Natl. Park. Resour. Stud. Unit. University of Hawaii, Honolulu.
- Fagerlund, G.O. 1947. The exotic plants of Hawai'i National Park. Natural History Bulletin No. 10. Department of Interior. 62 pp.
- Fagerlund, G.O. and A.L. Mitchell. 1944. A checklist of plants of Hawai'i National Park (Kilauea-Mauna Loa section). Natural History Bulletin. No. 9. Hawai'i National Park.
- Gardner, D.E. 1980. *Acacia koa* seedling wilt caused by *Fusarium oxysporum* f. sp. *koae*. f sp nov. *Phytopathology* 70:594-597.
- Hillebrand, W. 1856. The relation of forestry to agriculture. *Hawai'i Plant. Rec.*, 22:174-200. Original not seen; cited in P.H. Baldwin and G.O. Fagerlund. 1943. The effect of cattle grazing on koa reproduction in Hawai'i National Park. *Ecology* 24:118-122.
- Katahira, L.K., P. Finnegan, and C.P. Stone. 1993. Eradicating feral pigs in montane mesic habitat at Hawai'i Volcanoes National Park. *Wildl. Soc. Bull.* 21:269-274.
- Lockwood, J.P. 1987. Holocene eruptive history of Mauna Loa volcano. *In* *Volcanism in Hawai'i*, eds. R.W. Decker, T.L. Wright, and P.H. Stauffer. U.S. Geological Survey Professional Paper 1350. U.S. Govt. Printing Office, Washington DC.
- Mueller-Dombois, D. 1967. Ecological relations in the alpine and subalpine vegetation of Mauna Loa. *Hawai'i Bot. Soc.* 46(4):403-411.
- Mueller-Dombois, D. 1981 (a). Understanding Hawaiian forest ecosystems: The key to biological conservation. pp. 502-520 *In* *Island ecosystems: Biological organization in selected Hawaiian communities.* eds. D. Mueller-Dombois, K.W. Bridges, and H.L. Carson. US/IBP Synthesis Series 15. Hutchinson Ross Publishing Company.

- Mueller-Dombois, D. 1981 (b). Fire in tropical ecosystems. pp 136-176 In Fire regimes and ecosystem properties: Proceed. of the conf. December 11-15, 1978. Honolulu, Hawaii. eds. H.A. Mooney, T.M. Bonnicksen, N.L. Christensen, J.E. Lotan, and W.A. Reiner. U.S. Dept. Agric. Forest Service General Tech. Rept. WO-26.
- National Park Service. 1941. Grazing Report. Illustrated, typewritten report in Hawaii volcanoes National Park files. 45 pp.
- Parman, T.T. 1976. The effects of fire upon a Hawaiian montane ecosystem. pp. 171-178 In Proceedings, First Conference in Natural Sciences, Hawai'i Volcanoes National Park. Coop. Natl. Park Resour. Stud. Unit, Univer. of Hawai'i.
- Robyns, W. and S.H. Lamb. 1939. Preliminary ecological survey of the Island of Hawai'i. Bull. du Jardin botanique de L'Etat, Bruxelles 15:241-293.
- Spatz, G. 1973. Some findings on vegetative and sexual reproduction of koa. Technical Report No. 17. US. International Biological Program.
- Spatz, G. and D. Mueller-Dombois. 1973. The influence of feral goats on koa tree reproduction in Hawai'i Volcanoes National Park. Ecology 54(4): 870-876.
- Stone, C.P. 1985. Alien animal in Hawai'i's ecosystems: Toward controlling the adverse effects of introduced vertebrates. Pp. 251-288 In C.P. Stone, and J.M. Scott (eds) Hawai'i's Terrestrial Ecosystems: Preservation and Management. Coop. Natl. Park Resour. Stud. Unit, University of Hawai'i, Honolulu.
- Tomich, P.Q. 1986. Mammals in Hawai'i: A Synopsis and Notational Bibliography. Bishop Museum Special Publication 76. Bishop Museum Press, Honolulu, Hawai'i. 375 pp.
- Tunison, J.T., N.G. Zimmer, R.M. Mattos, and R.L. Loh. In prep. Alien plant control in Special Ecological Areas, Hawai'i Volcanoes National Park, 1985-1994.
- US Department of Agriculture. 1973. Soil Survey of Island of Hawai'i, State of Hawaii.



