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THE DISTRIBUTION OF SELECTED LOCALIZED ALIEN PLANT SPECIES IN HAWAI'I VOLCANOES NATIONAL PARK

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ABSTRACT

Prior to this study, the alien plant control program at Hawai'i Volcanoes National Park was hampered by the paucity and quality of alien plant distribution maps. A systematic program to map important localized alien plants was conducted 1983-1985 to determine the need and feasibility of controlling key alien plant species, establish a baseline for assessing the spread of these species, infer range expansions, locate all populations of a target species to assure thorough treatment, and assess the effectiveness of control programs. Thirty-six species were mapped, with emphasis given to localized alien plant species and those listed as target species in the 1982 Resources Management Plan (National Park Service 1982). The studies focused on Ainahou Ranch, Kilauea Crater, and the Coastal Lowlands west of the 1969-1974 Mauna Ulu flows. The species distributions were mapped on topographic maps at 1:24,000, 1:12,000, or 1:6,000 scales, although most species are displayed in this report on smaller scale maps. In addition, species profiles are provided. These characterize importance to management, significance as a pest in native ecosystems, effective treatment methods, and history of management. There were two important findings from the distribution studies. Eleven species, previously not targeted for management, were identified from mapping efforts to be invasive and require control efforts. These are Formosan koa, slash pine, loquat, sisal, orange pittosporum, oleaster, English ivy, paperbark, blackwood acacia, kudzu, and guavasteen. The second finding is that five target species were found to be much more widespread than previously thought. These include silky oak, koa haole, fountain grass, Russian olive, and raspberry. This finding lead to an approach in which control efforts on widespread species were carried out only in intensive management units called Special Ecological Areas. Additional distribution mapping studies are recommended for widespread species.

INTRODUCTION

Alien plants have significantly altered some plant communities in Hawai'i Volcanoes National Park (HAVO) (Fig. 1), and they pose a serious threat to others. Approximately 400 alien plant species have become naturalized in HAVO (Higashino et al. 1988). Most naturalized species are not disruptive to native ecosystems and do not require monitoring or management. These weakly aggressive species tend to be very localized or widespread at low densities. However, 34 of the 86 species Smith (1985) characterizes as serious pests in Hawaiian native ecosystems occur in HAVO. Many in this category are capable of forming monospecific stands or altering the soil-water, fire, or nutrient cylcing regimes (Smith 1985). Alien plants are very important components of HAVO ecosystems below 1,200 m and are now spreading rapidly and displacing native in some upland plant communities, especially in wet forest.

Alien plant control efforts at HAVO prior to 1983 were hampered by the paucity and quality of distribution maps. Warshauer and others (1983) and Whiteaker and Gardner (1985), respectively, had prepared small-scale, statewide maps of the distribution of banana poka (Passiflora mollissima) and faya tree (Myrica faya). Resources Management personnel had prepared partial, small-scale maps of 13 of the 26 species targeted for control in the 1982 Resources Management Plan (RMP). These maps were not detailed or accurate enough to plan management strategies or effectively carry out control actions. Maps had not been prepared for a number of other species, not targeted for control but possibly localized enough to be manageable.

In 1983, the distributions of 36 selected alien plant species were mapped within HAVO to accomplish the following objectives:

1. Determine the need and feasibility of controlling key alien plant species in the Park.

2. Establish a baseline for assessing the spread of alien plant species.
3. Infer apparent expansion from distribution patterns.
4. Locate all populations of a target species to assure thorough control.
5. Assess the effectiveness of control programs.

Distribution mapping emphasized species thought to be localized and target species identified in the 1982 RMP (National Park Service 1982). Mapping of all disruptive alien plant species in the Park was not undertaken because of limitations of funding. Alien plant species with widespread distributions or localized species not considered to be threats were not mapped.

Most target plant species were found primarily in one of the six major ecological zones of the Park characterized by Mueller-Dombois (1976) (Fig. 2). Therefore, this report is organized by ecological zone, with species distributions described in the ecological zone in which they are most common.

METHODS

Field work was conducted from 1983-1985. Methods of mapping varied by area, the number of alien species present, the abundance of individuals, and the importance of locating all individuals or populations. Roadsides and developed areas were mapped on foot and from vehicles. Trails were surveyed by walking. Areas with sparse vegetation were surveyed from a helicopter. The following areas were intensively or systematically searched:

1. Kipuka Puaulu and vicinity.
2. Ainahou from the gate on the ranch road (960 m elevation) to the coast.
3. The coastal lowlands from the shoreline to 120 m elevation between the western Park boundary and the 1969-1973 Mauna Ulu flows and from Paliuli to the base of Holei Pali north of Lae Apuki.
4. All areas within 50 m of Crater Rim Drive.
5. All Park Roads and front country trails (Stemmermann 1987).
6. All developed areas in the Park, Kilauea Military Camp, and Volcano (Stemmermann 1987).
7. The agricultural lots on Wright Road and adjacent portions of 'Ola'a Tract.

Intensive surveys were conducted in these areas, usually by 1-2 or more field technicians walking parallel transects 10-50 m apart, depending on terrain and density of vegetation. Field technicians used horses to do transects 50 m apart in the western coastal lowlands of the Park. All of the coastal lowlands and the Ka'u Desert were also surveyed systematically by helicopter, and portions of the upper Ka'u Desert were searched on foot.

Populations were mapped on 1:24,000 orthophotoquads, 1:24,000 U.S. Geological Survey topographic maps, or 1:12,000 or 1:6,000 enlargements of topographic maps. These are available in the Resources Management files. Smaller scale maps were prepared for publication purposes.

Ainahou Ranch was surveyed more systematically than any other area because of the high number of target alien plant species present and the density of vegetation. The northern limit of the study area was the gate on the ranch road near the intersection with Chain of Craters Road. The southern limit was the top of Poliokeawe Pali. Eastern and western limits were determined by substrate changes associated with the absence of target alien plant species. One hundred contiguous belt transects, each 50 m wide, were established in an east-west orientation across the Ranch. The belt transects averaged 1,500 m in length. These transects were marked along the north-south dirt road that bisects the ranch so resurvey is possible. Beginning and ending points of populations along the transects were determined by hip chain. Field data for Ainahou were entered into a dBase-II file, with species distributions along

transects entered as X,Y coordinates. A base map of the Ainahou transects was digitized, and a program was written to instruct a plotter to plot the distribution points along the transects. These rough maps were then translanted into hand-drawn maps at a scale of 1:12,000, in some cases denoting different density classes.

THE COASTAL LOWLAND ENVIRONMENT

Study Area

The coastal lowland environment includes all areas within HAVO from the shoreline to the base of the several pali that form the escarpment separating the coastal lowlands from the sub-montane seasonal environment (Fig. 2). It is a belt of generally gently sloping land varying from 3-5 km in width. Elevations range from sea level to approximately 250 m in the east to 575 m in the west. Mueller-Dombois and Fosberg (1974) describe the climate as warm-tropical, with a summer drought period. Mean annual rainfall is highest in the eastern coastal lowlands (1700 mm), located on the edge of the tradewind precipitation belt. Rainfall isohyets indicate that average annual rainfall drops to 500 mm per year in the central coastal lowlands but increases to the west to about 1200 mm at the Park boundary (Mueller-Dombois 1980; Doty and Mueller-Dombois 1966).

Substrates in the study area include deep, ash-derived loam, bare 'a'a, and pahoehoe lava flows with little or no ash. The most common substrate consists of pahoehoe flows blanketed with varying amounts of cinder and ash.

Introduced grasses dominate the vegetation in the coastal lowlands. Broomsedge (Andropogon virginicus) and beardgrass (Schizachrium condensatum) are the most common species in the eastern and extreme western coastal lowlands. Thatchinggrass (Hyparrhenia rufa), native pili (Heteropogon contortus), and redtop (Rhynchelytrum repens) are the most abundant species in the central lowlands. Thatchinggrass has spread greatly in the last 15 years and now dominates the coastal lowlands from Pu'u Kaone to the Keauhou Trail. Native pili and redtop tend to form an association found east and west of this area. All of these grasses are well-adapted to frequent fire which has a deleterious effect on woody native species that grow in the same plant communities. Fuel loadings increased greatly with the removal of feral goats in the 1970's and the invasion of broomsedge and bush beardgrass. Fire frequency has markedly increased since then. There were no reported fires in the coastal lowlands prior to 1980. Since then, there have been 18 fires in this ecological zones, burning 3,700 ha (Tunison et al. in prep.).

There is an open shrubland in the eastern coastal lowlands, which is best developed between Waha'ula and Kamoamoa (Williams 1990). This vegetation type is characterized by open mixed native and alien shrubs, with an alien grass understory and scattered 'ohi'a (Metrosideros polymorpha). The most common shrubs are 'a'ali'i (Dodonaea viscosa), pukiawe (Styphelia tameiameiae), u'ulei (Osteomeles anthyllidifolia), 'akia (Wikstroemia sandwicensis), and alahe'e (Canthium odoratum). Alien-dominated scrub, found scattered throughout the coastal lowlands, is made up mostly of small stands of lantana (Lantana camara) or koa haole. Lama (Diospyros sandwidcensis)-dominated forest is found on 'a'a in the eastern coastal lowlands. Scatttered 'ohi'a are also found on pahoehoe tumuli in pili-redtop grasslands east of Pu'u Loa and below Poliokeawe Pali or with little understory on 'a'a near Kamoamoa.

The coastal lowlands are the most disturbed and alien-dominated environment in the Park. Polynesians transformed lands in Puna and Ka'u Districts up to 400-600 m elevation (Kirch 1982; MacEldowney, pers. comm.) through agricultural and burning practices. Feral goats (Capra hircus) probably occupied these areas for nearly 200 years (Williams 1985), and high population levels were documented between 1917 and 1972 (Baker and Reeser, 1972), at least for the central and western sections of the Park. Goats and

human activity are probably responsible for the conversion of native scrublands and woodland to mostly alien grasslands in the latter areas (Mueller-Dombois and Spatz 1972). Seed sources of native woody species are probably depleted in the central and western coastal lowlands, and a planting program would be required to restore the central and western coastal lowlands. (Smith 1977).

Extensive stands of native pili grass occur near Pu'u Loa and Kalu'e in the drier, central section of the lowlands. Also, lama-dominated plant communities north of Kamoamoa comprise one of the most intact dryland forests in the State. The native pili grasslands and the lama-dominated plant community, including adjacent closed native scrub with little alien grass cover are proposed for intensive management and research efforts based on their intactness, diversity, and/or presence of rare plant species (Tunison and Stone, in press).

Species Profiles and Distributions

Sisal

Sisal (Agave sisalana, Amaryllidaceae) was introduced to Hawai'i from Mexico as a source of fiber, and has escaped from cultivation. The plant is a large, herbaceous rosette similar to century plant. The capsular fruit is rarely produced, but up to 2,000 bulbils, the source of new plants, can form on a single infloresence (Neal 1965). A solution of 3% Garlon 4 in water, used as a foliar spray, was a relatively effective control method.

A large population of sisal was located in the Kalapana section of the Park near the Waha'ula Vistor Center (Fig. 3). This population extended over 8.5 hectares and contained 700 mature plants and an estimated 500,000 small plants. Lava covered this population 1986-1990 while control efforts were underway. A population of at least 1,000 plants over 0.5 ha was located mauka of Kealakomo in the submontane seasonal at 600 m elevation (not illustrated). Less than 10 plants occurred along the Kalapana Trail at 300 m (Fig. 3). Systematic mapping led to identifying sisal as a target alien plant because of it disruptive character, localized distribution, and manageability (National Park Service 1985).

Koa Haole

Koa haole (Leucaena leucocephala, Fabaceae) is a upright shrub or small tree, 5-30 feet high. A native of tropical America, koa haole was an early introduction to Hawai'i (Haselwood and Motter 1966). Because of the high protein content of its foliage and fruits, it is grown widely in the state for cattle fodder and has become a common shrub or small tree, often forming dense thickets in lowland and lower mountain slopes up to about 750 m (Neal 1965). Koa haole reproduces entirely from seed.

The highly aggressive and disruptive nature of koa haole is demonstrated in lands immediately outside the Park in the Kalapana and Ka'u areas. Here it sometimes forms nearly monospecific, impenetrable stands. These features led Smith (1985) to consider it a serious pest of Hawaiian native ecosystems. Populations of koa haole in the lowlands of HAVO have become increasingly evident since the mid-1970's following the reduction of grazing pressure by feral goats (Jacobi, pers. comm.). For this reason, koa haole has been targeted for control at HAVO (National Park Service 1982). The introduced psyllid, Heteropsylla cubana, which has killed large areas of koa haole on Oahu (Smith, pers. comm.), has had little apparent impact in HAVO.

Attempts were made between 1976 and 1983 to control selected populations of koa haole in the Park. Tordon 10K was used on populations near the trail in the Keauhou area with limited success when permission to use this pesticide was revoked. Although Gardner (1985) tentatively concluded that koa haole is sensitive to several herbicides, conclusions about a definitive treatment method cannot be made because this investigation was terminated at six months.

A total of 256 populations of koa haole were located in three major infestations the Park (Figs. 3 and 4, large scale maps with detailed popula-

tion information available in Resources Management files). One hundred fifty-three populations were found near the Keauhou Trail below 300 m elevation (Fig 4). Two other major infestations occur, one on deep ash soil near Pu'u Kaone (Fig. 4) and the other on 'a'a or pahoehoe with thin ash mauka of Paliuli and makai of the Kalapana Trail between 120 m and 300 m elevation (Fig. 3). Size of the populations ranged from 0.25 m^2 (single individuals) to 44,500 m^2. A small infestation totalling 4 ha was located near the Ainahou Ranch house in the submontane seasonal zone (not illustrated). Because of the extensive character of the koa haole infestations, control efforts were suspended except in Special Ecological Areas, and specific funding for its control was requested (National Park Service 1984).

Cactus

Prickly pear cactus (Opuntia ficus-indica, Cactaceae) is a succulent, woody perennial of Mexican origin. Introduced to Hawai'i around 1800 for fodder (Neal 1965), prickly pear cactus spread throughout the drier lowland portions of the Hawaiian Islands, forming dense stands over large areas in many localities. Consistent with Benson's (1982) observation that spineless horticultural forms of Opuntia are common and widespread, plants in the Park have few or no spines, even though most plants elsewhere in Hawai'i are spiny. Cactus reproduces by seed and possibly by vegetative means.

Early attempts in HAVO to control prickly pear with Tordon 22 K were unsuccessful. Therefore, in 1985 biological control agents successful elsewhere in Hawai'i but not present in HAVO were introduced to the Park. The moth, Cactoblastis cactorum, and a cochineal insect, Dactylopus opuntiae, were introduced in a series of releases starting in 1985 (Davis et al., in press). Davis et al. (in press) found some localized establishment of C. cactorum but no significant reduction of the prickly pear populations in the Park.

Prickly pear cactus was identified as a target localized alien plant species in the Resource Management Plan (National Park Service 1982) prior to systematic mapping efforts when its distribution was thought to be confined to Poliakeawe Pali.

Seven populations of cactus were found in HAVO (Fig. 5). These populations ranged in size from a single plant to a relatively large colony on Poliokeawe Pali with dozens of individuals covering 19 ha. All other populations were found between Poliakeawe Pali and Keauhou Landing.

Fountain Grass

Fountain grass (Pennisetum setaceum, Poaceae), native to Africa, was introduced to Hawai'i in Kona in the early part of the twentieth century. It is well established on the leeward side of Hawai'i Island with highest densities in North Kona, South Kohala, and the Pohakuloa areas. Scattered populations occur in windward areas, mostly in ruderal habitats. Fountain grass is readily dispersed by vehicles, livestock, humans, wind, water, and possibly birds. Humans and vehicles are probably responsible for most long-range dispersal. Fountain reproduces from seed.

