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Technical Report 81

PRELIMINARY SURVEY OF FERAL UNGULATE AND ALIEN AND RARE PLANT OCCURRENCE ON HAKALAU FOREST NATIONAL WILDLIFE REFUGE

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ABSTRACT

Hakalau Forest National Wildlife Refuge on Hawai'i Island was surveyed for alien plant, feral pig (Sus scrofa), and cattle (Bos taurus) distribution and abundance in April and June of 1987. Fourteen transects were established from high to low elevations (1,200 to 2,200 m or 3,900 to 7,200 ft), and 2,293, 5 x 20-m plots (transect intervals) were sampled. Six permanent 20 x 20 m vegetation plots were established, three in heavily grazed areas and three in less intensely grazed areas. Results were primarily analyzed according to six major vegetative types, which represented 30 detailed vegetation types. Ungulate and cattle sign were significantly related to vegetation types. Six of 68 alien plants encountered on transects were similarly analyzed and found to be associated with certain communities more than others. Alien plant species considered special threats included sweet vernal grass (Anthoxanthum odoratum), meadow ricegrass (Microlaena stipoides), kikuyugrass (Pennisetum clandestinum), blackberry (Rubus penetrans), banana poka (Passiflora mollissima), and gorse (Ulex europaeus). Some rare plants were also encountered in the survey, and readily recognized large game birds and raptors were also tabulated. Management recommendations are provided, together with protocols for future monitoring, lists of plants encountered (rare or previously reported), and data from the six permanent plots established for long-term monitoring.

INTRODUCTION

The Hakalau Forest National Wildlife Refuge (HFNWR) on the island of Hawai'i was established in 1987, and the U.S. Fish and Wildlife Service (USFWS) has acquired about 4,800 ha (12,000 a) of the target 13,355-ha (33,000-a) total. USFWS has been directed by Congress to begin management of endangered forest birds, including the akepa (Loxops coccineus), akiapola'au (Hemignathus munroi), Hawai'i creeper (Oreomystis mana), 'io (Buteo solitarius), and 'o'u (Psittirostra psittacea) on Refuge lands. The endangered hoary bat (Lasiurus cinereus semotus) is also present throughout the area, which contains some of the best stands of koa (Acacia koa) and 'ohi'a (Metrosideros polymorpha) remaining in the world. The Refuge is located on windward Mauna Kea, 20 km northwest of Hilo. Elevation of the area ranges from 1,200 to 2,200 m (3,900-7,260 ft) (Stine n.d.).

Cattle (Bos taurus), feral pigs (Sus scrofa), and a number of alien plants on HFNWR are among the factors currently or potentially affecting the forest ecosystems upon which the native forest birds depend. The detrimental effects of both species of ungulates on native plant communities are well established (Baldwin and Fagerlund 1943; Spatz and Mueller-Dombois 1975; Jacobi 1976; Cooray and Mueller-Dombois 1981; Scowcroft 1983; Cuddihy 1984; Juvik and Juvik 1984; Mountainspring et al., in press; Stone and Holt, in press), and indirect effects of ungulates on birds in Hawai'i have been reported (Mountainspring 1986, 1987; Scott et al. 1986). A number of introduced plants also affect regeneration of native plant species (Williams 1980; Scowcroft and Hobdy 1986; J.T. Tunison, pers. comm.; C.P. Stone, unpubl. data), including native woody plant dominants and some rare species known to be present on the Refuge.

The purposes of this preliminary study were as follows:

1. to establish, in conjunction with the University of Idaho, semi-permanent transects and stations for future use in evaluating pig, cattle, and plant management programs;

2. to determine indices of feral pig and cattle abundance and distribution on the Refuge by transect, vegetation type, and elevation;

3. to determine indices to alien plant abundance and distribution by transect, vegetation type, and elevation on the Refuge;

4. to determine preliminary information about rare plant occurrence, abundance, and distribution on the Refuge;

5. to establish semi-permanent vegetation plots to monitor the effects of management in the future;

6. to provide recommendations to USFWS managers, especially as related to feral pig and alien plant management and future monitoring needs.

METHODS

Transects and Stations

Fourteen transects were established from higher to lower elevations (mauka-makai) across the Refuge from north to south. The State of Hawai'i Piha Game Management Area was also sampled because it is located between Refuge parcels, shares considerable boundary with the Refuge, and has high numbers of feral pigs and banana poka (Passiflora mollissima), an important alien plant. Azimuths and starting locations for transects are given in Appendix A, and locations are also shown on a topographic map of the area (Fig. 1). The first 7 transects (1-7) were established 500 m apart, and the last 7 (8-14) were located 1,000 m apart. Transect 7 was located 1,000 m from 8. Stations were marked at 200-m intervals along each transect, and the length of each transect (Table 1) was usually determined by acquired refuge boundaries

Table 1. Transect data for plant and feral ungulate surveys on Hakalau Forest National Wildlife Refuge, Spring 1987.

Transect	Transect Length (m)	No. 20-m Intervals
1	1,580	80
2	1,600	81
3	1,860	94
4	1,800	91
5	3,180	160
6	3,000	151
7	3,140	158
8	3,020	152
9	3,060	154
10	2,940	148
11	2,940	148
12	5,500	276
13	5,960	299
14	6,000	301
Total	45,580	2,293