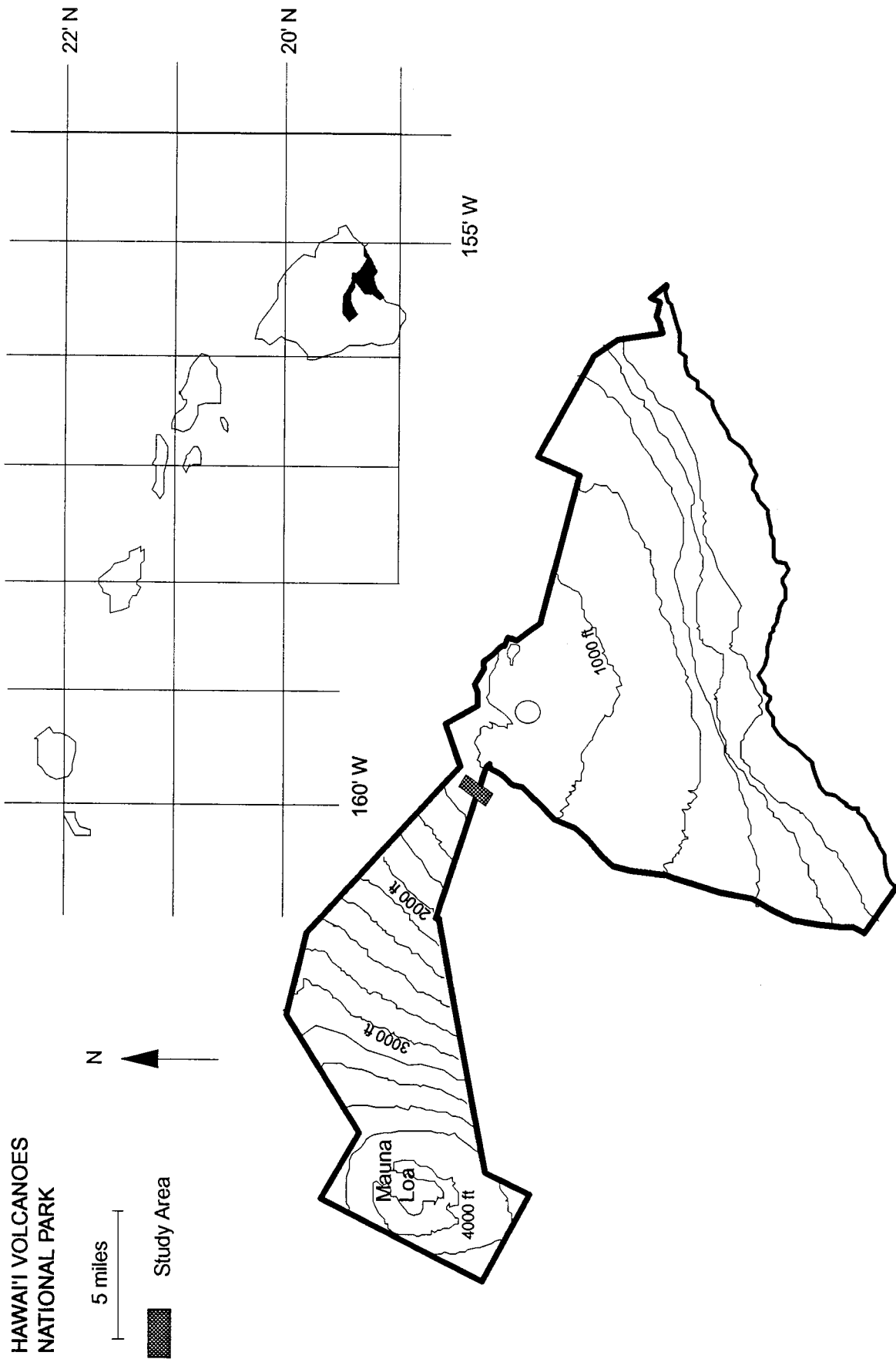


Figure 1. Outline map of Hawaii'i Volcanoes National Park showing location of study area on Mauna Loa.