Fountain grass is perceived as one of the most disruptive alien plants species in Hawaii (Smith 1985). This large bunchgrass can form monospecific stands. It is stimulated by fire and enhances fuel loadings, thus endangering the native woody plant communities it invades. Furthermore, fountain grass, unlike other non-native grasses, can colonizes bare or sparsely vegetated lava flows. In so doing, it disrupts primary succession in habitats that normally support intact plant communities. Fountain grass is capable of growing in xeric and mesic habitats from sea level to above 2,700 m elevation. Its potential distribution in HAVO may include all areas outside closed-canopy rain forest.

Control programs began in the mid-1960's with removal of plants colonizing roadsides in the Park and intensified in the late 1970's and early 1980's. Control efforts away from roadsides started in 1976 on a 400 ha infestation adjacent to the Kamo'oali'i Lava Flows, an area

in the southwestern part of HAVO with the Park's highest density of fountain grass. Control of populations disjunct from the main infestation at Kamo'oali'i was started in 1979. The primary treatment method consisted of uprooting plants by hand and destroying infloresences to exhaust the soil seed bank, with use of a two percent Roundup solution on very large plants. The current control strategy is to control fountain grass throughout HAVO, starting with outlying populations (National Park Service, 1991). Once control is achieved on outliers, then control efforts are extended toward the center of distribution. Approximately 75% of the infested area is searched annually or semi-annually to destroy fountain grass plants. Searching is also conducted in the vicinity of known disjunct populations and along roadsides inside and immediately outside HAVO.

Little distribution mapping had been conducted prior to 1983. Some populations along roadsides in the Park and populations disjunct to the main infestation found incidental to goat control efforts had been mapped.

Fountain grass in HAVO occurred primarily in two major infestations totalling approximately 8,000 ha (Fig. 6). The largest infestation was a 7,500 ha area in the southwestern corner of the Park and on adjacent State and private land in Ka'u. An approximately 500 ha infestation occurred north of Keauhou Point.

Fountain grass densities were relatively low throughout the Park. A 250 ha site near the center of the infestation at Kamo'oali'i had a density of 14.7 plants/ha. Essentially all other infested areas had a density of 0.4-0.6 plants/ha. Two hundred ninety-eight isolated populations were located in areas of moderate and low density (large scale maps indicating individual populations available in Resources Management files). These isolated populations were mostly small. Ninety-nine had one individual (when first discovered); 16 had two individuals; and 54 populations had six or more individuals. Also, 14 small populations, disjunct from the two main infestations in HAVO, and 40 small populations along roadsides in HAVO were located by mapping efforts.

A pattern of small isolated populations surrounding a relatively dense population at Kamo'oali'i suggests that fountain grass has spread from two centers of distribution, one at Kamo'oali'i and the other near Keauhou Landing. It also implies that densities in the outlying portions of the range will increase over time without management.

Kiawe

Kiawe (Prosopsis pallida, Fabaceae) is a tree reaching heights of 15 m. Kiawe was brought to Hawai'i in 1828 for its many human uses such as cattle fodder, fuel, and honey (Neal 1965). It grows well in dry, coastal areas in Hawai'i, reproducing rapidly from seed, thus forming large, dense stands in many areas up to 700 m elevation (Smith 1985). Smith (1985) characterizes it as an important pest of native ecosystems. Control efforts were attempted in 1977 and 1978 at Halape and Keauhou Landing using Kuron in diesel. When this pesticide was banned, kiawe was dropped as a target alien plant species (National Park Service 1982). Seventeen populations of kiawe were located with populations ranging in size from 1-19 individuals (Fig. 5). Most populations contained a number of dead trees, presumably the result of previous control efforts. All populations located were below 200 m elevation in the central coastal lowlands. Kiawe was restored to the target list of alien plant species in the Resources Management Plan (National Park Service 1984) because of systematic mapping efforts.

Castor Bean

Castor bean (Ricinus communis, Euphorbiaceae) is variable in form, ranging in size from an herb 1 m high to a tree more than 10 m tall. It is an early introduction to Hawai'i, probably originating from tropical Africa (Neal 1965). It has become common in many lowland areas and is considered a weed in pastures, rangelands and waste places (Haselwood and Motter 1966).

Smith (1985) characterizes it as one of the most important pests of Hawaiian native ecosystems, because it forms thickets that can shade out other species. Castor bean regenerates from seed, sometimes prolifically after disturbance such as fire.

Castor bean was identified as a target localized alien plant species in the Resources Management Plan (National Park Service 1982). Efforts to control castor bean with Kuron in diesel were attempted in 1978, resumed using Tordon pellets in 1981, and again in 1985 to the present using Banvel on cut stumps or Garlon 4 as a foliar spray, and uprooting smaller plants.

Eleven populations of castor bean were found in HAVO, eight of them in the central coastal lowlands between Poliokeawe Pali and the shoreline (Fig. 5). The largest populations were located at Kaone, Poliokeawe Pali, and Makahanau Pali. One population was also located at Kukalau'ula (not illustrated), one near Kamoamoa Campground, one at Waha'ula (Fig. 3), and one at the Park quarry near Kipuka Puaulu (not illustrated). Population sizes ranged from one individual to thousands of individuals covering 60 ha. All populations occurred on talus slopes, cracks, or collapsed lava tubes except for the one at Pu'u Kaone on deep ash. No populations were found on the dominant substrates in the coastal lowlands, pahoehoe with scattered pockets of thin ash and cinders and 'a'a.

THE SUBMONTANE SEASONAL ENVIRONMENT

Study Area

The submontane seasonal environment in HAVO is an ecological zone transitional between the coastal lowlands and rainforest or montane seasonal (Fig. 2). Major inland palis separate the submontane seasonal from the coastal lowlands in all but the extreme western part of the Park. The upper elevational limit varies from 300 m in the eastern part of the Park to 900 m elevation in the west. The submontane seasonal is essentially a leeward environment, with moderate to low rainfall (1400-2200 mm/yr) and a typically summer-dry climate (Mueller-Dombois 1976).

The most common vegetation types are pukeawe/a'ali'i scrub with scattered 'ohi'a', ohi'a savanna, and open to closed 'ohi'a forest. Pukeawe/'a'ali'i scrub with scattered 'ohi'a characterizes most of the sparse vegetation of the Ka'u Desert, the area south of Kilauea Caldera. The sparse vegetation of the Ka'u Desert possibly results from high ambient levels of sulfur dioxide from Kilauea Caldera and a pronounced summer drought rainfall regime (Mueller-Dombois 1976). The vegetation types are closely correlated with substrate in the submontane seasonal environment east of the Ka'u Desert. Pukeawe/'a'ali'i scrub with scattered 'ohi'a typically grows on pahoehoe with scattered, shallow ash pockets. The scarcity of grass in this vegetation type is associated with the paucity of soil. Native scrub with abundant grass occurs immediately above Poliokeawe Pali in the lower Ainahou Ranch, an area with a thin but relatively continuous soil on older lava flows. Both 'ohi'a savanna and open to closed 'ohi'a forest typically have an understory of alien grasses, particularily bush beardgrass, broomsedge, and molasses grass (Melinis minutiflora). Pukeawe and 'a'ali'i vary from sparse to abundant in the understory of 'ohi'a forest. These vegetation types characteristically grow on pahoehoe with mostly continuously distributed shallow ash and in kipukas on deep ash on the western edge of the Ka'u desert. Several other rare plant species, such as Pittosporum terminalioides, Exocarpos gaudichaudii, and Myrsine lanaiensis grow in 'ohi'a forests near Ainahou Ranch.

The talus slopes characteristic of Holei and Poliokeawe palis support lama-dominated plant communities. These plant communities include a number of rare plant species, including Antidesma pulvinatum, Pleomele hawaiiensis, Alphitonia ponderosa, and Bobea timonioides.

Alien grasses have altered the natural fire regime from one of low intensity and low fre-

quency to one of high intensity and frequency in 'ohi'a savanna, woodlands, and forest (Mueller-Dombois 1976). Beardgrass and broomsedge have invaded these plant communities in the last 30 years (Smith and Tunison in press), and molasses grass appears to have intensifed significantly in the last 20 years (Smathers, pers. comm.). Prior to the introduction of beardgrass and broomsedge, the submontane seasonal did not have a fuel bed capable of carrying large or intense fires (Mueller-Dombois 1976). Fire frequency and size have increased sharply in the submontane since 1970. Between 1920 and 1970 there were 27 fires averaging 4.5 ha; between 1970 and 1987 there were 80 fires averaging 150 ha, including a 500 ha and a 4,000 ha fire in 1987 (National Park Service 1990). These fires were highly destructive to native vegetation, particularly in the mortality of 'ohi'a and pukeawe and the intensification of alien grasses, especially molasses grass (Hughes et al. 1991).

A number of introduced woody species are also invading the submontane seasonal. Faya tree has spread nearly throughout much of this ecological zone during the last 15 years and now occurs at low to moderate densities (Whiteaker and Gardner 1985). Following invasion, it intensifies rapidly, as a nitrogen-fixer, adds more nitrogen than all other sources combined (Vitousek et al. 1987).

Ainahou Ranch is the locus of numerous incipient alien plant invasions. This 2,200 ha parcel lies between the Keauhou and Apua ahupua'as between 90 m and 990 m elevation. It is characterized by 'ohi'a forest and cleared pastures of kikuyu grass (Pennisetum clandestinum) and pangola grass (Digitaria decumbens). Ainahou Ranch was used as an active sheep and cattle ranch from the the 1930's to 1972 when it was purchased by the National Park Service. The leasee deliberately introduced alien plant species for fruit, reforestation, landscaping, and livestock fodder purposes. A number of these introduced species appeared to be spreading, possibly because they were released from grazing pressure when HAVO terminated livestock use in this ungulate-disturbed area.

Species Profiles and Distributions

Formosan Koa

Formosan koa (Acacia confusus, Fabaceae), a native of the Phillipines and Taiwan, is a tree attaining heights of 15 m. It has been planted ornamentally in Hawai'i for its displays of bright yellow flowers and ability to grow in poor, dry soils (Neal 1965). It reproduces exclusively from seed. Allelopathy is suspected because Formosan koa effectively suppresses the growth of plants beneath it (Smith 1985). It grows well from sea level to 700 m elevation in dry to mesic habitats, with major infestations on Oahu and Maui. Smith (1985) characterizes it as a serious pest of native ecosystems in Hawaii. A 5% Garlon 4 in diesel solution applied to the base of the bole is relatively effective in killing Formosan Koa (Tunison and Zimmer in press).

Formosan koa was found to be distributed more or less continuosly over approximately 100 ha at Ainahou Ranch between 820 m and 935 m elevation, mostly near the main north-south dirt road (Fig. 7). Approximately 150 planted individuals grew near the ranch house. Several individuals of Formosan koa were also found makai of the Ainahou study area along the Keauhou Trail at 200 m elevation (Fig. 4). Formosan koa was identified as a target localized alien plant after systematic mapping efforts indicated that it was naturalized in Ainahou Ranch (National Park Service 1984).

Blackwattle

Blackwattle (Acacia mearnsii, Fabaceae), introduced from Australia in the late nineteenth century, is a small tree up to 20 m in height. Growing rapidly, it forms dense stands from root suckers and copious seed production. It has become a weed in pastures and rangelands at higher elevations, with a major infestion in the Kula area of Maui. It has been declared a noxious weed (Haselwood and Motter 1966), and Smith

(1985) considers it a serious pest of native Hawaiian ecosystems. HAVO targeted it for control as a alien species prior to the onset of the mapping project at Ainahou because of its aggressiveness in the state (National Park Service 1982). A 5% Garlon 4 in diesel solution, applied to the base of the bole is effective in control (Tunison and Zimmer in press).

Blackwattle occurred almost exclusively in the Ainahou Ranch, with five small, widely scattered populations between 855 m and 945 m elevation (Fig. 7). Only seven individuals were observed because of control efforts in the past (Tunison and Zimmer in press). A single individual of blackwattle was located on the fitness trail near the Research Center (not illustrated).

Blackwood Acacia

Blackwood acacia (Acacia melanoxylon, Fabaceae) is a tree introduced from Australia. Smith (1985) considers it to be a potential pest in native ecosystems. It was deemed a target alien plant species at HAVO after 20 individuals were found near the ranch house during the systematic mapping project (National Park Service 1984). Tordon RTU on cut stumps was an effective treatment method (Tunsion and Zimmer in press).

Albizzia

Albizzia (Albizia sp., Fabaceae) are trees introduced to Hawai'i for shade and reforestation (Neal 1965). Smith (1985) considers one species, Albizia falcataria, to be a serious alien plant pest in Hawai'i.

An immature individual of albizia (not identifiable to species) was found along the shoulder of Chain of Crater's Road near Kealakomo (not illustrated). A solution of 2% Garlon 4 in diesel on basal bark was effective in treating this individual (Tunison and Zimmer in press).

Ironwood

Ironwood (Casuarina equisetifolia, Casuarinaceae) is an evergreen tree capable of growing to 25 m in height in 10 years (Neal 1965). It ability to form monospecific stands suggests allelopathic activity. Smith (1985) describes this species as a serious pest of native plant communities. Ironwood was identified as a target localized alien plant species in HAVO prior to systematic mapping because of its aggressiveness in some areas of the state (Resources Management Plan 1982). A 2-5% Garlon 4 in diesel solution is relatively effective in controlling ironwood (Tunison and Zimmer in press).

Three small ironwood populations were found in HAVO. Two populations occurred between 850 m and 910 m elevation in Ainahou Ranch with a total area of 1.2 ha (Fig. 8). A small ironwood population consisting of approximately 10 trees was found at Kamoamoa Campground (Fig. 3).

Loquat

Loquat (Eriobotrya japonica), Rosaceae) is a small evergreen tree which is occassionally planted in Hawai'i for its fruit Neal (1965). Mapping efforts at Ainahou indicated that loquat was naturalized with approximately 7,000 seedlings and saplings. There were six small populations at Ainahou covering 2.3 ha (Fig. 8), all near the ranch house. Other populations in the Park consisted of 1-2 possibly planted individuals near the Volcano House, Thurston Lava Tube, Park Headquarters, and Keanakakoi Crater (not illustrated).

Loquat was identified as a target localized alien plant as a result of mapping efforts (National Park Service 1985). Seedlings and saplings were uprooted and larger trees effectively treated with Tordon RTU in a cut-stump application.

Blue Gum

Blue gum (Eucalyptus globosus, Myrtaceae) is the Eucalpytus species naturalized in HAVO (Higashino et al. 1988). It is native to Australia and was introduced to Hawai'i for reforestation and ornamentation (Neal 1965). Smith (1985) identifies blue gum as a potential pest in natural communities. It was targeted for control prior to

systematic mapping (National Park Service 1982). Roundup concentrate is relatively effective in cut stump treatments, as is 2-5% Garlon in diesel on basal bark (Tunison and Zimmer in press). Four small populations comprising approximately 0.5 ha were found in Ainahou near the ranch house (Fig. 8), and a 2.5 ha stand occurred at Namakani Paio Campground (Fig. 17). The blue gum at Namakanio Paio Campground was spreading by root suckers and seed. Because the central portion of this stand was not removed, the control strategy in the Namakani Paio area is to prevent the expansion of blue gum. A single small blue gum was also located along Chain of Craters Road near Kealakomo (not illustrated).

Guavasteen

Guavasteen (Feijoya sellowiana, Myrtaceae), a native of South America, is a small tree introduced to Hawai'i for its edible fruits (Neal 1965). It is not described as a naturalized plant in Hawaii (Neal 1965, St. John 1973, and Wagner et al. 1990. Tordon RTU is an effective herbicide (Tunison and Zimmer in press).

Mapping efforts indicate that approximately 15 individuals were located in two populations immediately south of the Ainahou Ranch House (Fig. 9). A diversity of heights suggested that this species was naturalized. For this reason, it was targeted as a alien plant species (National Park Service 1984).