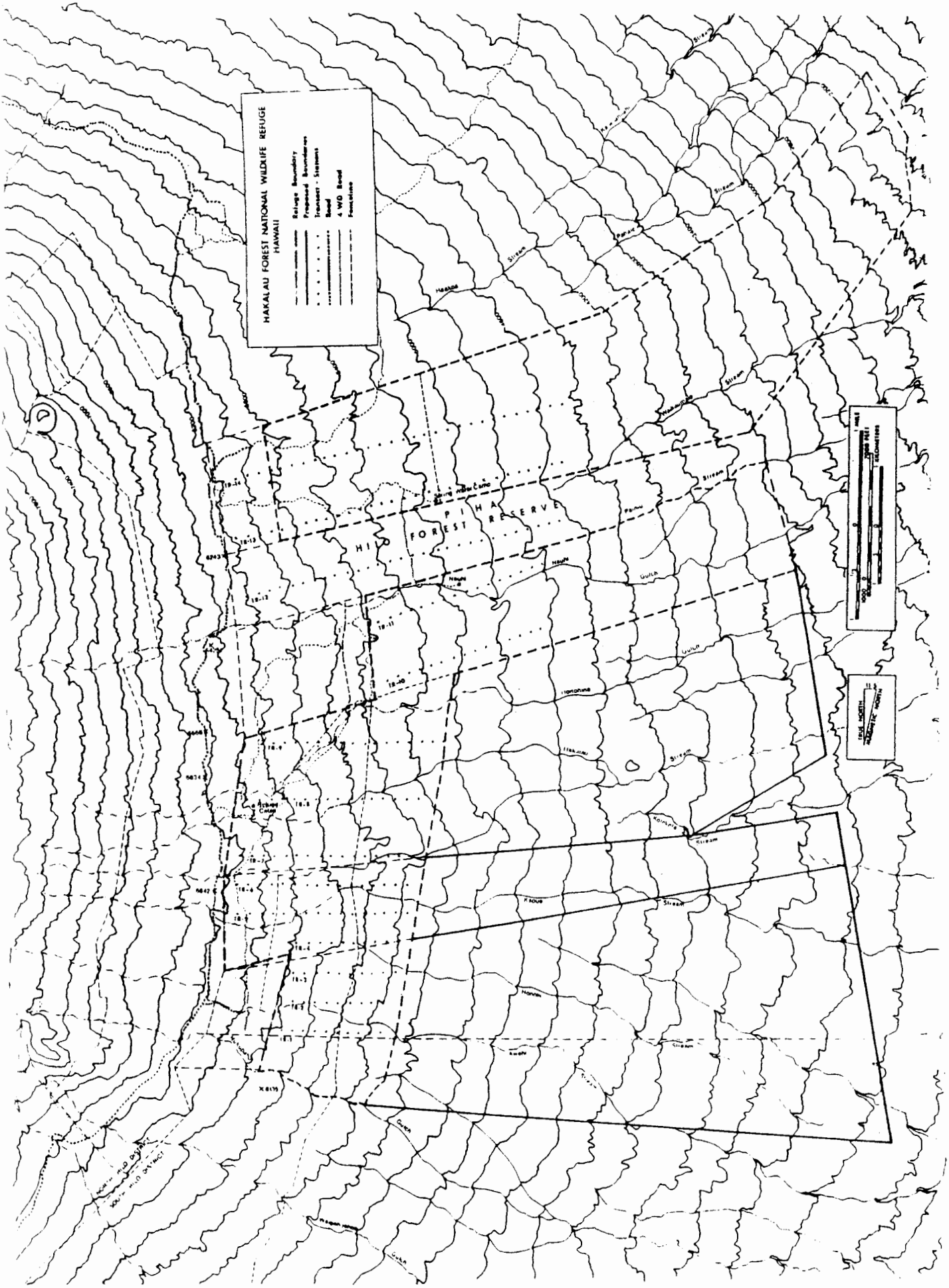

Figure 1. Locations of transects and Refuge boundaries, Hakalau Forest National Wildlife Refuge.

as of the time of the survey (April 6-10 and June 8-12, 1987). Lengths of the transects on Liliuokalani and The Nature Conservancy parcels were influenced by survey limitations and suspected native bird distributions, more than by Refuge boundaries. Blue plastic flagging was placed at 20-m intervals between stations, and stations in heavily grazed areas were marked with 3-ft high steel posts. Stations in heavily wooded areas were marked with aluminum tags and red and white striped flagging.

Vegetation Types

Vegetation maps prepared by J. Jacobi from the USFWS Hawai'i Forest Bird Survey (HFBS) in 1980 were used as a guide to vegetation types and acreages (Jacobi 1980a, 1980b, in press). Whenever vegetation type changed along each of the 14 transects, location was recorded in an effort to relate vegetation types accurately to pig and cattle sign and alien plant occurrence. Some vegetation types determined in this study differ from those determined previously, and the boundaries of some types determined 10 years ago have undoubtedly changed. However, we did not attempt to provide an updated vegetation map of the area.

Feral Pig and Cattle Indices

Presence of dung, tracks, digging, feeding on plants, trails, other sign, and sightings of ungulates were all recorded along transects as indicators of feral pig or cattle activity. Sign was rated as fresh, intermediate, or old, based on criteria listed in Appendix B. Each 20-m long x 5-m wide (2.5 m on either side of center) interval along transects was considered a sample plot, and animal sign was considered present when either fresh or intermediate evidence occurred within a plot. Occurrence of old sign was not used in data analysis. Data were summarized as percent frequency of occurrence (i.e., no. plots where fresh or intermediate sign present/total no. plots X 100). This information was recorded for each of the 2,293 plots sampled in the survey and was later sorted by computer according to elevation, transect number, and vegetation type.

Alien Plants

Presence of alien plants was recorded by species for each of the 2,293, 5- x 20-m plots (transect intervals) along transects. In addition, a visual estimate of cover was determined for each species in 3 categories (1-5%, 5-25%, and 25-50%). Percent frequencies of occurrence for species (no. plots with the species/total no. plots x 100) and species cover abundance were later sorted according to elevation, transect number, and vegetation type for 6 alien species of primary concern (of 68 alien plant species found).

Rare Plants

Rare plants encountered along or near transects were recorded, and special efforts were made to locate them in gulches and other areas of difficult access to cattle and

pigs. These areas were emphasized because they are generally less disturbed by ungulates, and rare plants often have a better chance to survive in undisturbed areas. A list of rare or vulnerable species, locations, and numbers of individuals was compiled from transect data. In addition, a list of rare plants which may be present on the Refuge was generated, and a preliminary checklist of all plant species thought to be on the Refuge was prepared.