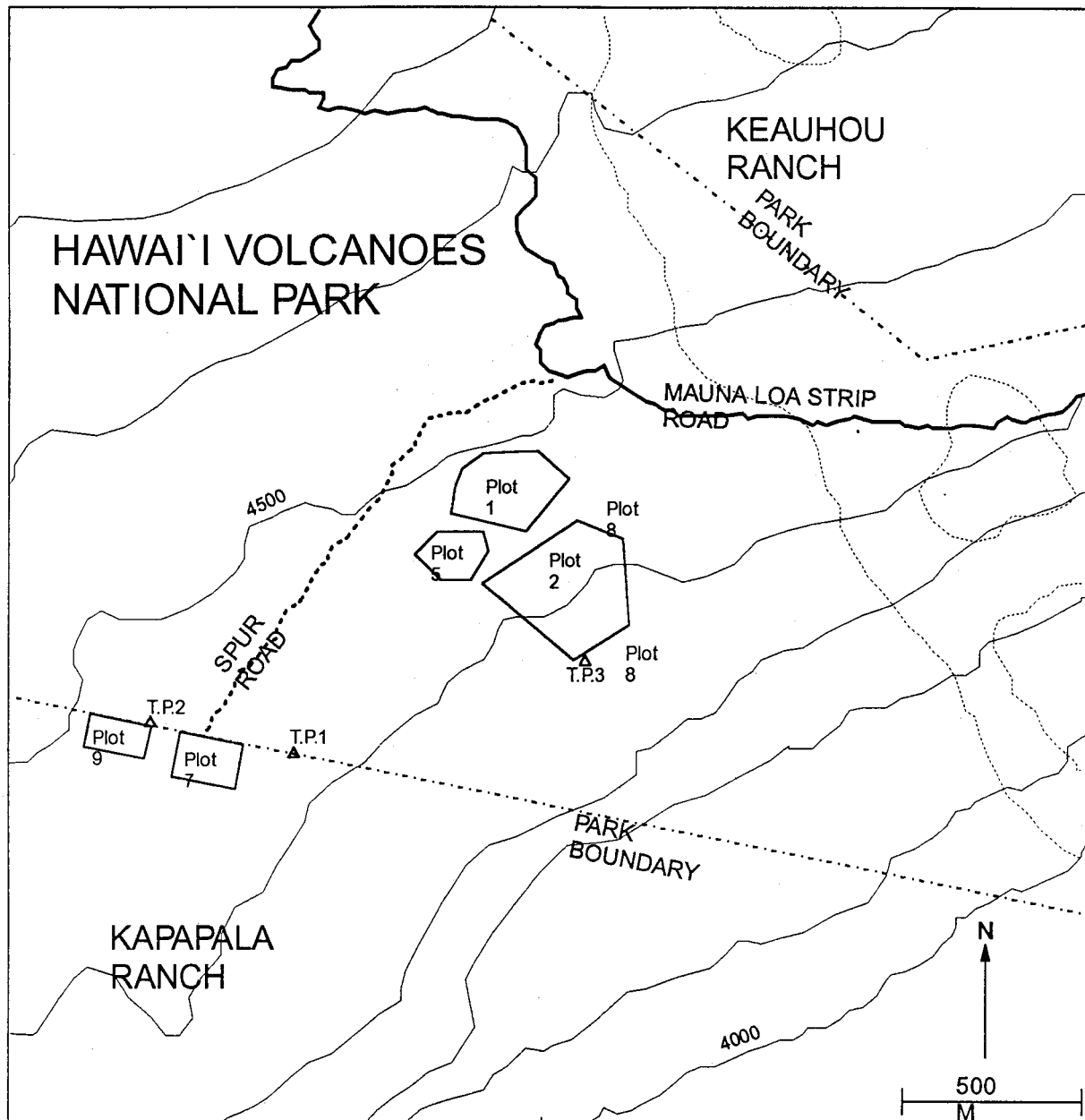


Figure 2. Location of plots in study area on Mauna Loa.



Fig. 3. Plot 1, subplot 2, 1941. This plot was fenced and protected from cattle in 1935. Sapling and pole-sized koa resulting from cattle exclusion are not visible from this viewpoint. Important understory plants were akala, thimbleberry, dallis grass, and *Deschampsia* in open areas (foreground).



Fig. 4. Plot 1, subplot 2, 1992. By 1992 plot was an all-aged stand with small root sprouts and saplings of koa on nurse logs. An 'ohi'a sapling is growing on a nurse log largely covered by grass in center of photograph. The understory is dominated by meadow ricegrass, with minor amounts of dallis grass and bracken fern.



Fig. 5. Plot 2, subplot 15, 1941. The photograph is taken from outside the plot, whose near margin is delineated by the enclosure fence. A dense stand of koa poles had developed inside the fence after 6 years of cattle exclusion.

Fig. 6. Plot 2, subplot 15, 1994. The location of the old fence line is indicated by distinct, oblique line of even-aged koa at center of photograph. The understory is comprised of dallis grass and orchard grass.



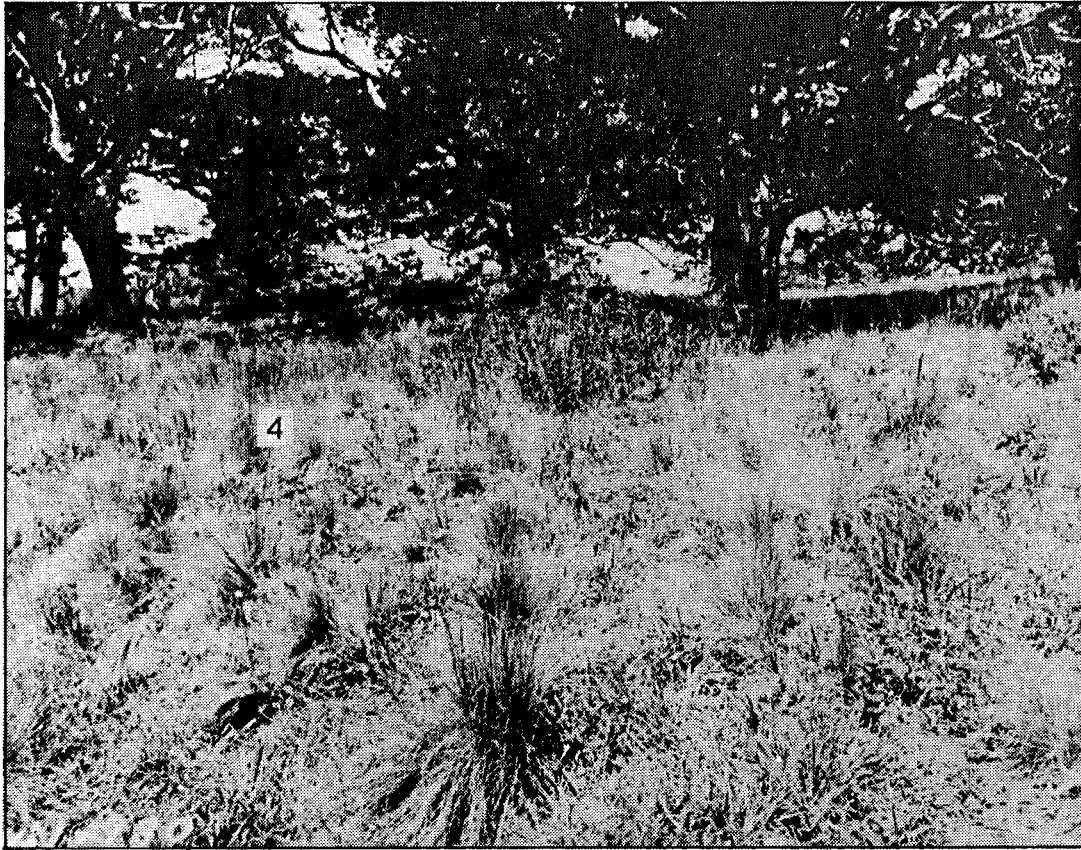


Fig. 7. Plot 5, subplot 4, 1941. Cattle were removed from this unfenced plot 6 months before the photograph was taken. The short root sprouts found by Baldwin and Fagerlund (1943) are not visible in the photograph. The bunchgrass visible in the opening in the foreground appears to be grazed *Deschampsia*, which was common in open areas in 1941.