Tropical Ash

Tropical ash (Fraxinus uhdei, Oleaceae) is a tall, deciduous tree with winged, wind-dispersed fruits. A native of Mexico, it was introduced to Hawai'i for reforestation purposes. It has become naturalized and is capable of forming nearly monspecific stands (Smith 1985). Smith (1985) considers it to be a serious pest of natural plant communties.

Four small populations were found, each consisting of a single, apparently planted large tree and associated seedlings and saplings. Three of these grew near the Ainahou Ranch House and one population near the end of the ranch road (Fig. 10).

Silky Oak

Silky oak (Grevillea robusta, Proteaceae) is a large tree from Australia, growing to heights of 30 m or more. Its seeds are exceptionally light and surrounded by a membranous wing which enables them to be carried for miles by the wind (Neal 1965). Over 100,000 trees were planted in forest reserves of the islands in 1938, and silky oak is now thriving at many different altitudes from sea level to 1,200 m elevation, often in dense stands (Neal 1965). Silky oak trees were apparently planted at Ainahou Ranch and Kapapala and the James Ranch near the Park in Ka'u. The leaves produce an allelopathic substance which inhibits establishment of all species including itself (Smith 1985). Smith (1985) characterizes it as a serious pest of native Hawaiian ecosystems. Silky oak was targeted for control as a widespread, disruptive alien species prior to the mapping project (National Park Service 1982). A few populations between Hilina Pali Overlook and Pepeiau Cabin and near the Great Crack were treated with unknown effectiveness between 1979 and 1982. Santos et al. (1986) determined that a 5% Garlon 4 in water solution applied to frill cuts on the stem is relalively effective in killing silky oak. This alien species is currently controlled in Ainahou Ranch and in one Special Ecological Area, Keamoku SEA in the Ka'u Desert (Tunison and Stone in press). A related species, G. banksii, occurs on lands adjacent to HAVO and seems to be spreading, but has not yet been found inside the Park.

Thirteen populations of silky oak were located and occupied a total area of approximately 300 ha (Fig. 11). Two hundred-sixty ha of silky oak occurred in 'ohi'a-dominated kipukas in or adjacent to the Ka'u Desert. Two populations occurred in Ainahou Ranch. Thirteen additional populations consisted of one individual.

Paperbark

Paperbark (Melaleuca quinquinerva, Myrtaceae) is a small to large tree native to southeast Asia and Australia. It was planted extensively as a reforestation species (Neal 1965).

With small, wind-dispersed seeds, it readily invades open swampy areas and appear to have allelopathic activity (Smith 1985). Smith (1985) considers it to be a serious plant pest in natural areas. Paperbark was discovered in Ainahou Ranch just prior to comprehensive distribution mapping in this area, and targeted for parkwide control because of its aggressivenss in some parts of the state (National Park Service 1984). Tordon RTU on cut stumps is an apparently effective treatment method (Tunison and Zimmer 1989). Six plants varying from seedlings to mature individuals were located in the lower paddock at Ainahou (Fig. 10). These occurred in a 0.5 ha area.

Gunpowder Tree

Gunpowder tree (Melochia umbellata, Sterculiaceae) is a fast growing small tree native to India and Southeast Asia. It has been used in Hawaii as a reforestation species (Neal 1965). Smith (1985) considers this species to be an important plant pest in native communities. Because of its potential to form dense thickets in the Puna District of the Big Island, Melochia was targeted for control (National Park Service, 1984). Tordon RTU used as a cut stump treatment is effective in controlling it (Tunison and Zimmer in press).

Gunpowder tree was found exclusively to date along roadsides, presumably carried in fill brought from rock quarries in the Hilo area where this species forms dense infestations (not illustrated). It occurred along the old Waldron Ledge Road, Chain of Craters Road near Puhimau Crater, between Thurston Lava Tube and Pu'u Puai Parking Lot on Crater Rim Drive, the gravel stockpile area on Highway 11 near the Park boundary, and Highway 11 near Kilauea Military Camp.

Russian Olive

Russian olive (Olea europea var. africana, Oleaceae) is a shrubby evergreen tree from the West Indies that appears to be capable of forming dense stands between 500 and 1500 m elevation (Smith 1985). The most important infestations are on Hawai'i Island at Waimea and HAVO. Smith (1985) considers Russian olive to be a serious pest of native plant communities. Its seeds are dispersed by alien fruigovorous birds (Neal 1965, Smith 1985) and possibly feral pigs (Larry Kathira, pers. comm.). Russian olive is wind resistant and has been planted as hedges and windbreaks in Hawai'i. The densest stands at Ainahou occur along a fence line on the east side of the Ranch, suggesting that Russian olive was introduced for this purpose.

Russian olive was identified as a target alien plant species at HAVO (National Park Service 1982) prior to systematic mapping, and intermittent but unsuccessful efforts were made to control it from 1976 to 1982. Santos et al. (in press) found that Tordon RTU and undiluted Garlon 4 in water were effective in controlling Russian olive in cut stump treatments. A 1-5% Garlon 4 in water solution was effective in controlling seedlings as a foliar application (Santos et al. 1986).

Russian olive was found to infest approximately 750 ha between 950 m and 650 m elevation in the Ainahou area (Fig. 12). It was more or less continuously distributed throughout this range, with 495 ha of high density and 255 ha of low density distribution. One small outlying populations was found in Kipuka Kahali'i.

Maile Pilau

Maile Pilau (Paederia foetida, Rubiaceae) is a malodorous vine adventive from India and Southeast Asia. It is locally common on some of the major islands in disturbed mesic forest (Wagner et al., 1990). A 2% solution of Tordon 22K was effective in treating this species (Tunison and Zimmer in press).

One population of maile pilau was found (not illustrated). This consisted of a single 0.1 ha colony growing along the Chain of Craters Road near Puhimau Crater. It was first noticed within a year of road construction in the area and is presumed to have been introduced in road fill quarried in the Hilo area. Because it infests forests in some areas of the lower Hilo and Puna Districts, it was targeted for control (National Park Service, 1985).

Slash Pine

Slash pine (Pinus caribea, Pinaceae) is an introduced conifer from Central America and the West Indies. It can form monotypic stands, and Smith (1985) considers it to be a serious plant pest of native ecosystems. This species does not resprout when cut; therefore felling is an effective means of control if the cut is made below the lowest branch or visible adventitious bud.

Slash pine was found to be distributed over 17 ha adjacent to and southwest of the Ainahou Ranch house between 880 m and 920 m elevation (Fig. 10). Approximately two hectares of this distribution was a dense stand near the ranch house consisting mostly of larger planted trees. The individuals peripheral of the stand were small and scattered, indicating that pines had spread from the plantation into pastures and forest. Because of this distribution and size class structure, slash pine was targeted for control measures (National Park Service 1985).

Elephant Grass

Elephant grass (Pennisetum purpureum, Poaceae) is a robust perennial grass that grows to 2-3 m tall (Hasslewood and Motter 1966). A native of tropical Africa, it is a weed in cultivated areas and pastures. Elephant grass was not targeted for control but was mapped to determine if it is spreading.

Eleven small elephant grass populations were found in HAVO. Nine of these occurred in Ainahou Ranch near the main ranch road (Fig. 9). These were located between 810 m and 940 m elevation and occupied 2.8 ha, with the largest covering 0.7 ha. Two populations, each covering approximately 0.1 ha, occurred in abandoned horse corrals, one near the Wahaula Visitor's Center (Fig. 3) and one near Kipuka Nene Campground (not illustrated).

Kudzu

Kudzu (Pueraria lobata, Fabaceae) is a twining herbaceous vine introduced from China (Wagner et al. 1990). It has naturalized on all major islands. The most effective treatment method found at HAVO was to grub out the rootstock (Tunison and Zimmer in press). Four populations of kudzu were found at Ainahou Ranch between 910 m and 935 m elevation occupying approximately 0.5 ha (Fig. 9). Kudzu was targeted for control because of its invasiveness in the Southeastern United States and its distribution in Ainahou Ranch, with smaller satellite populations near a larger central population.

Christmasberry

Christmasberry, Schinus terebinthifolius, Anacardiaceae), native to South America and introduced to Hawaii as an ornamental (Neal 1965), is an evergreen shrub or small tree that reaches heights of about 12 meters. Its lower, lateral branches remain attached and form a nearly impenetrable thicket that surrounds the tree to ground level, thereby shading out other species. Furthermore, Christmasberry is allelopathic (Ewel et al. 1982). It is widely dispersed by birds which feed on its copiously produced red fruits (Neal 1965). A defoliating insect has been introduced as a biological control, but has not been effective (Smith 1985). Subsequent explorations in Brazil have not identified any further biological control agents (Smith, pers. comm.). Smith (1985) characterizes Christmasberry as an important pest in native Hawaiian ecosystems. It is now found in lowland areas of all major Hawaiian Islands.

Christmasberry was identified by HAVO as a target alien plant species prior to the mapping project (National Park Service 1982). Manage-

ment is considered only for populations in the Ainahou Ranch, Ka'u Desert, and adjoining areas. Populations in the eastern coastal lowlands are too widespread for control and Christmasberry appears not to be intensifying in this area (Williams 1985). Christmasberry was therefore not mapped here. Ewel et al. (1982) found that a 5% Garlon 4 in diesel solution applied to bark at the base of the trunk is an effective control method. Resources Management personnel also found that undiluted Roundup applied to cut stems or in drilled holes is an effective treatment method.

In the areas of the Park surveyed, Christmasberry occurred primarily in 'ohi'a forest or savanna on the margins of the Ka'u Desert (Fig. 11). Four populations occupied a total area of approximately 102 ha. Twenty-four additional populations consisted of single individuals.

Charcoal Tree

Charcoal tree (Trema orientalis, Ulmaceae) is introduced from Southeast Asia. It forms locally dense stands in lower elevations of the Puna and Hilo Districts. For this reason, it was targeted for control (National Park Service 1984). A 5% Garlon 4 in diesel solution on basal bark provided effective control (Tunison and Zimmer in press).

Charcoal tree occurred in 10 populations. All but one population was located along roadsides in the submontane and rainforest zones (not illustrated). Charcoal tree was invariably found in new fill along roadsides or other disturbed sites, and was apparently introduced by contaminated road construction materials.

Wisteria

Wisteria (Wisteria sinensis, Fabaceae) is a climbing shurb native to China. It was introduced to Hawai'i as an ornamental for its showy flowers (Neal 1965). Smith (1985) recommends that this species be monitored in Hawai'i. Concern about the success of vines in Hawai'i prompted mapping of this species. Two mature plants were located near the Ainahou Ranch House (Fig 9). Wisteria was not targeted for control because it was apparently not spreading.

THE MONTANE RAINFOREST ZONE

Study Area

The montane rainforest ranges from 450 m to 1,300 m elevation on the eastern edge of HAVO (Fig. 2). This part of the Park receives the nearly daily trade wind precipitation. Montane rainforest has a humid climate without pronounced dry seasons. Rainfall varies from 1,800-3,000 mm annually, and mean air temperature is 12-20^0 C. Substrates include deep ash to shallow ash over pahoehoe or 'a'a.

The dominant plant species are 'ohi'a, tree fern (Cibotium spp.), and uluhe (Dicranopteris linearis). Varying mixes of the dominant species comprise the major vegetation types:

1. Dense tree fern with scattered 'ohi'a.
2. Closed to open 'ohi'a forest with tree fern.
3. Open 'ohi'a forest with uluhe (Dicranopteris linearis) understory. In disturbed or drier sites, patches of broomsedge (Andropogon virginicus) are present. In wetter sites, tree ferns are common.

Feral pigs (Sus scrofa) in Hawai'i reach their highest densities in rainforest. They are highly disruptive and responsible in large measure for the spread of many alien plant species. Feral pigs have been at least partially controlled in approximately 12,000 ha of rainforest in HAVO (Katahira and Finnegan 1986).

Many rainforest areas have been disrupted by alien plants. Banana poka, yellow raspberry (Rubus ellipticus), strawberry guava (Psidium cattleianum), and palm grass are widespread and abundant in Ola'a Tract. Kahili ginger (Hedychium gardnerianum), strawberry guava, and faya tree are the most disruptive species in the Kilauea area. The latter two alien plant species and broomsedge are important pests of East Rift rainforest. Research on biological con-

trol is underway on banana poka, faya tree, and strawberry guava. These species are also controlled by mechanical and herbicidal means in Special Ecological Areas in 'Ola'a Tract and Thurston Lava Tube area.

Species Profiles and Distribution

Oleaster

Oleaster (Elaeagnus umbellata, Elaeagnaceae) is a shrub from the Orient that grows to about 2 meters tall. It is locally naturalized in Volcano, Hawai'i (Wagner et al. 1990), and its red fruits are presumably attractive to birds. Oleaster was targeted for control for these reasons after four individuals were located near the Volcano House dormitory by systematic distribution mapping efforts (Stemmermann 1987) (not illustrated). Tordon RTU as a cut stump treatment was effective in killing oleaster (Tunison and Zimmer in press).

Fuchsia

Fuchsia (Fuchsia magellanica, Onagraceae) is an ornamental shrub introduced from South America. It has escaped locally in Hawai'i, primarily in the Volcano and Kilauea areas. It was apparently introduced to the Park in the 1930's as an ornmental along Crater Rim Drive. Fuchsia forms dense thickets and may also grow into trees as a vine, thus hindering the establishment of other species. Fuchsia was identified as a target localized alien plant species prior to the systematic mapping program (National Park Service 1982). A mite, first noticed in 1986, appears to adversely affect fuchsia by partially defoliating plants (Clif Davis, pers. comm.).

There were two major infestations of fuchsia in the Park (Fig 13): 1) Along Crater Rim Drive, starting between Puu Puai intersection and the sharp curve and ending before the Kilauea Iki overlook; and 2) along the Escape Road between Crater Rim Drive and Highway 11. Other small populations were found in the Park residence area, the physical fitness course, Escape Road near the old orchid farm, Crater Rim Drive near Thurston Lava Tube, Park Headquarters area, and Hwy 11 near the Park entrance.

Fuchsia was removed from the list of target alien plant species in HAVO because mapping indicated that it was confined to roadsides (NPS 1984). Fuchsia was found usually with 10-15 m of no more than 25 m from a road. Moreover, the spread of fuchsia is apparently vegetative. No viable seeds were located in a two year period (Kageler and Tunison, unpublished data). Monitoring was established to determine if fuchsia was spreading from the roadsides. Transects were established to detect the spread of fuchsia.

English Ivy

English ivy (Hedera helix, Araliaceae) is a climbing vine native to Eurasia. It occassionally produces dark fruits that may be dispersed by birds. English ivy was found to grow in two large planted colonies at Ainahou Ranch near the ranch house and nursery. It also occurs sparingly in the Park Residential area. One population, possibly adventive, was located north of Crater Rim Drive near the Park entrance. Another adventive population consisting of one small plant was found in rainforest near the Thurston Lava Tube. English ivy was targeted for control because it is a vine, plants at Ainahou fruited, and recruitment was detected at a considerable distance from other populations and sources of disturbance. A 2% Garlon 4 solution in water used as a foliar spray is fairly effective in controlling English ivy. Another treatment method recommended but not tried is to cut vines as the base and treat the stump repeatedly with heat from a torch (Kay Thomas, pers. comm.).

Pearl Flower

Pearl flower (Heterocentron subtriplinervium, Melastomataceae) is an herb or small, mostly deciduous shrub 0.5-2 m tall introduced from Mexico. The forma subtriplinervium with white flowers is much more common in HAVO than the forma roseum with pink flowers, typically more abundant on Hawai'i Island. Pearl flower is usually restricted to ruderal habitats

does not form dense or extensive colonies. However, pearl flower forms a dense shrub layer under an open 'ohi'a canopy in HAVO. This suggests that this alien species may prevent or diminish the regeneration of native species. It has been targeted for management partly for this reason. In addition, pearl flower is in the Melastomataceae, a family represented by a number of aggressive alien species in Hawai'i. Finally, unlike tibouchina (Tibouchina urvilleana), pearl flower produces viable seeds (Kageler and Tunison, unpublished data). An effective treatment method has not been found; however, pearl flower seems to be sensitive to Tordon 22-K.