Permanent Vegetation Plots

Six 20- x 20-m plots were established as indicated in Table 2, to initiate collection of detailed vegetation data in several locations. Three heavily grazed areas and 3 nearby areas much less intensely grazed by cattle were selected to sample upper and lower elevations and different parcels of lands on the Refuge. The lightly grazed areas included one with abundant pigs and potential problems with banana poka, another in which cattle had been at low density, and another with heavy native shrub and fern cover and seedlings. Permanent plots will allow monitoring of further degradation or forest recovery as management proceeds. These plots were numbered and marked by 4, 3-ft tall metal stakes with blue plastic flagging (one at each of the 2 off-transect corners, and one at each of the on-transect corners (Fig. 1). An additional stake was located on-transect, 30 m upslope from the upper (mauka) corner of the plot, to mark the line intercept transect discussed below. Native and alien species within each plot were listed, and counts of all woody plants and large ground ferns were made according to basal diameter classes. Data for individual plant species were analyzed and summarized according to the following 6 life form categories: native trees, alien trees, native shrubs, alien shrubs, native ferns, and alien ferns.

A short (50-m) line intercept transect was established along the existing transect for each of the 6 plots between a steel post at the makai end of the 20- x 20-m plot and a point 50 m upslope (Fig. 2). The length of transect intercepted by each species <2 m in height was recorded and later converted to percent cover for analysis. Data were analyzed for each species separately and combined into life form categories, including the 6 mentioned above plus 4 additional categories: alien grasses, native grasses, alien herbs, and native herbs.

A checklist of all vascular plants in each of the 6 plots was made, and a Braun-Blanquet cover-abundance value was recorded for each species. Braun-Blanquet cover estimates are made for each of 6 general strata categories (canopy, subcanopy, shrub 1, shrub 2, herb, and ground layer). In addition, cover values for bryophytes, litter, and exposed soil were recorded.

Examples of the 7 field forms used to collect data are included in Appendix C.

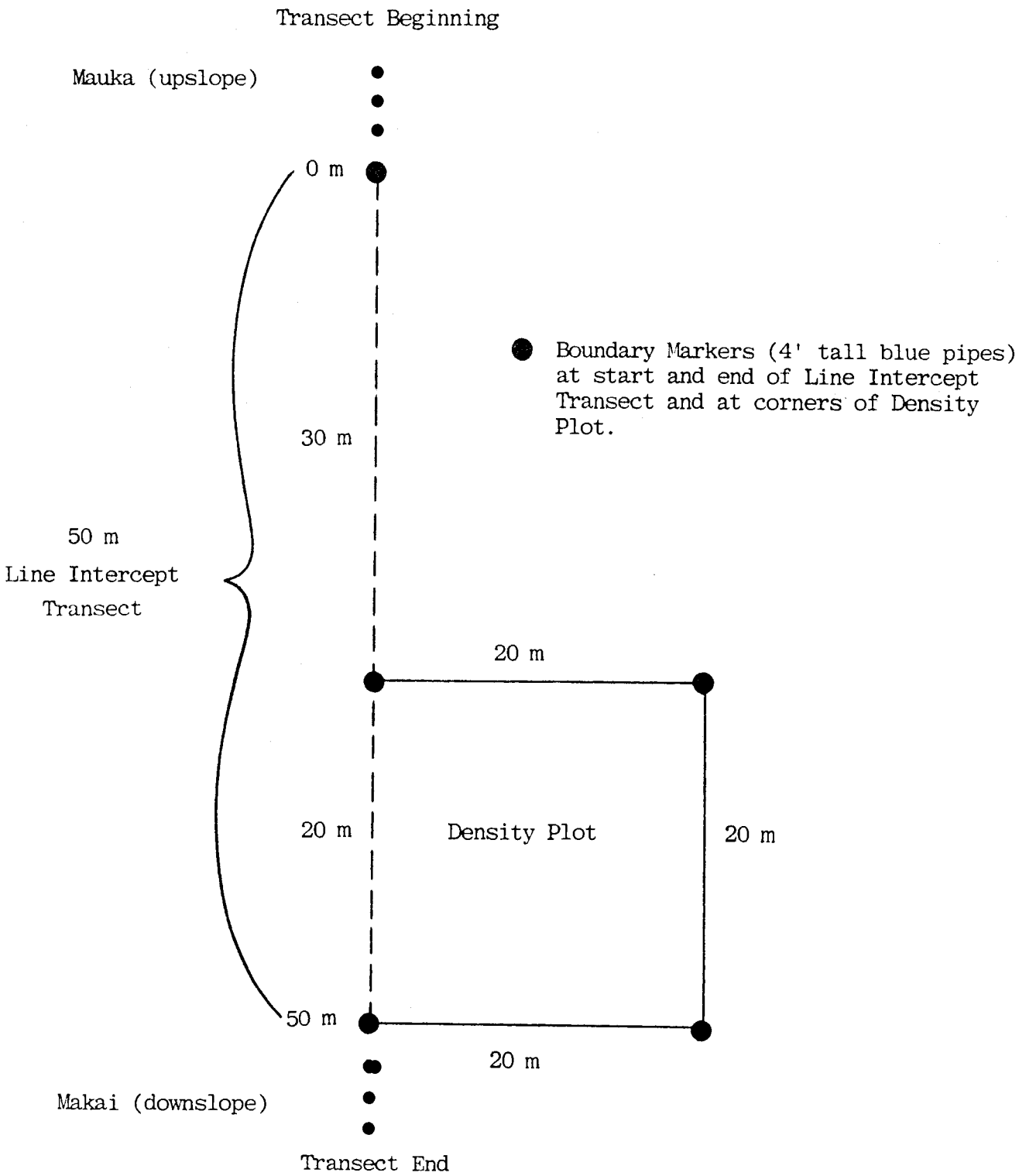

Figure 2. Arrangement of line intercept transect and density plot used in 6 locations, Hakalau Forest National Wildlife Refuge.

Table 2. Locations and purposes of permanent 20-x 20-m vegetation plots and line intercept transects, Hakalau Forest National Wildlife Refuge.