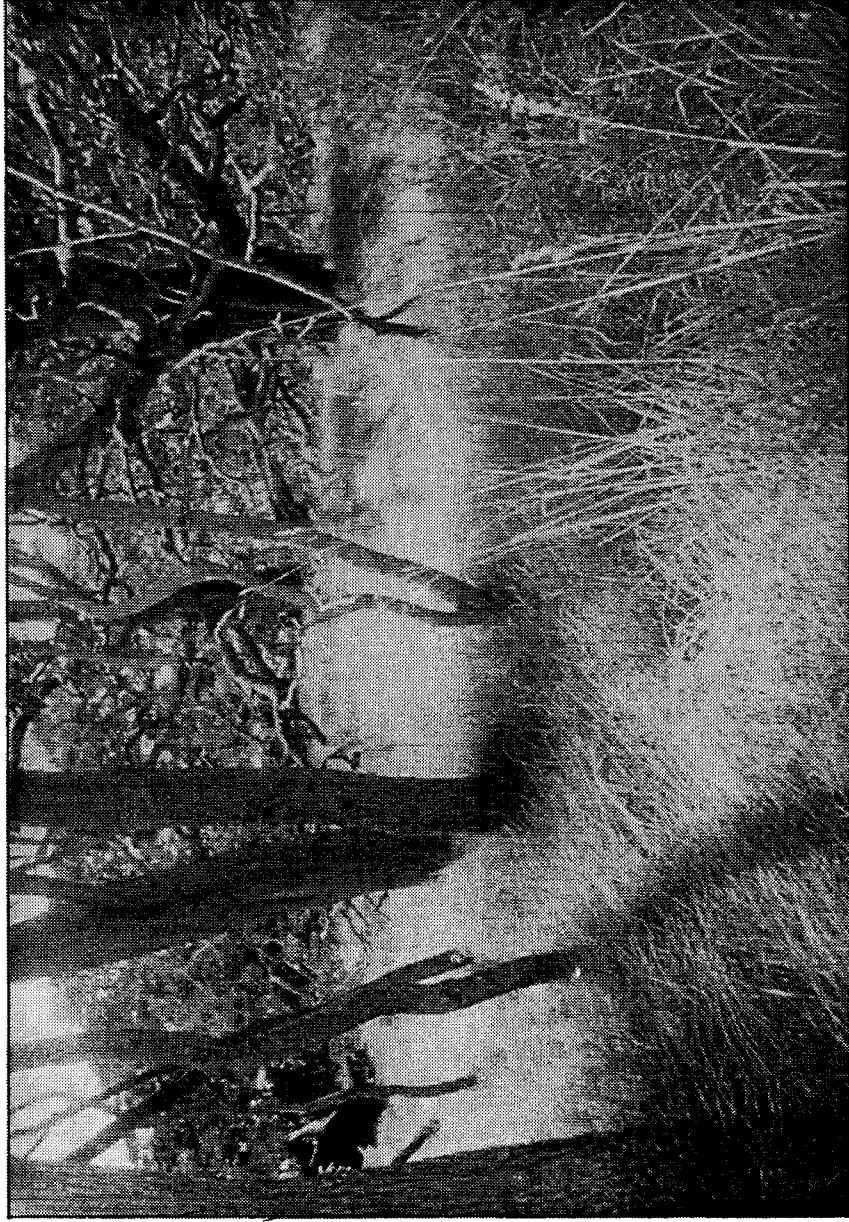


Fig. 8. Plot 5, subplot 4, 1992. Three signature koa trees are present in the background. The dominant understory plant is meadow ricegrass.



Fig. 9. Plot 8, subplot 11, 1941. Cattle were removed from this unfenced plot 6 months before the photograph was taken. **The short root sprouts found by Baldwin and Fagerlund (1943) are not visible in the photograph.** *Deschampsia* is apparent in foreground.



Fig. 10. Plot 8, subplot 11, 1994. A cohort of young trees visible in background. The dominant understory plants are dallis grass (foreground) and meadow ricegrass (background).



Fig. 11. Plot 7, subplot 7, 1941. Located on ranchland adjacent to the park, this area has probably been continuously grazed since the early 1800's. *Deschampsia* is visible in the opening in the foreground.



Fig. 12. Plot 7, subplot 7, 1992. Only one tree remains in the plot after grazing, which prevented regeneration, and a 1975 fire, which killed the aerial portions of the large koa present before the fire. The logs on the right are charred. The dominant grasses are Kikuyu grass and dropseed grass (*Sporobolus africanus*).



Fig. 13. Plot 9, 1941. This is an overview of the plot which was grazed at the time of the photograph. Koa trees are senescent or diseased.