There are two major infestations of pearl flower: One on Crater Rim Drive near the Pu'u Puai intersection, and the other at the sharp curve in Crater Rim Drive 1 km south of Thurston Lava Tube (Fig. 13). Scattered pearl flower plants occur around the parking lot at Park Headquarters, at Volcano House, in the Park residence area, and on Highway 11 near the Park's east entrance.

Wire Vine

Wire vine (Muehlenbeckia axillaris, Polygonaceae), a native of New Zealand, is an intricately branched woody plant growing in HAVO as a shrub and a clambering vine. Wire vine was targeted for control because vines have been notably successful in invading Hawaiian forest, and because of its manageablility. A 2% Garlon 4 in water solution used as a folior spray was effective in controlling this species (Tunison and Zimmer in press).

Three populations of wire vine were located in HAVO, two on Crater Rim Drive and one in the Park residence area (Fig. 14).

New Zealand Flax

New Zealand flax (Phormium tenax, Liliaceae) is an acualescent herbaceous perennial. It is native to New Zealand where it was formerly used as fiber for rope and twine (Neal 1965). New Zealand Flax is considered by Smith (1985) to be a serious pest of native plant communities in Hawai'i because it forms dense thickets in moist sites on Moloka'i and Hawai'i

Three small populations of New Zealand flax were found in HAVO, all in wet forest along Crater Rim Drive (Fig. 14). This species was targeted for control as a result of systematic distribution mapping (National Park Service 1984). A 2% solution of Roundup is relatively effective in controlling this species.

Bamboo

Bamboo (Phyllostachys sp. (possibly nigra), Poaceae) was targeted for control because of the tendency of bamboo to form monospecific stands (NPS 1982). A 5% Garlon 4 in water solution used as a foliar spray is effective in controlling one population but no herbicides have worked on the other two populations. Mechanical control was ineffecitive because of the difficulty of removing rhizomes from rocky soil. Three bamboo populations were found in HAVO, all in the Park Headquarters area (Fig. 13): one immediately east of the Volcano House on the edge and upper lip of Kilauea Caldera, and two colonies near the Sulfur Banks.

Orange Pittosporum

Orange Pittosporum (Pittosporum undulatum, Pittosporaceae) is a slender branched shrub or tree that rarely grows up to 5 m tall in Hawai'i. It was introduced to Hawai'i as an ornamental, and has become naturalized along roadsides and in open forests on the island of Hawai'i. It was declared by the State to be a noxious weed because of its behavior elsewhere (Haselwood & Motter 1966).

Orange pittosporum grows sparingly in the Kilauea and Ainahou Ranch areas. It was found in the Park Residential and Volcano House area, near Sandalwood Trail, along Halemaumau Trail, along Waldron ledge Trail, and at Park Headquarters (Fig. 14). It also occurs near the rainshed at Ainahou Ranch (not illustrated). Orange Pittosporum was added to the list of target alien plant species in HAVO after it was

located by systematic mapping (National Park Service 1985).

Raspberry

Raspberry (Rubus glaucus, Rosaceae) is a sprawling vine cultivated from Mexico to Ecuador for its abundant fruit (Neal 1965). The plant was introduced to the State of Hawai'i in the early 1960's at the University of Hawai'i Volcano Agicultural Experiment Station to determine the economic feasibility of commercial production of the raspberries. By the late 1960's, Rubus glaucus had spread within the Experiment Station and in neighboring agricultural lots on Wright Road (Kubojiri, pers. comm.). Smith (1985) characterizes Rubus glaucus as a serious pest of native plant communities because it is threatening rainforest in 'Ola'a Tract. It was targeted for control in HAVO (National Park Service 1982) but no effective treatment methods have been found.

One hundred fifty populations of Rubus glaucus were mapped and ranged in size from 1 m^2 to 7,347 m^2, mostly near the Agricultural Experiment Station (Fig. 15, detailed maps available in files). Seventy-five of these were located in cleared areas or along edges of clearings; seventy-five populations were found in forested areas. Only four populations were located within the in 'Ola'a Tract, and these were located immediately behind the Agricultural Experiment Station.

Rose Apple

Rose apple (Syzygium jambos, Myrtaceae) is a tree introduced from tropical Asia (Neal 1965). This species forms dense stands which exclude native plant species in wet lowland habitats (Smith 1985). Smith (1985) characterizes it as a serious plant pest of native plant communities.

Two rose apples trees were located below Volcano House in the Kilauea Crater (Fig. 13). Tordon RTU used as a cut stump treatment was an effective treatment method.

Tibouchina

Tibouchina (Tibouchina urvilleana, Melastomataceae) is a tall woody shrub introduced to Hawai'i from Brazil. This plant is confined to wet habitats at mid-elevations. In these areas, it forms dense thickets spread that exclude the establishment of other plant species. Reproduction is by vegetation spread as viable seeds are not produced (Kageler and Tunison unpublished data). Smith (1985) considers this species to be a serious pest of native ecosystems in Hawai'i. Tibouchina was targeted for control because of a major infestation immediately outside the Park in Volcano, which indicated the potential of the small scattered populations inside the Park. A 50% Garlon 4 solution in water on cut stumps, followed by 1% Garlon 4 solution in water on resprouts and piled slash is relatively effective (Santos et al, 1986).

Tibouchina is widespread in the Park Headquarters, Volcano House, and Park Residential areas at low densities. Additional populations of intermediate density are found on Crater Rim Drive near Pu'u Puai, at Thurston Lava Tube, along the Escape Road near Thurston, near the physical fitness trail at the Research Center, and along Hwy 11 near the Park entrance (Fig. 14).

THE MONTANE SEASONAL ZONE

Study Area

The lower portion of the montane seasonal environment is described here because alien plants were mapped only in this portion of the ecological zone. The study area is located on the southeast slope of Mauna Loa between 1200 m and 1300 m elevation and consists of Kipuka Puaulu and vicinity. The climate is characterized as summer-dry with a mean annual rainfall of 1250 mm, (Cuddihy 1984; Mueller-Dombois 1976).

Substrates and vegetation types are closely related in the study site. The deep ash substrate of Kipuka Puaulu support these communities unique to HAVO: mixed koa (Acacia koa)-soap-

berry-(Sapindus saponaria)-'ohi'a forest with lower story trees and arborescent shrubs; a savanna of mixed tall-grass with scattered koa, soapberry, and 'ohi'a; and a mixed 'ohi'a-koa forest with an understory of native trees and shrubs (Mueller-Dombois and Lamoureux 1967). 'A'a flows with thin ash east of Kipuka Puaulu support a closed koa-ohia forest with few shrubs and dense understory of alien grasses. 'A'a flows between Kipuka Puaulu and Kipuka Ki support open 'ohi'a forest with dense native shrub cover and few herbaceous plants. Pahoehoe with thin ash south and west of Kipuka Puaulu supports open 'ohi'a forest with scattered native shrubs and dense alien grasses, interrupted by koa stands. These vegetation types, especially the understory, have been affected historically by grazing of feral goats, feral pigs, domestic cattle, and by fire (Cuddihy 1984; Mueller-Dombois and Lamoureux 1967; National Park Service, 1985). All of the study area is considered to be free of ungulates (Katahira and Finnegan 1986). It lies within Kipuka Pualulu Special Ecological Area and buffer zone. A management plan for this SEA requires control of all disruptive and manageable alien plant species, including fire tree, kahili ginger, strawberry guava, Jeruasalem cherry (Solanum pseudocapsicum), kikuyu grass (Pennisetum clandestinum), and nasturtium (Tropaeolum majus) (Tunison 1985).

Species Profiles and Distribution

Agave

Agave (Agave americana, Agavaceae) is a succulent, monocarpic rosette introduced from tropical America. Normally this species is not adventive (Neal 1965, St. John 1973, and Wagner et al. 1990). It was targeted for management because it was apparently spreading at Namakani Paio Campground. In addition to the 25 plants located here, eight plants were found at the Volcano House and Park housing area (Fig. 16), and two plants were found at Ainahou Ranch (not illustrated).

Chinese Melon

Chinese melon (Benincasa hispida, Cucurbitaceae) is an vine native of tropical Asia. It apparently spread in the Park mostly by vegetative means. In Kipuka Puaulu this species formed a dense mat excluding existing understory vegetation. In some cases, it climbed into short trees. It was targeted for control for these reasons and because it was localized enough to be manageable (National Park Service 1982). Manual uprooting was an effective control technique.

Two colonies of this species were found near the picnic area in Kipuka Puaulu (Fig. 16). Prior to control efforts, the colonies had over 90% cover of Chinese melon, as determined by point-intercept transects located in the populations. This species has apparently been eradicated in HAVO.

Lupine

Lupine (Lupinus hybridus, Fabaceae) is an annual herbaceous plant. One population occurs in the Park at the intersection of the Golf Course Subdivision Road and Highway 11 (Fig. 16). It was targeted for control because of its localized character and manageability (NPS 1982). It is manually uprooted.

Nasturtium

Nasturtium (Tropaeolum majus, Tropaeolaceae) was planted in Kipuka Puaulu and some Park roadsides in the 1920's by HAVO staff (National Park Service 1922). This species is a succulent, sprawling perennial (Neal 1965) targeted for control prior to the systematic mapping project (National Park Service 1982). Attempts to control three populations of nasturtium in Kipuka Puaulu by uprooting were abandoned in 1980 when found to be prohibitively labor intensive. Eldredge and Gardner (1984) found that a solution of 0.2% Garlon 4 in water, applied at a rate of 0.16 lbs of active ingredient per acre effectively killed nasturtium, at least populations comprised of older, larger individuals. Tunison

and Zimmer (1985) found this rate to be ineffective for younger cohorts recruited after treatments, and revised it to 0.4% and 0.24 lbs of active ingredient per acre. A control program was started on nasturtium in 1984 because it was invading the canopy and understory of native forest understory, was forming monospecific stands in forest gaps, and apparently has spread rapidly in recent years.

Forty-five populations of nasturtium were located, measured and mapped (Fig. 17). Populations ranged in size from 1.9 ha to 35 m^2. Most populations were located on deep ash soil near the nature trail in Kipuka Puaulu. Seven outlying populations occurred mostly or wholly on 'a'a with thin ash. Six populations grew on pahoehoe with thin ash. The distribution pattern of nasturtium suggests that this species has been expanding its range. Numerous smaller populations occurred peripherally to several larger populations. The occurrence of disjunct populations populations indicates that nasturtium has dispersed over short to medium distances, probably by birds or mammals. Eight populations were found almost 0.5 km away from the nature trail populations.

DISCUSSION

The alien plant distribution mapping project described in this report stimulated important changes in the alien plant control program. The two most significant findings of the distribution mapping studies were these:

1. Twelve new potentially disruptive alien plants not previosuly recognized were found to be spreading in HAVO. These species include Formosan koa, slash pine, loquat, sisal, orange pittosporum, English ivy, oleaster, paperbark, blackwood acacia, kudzu, and guavasteen.
2. Six alien plant species targeted for alien plant control for a number of years prior to systematic distribution mapping had much broader ranges, more individuals, and larger numbers of populations than previously thought. These species include Christmasberry, silky oak, koa haole, fountain grass, Russian olive, and raspberry. Because of this, control of these species would be very expensive. (Workload requirements were determined only for fountain grass.) Management of localized alien plants is now a high priority in the Park. The number of localized species has increased from 12 to 43, all localized species have been categorized in a single unprioritized target list, and this group of species is given higher priority than any other for management (NPS 1988). Management of koa haole, Christmasberry, silky oak, Russian olive, fountain grass, and raspberry have been deemphasized. They are more abundant and widespread than thought prior to mapping, and parkwide control would require considerable funding increases. Requests for additional funds to control these species have been made. These species, along with other widespread species such as banana poka, fire tree, strawberry guava, and palm grass, are controlled now in selected areas of the Park called Special Ecological Areas (Tunison and Stone, 1989). These areas are the most intact, diverse, and manageable sites in the Park. Prior to the Special Ecological Area approach, widespread species were not controlled if they could not be managed on a parkwide basis. The recognition that important target species are too widespread for current management resources was an important factor in organizing alien plant control efforts around Special Ecological Areas.

RECOMMENDATIONS

The current distribution study emphasized localized alien plant species. Similar mapping is also needed for widespread species such as palm grass, yellow raspberry, strawberry guava, thatchinggrass, Jerusalem cherry, blackberry (Rubus argutus), kikuyu grass, and others. Faya tree should be remapped. Many of these can be mapped incidental to other studies. Remonitoring of permanent transects may be required to map others. Key areas in the Park should be periodically remapped or surveyed intensively to monitor the spread of localized alien plant species. These include upper Ainahou Ranch

and roads, trails, and developed areas in the Park. This will evaluate thoroughness of control programs and will survey for areas vulnerable to new introductions.

Mapping is one of the first steps in understanding and managing alien plants (Tunison in press). Additional research should be considered for key species to formulate management priorities and strategies. Studies of demography, growth rates, establishment requirements, and seed biology (including dispersal and viability in the soil) may help identify vunerable links in the life cycles and predict potential range. These kinds of studies are relatively complete only for faya tree (Vitousek and Walker 1989) and banana poka (LaRosa 1984). They are needed, for example, for species such as strawberry guava, kahili ginger and yellow raspberry.

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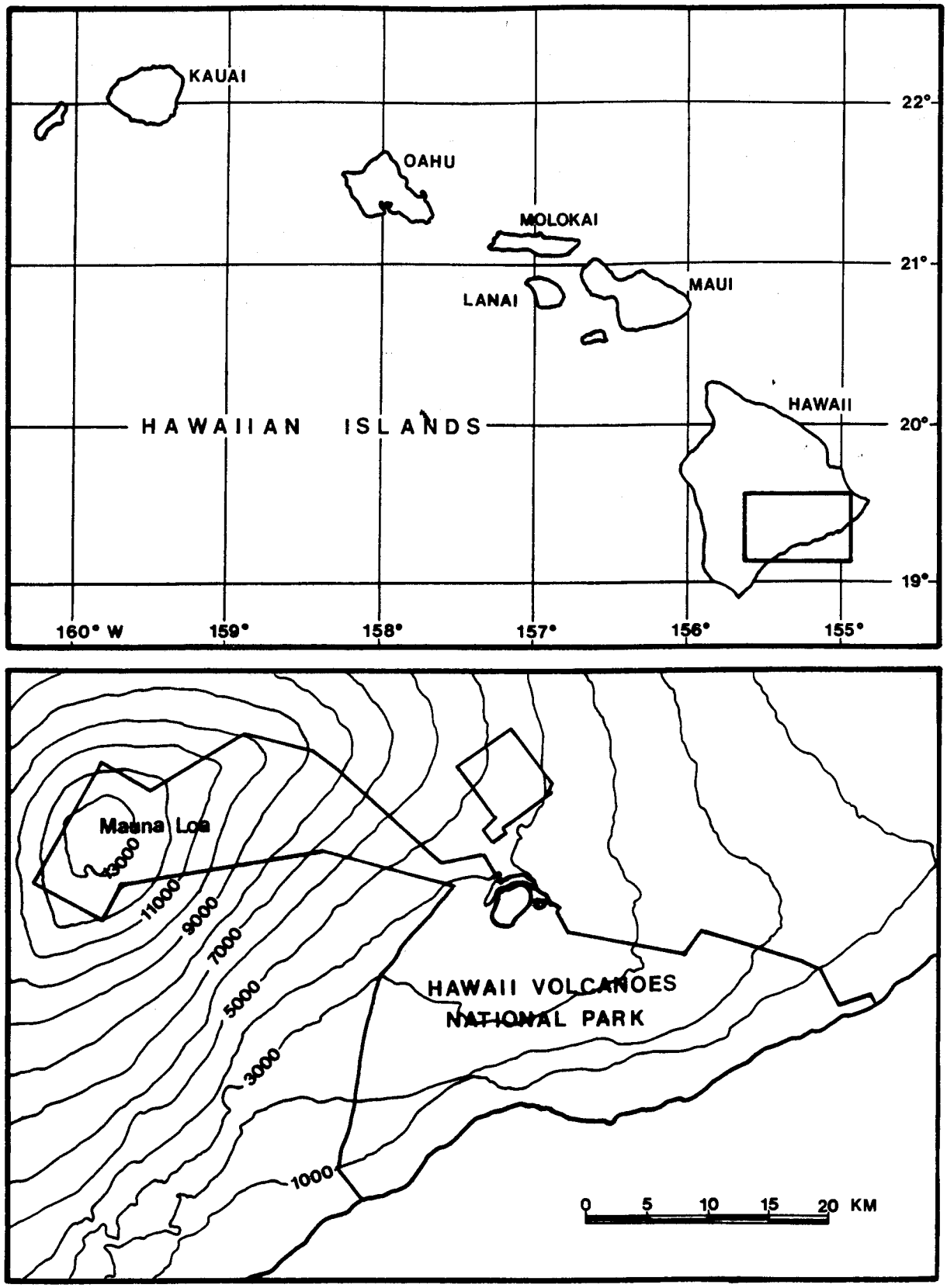

Figure 1. Location of Hawaii Volcanoes National Park (HAVO).

