DISTRIBUTION AND SPREAD OF ALIEN PLANTS IN KĪPAHULU VALLEY, HALEAKALA NATIONAL PARK, ABOVE 2,300 FT ELEVATION

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ABSTRACT

The National Park Service interdisciplinary and feral pig research projects, together with the fencing of Kīpahulu Valley in Haleakala National Park for feral pig control, have provided an opportunity for determining seasonal status of alien plants in the Valley over a span of five years (1983-1988). A network of 20 transects and 97, 400-m^2 plots has been established in the 9,000-a (3,640-ha) restricted-entry Scientific Reserve. Nineteen plant communities from the Kalapawili grasslands at 7,800 ft (2,380 m) elevation to the "Dogleg" rain forest area at 2,350 ft (720 m) elevation have been sampled. Comparison of these data with those of past surveys and research efforts have made it possible to assess the threat of alien plants in the Valley, the spread of weeds through time, the impact of research efforts, and the feasibility and prioritization of control efforts. This study, in conjunction with previously constructed exclosures, provided important baseline information on alien plant distribution during feral pig removal and prior to alien plant control efforts in the Valley.

INTRODUCTION

Kīpahulu Valley is located on the eastern slope of Haleakalā Volcano on the island of Maui and is managed as a closed-entry Scientific Reserve within Haleakala National Park. The Valley floor has two levels, referred to as the Upper Plateau and the Lower Plateau; these are separated by a ridge termed the Central Pali (Fig. 1).

The study area extends from 7,800 ft (2,380 m) elevation in the Kalapawili grasslands to a bend in the Valley at 2,350 ft (720 m), referred to as the "Dogleg." Kīpahulu supports some of the best remaining relatively intact forest bird habitat in the State and a diversity of forest bird species, including the endangered Maui parrotbill (*Pseudonestor xanthophrys*), crested honeycreeper (*Palmeria dolei*), Maui nukupu'u (*Hemignathus lucidus affinus*), and Maui 'ākepa (*Loxops coccineus ochraceus*) (Conant and Stemmermann 1980). Native plant species

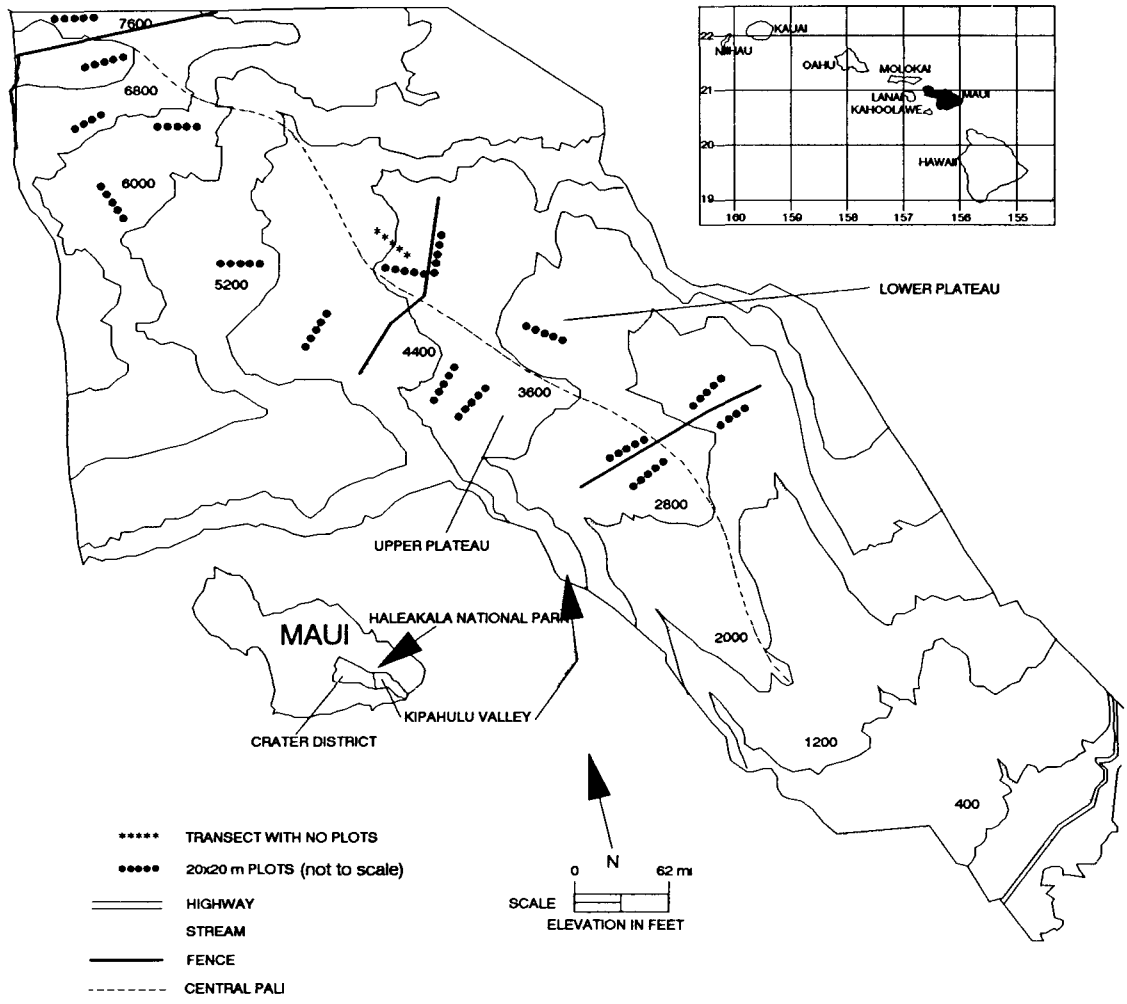

Figure 1. Kīpahulu Valley, Haleakala National Park, island of Maui, Hawai'i.

diversity is also high, with over 89 species of ferns and 209 species of flowering plants, including over 20 species of endemic woody lobelioids (Higashino *et al.* 1988).

The rich ecological resources of Kīpahulu are threatened by feral animal and alien plant invasions. Rooting and trampling of vegetation by feral pigs (*Sus scrofa*) and trampling by goats (*Capra hircus*) create seed beds for the establishment of weeds, which outcompete native species on disturbed sites. Some weedy species do not need disturbance to spread or become established in the Valley. Research and management efforts began in Kīpahulu with the long-term objective of controlling alien plants and animals. The Valley has been partitioned into feral pig and goat management units, with fences constructed across the Valley at the Dogleg, at 4,700 ft (1,430 m) elevation, and above the Valley headwall across the Kalapawili grasslands. Steep cliffs *(pali)* on the sides of the Valley provide topographic barriers that enclose three discrete areas with the

cross fencing. Permanent vegetation plots have been established to study rain forest dynamics and the distribution and spread of alien plant populations, particularly between the 4,700-ft elevation fence (Fig. 1) and the Dogleg area, where displacement of the native flora is evident.

Past work on the status of alien plants in Kīpahulu has focused on distribution and occurrence at a given point in time (Warner 1967; Lamoureux and Stemmermann 1976; Yoshinaga 1980). Little was known about the rate of spread or population dynamics of weedy species in the Valley. Such information is critical to managers addressing the questions of prioritization and feasibility of alien plant control. It is equally important to determine the responses of weedy plants to the removal of feral pigs within the variety of plant communities in the Valley.

METHODS

Permanent transects and plots were laid out in stages as field work began in different areas of the Valley. Six 500-m transects were established in 1983 in six vegetation zones between 4,100 and 6,800 ft (1,250-2,070 m) elevation. During the Kīpahulu Interdisciplinary Study (Stone *et al.* 1984; Stone *et al.*, unpub. data), frequency of alien plant species was recorded in 50, 1-m^2 plots spaced at 10-m intervals on each 500-m transect. Presence of pig activity (tracks, feces, rooting, or plant feeding) within 2.5 m of each 10-m interval was recorded. Percent cover of both native and alien plant species was estimated in five 20- x 20-m plots spaced at 100-m intervals equidistant along each transect. Cover was estimated in three vertical layers (0-0.5 m, 0.5-2 m, and >2 m) using the modified Braun-Blanquet Cover-Abundance scale (Mueller-Dombois and Ellenburg 1974). Qualitative observations of weedy species were made for all camp sites, designated helicopter use sites ("helipads"), and trail systems. Frequency of occurrence data and casual observations were recorded on each of the three trips during the interdisciplinary study (Stone *et al.* 1984).

With the onset of the Kīpahulu feral pig project in April 1985, seven additional 500-m transects (Fig. 1) were added to represent the area considered for feral pig control research. The upper elevational limits of the study area were extended to 7,800 ft (2,380 m) in the Kalapawili grasslands, and the lower elevational range was lowered to 2,350 ft (720 m) in the Dogleg area; transects were also added to fill in gaps in the existing sampling scheme. The methods used for the six original transects were continued, with modifications, to increase the alien plant frequency sampling scheme. The 1-m^2 plots were enlarged to a 10-m long x 5-m wide continuous belt transect, the same area used in assessing pig activity. Five intensive 20- x 20-m plots were read on each of the new transects except on the transect at 6,800 ft (2,070 m) elevation; this transect traverses the Valley headwall shrublands and ends abruptly at a steep gulch, allowing space for only four plots. Plots were not established on the 4,400-ft (1,340-m) elevation transect on the Lower Plateau, as the vegetation there is dominated by matted fern or uluhe *(Dicranopteris linearis)*, and plot establishment would negatively impact

the area. The vegetation on the Kalapawili transects facilitated the use of a point-frequency frame rather than visual estimates, allowing more accurate estimations of percent cover.