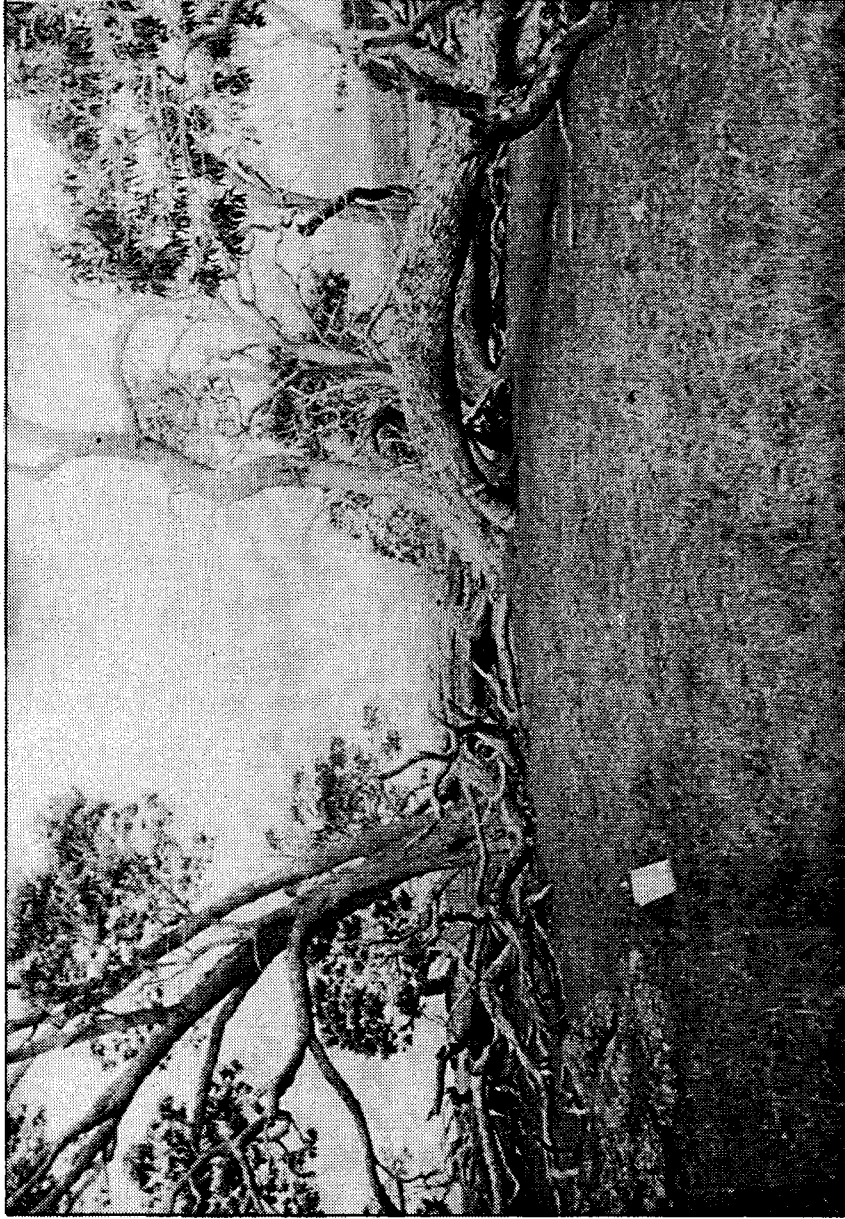


Fig. 14. Plot 9, 1992 thinned by 1975 fire and grazing. A signature tree on left margin of photo has fallen.