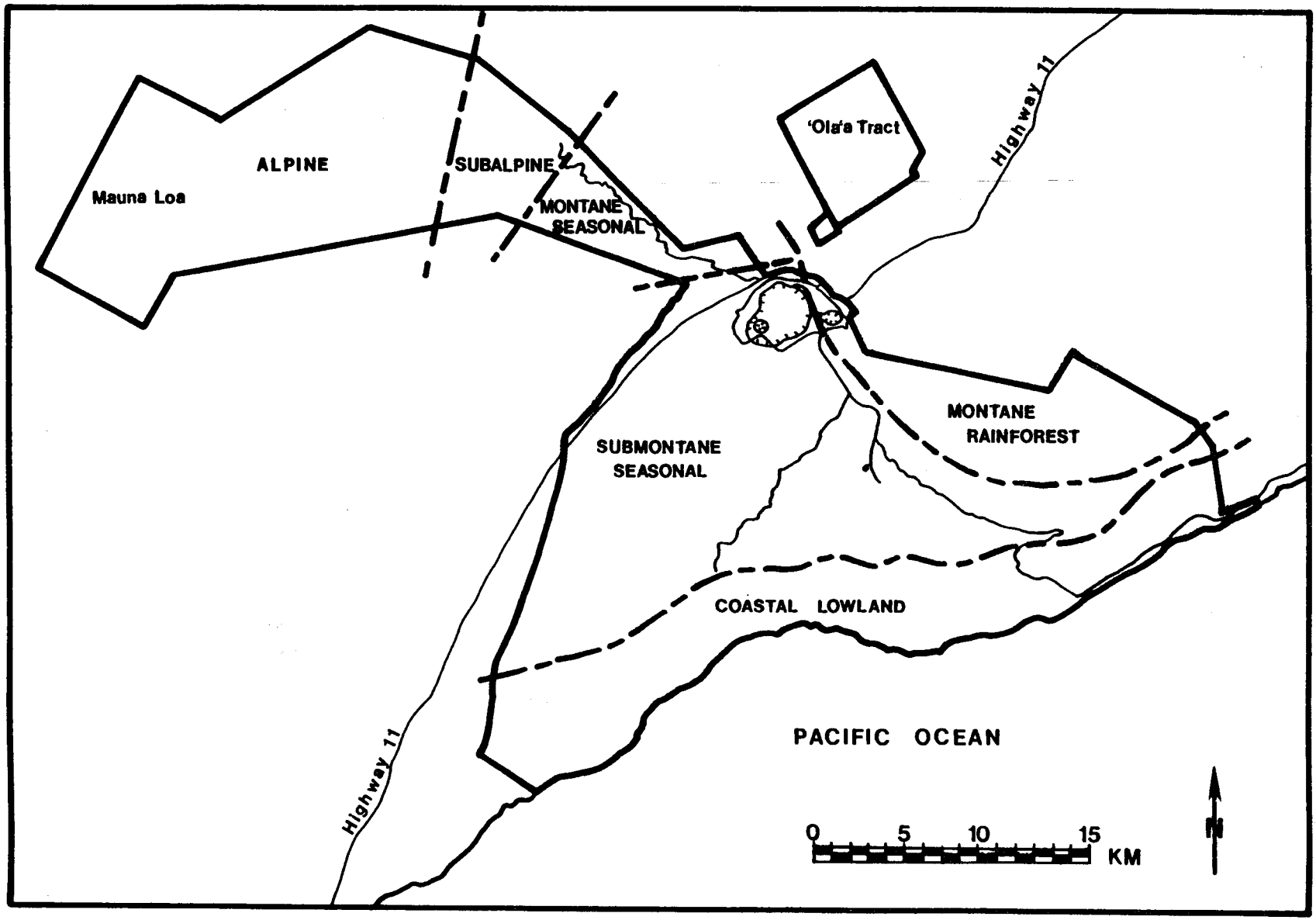

Figure 2. Distribution of the six major ecological zones of HAVO.

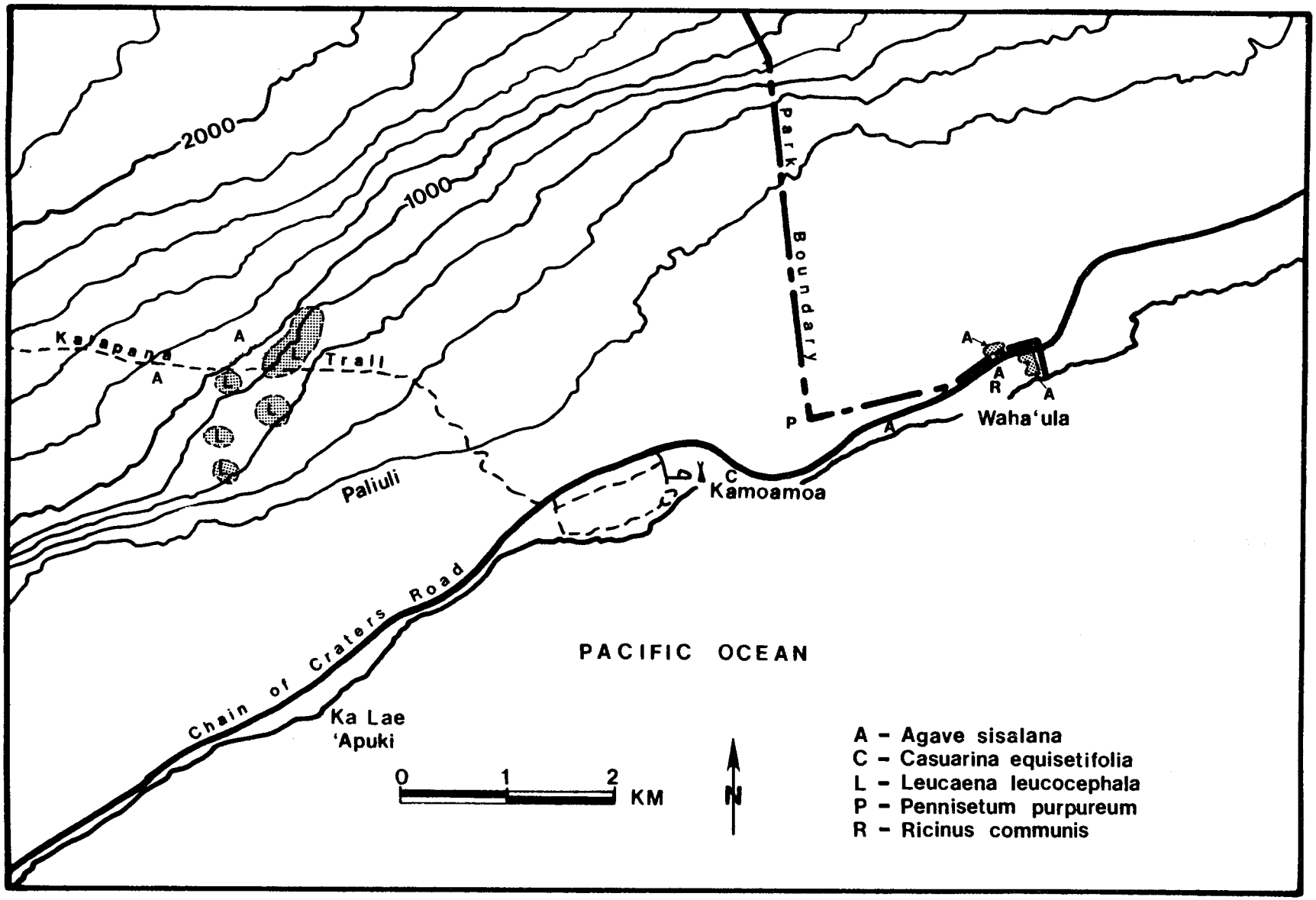

Figure 3. Distribution of sisal, ironwood, koa haole, elephant grass, and castor bean in eastern coastal lowlands, HAVO.

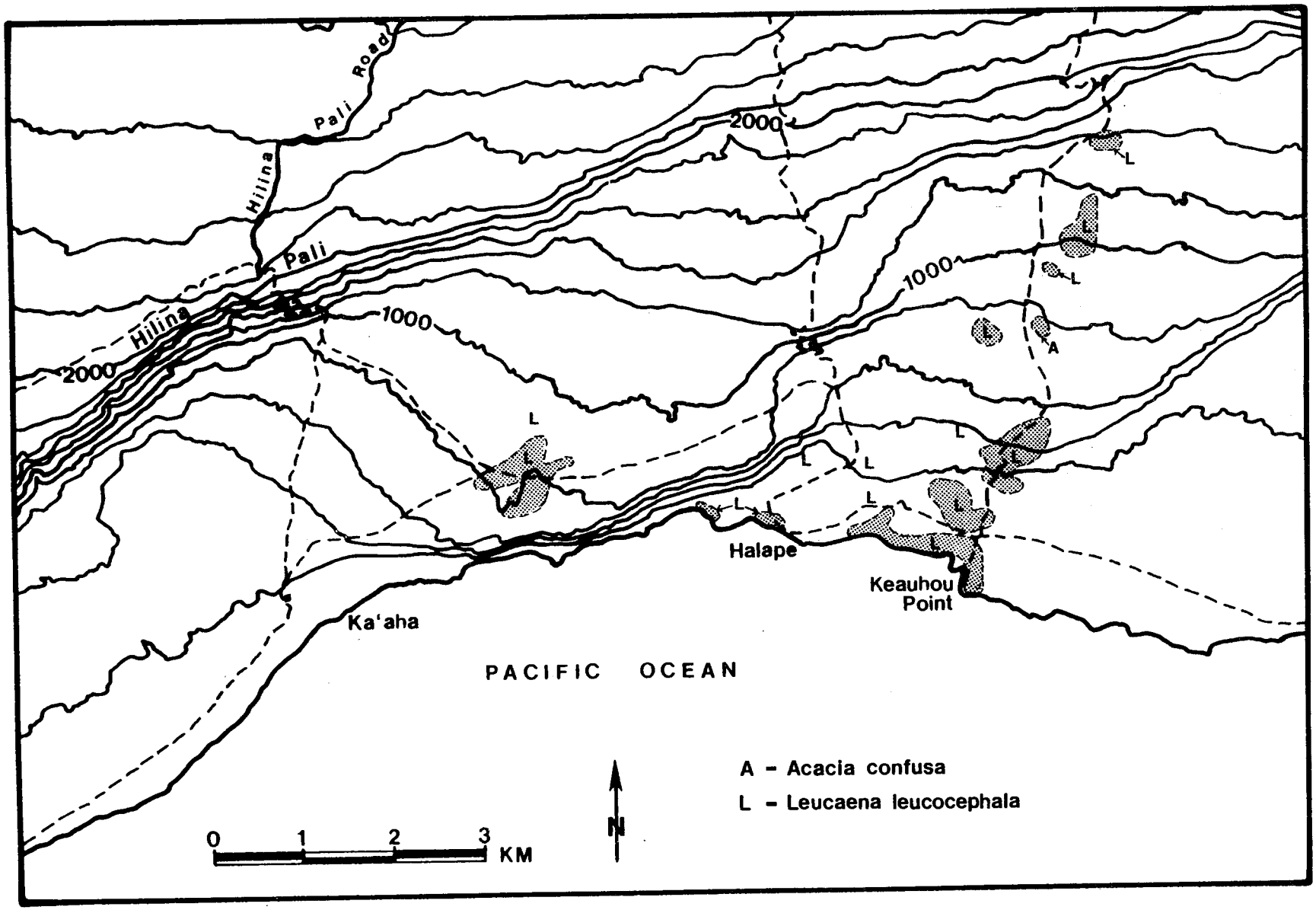

Figure 4. Distribution of Formosan koa and koa haole in central coastal lowlands, HAVO.

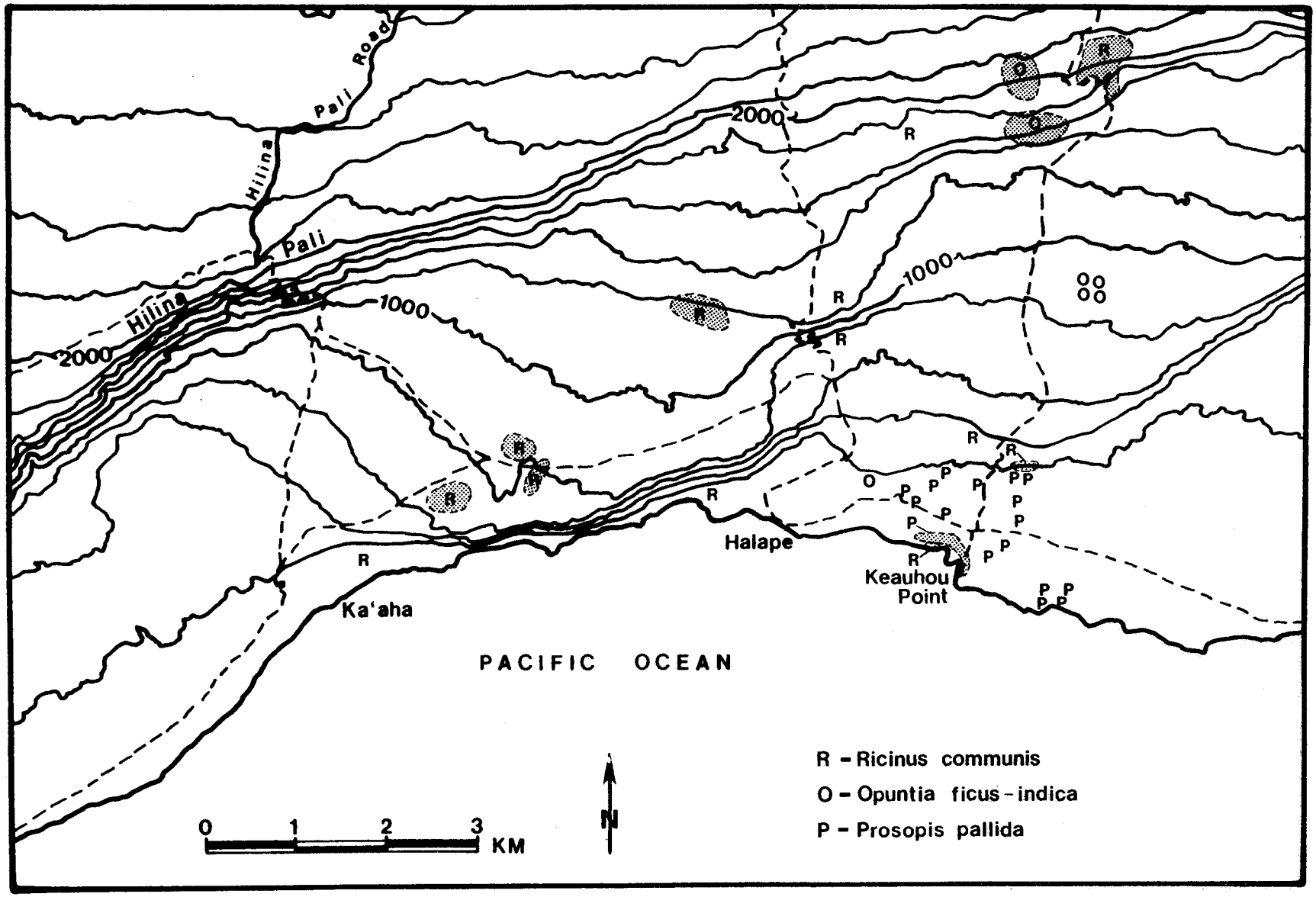

Figure 5. Distribution of cactus, kiawe, and castor bean in central coastal lowlands, HAVO.