To monitor the effects of the feral pig control fence completed across the Valley in 1985 at the Dogleg, four 500-m transects were established in 1986, one on each side of the fence, for both the Upper and the Lower plateaus. The layout and sampling scheme were similar to those for the existing plots and transects. Percent cover was estimated for only the weed species and native dominants in each vertical vegetation layer. Individuals of the alien tree strawberry guava (*Psidium cattleianum*) were counted in basal diameter size classes to determine population structure and status of the invasion. If the ground cover contained an alien grass component greater than 25%, counts were made of native dominant woody species in basal diameter size classes to determine if seedlings and saplings can grow through the thick grass. Five 20- x 20-m plots were established on each of the transects at 100-m intervals except the fourth transect on the Lower Plateau below the fence. This transect was truncated at a steep gulch and contained only four plots. The 20- x 20-m plots on the 500-m transects were sampled only once, and plant communities were distinguished using Sorenson's quantitative index of similarity.

Three transects were established perpendicular to elevational contours to define the density gradient and location of the invasion front for the weed species invading from lower elevations. These transects followed old trail systems along the Ko'ūko'ūai Stream and the top of the Central Pali from 4,700 ft (1,430 m) to 3,100 ft (950 m) elevation on the Upper Plateau and along the Palikea Stream from 4,000 ft (1,220 m) to 2,350 ft (720 m) elevation on the Lower Plateau. Along the transects, abundance of weed species was recorded for each 100-ft (30-m) decrease in elevation. Abundance ratings used were common: occurring in high numbers or comprising a high percentage cover in an area; occasional: seen in low numbers throughout an area; and sparse: encountered infrequently and in low numbers. Forays off the trail system were used to record weed abundance in previously untraveled areas. A 20- x 20-m plot was established with each 200-ft (60-m) drop in elevation along the transects. Layout and sampling followed the methods used on the Dogleg transect plots (*i.e.*, weed and native dominant cover estimate only).

RESULTS

Frequency of Occurrence

A total of 38 weed species (Appendix) was recorded within the transect frequency plots. Five of these were ferns, 11 were grasses or sedges, 20 were herbs, and two were trees. Only five of the species found in the frequency plots are considered to have major disruptive potential (Appendix). Nine species (five ferns, two grasses, and two herbs) were new records for the study area.

Alien plants were found on each of the 500-m long transects. Highest total frequencies (100%) were recorded on the Kalapawili *(Deschampsia)*

grasslands and Dogleg (open and closed *Acacia*) transects, and lowest total frequencies (8%) on the transect at 5,960 ft (1,820 m) elevation in the open-closed ʻōhiʻa *(Metrosideros polymorpha)* forest near the head of the Valley (Figs. 2, 3). The most rapid spread (increase in frequency) of weeds recorded was during the five-month period between November 1985 and March 1986, on the 4,300-ft (1,310-m) elevation transect on the Lower Plateau in wet ʻōhiʻa forest; a 17% increase in alien plant frequency was noted there. The ground cover in these areas is dominated by uluhe, which typically grows under open canopy tree layers and is slow to recover from disturbance. After transect establishment, an increase in pig activity was recorded (Fig. 3). Wind-dispersed Maui pāmakani (*Ageratina adenophora)* and bird-dispersed thimbleberry (*Rubus rosifolius*) (Appendix) were the invading species.

Some fluctuations in weed frequency among trips into the Valley were evident on all but the Kalapawili grasslands and Dogleg transects. Occurrence of velvet grass (*Holcus lanatus*) and gosmore (*Hypochoeris radicata*) remained at frequencies of 100% along the pig-disturbed Kalapawili transects. The constant occurrence of Hilo grass (*Paspalum conjugatum*) and a host of other weeds kept frequencies of weeds in the Dogleg area at 100%. Frequencies on the transects at 5,960, 5,240, and 4,200-ft (1,820, 1,600, and 1,280-m) elevations varied less than 12% during the study. Seasonal patterns in weed distribution and occurrence were not evident on any transect.

An elevational pattern of weed occurrence emerged from the plotting of the frequency transect data (Figs. 2, 3). The central core of the Valley, which contains the thickest forest canopy and has been the least disturbed by pigs, showed the lowest pig and weed frequencies. The open grasslands and shrublands at the head of the Valley, and the thin koa *(Acacia koa)* canopy at lower elevations allow the light needed for the proliferation of many alien plant species. Disturbance by pigs is also greater in these areas. The removal of pigs, resulting in decreased frequency of pig activity over time, did not result in decrease in weed occurrence in these areas. The number of weed species found on the frequency transects (Fig. 4) showed an increase with decreasing elevation.

Percent Cover

The 73 cover plots on the 500-m transects were categorized into 19 plant communities using Sorenson's quantitative index of similarity (Mueller-Dombois and Ellenberg 1974). Tallies of alien plant cover in these communities are presented in Table 1. Although weedy species occur throughout the study area, 10 plant communities sampled between 4,100 and 6,800 ft (1,250-2,073 m) remain relatively pristine. Seven of these communities contain 1% or less alien plant cover, while the remaining three communities contain 3% or less. The weed species that occur in this elevational range (Appendix) are not significant threats to the communities but are indications of disturbance. These 10 communities range from open to closed canopy ʻōhiʻa and/or koa forests, each with a variety of native tree and shrub subcanopies. Ground cover varies from dense mats of uluhe fern to bogs dominated by the native sedge *Carex alligata*, and from

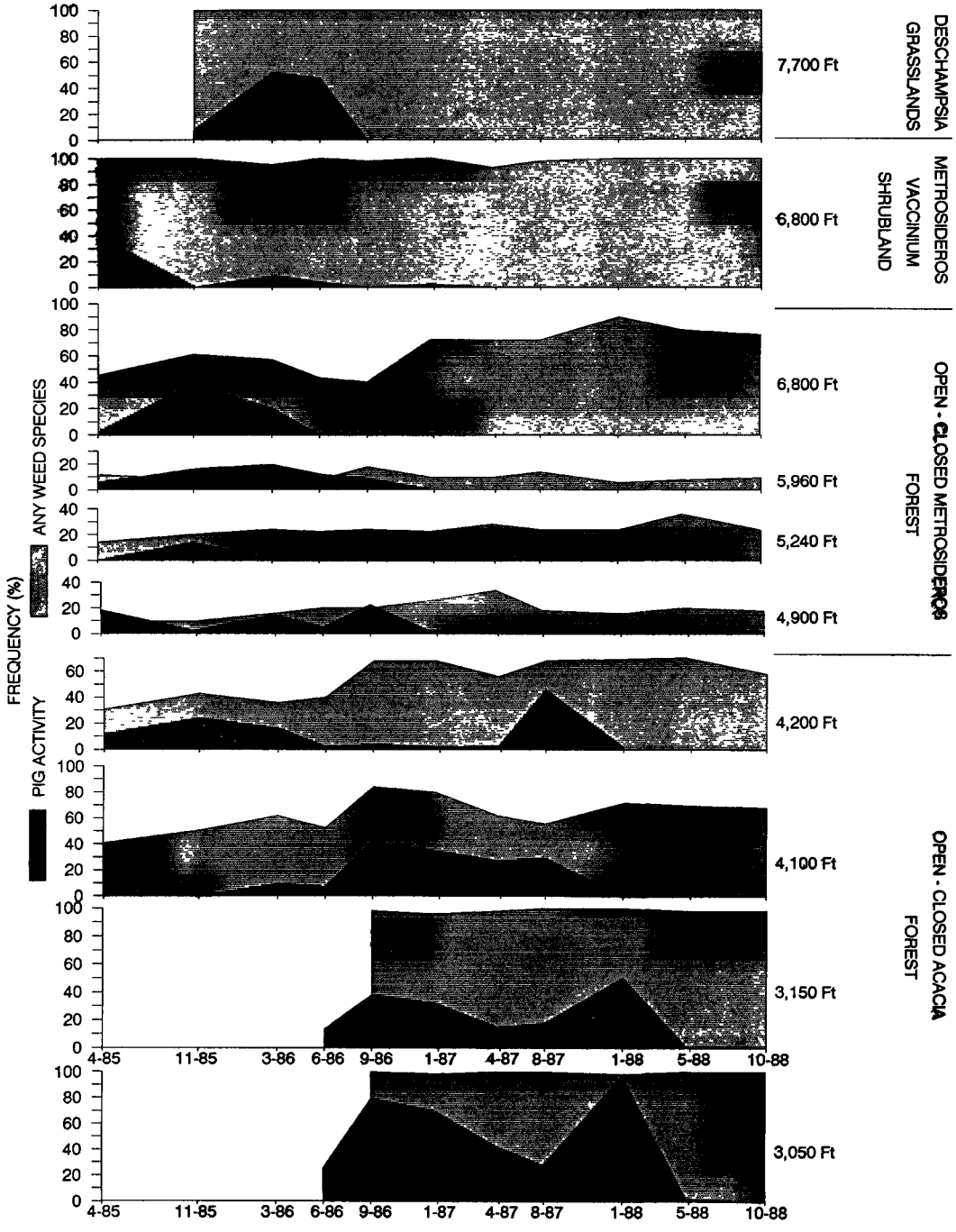

Figure 2. Frequency of pig activity and alien plant species on 10 transects in four vegetation types on the Upper Plateau in Kīpahulu Valley, Haleakala National Park, 1985-1988. (Pig activity data not available for 7,800-ft transect.)