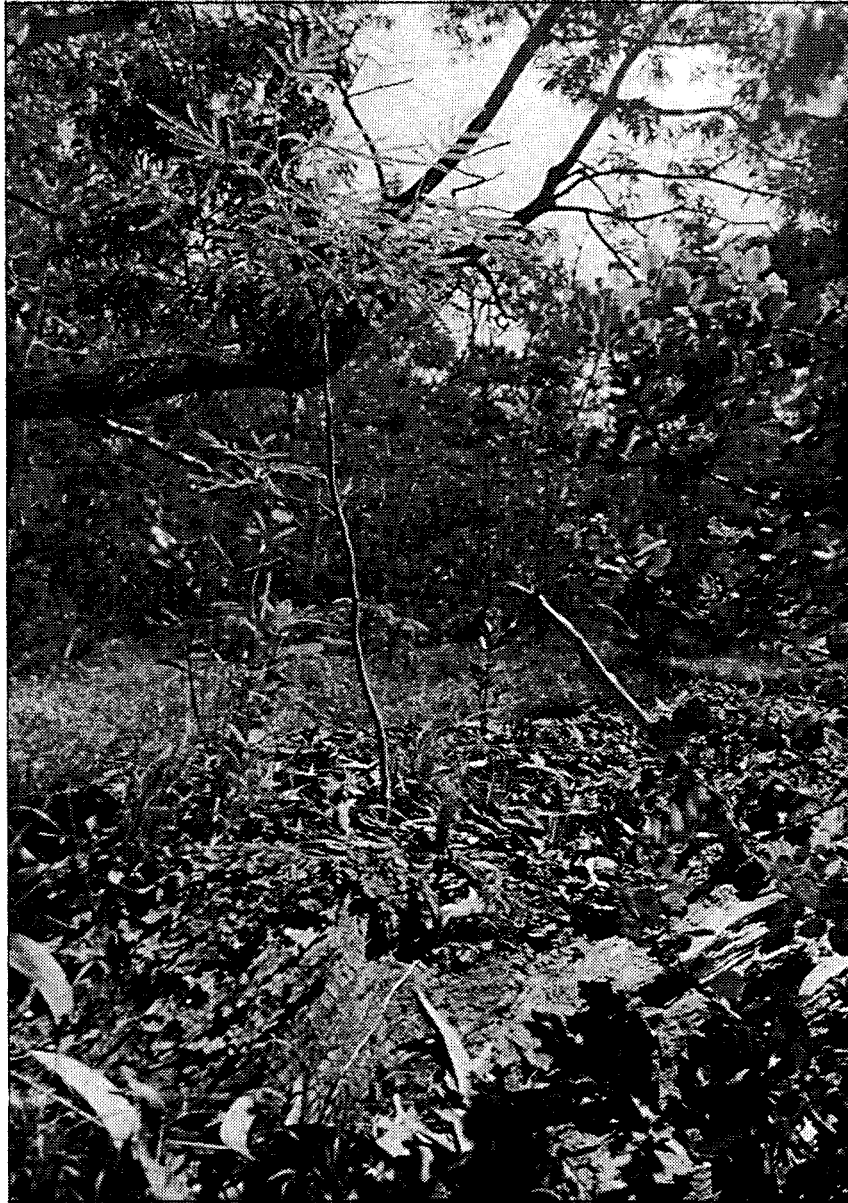
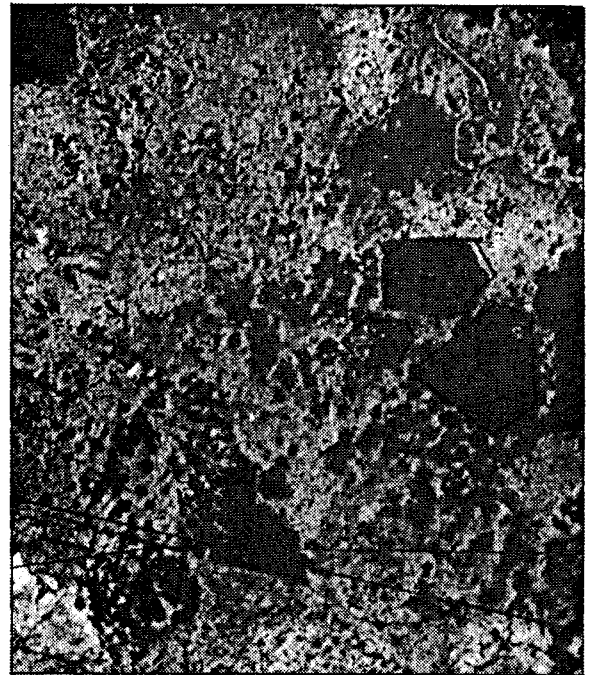
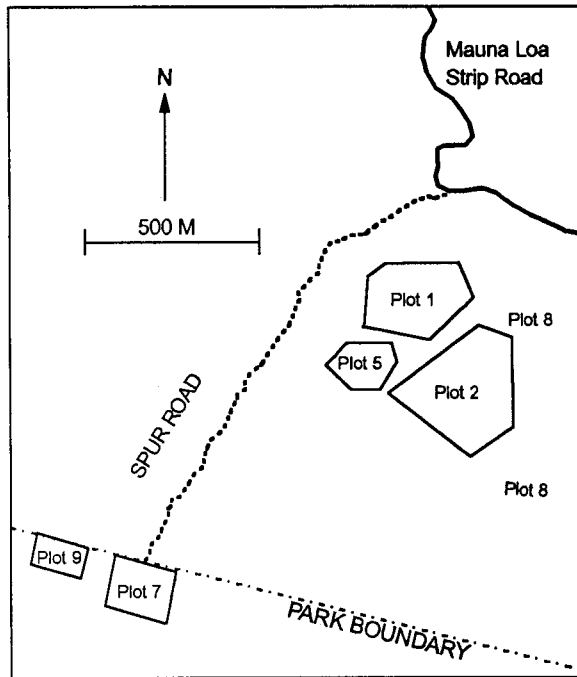
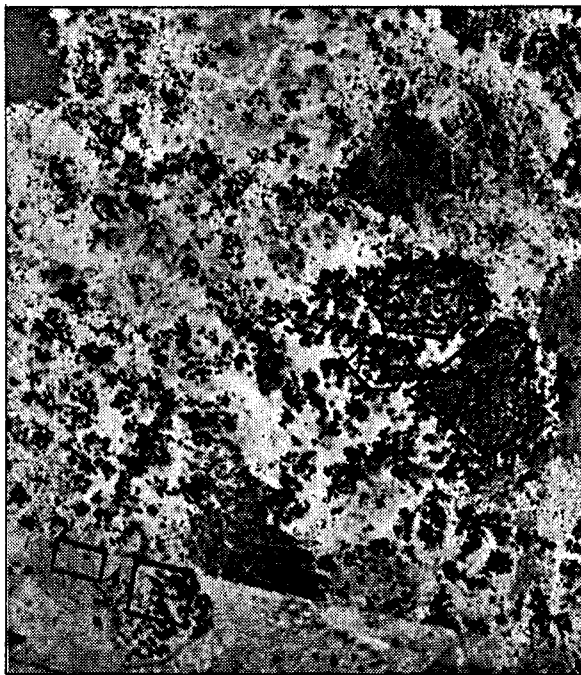


Fig. 15. 'Ohi'a and koa on a nurse log in plot 2. Koa is in the center of the photograph with 'ohi'a on the right and left of the koa. All 'ohi'a and all koa root sprouts and saplings in the study area were found on nurse logs, some of which were well rotted and partially buried by understory grasses.

1954



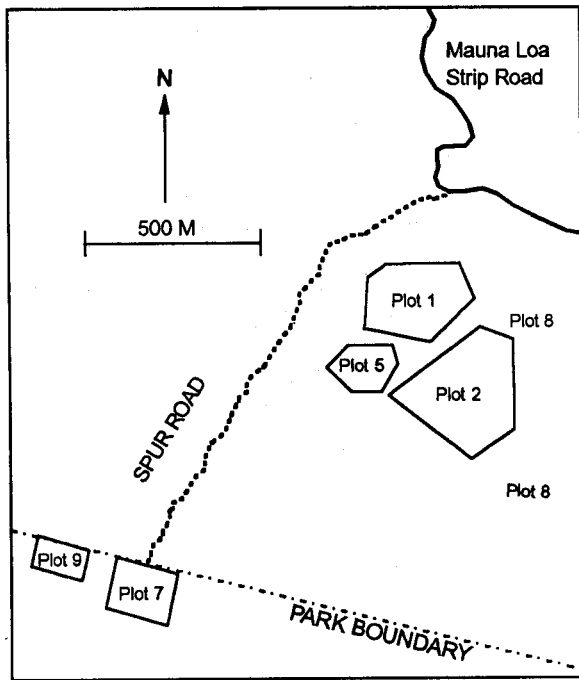
1965



1977



Figure 16. Aerial photographs of study area, 1954, 1965, and 1977. The scale of the aerial photographs and drawing above has been standardized. The outlines of the plots have also been drawn on the aerial photographs..