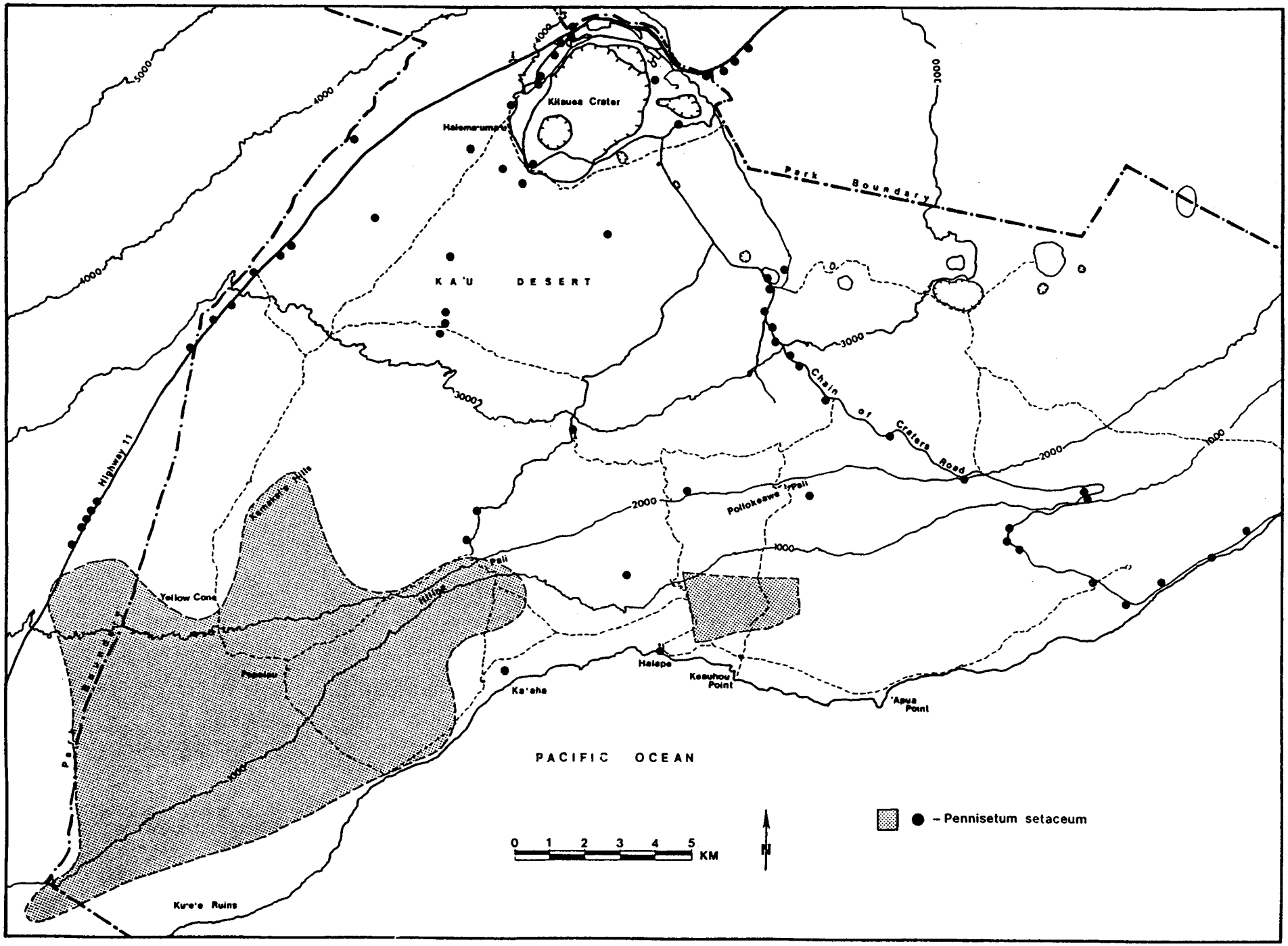

Figure 6. Distribution of fountain grass in HAVO and vicinity.

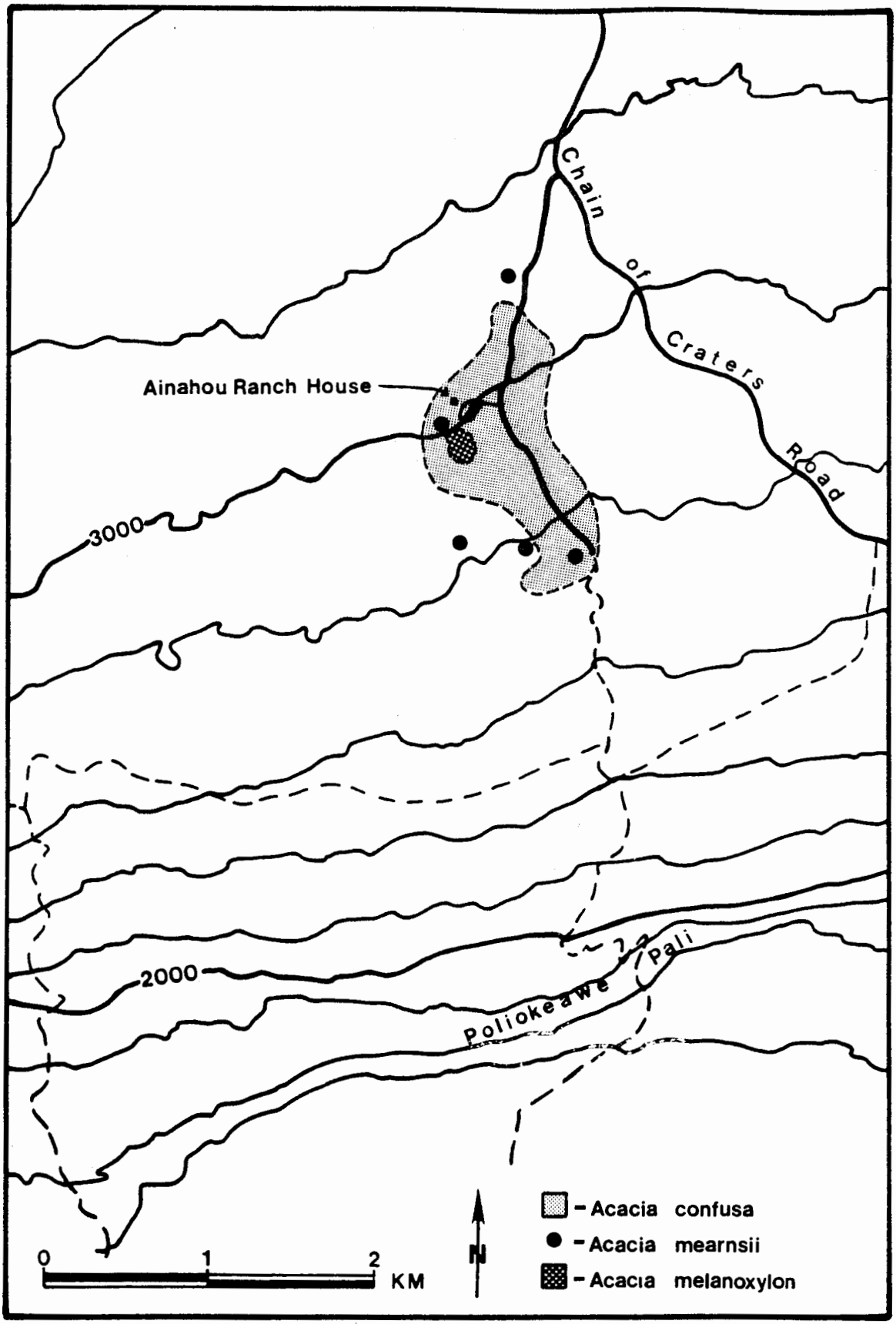

Figure 7. Distribution of Formosan koa, blackwood acacia, and blackwattle in submontane seasonal zone, HAVO.

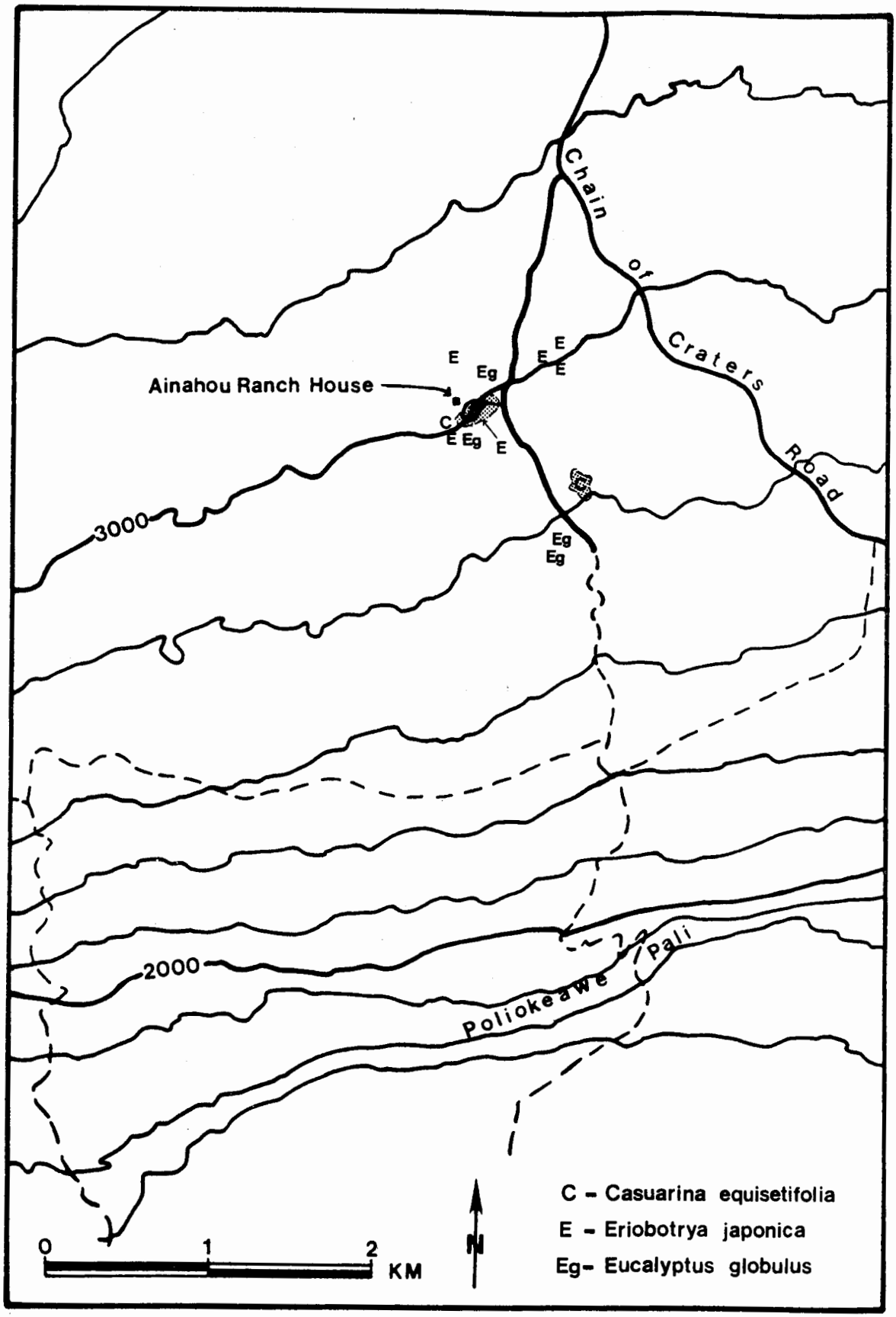

Figure 8. Distribution of ironwood, loquat, and bluegum in submontane seasonal zone, HAVO.

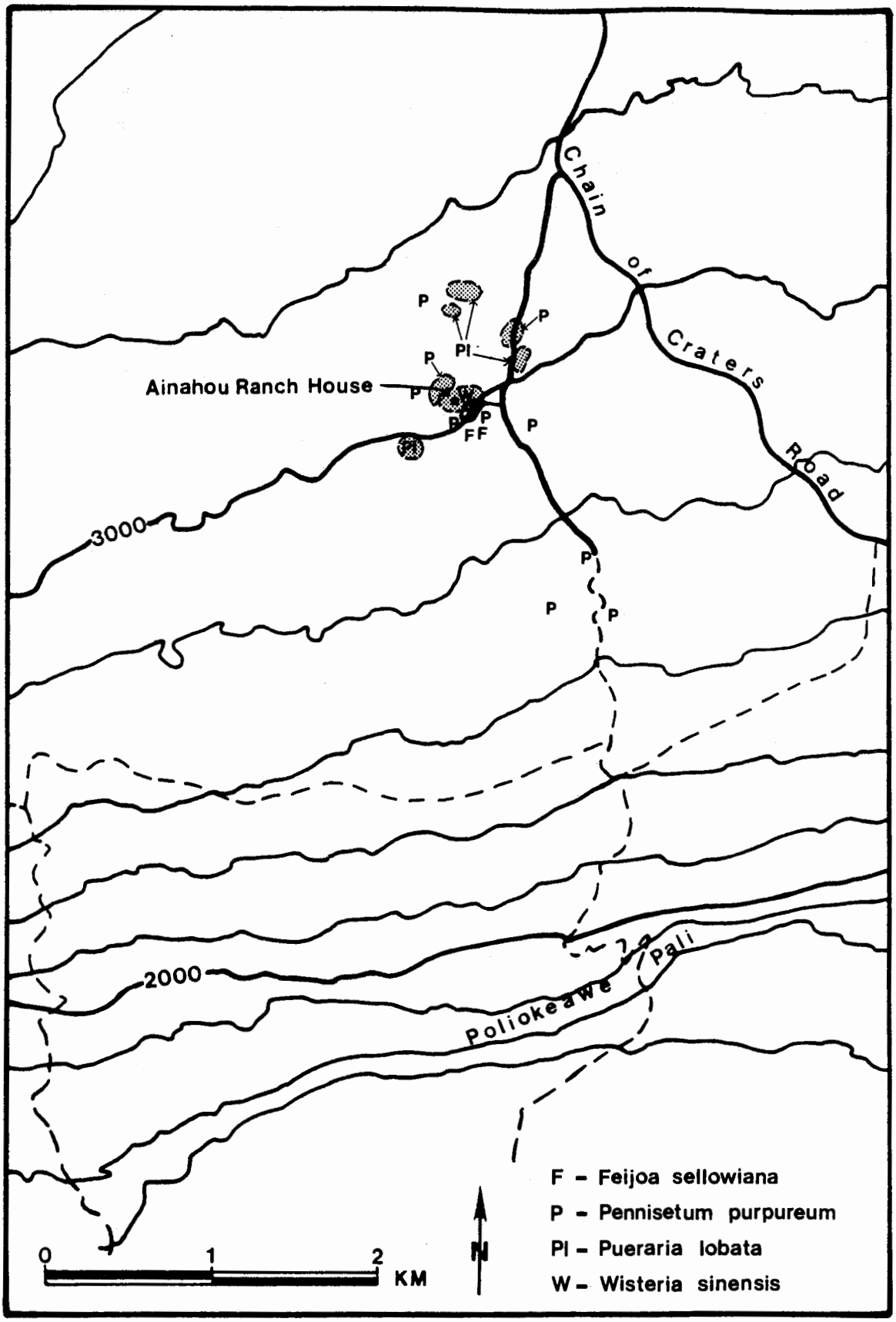

Figure 9. Distribution of guavasteen, elephant grass, kudzu, and wisteria in submontane seasonal zone, HAVO.