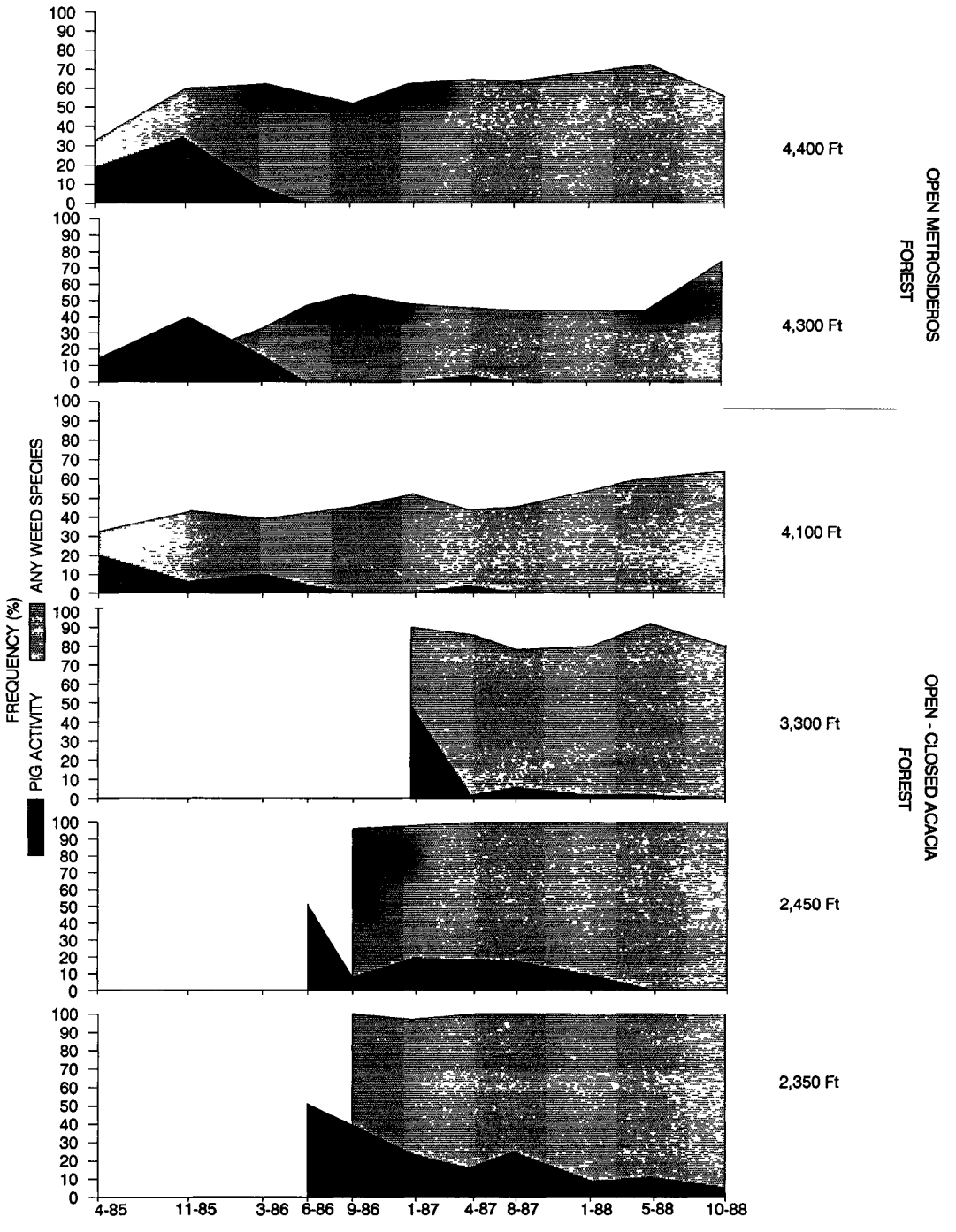

Figure 3. Frequency of pig activity and alien plant species on six transects in two vegetation types in Kīpahulu Valley, Haleakala National Park, 1985-1988.

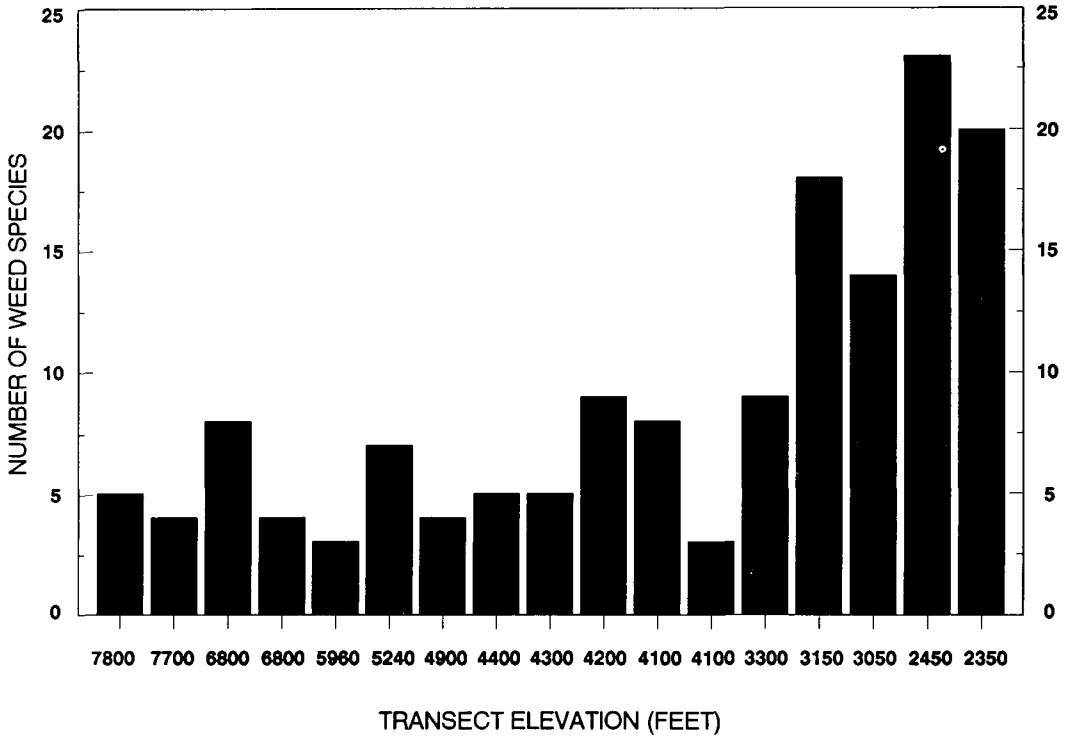

Figure 4. Number of weed species found on transects in Kīpahulu Valley.

thick litter accumulations with sparse vegetation cover to diverse assemblages of native herbs, ferns, and bryophytes.

At upper elevations in the study area at 6,800 ft (2,070 m) elevation and above are several distinct plant communities that vary in alien plant components. The shrubland of open ʻōhiʻa, pūkiawe (*Styphelia tameiameiae*), ʻōhelo (*Vaccinium* spp.), and amaʻu fern (*Sadleria cyatheoides*) on the back wall of the Valley is impacted severely in places by erosion following rooting and trampling of feral pigs and trampling of goats. Exposed areas are invaded by velvet grass, gosmore, and sheep sorrel (*Rumex acetosella*), introduced species that crowd out natives on disturbed sites. These aliens comprise 1 to 5% of the vegetation cover in unexposed areas but may have 100% cover in patches where rooting and erosion have been severe.

The *Deschampsia nubigena*-dominated grassland areas were more severely impacted by pigs and goats. The total percent cover of weed species in the sampled grassland transects was 41% (24% velvet grass, 16% gosmore, 1% sheep sorrel). Grassland plots closest to the top of the Valley headwall, where erosion is most severe, contained the greatest total weed cover (50%).

Weed invasions below 4,200 ft (1,280 m) elevation are most severe due to the amount of light that penetrates the koa canopy, the higher densities of pigs that occurred in these areas, and elevational limits of some of the

Table 1. Percent cover of alien plants in plant communities of Kīpahulu Valley, Haleakala National Park.