Plot	Area and Transect	Vegetation Type	Purpose	Distance from 50-m Line Intercept Start to Nearest Station	Azimuth of Transect and Additional Information to Locate Plot	Elevation (ft)
1	Robertson et al. Transect 13	O3Ac-Me,2NT(xg-nf)	Monitor recovery of native trees, shrubs, and ferns. Cattle recently reduced. Thick *Pennisetum clandestinum*. *Dryopteris* slowly recovering	50 m past stn. 227	70°; 1,850 m from 0 m of transect; transect parallels road	5,580
2	Robertson et al. Transect 13	C3Ac-Me,2NT(ns-tf-xg-nf)	Cattle partly excluded from the area; heavily infested with pigs. Potential problem with spread of *Passiflora mollissima* and *Microlaena stipoides*	65 m past stn. 238	70°; 4,085 m from 0 m of transect	5,120
3	Liliuokalani Transect 10	O3Ac-Me,2NT(xg-nf,ns)	Monitor recovery of native trees, shrubs, and ferns. Area is heavily grazed	130 m past stn. 127	60°; 1,110 m from 0 m of transect; end of 50-m line intercept transect is 20 m before stn. 128	5,320
4	Liliuokalani Transect 10	O3Ac-Me,2NT(xg-nf,ns)	Cattle have been partially excluded from the area	150 m past stn. 129	60°; 1,530 m from 0 m of transect	
5	Shipman Transect 5	C3Ac,Me,2NT(xg)	Monitor recovery of native trees, shrubs, and ferns. Area is heavily grazed	30 m before stn. 38	60°; 895 m from 0 m of transect	6,120
6	Shipman Transect 5	C3Me,Ac,2NT(ns-xg)	Area with native shrub and fern cover and tree seedlings	2 m before stn. 42	60°; 1,768 m from 0 m of transect	5,980

Gallinaceous Birds and Raptors

Although the bird inventory was the responsibility of University of Idaho personnel and will be reported separately by them, we noted observations of gallinaceous (chicken-like) and raptorial (predaceous) birds. These species were readily identified by all observers, and the observations are presented according to numbers seen and vegetation type in which birds were observed.

RESULTS

Vegetation Types

Six major vegetation types were identified along transects surveyed on HFNWR (Table 3). The most prominent of the types based on percentage of plot occurrence was closed canopy koa-'ohi'a (55.3% of plots), followed by open canopy koa-'ohi'a (24.3%). Very scattered koa-'ohi'a with alien grasses (7.0%), very scattered koa with alien grasses (6.5%), scattered koa-'ohi'a with mixed alien grasses (5.7%), and closed canopy alien trees (1.2%) were other major types.

Comparison of planimetered acreages of the 6 major types from USFWS maps (Jacobi 1980a, 1980b) showed that open canopy koa-'ohi'a was over-represented along transects (compared with representation in the total area). The most serious undersampling (in comparison to planimetered areas) was of the alien tree type, the least abundant type on the area.

Thirty detailed vegetation types were identified within the 6 major types above (Table 4). Most prominent of these, based on percentage of plot occurrence (24.42% of plots), was closed canopy koa-'ohi'a forest with native tree understory, native shrubs, and alien grasses [C3Ac-Me,2NT(ns-xg)]. (Dashes between 2 species indicate similar percent cover; commas signify lower percent cover for species after commas; parentheses indicate overstory if species outside, understory is species inside.) Open canopy koa-'ohi'a with native tree understory, native shrubs, and alien grasses and native ferns [O3Ac-Me,2NT(xg-nf,ns)] was next in abundance with 7.02% of stations; and closed canopy koa-'ohi'a with alien tree understory, banana poka and native shrubs [C3Ac-Me,XT(pm-ns)], found along transects only in the Piha unit, was next with 5.76% of stations. Fourth in abundance (5.23% of stations) was closed canopy koa-'ohi'a with native tree understory, native shrubs, alien grasses, and native ferns [C3Ac-Me,2NT(ns-xg-nf)]. The remaining 26 vegetation types each accounted for less than 5% of the stations.

Indices to Feral Pigs and Cattle in Different Vegetation Types

Fresh to intermediate-aged feral pig sign was observed on 26 percent of the 2,293 transect intervals (plots) surveyed. Fresh to intermediate cattle sign was observed on 31 percent of all plots surveyed. Omission of data from the transect which sampled the State Piha Game Management Area from the analysis resulted in reduction of the feral pig index to 17

Table 3. Numbers and percentages of 5- x 20-m plots in each of 6 major vegetation types, Hakalau Forest National Wildlife Refuge, Spring 1987.

Major Vegetation Type	Plots		Planimetered Area	
	No.	% of Total	Hectares	% of Total
Closed canopy koa-ʻohiʻa	1,269	55.3	2,393.3	54.5
Closed canopy alien trees	28	1.2	150.2	3.4
Open canopy koa-ʻohiʻa	557	24.3	744.6	17.0
Scattered koa-ʻohiʻa	130	5.7	332.6	7.6
Very scattered koa-ʻohiʻa/alien grasses	160	7.0	376.9	8.6
Very scattered koa/alien grasses	149	6.5	394.3	9.0
Totals	2,293	100.0	4,391.9	100.1

Table 4. Numbers and percentages of 5- x 20-m plots in each of 30 vegetation types, Hakalau Forest National Wildlife Refuge, Spring 1987 (vegetation types after Jacobi, in press).