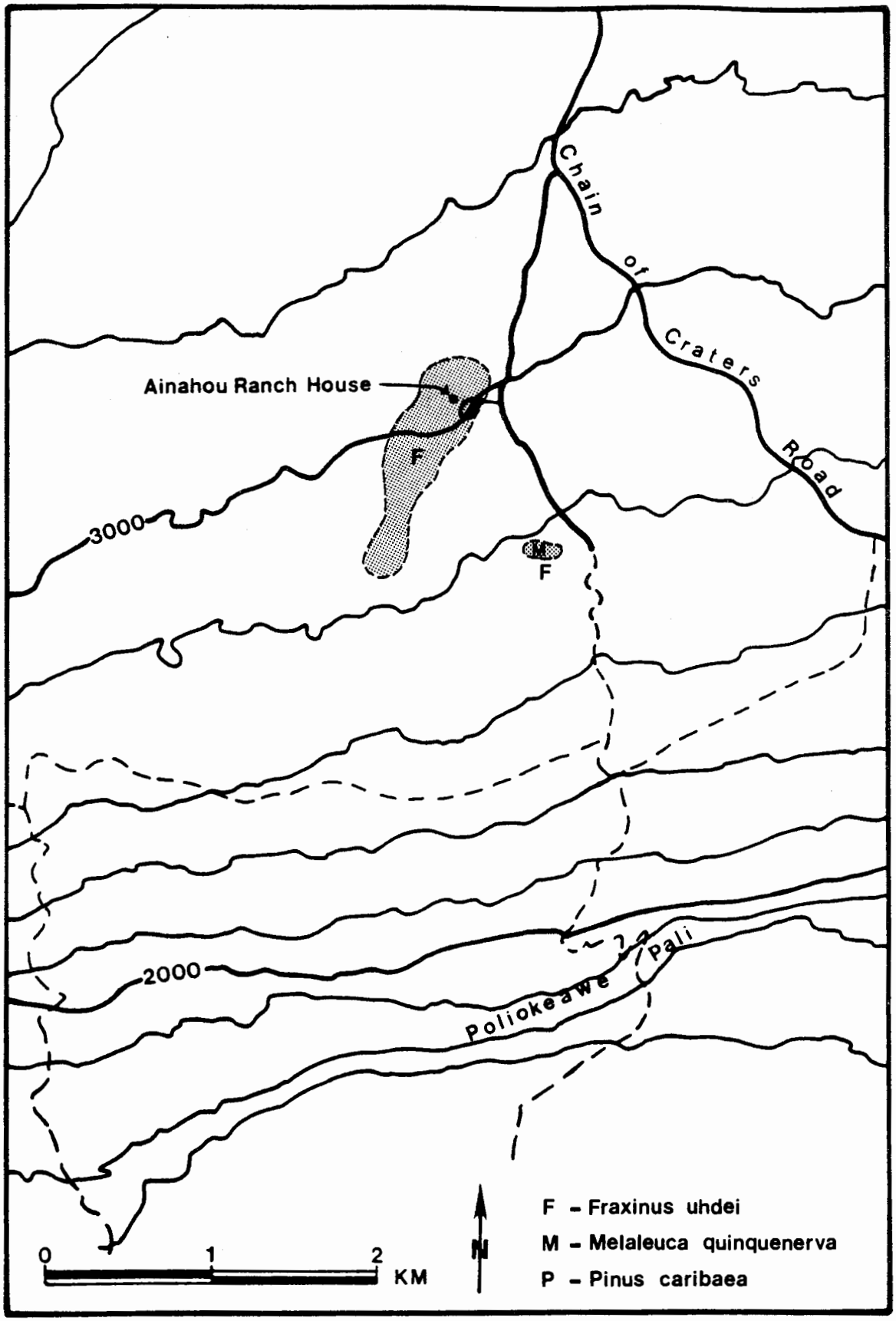

Figure 10. Distribution of tropical ash, paperbark, and slash pine in HAVO.

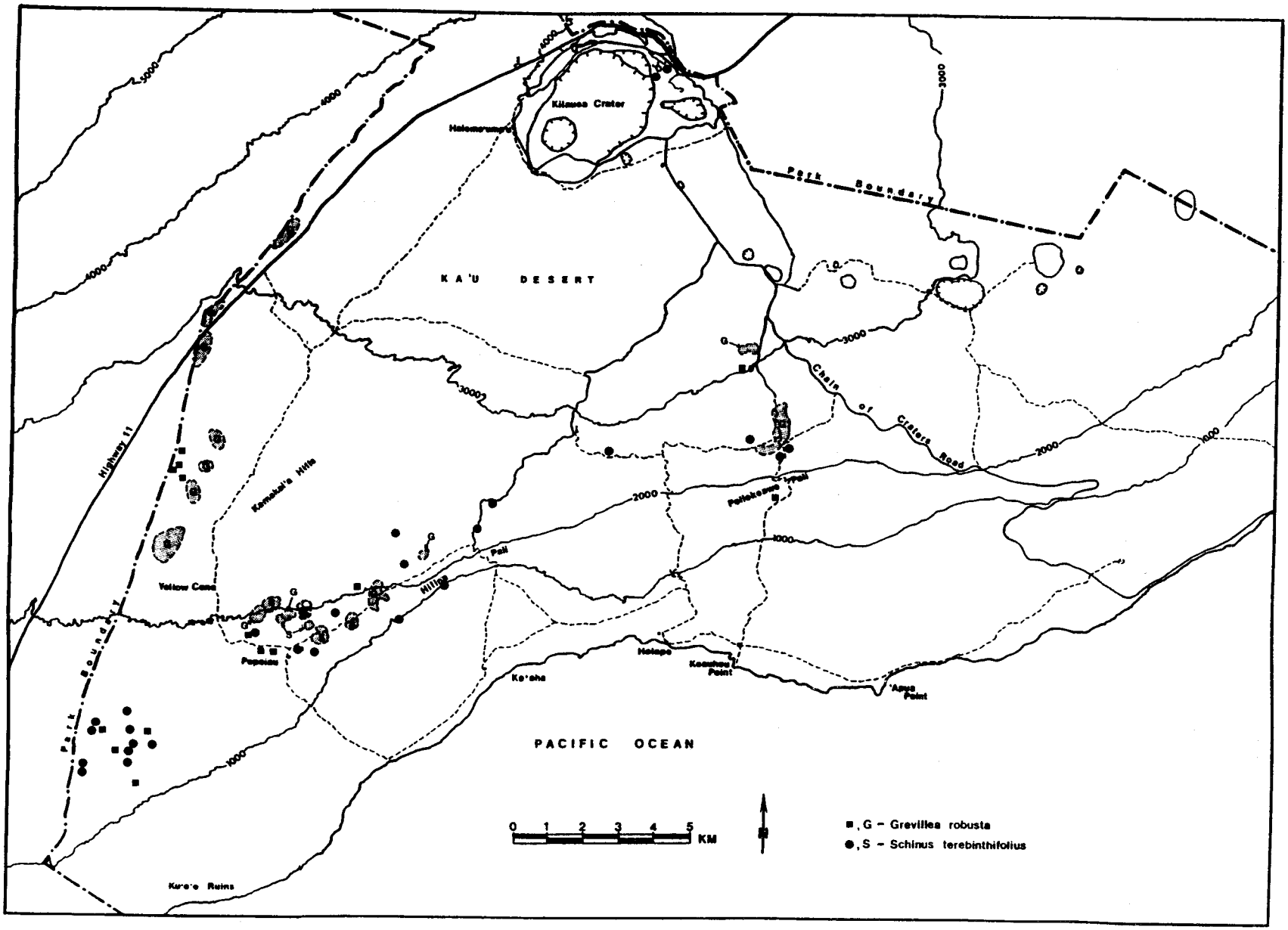

Figure 11. Distribution of silky oak and Christmasberry in HAVO.

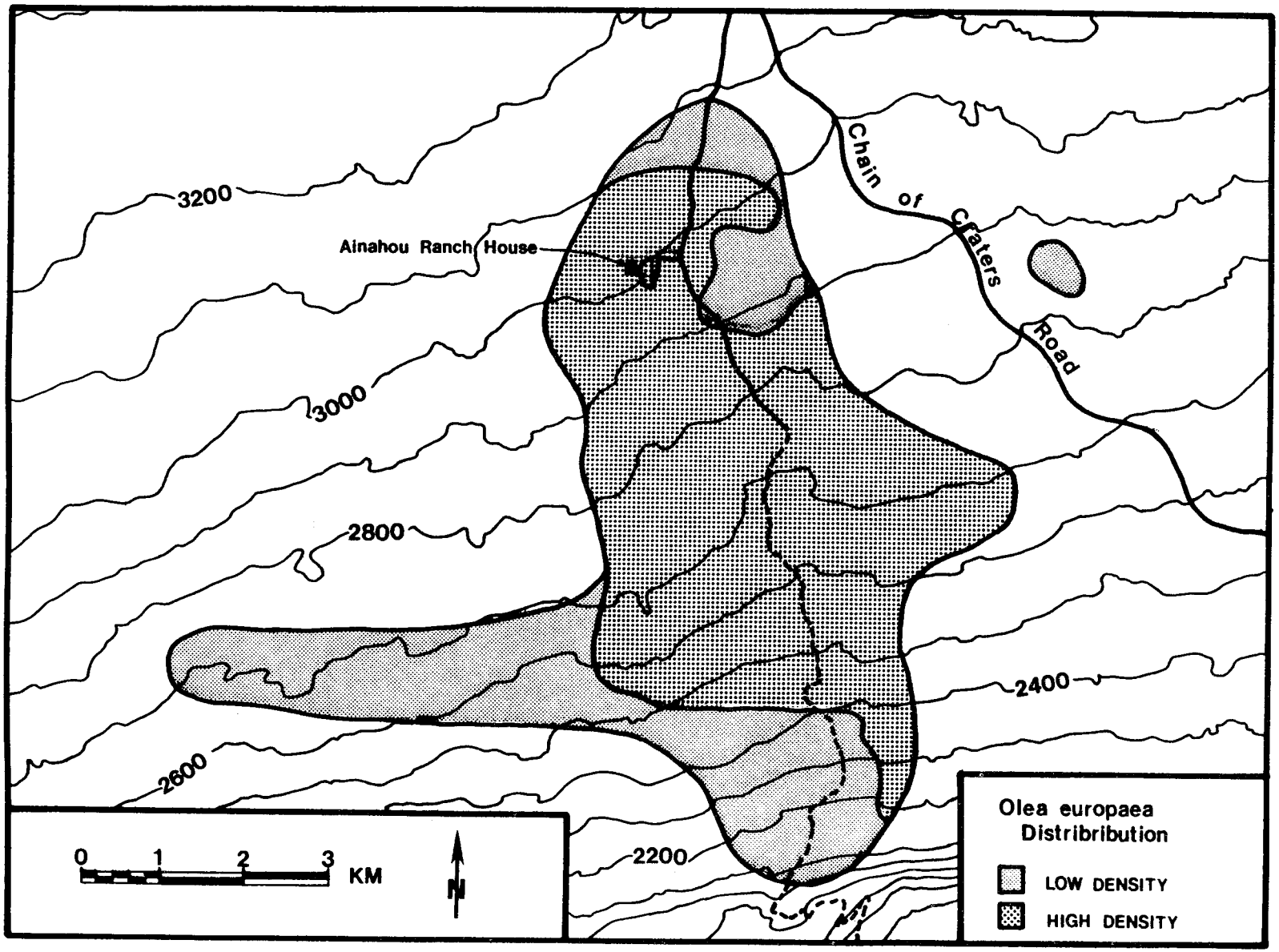

Figure 12. Distribution of Russian olive in HAVO.

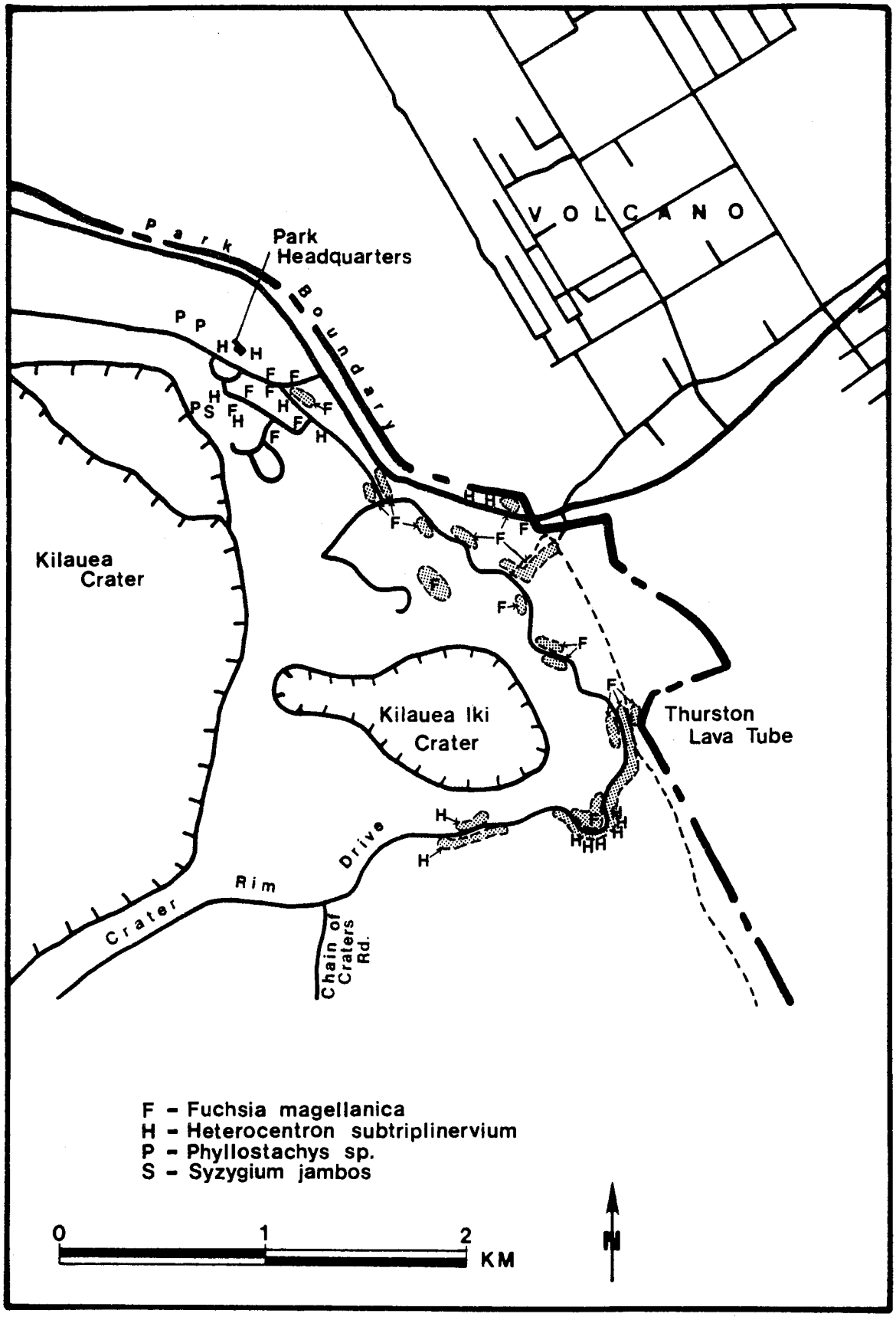

Figure 13. Distribution of fuchsia, rose apple, pearl flower, and bamboo in HAVO.