1986



Figure 17. Aerial photographs of study area, 1986 and 1992. The scale of the aerial photographs and drawing of plot outlines above has been standardized. The outlines of the plots have also been drawn on the aerial photograph.

1992

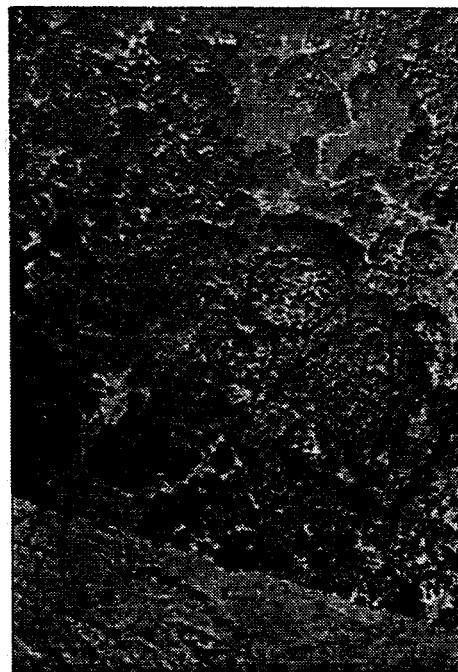


Table 1. Number of koa stems in three height/diameter classes in 1941 and 1994. Size classes were originally used by Baldwin and Fagerlund (943).

PLOT/SUBPLOT #	GRAZING ENDED	<75 CM HT		>75 CM HT <15 CM DBH		>15 CM DBH	
		1941	1994	1941	1994	1941	1994
<i>Cattle removed six years prior to first sampling</i>							
Plot 1							
Subplot 1	1935*	0	57	33	11	3	15
Subplot 2	1935*	0	52	13	3	2	10
Subplot 3	1935*	5	1	327	11	0	23
Plot 2							
Subplot 14	1935*	1	0	107	3	4	14
Subplot 15	1935*	3	0	59	6	4	16
Subplot 16	1935*	5	0	18	7	6	9
<i>Cattle removed six months prior to first sampling</i>							
Plot 5							
Subplot 4	1940+	89	0	0	4	2	12
Subplot 5	1940+	45	6	0	1	2	3
Subplot 6	1940+	2	18	0	3	7	8
Plot 8							
Subplot 11	1940+	21	0	0	1	2	9
Subplot 12	1940+	159	0	0	8	2	26
Subplot 13	1940+	77	0	13	6	2	13
<i>Cattle never removed</i>							
Plot 7							
Subplot 7	N/A	3	0	0	0	1	1
Subplot 8	N/A	0	0	0	0	2	0
Subplot 9	N/A	1	0	0	0	4	3
Plot 9							
Subplot 17	N/A	32	0	0	0	4	0
Subplot 18	N/A	32	0	0	0	5	0
Subplot 19	N/A	5	0	0	0	2	0

*Plots 1 and 2 fenced in 1935 and read in 1941.

+Plots 5 and 8 not fenced. Cattle removed from park 1940-1942 and plots read in 1941.

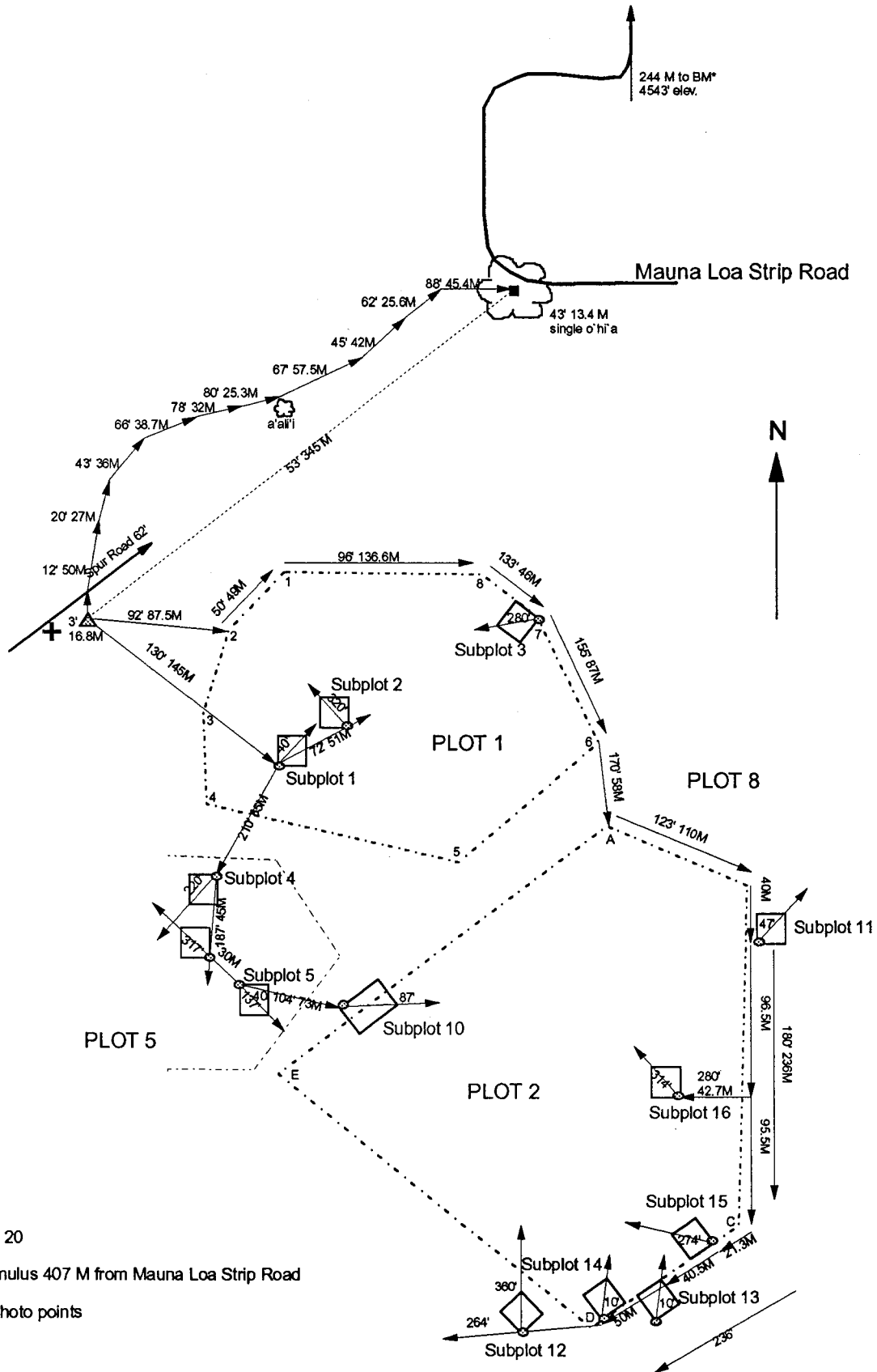
Table 2. Number of koa stems in 5 cm diameter classes in Baldwin and Fagerlund's plots, 1992.