Plant Community	Transect Elevation (ft)	No. Plots	Percent Cover of Alien Plants									
			Ferns		Grasses/Sedges		Herbs		Trees		Total	
			$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Deschampsia Grassland	7,700, 7,800	9	0	--	24	12	17	4	0	--	41	11
Vaccinium-Deschampsia Shrubland	7,700	1	0	--	16	--	21	--	0	--	37	--
Open *Metrosideros-Styphelia-Rubus* Shrubland	6,800	6	0	--	3	5	1	2	0	--	4	7
Open *Metrosideros-Vaccinium* Forest	6,800	1	0	--	0	--	0	--	0	--	0	--
Closed *Metrosideros,Cheirodendron* Forest with *Rubus,Vaccinium,* and *Dryopteris*	6,800	2	0	--	<1	--	<1	--	0	--	<1	--
Open *Metrosideros,Cheirodendron* Forest with *Rubus,Coprosma,Broussaisia,Dryopteris,* and *Athyrium*	5,960	5	0	--	<1	--	<1	--	0	--	<1	--
Open *Metrosideros,Cheirodendron* Forest with *Athyrium* and *Carex*	4,900, 5,240	9	0	--	<1	--	<1	--	0	--	<1	--
Open *Metrosideros,Cheirodendron* Forest with native shrubs and *Dicranopteris*	4,200, 5,240	2	0	--	<1	--	2	1	0	--	2	1
Closed *Metrosideros,Cheirodendron* Forest with native shrubs, dense *Athyrium*, and *Dicranopteris*	4,200, 4,300	4	0	--	<1	--	<1	--	0	--	<1	--

Plant Community	Transect Elevation (ft)	No. Plots	Percent Cover of Alien Plants									
			Ferns		Grasses/Sedges		Herbs		Trees		Total	
			$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Open *Metrosideros,Cheirodendron* Forest with dense *Dicranopteris*	4,200, 4,300	4	0	--	<1	--	1	1	0	--	1	1
Open *Metrosideros,Acacia* Forest with native shrubs, *Athyrium*, and *Dicranopteris*	4,100	1	0	--	0	--	3	--	0	--	3	--
Open *Acacia,Metrosideros* Forest with native shrubs and dense *Dicranopteris*	4,100	1	0	--	0	--	<1	--	0	--	<1	--
Closed *Acacia,Metrosideros* Forest with native shrubs and native ferns	4,100	8	0	--	<1	--	3	6	0	--	3	6
Open *Acacia,Metrosideros* Forest with dense *Dicranopteris*	3,000, 3,100	3	<1	--	8	4	<1	--	<1	--	9	4
Open *Acacia,Metrosideros* Forest with *Paspalum* and *Dicranopteris*	3,000, 3,100	4	<1	--	43	8	<1	--	<1	--	43	8
Open *Acacia, Metrosideros* Forest with dense *Paspalum*	2,200, 3,000	3	<1	--	75	9	2	1	<1	--	77	8
Closed *Acacia*, diverse understory Forest with dense *Paspalum*	2,400	5	<1	--	57	8	9	3	2	2	67	9

Table 1, continued.

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Plant Community	Transect Elevation (ft)	No. Plots	Percent Cover of Alien Plants									
			Ferns		Grasses/Sedges		Herbs		Trees		Total	
			$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd	$\bar{x}$	sd
Open *Acacia*, diverse understory Forest with dense *Paspalum*	2,200	3	0	--	27	10	18	14	2	2	46	8
Open *Acacia,Psidium* Forest with dense *Paspalum*	2,200	1	0	--	51	--	33	--	10	--	94	--

weed species. The koa-dominated plant communities (Table 1) (with total weed cover up to 94%) are most vulnerable to invasion by the suite of weed species now present in Kīpahulu Valley. Invasion profiles along transects established perpendicular to elevational contours (Fig. 5) illustrate overall increases in cover percentages in total weed species with decrease in elevation. A total of 24, 20- x 20-m plots was sampled on the three transects between the 4,700 ft (1,430 m) and 2,350 ft (720 m) fence lines. Below 4,100 ft (1,250 m) elevation, the 20- x 20-m plots showed increasing percentage cover and numbers of nonnative species with decreasing elevation. Alien grasses and sedges, primarily Hilo grass and *Cyperus* spp., comprised 84% of the weedy vegetation cover below 3,600 ft (1,100 m) on the Upper Plateau (Koʻūkoʻūai and Central Pali) and 89% below 3,200 ft (975 m) elevation on the Lower Plateau. Above these elevations, alien herbs constituted most of the weedy component of vegetative cover. Alien herbs were less invasive and occupied less cover than weedy grass species. The only vegetation component evidently inhibiting alien plant invasion is matted fern or uluhe, which forms thick, impenetrable thickets.

A particularly weedy plot at 4,200 ft (1,280 m) elevation along the Koʻūkoʻūai Stream reflected the greater extent of the alien grass and herb populations up this major stream gulch. However, the weedy tree species strawberry guava and common guava (*P. guajava*) have spread farther upslope and more continuously on the Lower Plateau and Central Pali than along Koʻūkoʻūai Stream. Total weedy plant cover is greater on the Lower Plateau (75%) than on the Upper Plateau (48%).

Habitat modification by feral pigs is a primary factor in replacement of native by alien plants. Pahole or hōʻiʻo *(Diplazium sandwichianum)*, a native fern, is particularly vulnerable. This succulent fern probably once dominated large areas of the ground cover at lower elevations in the Valley. The tender shoots and starchy, easily accessible rhizomes are a preferred food of feral pigs. As areas once dominated by this fern are rooted up, a seedbed is prepared for alien plant species such as Hilo grass and strawberry guava.

Major Alien Plant Threats

Three weeds comprise the greatest and most immediate threats to displacement of the native flora in Kīpahulu.

Hedychium gardnerianum **(kāhili ginger)** is a prolific fruit producer that is dispersed by birds as well as spread vegetatively by rapidly growing rhizomes. These plants, which grow over a meter tall in the deepest shade, displace all other plants in the forest understory, making natural forest regeneration an impossibility. The infestation of kāhili ginger in the Valley is at the incipient stage. Isolated individuals have been recorded up to 3,600 ft (1,100 m) on top of the Central Pali and at 2,900 ft (880 m) along Palikea Stream. A population in full fruit was seen at 3,600 ft (1,100 m) in Koʻūkoʻūai Gulch, but the steep terrain prohibited a reliable estimate of size.

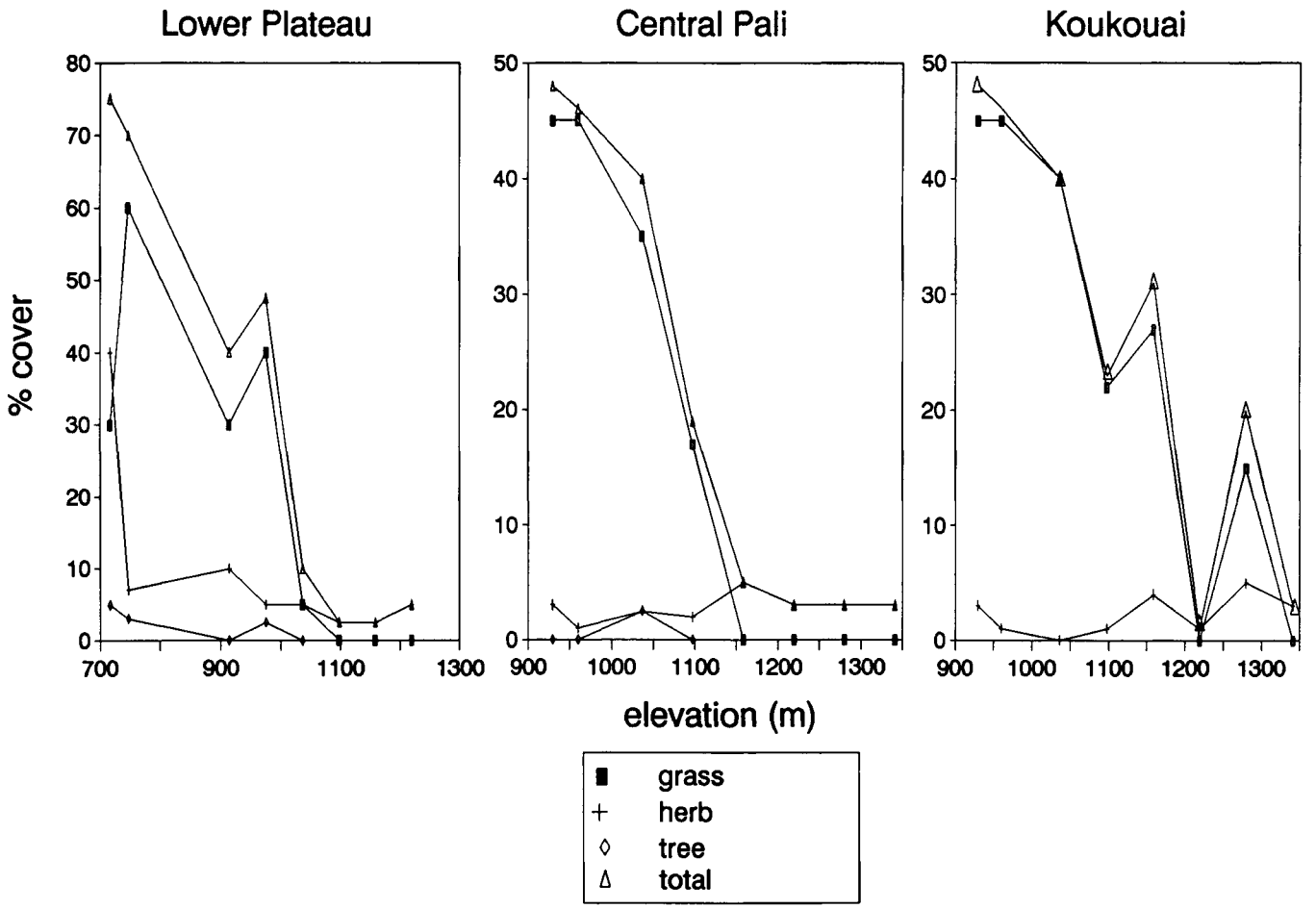

Figure 5. Invasion profiles for alien grass, herb, and tree species along three elevational transects in Kīpahulu Valley.