Vegetation Type					
Dominant Canopy	Secondary Species	Sub-canopy	Shrub	Ground	20-m Intervals (No./%)
				XG	20/ 0.87
C3AcMe		2NT	NS		87/ 3.79
C3AcMe		2NT	NS	MG	52/ 2.27
C3AcMe		2NT	NS	NF,XG	48/ 2.09
C3AcMe		2NT	NS	XG	560/24.42
C3AcMe		2NT	NS	XG,NF*	120/ 5.23
C3AcMe		2NT	NS	XG*	9/ 0.39
C3AcMe		2NT	NS,TF	XG,NF	49/ 2.14
C3AcMe		2NT	NS*	XG	41/ 1.79
C3AcMe		2NT	NS,TF	XG*	50/ 2.19
C3AcMe	XT		PM,NS		132/ 5.76
C3Me	Ac	2NT		XG	10/ 0.44
C3Me	Ac	2NT	NS	XG	111/ 4.84
C3XT	AcMe		PM,NS	XG	28/ 1.22
O3AcMe				XG	49/ 2.14
O3AcMe		2NT		XG	65/ 2.83
O3AcMe		2NT		XG,NF	50/ 2.19
O3AcMe		2NT	NS*	XG	100/ 4.36
O3AcMe		2NT	NS*	XG,NF	161/ 7.02
O3Me	Ac			XG,NF	50/ 2.19
O3Me	Ac	2NT		XG	10/ 0.44
O3Me	Ac	2NT		XG,NF	10. 0.44
O3Me	Ac	2NT	NS	XG	62/ 2.70
S3AcMe		2NT	NS	MG	12/ 0.52
S3AcMe		2NT		XG	69/ 3.01
S3AcMe			NS*	XG	49/ 2.14
VS3Ac				XG	50/ 2.19
VS3Ac		2NT		XG	79/ 3.45

Table 4, continued.

Vegetation Type					
Dominant Canopy	Secondary Species	Under-story	Shrub	Ground	20-m Intervals (No./%)
VS3AcMe				XG	108/ 4.71
VS3AcMe		2NT		XG	52/ 2.27
Totals					2,293/100.00

Key:

Canopy Cover:

C = Closed (60-80%)
O = Open (20-60%)
S = Scattered (5-20%)
VS = Very Scattered (<5%)

Canopy and Secondary Species:

Ac = Acacia koa (koa)
Me = Metrosideros polymorpha ('ohi'a)
XT = Alien Tree (Eucalyptus, gymnosperm, etc. plantings)

Height:

1 = 3-5 m
2 = 5-10 m
3 = >10 m

Understory:

NT = Native Tree
XT = Alien Tree

Table 4, continued.

Shrub:

ns = Native Shrub
tf = Tree Fern
ns* = Native shrub less dominant than other ground cover
pm =*Passiflora mollissima*

Ground:

xg = Alien Grass
mg = Mixed Grass (native *Carex* and alien grass)
nf = Native Fern
xg* = Alien grass less dominant than other ground cover

Dashes between 2 species or categories indicate similar percent cover. Species or categories after commas are of less cover than those before for overstory (outside parentheses) or understory (inside parentheses). Notation after Jacobi, in press.

Table 5. Occurrence of ungulate sign in 5- x 20-m plots in 6 major vegetation types on Hakalau Forest National Wildlife Refuge, Spring 1987.

Major Vegetation Type	(1) Plots		(2) Pig Sign		(3) Cattle Sign	
	No.	% of Total	No.	% of Total	No.	% of Total
Closed canopy koa-'ohi'a/alien grasses	1,269	55.3	496	83.4*	318	45.4**
Closed canopy alien trees	28	1.2	24	4.0*	1	0.1**
Open canopy koa-'ohi'a/alien grasses	557	24.3	52	8.7**	211	30.1*
Scattered koa-'ohi'a/alien grasses	130	5.7	6	1.0**	20	2.9**
Very scattered koa-'ohi'a/alien grasses	160	7.0	6	1.0**	100	14.3*
Very scattered koa/alien grasses	149	6.5	11	1.9**	51	7.3
Totals	2,293	100.0	595	100.0	701	100.1

*Chi-square values indicate significantly more ($p = 0.05$) sign than expected according to plot percentages (column 1)

**Chi-square values indicate significantly less ($p = 0.05$) sign than expected according to plot percentages (column 1)

percent but increased in the cattle index to 33 percent (n = 2,017 plots).

Indices to feral pig and cattle abundance are presented in Table 5 for each of the 6 major vegetation types. An indication of preference for or avoidance of vegetation types by pigs was obtained by comparing the distribution of plots with pig sign with the distribution of all plots according to vegetation type. If pigs showed no preference or avoidance, the percentage occurrence of pig sign in each type should be similar to the percentage of plots in each vegetation type. However, the comparison of the two percentage columns for each vegetation type suggests that feral pigs used the closed canopy koa-ʻohiʻa and closed canopy alien tree types more than expected. In contrast, open to very scattered vegetation types were used less than expected, if pig occurrence was distributed similarly to plot occurrence. That pigs favor more protected areas where food supplies and cover are probably more favorable is not surprising. However, pig sign is more difficult to detect in grassland areas than in areas with sparse ground cover; a slight bias in data collection may have resulted.

Cattle sign was more abundant than expected from plot distribution in very scattered koa-ʻohiʻa forest and open canopy koa-ʻohiʻa. However, it can also be inferred that cattle on the Refuge use closed koa-ʻohiʻa and alien forest types less than would be expected, based on plot distribution percentages in different vegetation types. Again, it is not surprising that cattle seem to prefer open areas to closed forest. However, the preference pattern is not as evident as with pigs, probably because fencing restricts movements of livestock to a greater extent. This will be discussed later in this report.

Cattle and pigs seemed negatively associated in closed koa-ʻohiʻa and closed canopy alien trees (pigs more than expected and cattle less) and in open koa-ʻohiʻa and very scattered koa-ʻohiʻa (cattle more than expected and pigs less). Avoidance of one species by the other or different food and cover requirements are possible explanations.

Percent frequency of occurrence data for feral pig and cattle sign found in each of 30 vegetation types are presented in Table 6. These figures are based on the percentages of total 5- x 20-m plots in <u>each</u> type (rather than in <u>all</u> types, as with the last analysis) with fresh or intermediate-aged sign. No inferences about preferences or avoidances of types are made because sample sizes are often small. However, percentages of sign within a type give an indication of how widespread pigs are in that type.