PLOT/SUBPLOT #	DIAMETER AT BREAST HEIGHT															
	<5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	>75
<i>Cattle removed 1935</i>																
Plot 1																
Subplot 1	58	4	6	6	1	3	4	0	0	0	0	0	1	0	0	0
Subplot 2	3	1	0	3	2	1	1	2	0	0	0	0	0	0	0	1
Subplot 3	2	2	3	7	2	9	4	6	4	1	0	1	1	0	0	0
Plot 2																
Subplot 14	0	0	0	3	2	2	4	0	2	1	0	0	0	0	0	0
Subplot 15	1	1	4	4	8	1	3	0	0	0	0	0	0	0	0	0
Subplot 16	3	1	3	4	4	0	0	0	0	0	1	0	0	0	0	0
<i>Cattle removed 1940+</i>																
Plot 5																
Subplot 4	0	0	4	3	0	4	2	1	0	0	0	0	1	0	0	1
Subplot 5	6	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0
Subplot 6	18	1	2	3	2	1	1	0	0	0	1	0	0	0	0	0
Plot 8																
Subplot 11	0	1	0	1	1	4	2	0	0	0	1	0	0	0	0	0
Subplot 12	1	1	6	4	10	9	3	0	0	0	0	0	0	0	0	0
Subplot 13	0	2	4	0	8	1	1	2	0	0	1	0	0	0	0	0
<i>Continuously grazed</i>																
Plot 7																
Subplot 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Subplot 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subplot 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Plot 9																
Subplot 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subplot 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subplot 19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

+Plots 5 and 8 were not fenced as were Plots 1 and 2. Cattle were removed in 1940, but returned 1942-48. Cattle were finally removed from the park in 1948.

Table 3. Percent cover of understory plants by subplot in 1994.

PLOT SUBPLOT	1		2		3		4		5		6		7		8		9	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
<i>Acacia koa</i>	1	4	2	0	0	0	0	<1	<1	<1	6	1	0	0	0	0	0	0
<i>Anthoxanthum odoratum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cirsium vulgare</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	<1	0	0	0	0
<i>Dactylis glomeratus</i>	2	0	4	4	10	6	0	2	2	2	2	0	0	0	0	5	0	0
<i>Deschampsia nubigena</i>	<1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Dodonaea viscosa</i>	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Ehrharta stipoides</i>	71	71	78	2	6	36	93	69	63	11	0	4	0	0	0	0	0	0
<i>Eragrostis variabilis</i>	0	0	1	0	1	0	0	0	0	33	0	27	0	0	0	0	0	0
<i>Holcus lanatus</i>	0	0	0	0	0	1	0	0	0	0	0	<1	2	0	<1	0	0	0
<i>Hypochoeris radicata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lythrum maritimum</i>	0	0	<1	12	6	0	0	0	0	<1	0	1	0	0	0	0	0	0
<i>Paspalum dilatatum</i>	<1	16	11	24	44	8	2	1	1	40	0	46	5	<1	<1	5	10	5
<i>Pennisetum clandestinum</i>	0	0	0	<1	7	0	0	0	0	0	0	<1	45	60	90	65	50	50
<i>Plantago lanceolata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	<1	0	<1	<1	0
<i>Pteridium aquilinum</i>	13	4	0	23	4	32	1	20	8	10	4	4	0	0	0	0	0	0
<i>Rubus argutus</i>	0	0	0	21	0	3	0	0	0	<1	0	5	0	0	0	0	0	0
<i>Rubus rosaeifolius</i>	0	0	0	0	0	0	0	0	0	<1	0	0	0	0	0	0	0	0
<i>Rumex acetosella</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Solanum pseudocapsicum</i>	1	2	0	0	0	7	0	0	1	0	0	7	0	0	0	0	0	2
<i>Sporobolus africanus</i>	0	0	0	0	0	0	0	0	0	0	0	0	30	15	5	15	30	25
<i>Syphelia tametameiae</i>	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
<i>Trifolium repens</i>	0	0	0	0	0	0	0	0	0	0	0	0	15	15	0	12	<1	10



Appendix. Koa study plots and subplots, Hawai'i Volcanoes National Park.