Paspalum conjugatum **(Hilo grass)** spreads vegetatively by stolons or by seeds that are eaten by birds or stick to humans or other animals. This perennial grass rapidly invades wet habitats from sea level to 6,500 ft (2,000 m) and is suspected of being allelopathic (Smith 1985). It typically invades disturbed areas, forming a dense carpet even under closed-canopy forests. Disturbance is not a prerequisite for establishment, as small patches of Hilo grass can be found in intact areas. The distribution of this species is continuous from 4,400 ft (1,340 m) elevation on the Upper Plateau and 4,000 ft (1,220 m) on the Lower Plateau, downslope to where it dominates the ground cover (>50% cover) at 3,800 ft (1,160 m) on the Upper Plateau and 3,740 ft (1,140 m) on the Lower Plateau. The upper range of Hilo grass is now 4,700 ft (1,430 m) on the Upper Plateau and 4,100 ft (1,250 m) on the Lower Plateau. The thick carpets formed by Hilo grass present a barrier to establishment of seedlings of native woody plants. An exclosure constructed at Upper Dogleg by Yoshinaga in 1979 has been pig free for over 10 years but shows little hope for ground cover and shrub layer regeneration where Hilo grass carpet is established. In contrast to outside the exclosure, alien grass and sedge components other than Hilo grass are absent inside; a pure carpet of Hilo grass now exists there.

Counts of individual native trees were made by size classes for plots on the 3,050 ft (930 m) and 3,150 ft (960 m) elevation transects where ground cover of Hilo grass and other alien species was greater than 25%. Typically, terrestrial shrubs and trees such as pū'aha-nui *(Broussaisia arguta)*, pilo (*Coprosma* spp.), and olomea *(Perrottetia sandwicensis)* were conspicuously absent. Intact native vegetation with abundant reproduction of these species remains on steep hillsides that have not been disturbed by feral pigs. With the exception of koa, only tree species that become established epiphytically demonstrated some reproduction in areas dominated by Hilo grass.

Psidium cattleianum **(strawberry guava)** is a small tree capable of forming dense, monotypic stands even under closed canopy forests. One of the few weed species that can become established in thick uluhe, it requires no disturbance for invasion of an area and can be spread over considerable distances by feral pigs and alien frugivorous birds. The uppermost elevation at which this species was sighted was 4,000 ft (1,220 m) (one individual plant) on the Central Pali. Scattered individuals are present downslope, and this species forms locally thick stands below 3,200 ft (975 m) elevation. Counts of individual strawberry guava trees in plots on the Dogleg transect at the 3,150-ft (960-m) transect elevation were used to extrapolate an estimated density of 2,000 individuals per hectare for this area.

Other Alien Plant Threats

Several other weedy species present in the study area pose additional threats to native communities through direct competition with native plants and their ability to regenerate in disturbed areas.

Andropogon virginicus (**broomsedge**), a perennial bunchgrass capable of forming a dense, monotypic ground cover excluding natives, spreads readily by wind-borne seeds. Distribution in the study area consisted of one plant in a *Carex* bog at 4,400 ft (1,340 m) on the Lower Plateau, several individuals at 4,100 ft (1,250 m) elevation on the transect in closed-canopy koa-ʻōhiʻa forest on the Upper Plateau, and a few plants at 3,280 ft (1,000 m) on Palikea Stream and 3,500 ft (1,070 m) in Koʻūkoʻūai gulches and also in closed-canopy ʻōhiʻa-koa forest. All of these plants were uprooted. Continuing work in the Valley has led to the discovery of a major population of broomsedge extending along the sheer eastern wall of the Valley from 3,600 ft (1,100 m) to east of Kaumakani Peak.

Anthoxanthum odoratum (**sweet vernalgrass**) invades disturbed sites at higher elevations. It occurs on the 6,800-ft (2,070-m) transect in shrubland areas that have been disturbed by foraging of feral goats and pigs.

Axonopus fissifolius (**narrow-leaved carpetgrass**), a stoloniferous, mat-forming grass, was found in koa-ʻōhiʻa forest between 3,800 ft (1,160 m) (in an undisturbed riparian site along Koʻūkoʻūai Gulch) and the lower limits of the study area, where it occurs in patches up to 25 m^2 in size.

Clidemia hirta (**Koster's curse**) was discovered in 1988 in Kīpahulu at 2,800 ft (850 m) elevation along the trail at the base of the Central Pali. One plant 1.5 ft (0.5 m) tall was found; apparently it had never fruited. The plant was removed, and a thorough search of the area revealed no other individuals. This noxious weed was probably dispersed into the Valley by a careless hiker or researcher. Clidemia is recognized as one of the most serious weed pests in Hawaiʻi, because it spreads rapidly, competes with native understory plants, and invades undisturbed sites.

Cyathea cooperi (**Australian tree fern**) was discovered in the Dogleg area at the base of the Central Pali in 1987 (L.W. Cuddihy, pers. comm.). Once other botanists were informed, isolated individuals and several substantial populations were located. One population covering approximately 20 m^2 was found at 3,300 ft (1,006 m) elevation on the top of the Central Pali. Countless individuals forming a nearly monotypic stand were discovered between 2,400 and 2,600 ft (732-793 m) elevation along Palikea Gulch. Spores carried on winds up the Valley from gardens near sea level began the initial invasion. These alien tree ferns occur in all size classes from several inches to nearly 20 ft (6 m) in height, indicating success of ongoing reproduction in the Valley. We saw no evidence that the alien tree ferns were eaten by feral pigs, whereas native tree ferns (*Cibotium* spp.) are frequently devoured. This competitive advantage, in addition to a faster growth rate than native ferns, could lead to replacement of native tree ferns in the Valley.

Cyperus halpan, a sedge, one of the first colonizers of pig-rooted areas below 3,280 ft (1,000 m), forms thick cover in forest openings. With removal of pigs, other alien species such as Hilo grass are able to compete with and reduce this species.

Ageratina adenophora **(Maui pāmakani)**, a weedy composite from Mexico, is distributed throughout the study area by wind-borne seeds. Primarily a threat at mid elevations in forest openings or riparian stiuations, it forms dense mats with other weeds and hinders native plant regeneration. Biological control agents introduced to reduce this pest in Hawai'i are present in Kīpahulu but fail to significantly affect populations in wet areas (Bess and Haramoto 1972).

Holcus lanatus **(velvet grass)** occurs throughout the study area. In the *Deschampsia* grasslands it invades pig-rooted areas and competes with native grass regeneration (Jacobi 1976). When it grows in forested areas it is shaded out and never gains a competitive advantage.

Hypochoeris radicata **(gosmore)**, a weedy composite of Mediterranean origin, is distributed throughout the study area by wind-borne seeds. Abundantly and widely distributed in the *Deschampsia* grassland areas at upper elevations, it invades pig-dug and eroded areas. Pigs seek out these plants and uproot them for the starchy tap roots. Gosmore cover intensifies and increases in distribution as pigs dig up the roots and create more niches for this plant and other weedy species.

Melinis minutiflora **(molasses grass)** spreads by stolons as well as seeds. Although primarily adapted to drier conditions, it has been found in koa-'ōhi'a forest at 4,200 ft (1,280 m) on the Upper Plateau and forms patches at elevations as high as 3,800 ft (1,160 m) along the Ko'ūko'ūai and 2,950 ft (900 m) along the Palikea gulches.

Ehrharta stipoides **(meadow ricegrass)** is a perennial with the capacity to form a dense monotypic ground cover even under shaded conditions. In ungulate-disturbed areas of Hawaiian rain forests it is spread by barbed fruits that penetrate clothing and animal fur and skin. Several plants discovered at 4,200 ft (1,280 m) elevation along the trail on top of the Central Pali at the onset of this study were removed. Several additional plants found in April 1986 at the 4,700 ft (1,430 m) campsite were also uprooted.