Feral pig sign was most frequent (91% of plots in that type) in closed canopy koa-ʻohiʻa, with alien tree subcanopy, banana poka, and native shrub [C3Ac-Me,XT(pm-ns)]; in closed

Table 6. Ungulate sign in 5- x 20-m plots in each of 30 vegetation types, Hakalau Forest NWR, Spring 1987.

Vegetation Type	% Frequency of Occurrence		Animals Seen	
	Feral Pig Sign	Cattle Sign	Pigs	Cattle
(xg)	10	45	0	23
C3Ac-Me,2NT(ns)	18	7	1	0
C3Ac-Me,2NT(ns-mg)	71	0	2	0
C3Ac-Me,2NT(ns-nf-xg)	60	2	0	0
C3Ac-Me,2NT(ns-xg)	35	41	3	14
C3Ac-Me,2NT(ns-xg-nf)	7	3	0	8
C3Ac-Me,2NT(ns,xg)	56	56	0	0
C3Ac-Me,2NT(ns-tf-xg-nf)	82	0	0	0
C3Ac-Me,2NT(xg,ns)	0	2	0	0
C3Ac-Me,2NT(ns-tf,xg)	82	0	0	0
C3Ac-Me,XT(pm-ns)	91	2	2	0
C3Me,Ac,2NT(xg)	0	40	0	0
C3Me,Ac,2NT(ns-xg)	5	60	0	7
C3XT,Ac-Me(pm-ns-xg)	86	4	0	0
O3Ac-Me(xg)	4	22	0	0
O3Ac-Me,2NT(xg)	2	6	0	0
O3Ac-Me,2NT(xg-nf)	0	48	0	5
O3Ac-Me,2NT(xg,ns)	6	38	3	23
O3Ac-Me,2NT(xg-nf,ns)	18	44	0	38
O3Me,Ac(xg-nf)	2	64	0	15
O3Me,Ac,2NT(xg)	20	70	0	0
O3Me,Ac,2NT(xg-nf)	0	30	0	0
O3Me,Ac,2NT(ns-xg)	18	34	0	15
S3Ac-Me,2NT(ns-mg)	15	0	0	0
S3Ac-Me,2NT(xg)	4	25	0	11
S3Ac-Me(xg,ns)	2	6	0	15
VS3Ac(xg)	2	24	0	0
VS3Ac,2NT(xg)	13	38	0	39

Table 6, continued.

Vegetation Type	% Frequency of Occurrence: Feral Pig Sign	% Frequency of Occurrence: Cattle Sign	Animals Seen: Pigs	Animals Seen: Cattle
VS3Ac-Me(xg)	1	61	0	116
VS3Ac-Me,2NT(xg)	10	65	0	65
Means and Totals	17	33	11	394

Key:
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S = Scattered (5-20%)
VS = Very Scattered (<5%)

Canopy and Secondary Species:
Ac = Acacia koa (koa)
Me = Metrosideros polymorpha ('ohi'a)
XT = Alien Tree (Eucalyptus, gymnosperm, etc. plantings)

Height:
1 = 3-5 m
2 = 5-10 m
3 = >10 m

Understory:
NT = Native Tree
XT = Alien Tree

Table 6, continued.

Shrub:
ns = Native Shrub
tf = Tree Fern
pm = Passiflora mollissima

Ground:
xg = Alien Grass
mg = Mixed Grass (native sedge and alien grass)
nf = Native Fern

Dashes between 2 species or categories indicate similar percent cover. Species or categories after commas are of less cover than those before for overstory (outside parentheses) or understory (inside parentheses). Notation after Jacobi, in press.

canopy alien tree type with koa-'ohi'a subcanopy, and banana poka, native shrub and alien grass understory [C3XT,Ac-Me(pm-ns-xg)] (86% of plots in that type); and in closed canopy koa-'ohi'a with native tree subcanopy, native shrub, and tree fern understory, with either alien grasses [C3Ac-Me,2NT(ns-tf,xg)] or alien grasses and native ferns [C3Ac-Me,2NT(ns-tf-xg-nf)] (82% of plots each). C3XT,Ac-Me(pm-ns-xg) type was present only on the Piha Game Management Unit.

Cattle sign was most abundant (70% of plots in that type) in open 'ohi'a with koa, native tree understory and alien grasses [O3Me,Ac,2NT(xg)]; in very scattered koa-'ohi'a with native tree subcanopy and alien grasses [VS3Ac-Me,2NT(xg)] (65%); in open 'ohi'a with koa and alien grasses and native ferns [O3Me,Ac(xg-nf)] (64%); in very scattered koa-'ohi'a with alien grasses [VS3Ac-Me(xg)] (61%); and in closed 'ohi'a with koa, native trees and shrubs and alien grasses [C3Me,Ac,2NT(ns-xg)] (60%).

Indices to Alien Plants in Different Vegetation Types

A list of the 68 alien plants encountered on transects in this study is given in Appendix D. Of these, 6 important species were selected for analysis of percent frequency of occurrence and cover abundance.

Sweet vernal grass (Anthoxanthum odoratum) and meadow ricegrass (Microlaena stipoides) were present in 72 and 71 percent of all 2,293 plots (transect intervals), and kikuyugrass (Pennisetum clandestinum) was present in 50 percent of all plots. Banana poka was present in 15 percent of all plots, blackberry (Rubus penetrans) in 7 percent, and gorse (Ulex europaeus) in less than 1 percent (0.1%).