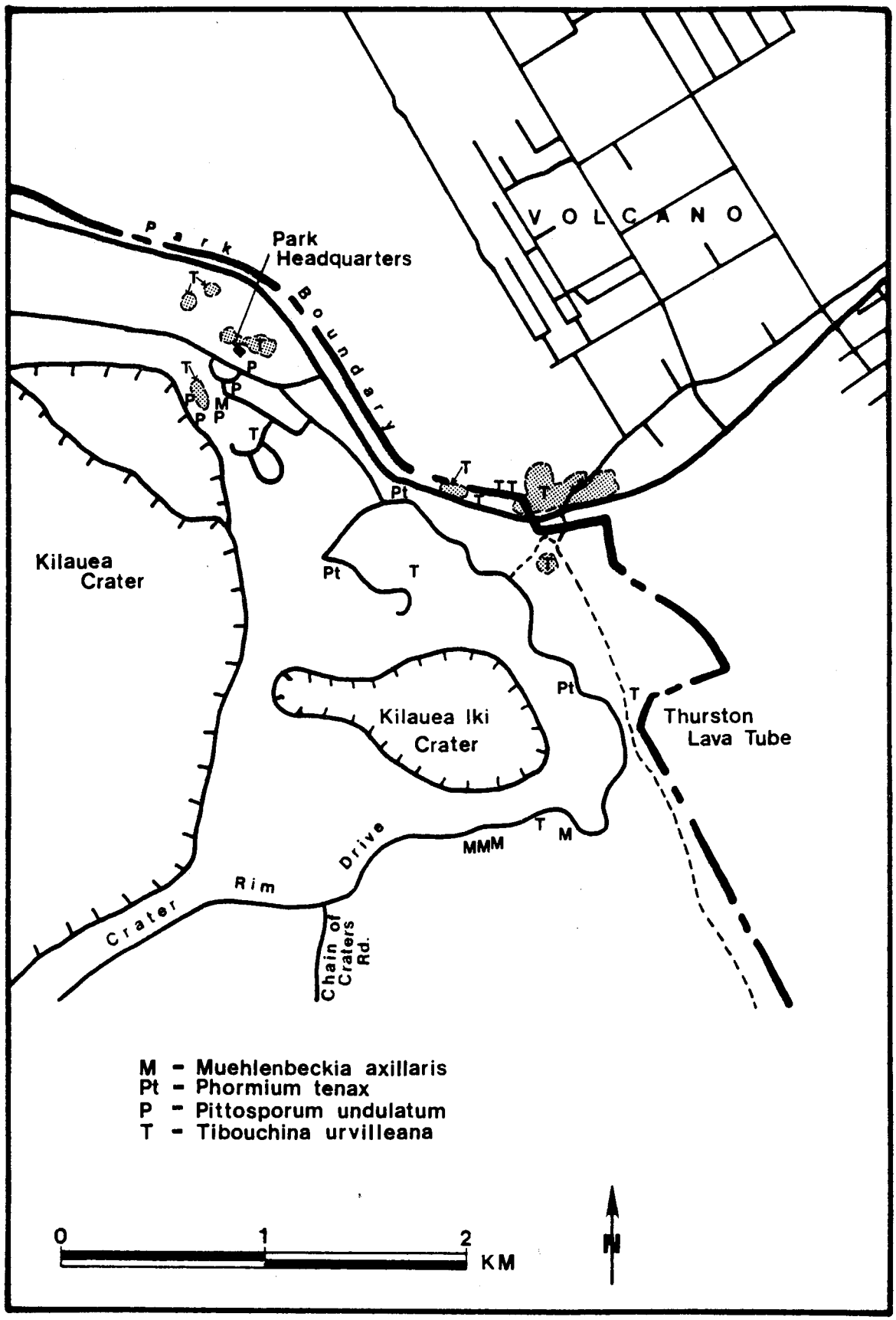

Figure 14. Distribution of wire vine, New Zealand flax, orange pittosporum, and tibouchina in HAVO.

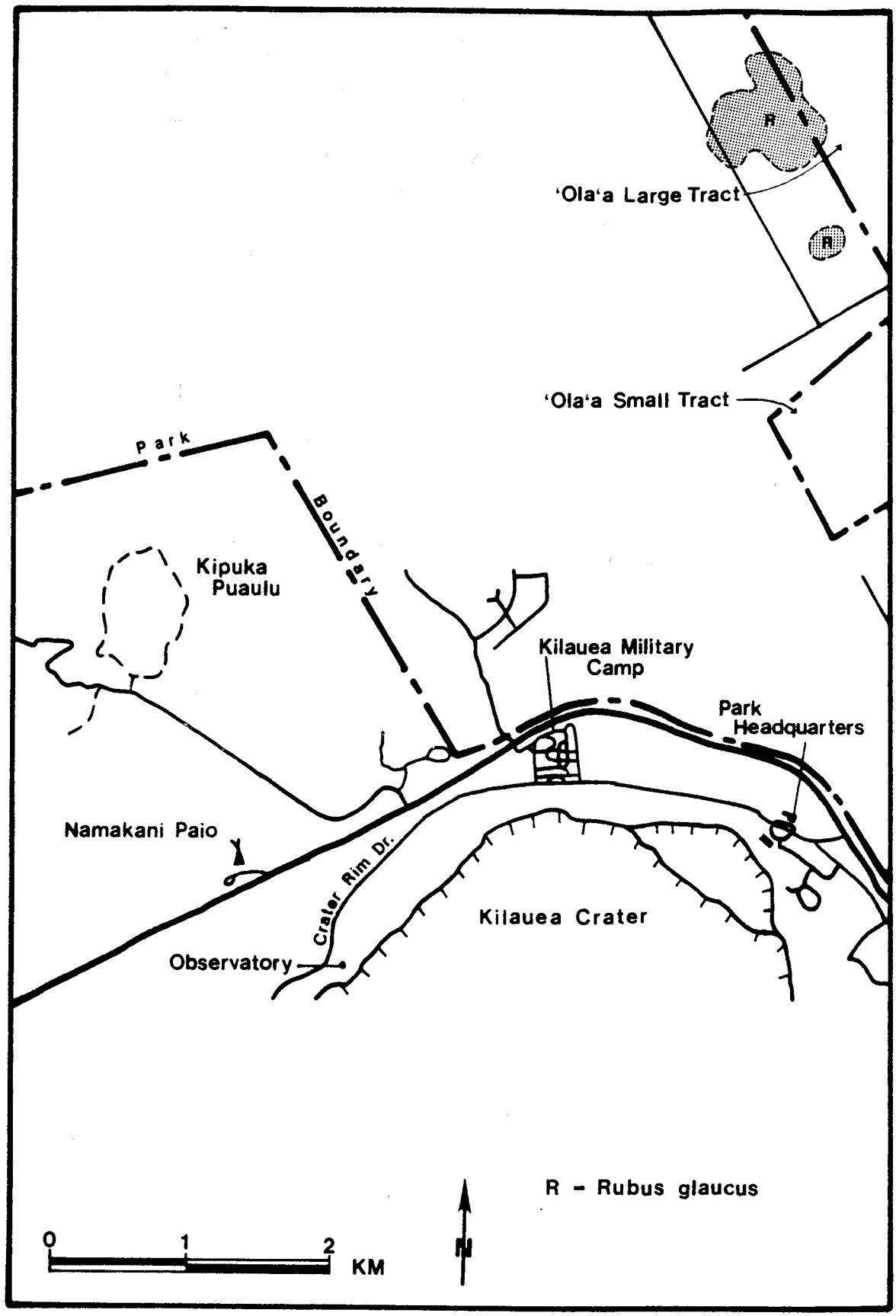

Figure 15. Distribution of raspberry in HAVO and vicinity.

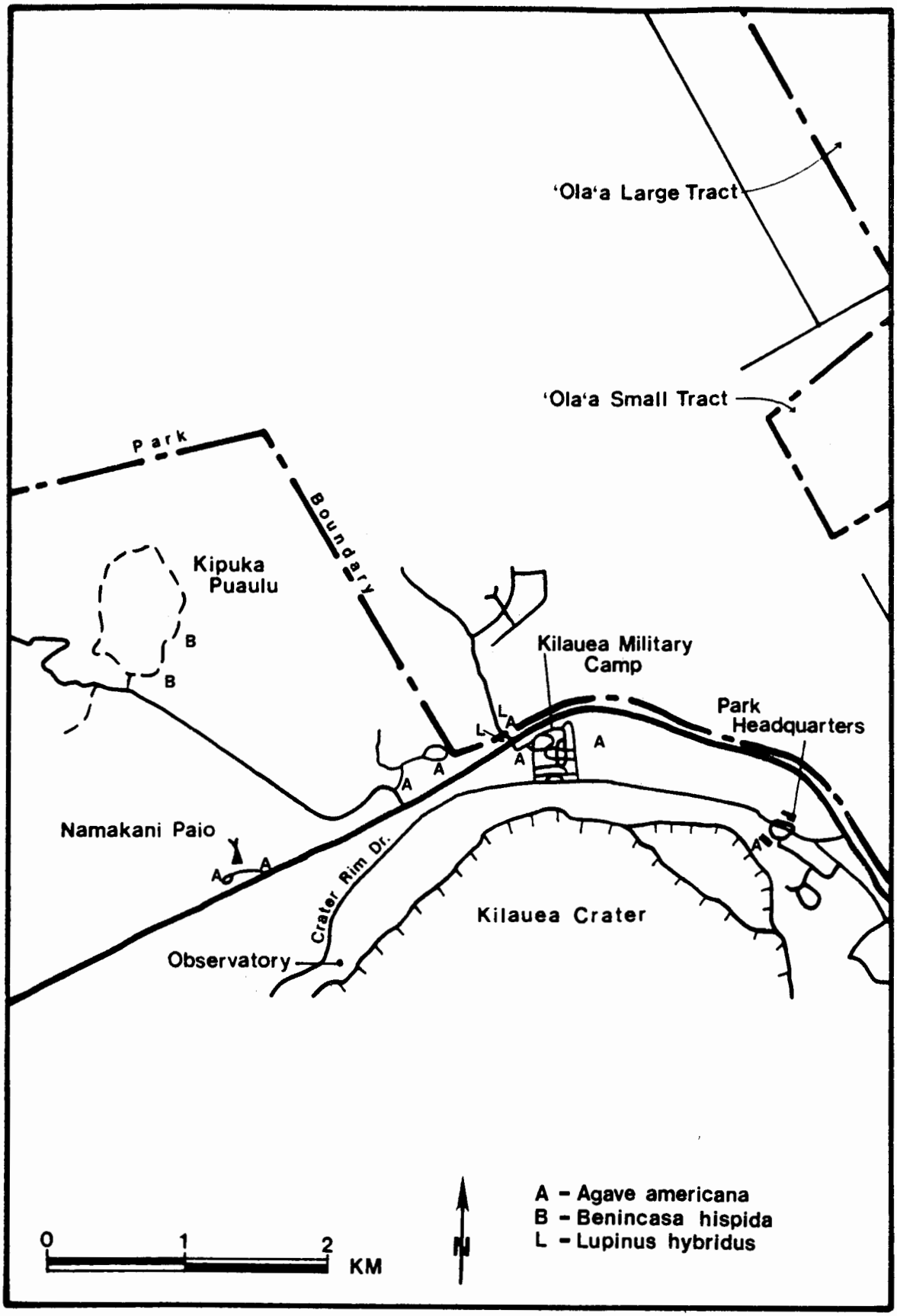

Figure 16. Distribution of century plant, chinese melon, and lupine in HAVO.

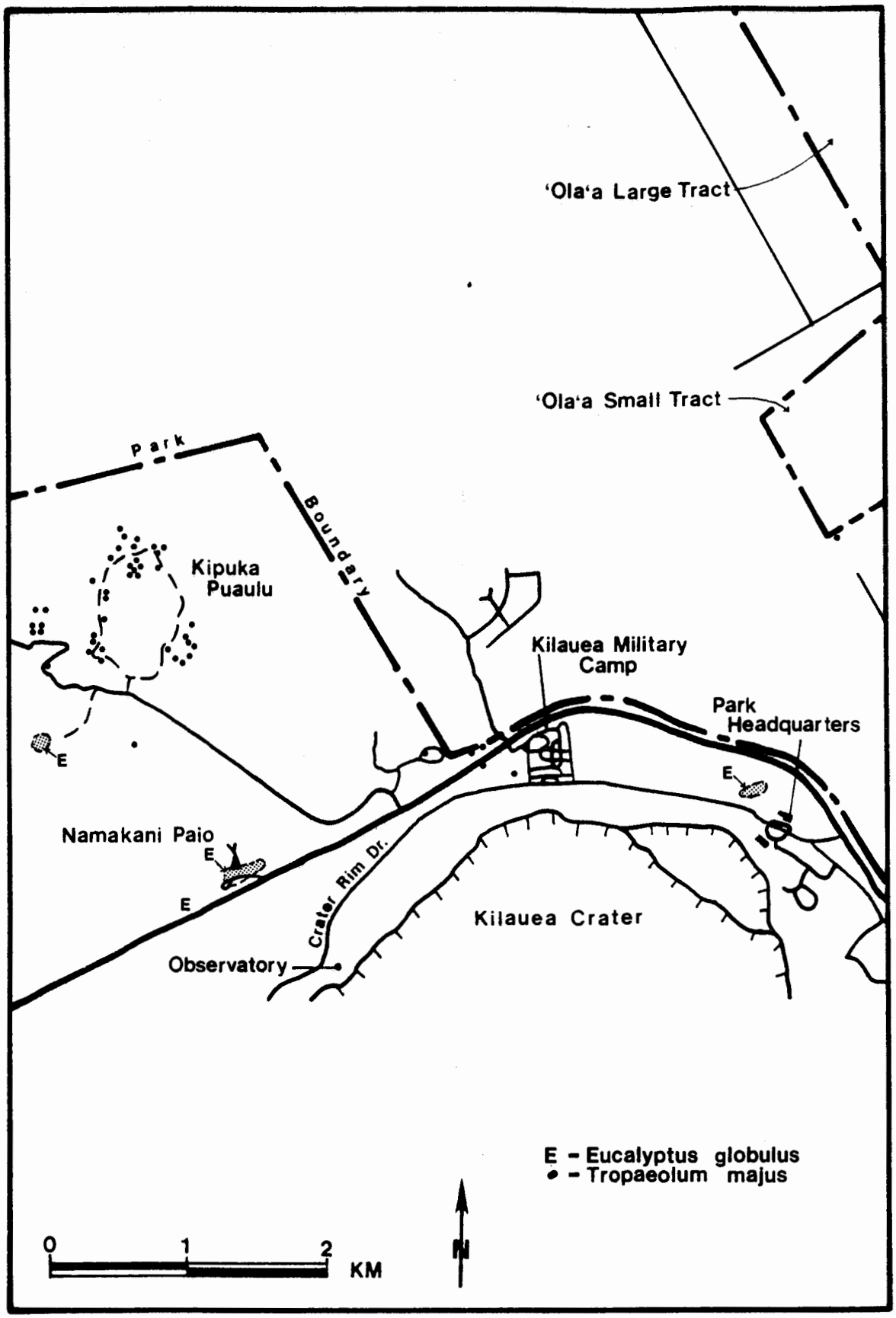

Figure 17. Distribution of nasturtium and bluegum in montane seasonal zone, HAVO.