Paspalum dilatatum **and** *P. urvillei* **(dallis grass and vasey grass)**, commonly over 3.3 ft (1 m) in height, are perennial grasses that invade disturbed areas with open tree canopies. Copious seed production and the potential height of these species form a barrier to forest gap regeneration. Distribution is limited to the Lower Plateau, with highest elevational sightings at 2,950 ft (900 m).

Pennisetum clandestinum **(kikuyu grass)** is a fast-growing, mat-forming plant that spreads primarily by rhizomes. It is known to release allelopathic substances (Smith 1985) and displace native plants. It was found at the 4,800 ft (1,460 m) feral pig trap site on the upper plateau and removed. It was probably introduced in cattle offal that was used in the trap for bait.

Psidium guajava **(common guava)**, although not as invasive as strawberry guava, forms dense stands in riparian habitat and cleared areas,

where it is spread by feral pigs and alien birds. This small tree is growing between sea level and 2,360 ft (720 m) elevation in Kīpahulu. Elsewhere in the Islands it can be found up to 4,920 ft (1,500 m) elevation. On Kapāpala Ranch on the island of Hawai'i it also occurs up to 4,920 ft (1,500 m) elevation.

Rubus argutus **(Florida blackberry)** is a bramble-forming vine or shrub with juicy fruit spread by birds. It is of primary concern in the *Deschampsia* grassland areas, where it has been kept in check by the browsing of feral goats. Goats have now been eradicated from these grassland areas, leaving the blackberry unchecked. Blackberry is capable of changing the unique *Deschampsia* grassland areas into alien shrublands.

Sacciolepis indica **(Glenwood grass)** invades disturbed sites at mid elevations (3,450-4,600 ft or 1,050-1,400 m) in the Valley. This perennial grass appears to be a successional precursor to other species, as it is typically found on recently disturbed sites.

Spathodea campanulata **(African tulip tree)** spreads through wind-borne seeds and floating fruits; it is shade tolerant and capable of attaining heights of 100 ft (30 m) in riparian situations. It is distributed primarily along Ko'ūko'ūai Gulch but has been found up to 2,800 ft (850 m) elevation on the Lower Plateau.

Distribution of relatively innocuous alien species that are present on transects in the study area can be found in the Appendix.

Weeds On and Off Trails

Forays off the Central Pali and Ko'ūko'ūai trail systems were used to assess the impact of researchers on the spread of weeds along trail systems. No apparent differences in weedy vegetation were noted on versus off the trails at the four elevations sampled (Table 2).

Table 2. Number of alien species found on versus off two elevational trail systems in Kīpahulu Valley, Haleakala National Park.

	Number of Alien Species			
Elevation	Central Pali		Ko'ūko'ūai Stream	
(feet)	On Trail	Off Trail	On Trail	Off Trail
4,300	4	2	2	2
3,700	2	4	2	4
3,500	3	3	6	3
3,150	4	4	4	4

DISCUSSION

Two alien plant invasion fronts threaten Kīpahulu Valley: the Kalapawili grasslands-Valley headwall area, and that section of the Valley below the 3,940-ft (1,200-m) elevational contour. The primary catalyst of vegetation change along both these fronts is the feral pig; feral goats were also important in the Valley headwall area. The central to upper portions of the Valley with relatively low feral pig densities remain nearly pristine, with less than one percent cover of alien vegetation. Weedy species now present in this area are innocuous for the most part, as they do not appear capable of dominating vegetation cover in the absence of feral animal disturbance.

Seed sources for the plant invasion on the Valley headwall are Haleakalā Crater and the Kalapawili grassland area. The primary weed species in this area, velvet grass, gosmore, sweet vernalgrass, and sheep sorrel, become established in ungulate-disturbed sites. In *Deschampsia* grasslands, velvet grass colonizes preferentially in pig-rooted areas and increases in cover and abundance as feral pig disturbance continues (Jacobi 1976, 1981; Stone *et al.*, this volume). Grassland and headwall areas of the Valley were fenced in 1986 to facilitate feral animal control. With the elimination of feral pigs and goats in these units, further replacement of native vegetation by weedy species will be minimized. However, removal of feral animals will not solve the alien plant invasion problem in the Valley. Goats and pigs have been removed from the fenced portions of the Kalapawili grasslands and Valley headwalls, and nearly eliminated above the 4,600-ft (1,400-m) elevation fence line. Frequencies of weeds have fluctuated, remained constant, or increased in these areas, but weeds have not decreased even after the near-elimination of pigs and goats.

The primary alien plant invasion front extends from the pasturelands and gardens below the study area upslope to the 3,940-ft (1,200-m) contour across the Valley. The replacement of the native vegetation in this area has been extensive and is proceeding at a rapid rate. Lamoureux and Stemmermann (1976) described Hilo grass as common in 1967 in disturbed wet areas to above 4,000 ft (1,220 m) but stated that only one area (1967 Expedition Base Camp I) had more than a few square meters dominated by Hilo grass above 2,500 ft (760 m) elevation. Personnel on the 1976 Expedition noted dozens of such openings, a marked increase in pig activity, and increased distribution of strawberry guava since 1967 (Lamoureux and Stemmermann 1976). They described the invasion as "probably an emergency." In 1980, Yoshinaga reported Hilo grass to be abundant, especially below 3,280 ft (1,000 m) where it formed solid stands in openings and under thin canopy (Yoshinaga 1980). By 1986, Hilo grass growing in solid stands had replaced the native ground cover in areas up to 3,800 ft (1,160 m) elevation.

Strawberry guava has extended its elevational range upslope 1,738 ft (530 m) from that reported by Lamoureux (1967) in less than 20 years. The potential distribution for this species is unknown, as it invades undisturbed sites under closed canopy tree layers and has been reported to be frost resistant (Popenoe 1935). Feral pigs seek out the fruit and

migrate seasonally into areas of heavy fruit production, spreading the seeds over considerable distances (Diong 1983). The potentials of both strawberry guava and feral pigs to alter native communities are independently extreme and synergistically disastrous.

Kāhili ginger is among the most serious of weed threats to the Kīpahulu rain forest. Although it is now only in incipient stages, it has the potential of dominating the forest understory from the lower bounds of the study area to well above 5,000 ft (1,524 m) even in the absence of pig disturbance. In Hawaii Volcanoes National Park, large areas of native rain forest have been invaded, and hope for successful chemical or mechanical control may be limited to areas of light infestation.

MANAGEMENT RECOMMENDATIONS

An alien plant control program must be established for Kīpahulu Valley. Transects, 20- x 20-m plots, and exclosures established during this and previous studies provide precontrol baseline information on plant species distribution and density. Priority species for control are kāhili ginger, strawberry guava, Hilo grass, broomsedge, molasses grass, meadow ricegrass, African tulip tree, Australian tree fern, and Florida blackberry.

Control efforts for target species should start at the upper elevational extent of distribution (4,000 ft or 1,220 m level on both the Upper and Lower Plateaus) and proceed downslope toward the Dogleg fence until alien plant densities are too great to justify control. This will create a buffer zone between the near-pristine upslope areas and the weedy lower elevations. Recommendations were made by Yoshinaga (1980) and Smith (1985) for the establishment of a feral pig and strawberry guava buffer zone to separate the weedy lower elevations below 2,000 ft (610 m) from the more pristine area above. The Valley has been fenced into management units with this objective. A cross-Valley fence is in place at the Dogleg, another has been built at 4,700 ft (1,430 m) elevation, and feral pig control research is complete. Alien plant control needs to be initiated to create a buffer zone against strawberry guava, kāhili ginger, and Hilo grass ingress to the near-pristine upper elevations. Biological control research is not likely for any of the weedy grass species, ginger species, or either guava species, due to the conflict posed by the sugar cane industry and other agricultural interests.

All target species should be searched out and pulled or treated with herbicide. Kāhili ginger, meadow ricegrass, African tulip tree, dallis grass, vasey grass, and molasses grass can be controlled throughout the study area. Kāhili ginger eradication should be given priority, because complete control of this incipient population is still feasible and the potential population explosion and negative effects are horrendous. Hilo grass control will only be possible in the upper half of the buffer zone where it occurs in patches. Methodological tests of strawberry guava control in Kīpahulu Valley have been performed (Gardner 1980), and recent herbicide control methods have been developed (Santos *et al.*, this volume). Sweeps by weed control personnel along parallel belt transects

have been used in Hawaii Volcanoes National Park with success and involve an effort of 3.0 person-days per acre (7.5 person-days per hectare) in easily accessible areas with level ground in areas where strawberry guava densities reach 200 plants per acre (500/ha) (J.T. Tunison, unpub. data). Common guava occurs in much lower numbers and can be treated along with strawberry guava when located on control sweeps above the Dogleg.

Florida blackberry should be eradicated from the Kalapawili grasslands, as removal of feral goats and pigs will surely release it from foraging pressure and probably result in a blackberry population explosion. Effective herbicidal methods of control are available for this species (Santos *et al.*, this volume).