Percent frequencies of occurrence (no. plots with species in type/total no. plots in which species occurred x 100) of the 6 important alien plants (excluding gorse, which occurred in <1% of plots) in the 6 major vegetation types on HFNWR are given in Table 7. Based on comparison with the distribution of all plots in the sample, meadow ricegrass (MiSt) occurred more often than expected in the closed canopy koa-'ohi'a type, and less than expected in the 3 scattered and very scattered koa and koa-'ohi'a types. In contrast, sweet vernal grass (AnOd) occurred more than expected in open koa-'ohia and very scattered koa, but less than expected in closed koa-'ohi'a, closed canopy alien trees, and scattered koa-'ohi'a. Kikuyu grass (PeCl), like sweet vernal grass, occurred more than expected in open koa-'ohi'a and the 2 very scattered koa and koa-'ohi'a types. It also occurred more than expected in the alien tree and scattered koa-'ohi'a types, and less than expected in closed koa-'ohi'a. This is quite consistent with the biological knowledge of the 3 alien grasses: meadow ricegrass does well in closed canopy forests and less so in open habitat, while sweet vernal grass and kikuyugrass favor open sites and are less shade tolerant.

Table 7. Percent frequency of occurrence of 5* most important alien plants in 5- x 20-m vegetation plots in 6 major vegetation types, Hakalau Forest National Wildlife Refuge, Hawai'i, Spring 1987.

Vegetation Type	Percent of Total Plots	MiSt[1]		AnOd[2]		PeCl[3]		PaMo[4]		RuPe[5]	
		No.	%	No.	%	No.	%	No.	%	No.	%
Closed canopy koa-'ohi'a/ alien grasses	55.3	1204	72.6*	744	45.8**	353	30.9**	253	73.5*	84	50.9
Closed canopy alien trees	1.2	28	1.7	7	0.4**	0	0.0*	22	6.4*	4	2.4
Open canopy koa-'ohi'a	24.3	364	21.9	507	31.2*	377	33.0*	53	15.4**	37	22.4
Scattered koa-'ohi'a	5.7	39	2.3**	60	3.7**	123	10.8*	16	4.7	39	23.6*
Very scattered koa-'ohi'a	7.0	3	0.2**	160	9.8*	117	10.3*	0	0.0**	0	0.0**
Very scattered koa/alien grasses	6.5	21	1.3**	148	9.1*	172	15.1*	0	0.0**	1	0.6**
Totals	100.0	1659	100.0	1626	100.0	1142	100.1	344	100.0	165	99.9

* Occurred significantly more often than expected according to distribution of plots (Chi square, p = 0.05)

** Occurred significantly less often than expected according to distribution of plots (Chi square, p = 0.05)

1 Microlaena stipoides, 1,659 plots
2 Anthoxanthum odoratum, 1,626 plots
3 Pennisetum clandestinum, 1,142 plots
4 Passiflora mollissima, 344 plots
5 Rubus penetrans, 165 plots

Banana poka (PaMo) occurred much more than would be expected from sample plot distribution in closed koa-ʻohiʻa, the major vegetation type based on plot frequencies on the Refuge. It also occurred more in the alien tree type than the plot distribution would warrant, and less than expected in most other vegetation types. It is well known (Warshauer et al. 1983) that banana poka is an excellent invader of natural and artificial gaps in dense forest, and, like meadow ricegrass, this species will continue to present problems even after recovery of vegetation and subsequent canopy closure.

Blackberry (RuPe) occurred more than expected in scattered koa-ʻohiʻa, but less than expected in very scattered koa-ʻohiʻa and koa.

Estimated ground cover was often (46% of all 2,293 plots) in the highest density category (26-50%) for meadow ricegrass (Table 8). Sweet vernal grass cover was in the 26-50% category for 27% of plots, and kikuyugrass for 23%. Thus, meadow ricegrass attains the highest densities of the alien

Table 8. Percent frequency of occurrence of the 6 most important alien species according to cover abundance on Hakalau Forest National Wildlife Refuge, Spring 1987.

Alien Plant Species	Ground Cover 26-50%	6-25%	1-5%	Total
Microlaena stipoides (Meadow ricegrass)	46	15	12	73
Anthoxanthum odoratum (Sweet vernal grass)	27	20	24	71
Pennisetum clandestinum (Kikuyugrass)	23	12	15	50
Passiflora mollissima (Banana poka)	5	3	6	14
Rubus penetrans (Blackberry)	0	2	5	7
Ulex europaeus (Gorse)	0	0	0	0*

* < 0.1%

grasses on HFNWR over the most areas. As indicated earlier, it is also able to tolerate shading. Since it inhabits many different vegetation types at high density, it is probably is the one grass most capable of inhibiting native plant reproduction through smothering seedlings.

Percent frequencies of occurrence and high cover abundance (26-50%) of the 6 major alien plants in each of 30 vegetation types are presented in Table 9. These figures are based on the percentages of 5- x 20-m plots in each vegetation type containing each species discussed. No comparisons with overall plot distribution frequencies are made here. Meadow ricegrass occurred in 100 percent of the plots in a wide range of vegetation types, from closed canopy to very scattered trees. In the alien grass type, however, it did not occur, possibly as a result of competition with other alien grasses such as sweet vernal grass and kikuyugrass, but possibly because Microlaena has a lower optimal elevational limit than other common alien grasses of Hakalau. Meadow ricegrass was absent in 2 of the 5 scattered and very scattered koa-'ohi'a types. Meadow ricegrass is probably less able to compete with the stoloniferous kikuyugrass under grazing pressure.

Sweet vernal grass was also present at 100 percent frequencies over a wide range of light conditions but was a major cover component less often in closed canopy types. This species was especially well distributed in open 'ohi'a and very scattered koa and koa-'ohi'a types as well as in the alien grass type.

Kikuyugrass, like sweet vernal grass, was nearly ubiquitous in sites with scattered, very scattered, or no trees. It also was widespread in open koa-'ohi'a types.

As indicated in Table 9, all 3 grasses occur in very high frequencies in types C3Ac-Me,2NT(xg,ns) and O3Me,Ac,2NT(xg); and 2 of the 3 species occur in high percentages of plots in many other types. Where this occurs, ground cover is often 100% alien grasses, and the alien species simply vary in abundance with the environmental conditions (including grazing) most favorable to them. The end result is inhibition of native plant reproduction by combined effects of the 3 species.