Australian tree fern control needs to be researched. The top of one plant was cut off and the remaining stump died. The apical portions will reroot if left in the Valley, however. Removal of the tops of all the Australian tree ferns from the Valley by helicopters would be logistically difficult and may spread spores into new areas.

The remaining invasive species -- sweet vernalgrass, narrow-leaved carpetgrass, *Cyperus halpan*, Maui pāmakani, velvet grass, gosmore, and Glenwood grass -- are not as serious a threat, although frequently they are more widespread than the target species; they are not recommended for control at this time.

It is essential that records of numbers of individuals, locations, and age classes of each alien plant species controlled be recorded. Control programs should be analyzed as they progress and modified as needed. Where densities of target weed species become too great, acceptable limits of control short of eradication will need to be defined. Managers must recognize at the onset of any weed control program that continual, ongoing maintenance programs will be needed to sustain control. Dispersal of weedy propagules into the control area by water, wind, birds, and possibly people will be unceasing, and exhaustion of soil seed banks will take repeated control efforts and continual monitoring. Control of strawberry guava at the Dogleg area, where densities approach 810 plants per acre (2,000/ha), could require 12 person-days per acre (30/ha), at least until densities are considerably reduced.

All workers in the Valley should be aware of target species and remove them on discovery, or at least record distributional information. Monitoring of existing transects, plots, campsites, and trail systems, to detect new weed species and expansion of known weed distributions, should continue. Priority should be given to control of satellite populations of any of the invasive weedy species discussed (Mack, this volume) to limit spread of aliens.

The impact of people in the Valley has been a controversial issue since the 1967 Expedition sponsored by The Nature Conservancy of Hawaii. The Expedition organized in 1976 to assess the frequently implied negative impacts of the 1967 Expedition indicated that the natural resources in the Valley were deteriorating as a result of lack of active management

(Lamoureux and Stemmermann 1976; Smith 1978). Observations on abundance of weedy species made for all campsites, helipads, trail systems, and transects used for research activities showed that spread of alien plants was not restricted to trail systems. The uppermost populations of Hilo grass and all known populations of meadow ricegrass have been treated with herbicide or pulled to prevent spread to higher elevations. The survey of trail systems in the critical area between 4,700 ft (1,430 m) and 2,350 ft (720 m) included forays off the trail to allow comparison of weed invasion on frequently used paths with previously untraversed areas. Until recently, the only new weed species recorded have been in areas not previously visited during this study. The discovery and removal of an individual clidemia plant on a trail in the study area has reinforced the policy of thorough equipment and personal gear inspection and cleaning prior to use in the Valley. Areas where particularly noxious plants (*i.e.*, Koster's curse, meadow ricegrass, kikuyu grass) were removed should be monitored for recurrence and further treatment.

Any work carried out on a Valley-wide basis must proceed from upper elevations to lower, to avoid dispersal of weedy propagules upslope, particularly on helicopter skids. All field workers should check clothing and equipment for weed seeds prior to entry into the Valley. Transects and trails should not be established in areas dominated by uluhe or matted fern, as these areas recover slowly and are subject to invasion by alien plants.

The commitment to control pigs in the Valley has been made. Removal of feral pigs will result in changes in weed species composition and abundance, as evidenced by the monotypic ground cover of Hilo grass now present (after six years' exclusion of feral pigs) in the Dogleg exclosure established by Yoshinaga. In rain forest areas of Hawaii Volcanoes National Park, a dramatic increase in alien grasses was noted after reduction in feral pig densities (Stone *et al.*, this volume). Clearly, the decision to remove feral pigs from the Valley must be matched by a strong commitment toward continued vegetation monitoring, research, and development of a sound alien plant control program.

Kīpahulu Valley represents one of the best opportunities left in Hawai'i for terrestrial ecosystem preservation. But preservation will not be realized without a properly monitored, active, and continual management effort.

Appendix. Frequency of occurrence (%) of alien plants in the Kīpahulu Valley study area, Haleakala National Park.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
FERNS																	
Athyriopsis japonica+																	
04/85	*	*								**	**				x	**	**
11/85										**	**				x	**	**
03/86										**	**				x	**	**
09/86										32	36				x	96	86
01/87								8	6						10		8
04/87										38	26		--			83	84
08/87	--	--						2		36	32		6			89	92
01/88								--		68	30	--	--	--		100	59
05/88	--	--								38	20				10	83	81
10/88										36	18		2			87	81
Blechnum occidentale+																	
09/86															x	21	
04/87										6			--			11	3
08/87	--	--								2						9	3
01/88								--				--	--	--		13	
10/88										4						17	3
Christella dentata+																	
04/87													--				5
10/88																2	

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Christella parasitica+																	
04/87																4	
08/87	--	--														2	3
10/88										2	2						
# *Cyathea cooperi*+																	
08/87	--	--														6	
05/88	--	--														4	
10/88																6	
GRASSES AND SEDGES																	
# *Andropogon virginicus*+																	
04/85	*	*								**	**	2			x	**	**
11/85										**	**				x	**	**
03/86										**	**				x	**	**
08/87	--	--						2							2		
Anthoxanthum odoratum																	
04/85	*	*								**	**				x	**	**
11/85			5							**	**				x	**	**

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Axonopus fissifolius +																	
09/86										28	36				x		
04/87										22	12		--				
08/87	--	--								24	10						
01/88								--		30	22	--	--	--			
05/88	--	--								20	12						
10/88										16	8						
Cyperus halpan																	
09/86										54	46				x	6	
01/87										50	52					13	8
04/87										54	76		--			11	5
08/87	--	--								66	78					11	14
01/88								--		78	92	--	--	--		6	8
05/88	--	--								64	84					11	11
10/88										58	74					11	16
Holcus lanatus																	
04/85	*	*	100	8	6	10	2	2		**	**	4	2	4	x	**	**
11/85	100	100	98	8	6	10	2	2		**	**	6			x	**	**
03/86	100	100	80	8	4	12	2			**	**	10	2		x	**	**
06/86	100	100	92	6	6	16	2		2	**	**	--	2	--	x	**	**
09/86	100	100	95		14	10	2	2				2			x		
01/87	100	100	93	6	10	18	4	4				4	2				

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Holcus lanatus																	
04/87	100	100	88	16	8	20	2	2	2			10	--		2		
08/87	--	--	93	10	8	10	4	2	2			8			2		
01/88	100	100	98	14	6	14	2	--	2			--	--	--	2		
05/88	--	--	93	14	6	28		2	2			6	2		2		
10/88	100	100	95	10	6	20	2		2			4	2		2		
Kyllinga brevifolia																	
09/86															x	6	
04/87													--			4	
08/87	--	--								2	2					2	
01/88								--				--	--	--		6	
05/88	--	--														6	3
10/88										2	2					6	
# *Melinis minutiflora*																	
09/86															x	4	
01/87																2	5
04/87													--			4	
08/87	--	--								2						2	
01/88								--				--	--	--		2	
05/88	--	--														2	
10/88																2	

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET															
	Kalapawili Grasslands		Upper Plateau								Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Oplismenus hirtellus																	
09/86															x		17
04/87													--				8
08/87	--	--															11
01/88							--					--	--	--			11
05/88	--	--															14
10/88																	16
# ***Paspalum conjugatum***																	
04/85	*	*							2	**	**				x	**	**
11/85										**	**				x	**	**
03/86										**	**				x	**	**
06/86									2	**	**	--		--	x	**	**
09/86									4	98	100				x	89	100
01/87									4	96	98				10	98	89
04/87									2	96	100		--		8	100	100
08/87	--	--							6	96	100				8	100	100
01/88								--		98	98	--	--	--	6	98	68
05/88	--	--							2	98	100				10	100	100
10/88								2	2	98	100				6	98	100
Rhynchospora caduca																	
04/87										62	66		--			2	
08/87										54	74					2	

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Rhynchospora caduca																	
01/88								--		42	62	--	--	--			
10/88										50	58					2	
Sacciolepis indica																	
04/85	*	*							2	**	**				x	**	**
11/85								2	2	**	**				x	**	**
03/86									4	**	**				x	**	**
09/86									8	36	8				x	11	
01/87									4	24					2	19	5
04/87									2	54	34		--			23	5
08/87	--	--							8	72	48				2	23	5
01/88								--	14	56		--	--	--	4		
05/88	--	--							4	72	68				2	40	14
10/88									6	62	44				8	9	11
HERBS																	
Ageratina adenophora																	
04/85	*	*					8	12		**	**	34	4	8	x	**	**
11/85							8	20	4	**	**	44		8	x	**	**
03/86							14	24	2	**	**	58	2	6	x	**	**
06/86						2	20	16	2	**	**	--	2	--	x	**	**
09/86							18	38	6	20		40	6	6	x	11	42

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Ageratina adenophora																	
01/87							26	38	4	6	6	50	4	6	30	19	43
04/87							28	22	2	6	4	48	--	2	34	19	32
08/87	--	--					10	26	4	6	4	42	4		22	19	38
01/88							12	--			2	--	--	--	16	17	32
05/88	--	--					16	30		8	6	46	4	6	20	21	38
10/88						2	12	22	2	8	4	42	6	8	26	19	41
Ageratina riparia																	
09/86								2							x		
01/87									2	4							
01/88								--		4		--	--	--			
Ageratum conyzoides																	
09/86										8					x		42
01/87										10							3
04/87										4			--			2	
08/87	--	--								6						2	5
01/88								--		16		--	--	--			22
05/88	--	--								8							3
10/88										8	2						3
Commelina diffusa																	
04/87													--				3

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Cuphea carthagenensis																	
09/86										34	34				x	6	36
01/87										30	8						14
04/87										24	12		--			13	3
08/87	--	--								50	26					28	11
01/88								--		32	22	--	--	--		15	19
05/88	--	--								36	30				4	13	11
10/88										30	26					13	19
Drymaria cordata																	
09/86										14	2				x	45	67
01/87										10	2					36	68
04/87										12	2		--			32	70
08/87	--	--								10	2					32	59
01/88								--				--	--	--		36	51
05/88	--	--								10	2					34	51
10/88										10						26	70
Epilobium billardierianum subsp. *cinerium* [+]																	
04/85	*	*	60							**	**				x	**	**
11/85			50	4		2				**	**				x	**	**
03/86		2	50			6				**	**				x	**	**
06/86		2	42			2				**	**	--		--	x	**	**
09/86			63	2		4									x		

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Epilobium billardierianum subsp. *cinerium* +																	
01/87		2	63			2											
04/87		8	60	4		6							--				
08/87	--	--	55	2													
01/88		6	70	4				--				--	--	--		4	
05/88	--	--	55	2													
10/88	8		63	2		8											
Erechtites valerianifolia																	
04/85	*	*						2	8	**	**				x	**	**
11/85								2	8	**	**	6		4	x	**	**
03/86								6	4	**	**	4			x	**	**
06/86								8	2	**	**	--		--	x	**	**
09/86								16	24	30	56	3	2	4	x	26	50
01/87						2		12	20	56	52	2			12	17	8
04/87								10	10	56	54	2	--		4	19	24
08/87	--	--						12	10	58	66	4			14	30	30
01/88							2	--	2	46	34	--	--	--	20	13	
05/88	--	--					2	18	8	36	68	4	2		20	15	24
10/88								14	2	66	72	2	2		20	19	16
Hydrocotyle verticillata																	
09/86															x	9	17
04/87													--			15	8

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Hydrocotyle verticillata																	
08/87	--	--														15	8
01/88								--				--	--	--	2	17	5
05/88	--	--					2								4	11	8
10/88															4	11	11
Hypochoeris radicata																	
04/85	*	*	98	43	6	8				**	**				x	**	**
11/85	100	100	95	62	2	2			2	**	**				x	**	**
03/86	100	100	85	56	6	20		4		**	**				x	**	**
06/86	100	100	98	40	4	14				**	**	--		--	x	**	**
09/86	100	100	95	40	4	16	2	4							x		
01/87	100	100	100	72		14	2	2									
04/87	100	100	90	72	4	22	4	2	2				--				
08/87	--	--	98	72	8	14	4	4									
01/88	100	100	98	90	2	10		--	2			--	--	--		4	
05/88	--	--	100	80	4	16			2								
10/88	100	100	100	76	6	16	6										
Lapsana communis +																	
04/85	*	*								**	**				x	**	**
11/85			5			6				**	**				x	**	**
03/86			3							**	**				x	**	**
06/86										**	**	--		--	x	**	**

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET															
	Kalapawili Grasslands		Upper Plateau									Lower Plateau				
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Lapsana communis +																	
09/86			3		2	16									x		
01/87						12				2							
08/87	--	--				10											
05/88	--	--	3			18	4										
10/88			5			20			2								3
Ludwigia octovalvis																	
09/86										2					x	13	31
01/87																6	14
04/87										2	4		--			4	8
08/87	--	--														4	16
01/88								--				--	--	--		6	14
05/88	--	--														2	22
10/88										2						2	16
Lythrum maritimum																	
04/85	*	*								**	**				x	**	**
11/85			8							**	**				x	**	**
03/86										**	**				x	**	**
06/86			8							**	**	--		--	x	**	**
09/86			15												x		
01/87			10														
04/87			20										--				

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	Kalapawili Grasslands 7800 A	Kalapawili Grasslands 7700 AA	Upper Plateau 6800 WAI	Upper Plateau 6800 6	Upper Plateau 5960 5	Upper Plateau 5240 4	Upper Plateau 4900 P2	Upper Plateau 4200 2	Upper Plateau 4100 1	Upper Plateau 3150 DL4	Upper Plateau 3050 DL3	Lower Plateau 4400 P1A	Lower Plateau 4300 P1B	Lower Plateau 4100 3	Lower Plateau 3300 DLT	Lower Plateau 2450 DL1	Lower Plateau 2350 DL2
LOCATION OF TRANSECT AND ELEVATION IN FEET																	
Lythrum maritimum																	
08/87	--	--	8					2									
01/88			15					--				--	--	--			
05/88	--	--	23														
10/88			25					2									
Musa sp.																	
05/88																	3
Polygonum punctatum																	
09/86															x		31
01/87																9	8
04/87													--			6	11
08/87	--	--														6	16
01/88								--				--	--	--			14
05/88	--	--														13	22
10/88																2	11
Prunella vulgaris																	
04/85	*	*				8				**	**				x	**	**
11/85	2	4				18				**	**				x	**	**
03/86			3			14				**	**				x	**	**
06/86			3			18				**	**	--		--	x	**	**
09/86	2	6	3			20									x		

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Prunella vulgaris																	
01/87						16											
04/87						22							--				
08/87	--	--	3			18								2			
01/88			3			24		--				--	--	--	4		
05/88	--	--	3			26									2		
10/88	12		3			24											
Rubus rosifolius																	
04/85	*	*						14	36	**	**	4	10	28	x	**	**
11/85								24	48	**	**	10	16	34	x	**	**
03/86								18	60	**	**	20	32	34	x	**	**
06/86								18	50	**	**	--	46	--	x	**	**
09/86								40	80	64	68	16	46	44	x	87	100
01/87								42	76	70	46	8	44	52	72	83	84
04/87							2	32	58	66	54	14	--	44	64	81	95
08/87	--	--					2	46	50	62	50	16	42	46	54	81	95
01/88								--	46	74	44	--	--	--	64	85	100
05/88							2	36	64	68	46	16	38	56	68	81	95
10/88							2	36	66	68	54	12	34	62	56	83	92
Rumex acetosella																	
04/85	*	*	25	8						**	**				x	**	**
11/85	90	90	23	14		2				**	**				x	**	**

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Rumex acetosella																	
03/86	100	100	13	10		2				**	**				x	**	**
06/86	88	92	22	8		2				**	**	--		--	x	**	**
09/86	88	84	20	8											x		
01/87	82	88	18	10													
04/87	86	100	18	12		2							--				
08/87	--	--	15	8													
01/88	100	86	8	10				--				--	--	--			
05/88	--	--	15	4													
10/88	84	100	10	10													
Stachytarpheta urticifolia																	
09/86															x		6
04/87													--				3
08/87	--	--															5
01/88								--				--	--	--			5
05/88																	3
10/88																	3
Youngia japonica																	
04/85	*	*						2	2	**	**				x	**	**
11/85										**	**				x	**	**
03/86						20				**	**				x	**	**
06/86						12			2	**	**	--		--	x	**	**

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET																
	Kalapawili Grasslands		Upper Plateau									Lower Plateau					
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
Youngia japonica																	
09/86								2	8	2					x	4	
01/87								6	6	6	2				4	26	
04/87						20		2	4	8			--			45	19
08/87	--	--						4	2	4						19	14
01/88			3			12		--	14	2		--	--	--		21	14
05/88	--	--								8						32	14
10/88										4	4					17	
TREES																	
# *Psidium cattleianum*																	
09/86										26	6				x	26	58
01/87										16	20					28	22
04/87										16	34		--			23	27
08/87	--	--								6	28					28	35
01/88								--		16	52	--	--	--		47	46
05/88										8	18					55	51
10/88										10	2					38	27
# *Psidium guajava*																	
09/86															x	4	17
04/87													--			2	11

Appendix, continued.

Appendix, continued.

CATEGORY, SPECIES, AND DATE	LOCATION OF TRANSECT AND ELEVATION IN FEET															
	Kalapawili Grasslands		Upper Plateau									Lower Plateau				
	7800	7700	6800	6800	5960	5240	4900	4200	4100	3150	3050	4400	4300	4100	3300	2450	2350
	A	AA	WAI	6	5	4	P2	2	1	DL4	DL3	P1A	P1B	3	DLT	DL1	DL2
# *Psidium guajava*																	
08/87	--	--									2					2	5
01/88								--		12		--	--	--		4	11
05/88	--	--														6	8
10/88										2	26					4	5

\+ New record for study area.
* Kalapawili Grasslands transects were not established until 11/85.
** Transects at 960 m and below were not established until 06/86.
-- No data.
x Delta transect was not established until 1/87.
\# Major disruptive potential.

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