Banana poka was most widespread in closed canopy koa-'ohi'a and closed canopy alien tree types. It was absent in vegetation types with very scattered trees and in open and closed canopy 'ohi'a forests. As indicated, this species is not shaded out and is able to invade openings in closed canopy forests. It is absent in some areas near Piha only because of grazing by cattle, but it survives well in areas inaccessible to cattle. Cattle also distribute seeds of banana poka. The current distribution of this species most likely results more from gradual dispersion than from lack of available habitat.

Table 9. Percent frequencies of occurrence and high cover abundance distribution of 6 important alien plants in 5- x 20-m plots in each of 30 vegetation types, Hakalau Forest National Wildlife Refuge, Hawai'i, Spring 1987.

Vegetation Type	Alien Species**					
	MiSt	AnOd	PeCl	PaMo	RuPe	UlEu
(xg)	0	100*	95	0	0	0
C3Ac-Me,2NT(ns)	86*	14	34	43	24	0
C3Ac-Me,2NT(ns-mg)	100*	0	0	12	4	0
C3Ac-Me,2NT(ns-nf-xg)	88	6	0	10	0	0
C3Ac-Me,2NT(ns-xg)	99*	81	41	5	7	0
C3Ac-Me,2NT(ns-xg-nf)	74*	35	34	29	8	0
C3Ac-Me,2NT(ns,xg)	100*	44	0	0	0	0
C3Ac-Me,2NT(ns-tf-xg-nf)	100*	35	4	41	4	0
C3Ac-Me,2NT(xg,ns)	98*	100	100	0	7	0
C3Ac-Me,2NT(ns-tf,xg)	100	18	0	0	2	0
C3Ac-Me,XT(pm-ns)	93	35	3	92*	4	0
C3Me,Ac,2NT(xg)	90*	90	40	0	0	0
C3Me,Ac,2NT(ns-xg)	99*	95	0	0	1	0
C3XT,Ac-Me(pm-ns-xg)	100	25	0	79	14	0
O3Ac-Me(xg)	78	100*	33	0	20	0
O3Ac-Me,2NT(xg)	86	86	94	18	18	0
O3Ac-Me,2NT(xg-nf)	16	90	100*	20	0	0
O3Ac-Me,2NT(xg,ns)	72	80	94*	13	4	0
O3Ac-Me,2NT(xg-nf,ns)	45	91	76*	11	6	0
O3Me,Ac(xg-nf)	70	100*	32	0	0	0
O3Me,Ac,2NT(xg)	100	90	100*	0	0	0
O3Me,Ac,2NT(xg-nf)	100*	100*	20	0	0	0
O3Me,Ac,2NT(ns-xg)	100*	100*	10	0	3	0
S3Ac-Me,2NT(ns-mg)	0	0	92*	25	0	0
S3Ac-Me,2NT(xg)	25	22	99*	14	0	0
S3Ac-Me(xg,ns)	45	92*	90	6	80	0
VS3Ac(xg)	28	100*	98	0	0	0
VS3Ac,2NT(xg)	9	99*	86	0	0	3
VS3Ac-Me(xg)	0	100*	97	0	0	0
Vs3Ac-Me,2NT(xg)	6	100*	92	0	2	0
Overall Percent Occurrence	72	71	50	15	7	0

*Over 50% of total plots in 26-50% cover category.

**Microlaena stipoides - meadow ricegrass
Anthoxanthum odoratum - sweet vernal grass
Pennisetum clandestinum - kikuyugrass
Passiflora mollissima - banana poka
Rubus penetrans - blackberry
Ulex europaeus - gorse

Table 9, continued.

Key:
Canopy Cover:
C = Closed (60-80%)
O = Open (20-60%)
S = Scattered (5-20%)
VS = Very Scattered (<5%)

Canopy and Secondary Species:
Ac = Acacia koa (koa)
Me = Metrosideros polymorpha ('ohi'a)
XT = Alien Tree (Eucalyptus, gymnosperm, etc. plantings)

Height:
1 = 3-5 m
2 = 5-10 m
3 = >10 m

Understory:
NT = Native Tree
XT = Alien Tree

Shrub:
ns = Native Shrub
tf = Tree Fern
pm = Passiflora mollissima

Ground:
xg = Alien Grass
mg = Mixed Grass (native sedge and alien grass)
nf = Native Fern

Dashes between 2 species or categories indicate similar percent cover. Species or categories after commas are of less cover than those before for overstory (outside parentheses) or understory (inside parentheses). Notation after Jacobi (in press).

Blackberry reached the highest frequency of occurrence in scattered koa-ʻohiʻa without subcanopy trees. It was absent in very scattered koa, scattered koa-ʻohiʻa with subcanopy, and open ʻohiʻa with subcanopy. Blackberry was not well distributed in very scattered koa-ʻohiʻa. This species is likely to increase with removal of cattle.

Although abundant near the Refuge, gorse was found in only 2 of the 2,293 plots, both in very scattered koa with no understory. This species also may increase with removal of cattle and needs to be monitored closely.

Relationships of Ungulates to Transects, Elevations, and Land Management

Frequency of occurrence of feral pig sign was sorted according to vegetation type and elevation along each of the 14 transects (Table 10). Feral pig sign showed greatest distribution within all vegetation types on transect 12 (82-100%). This transect sampled the State Piha Game Management Area. Some closed canopy koa-ʻohiʻa on transects 10 (56-82%), 13 (59%), and 14 (53%) also showed high frequencies of occurrence of feral pig sign. Transects 13 and 14 sampled the Robertson et al. parcel.

Cattle sign was most frequent within vegetation types on transects 5 (40-70%), 7 (30-78%), and 8 (28-68%). These transects sampled the Shipman parcel. Very scattered koa-ʻohiʻa on transect 9 (61%), closed koa-ʻohiʻa on transect 10 (56%), and open koa-ʻohiʻa on transect 13 (53 and 63%) also showed high frequencies of occurrence of cattle sign. Transect 10 sampled the Liliuokalani parcel.

An analysis of the distribution of ungulate sign according to elevation on Refuge lands under previous ownership in the past is presented in Table 11. Fences on the Shipman, Liliuokalani, and Robertson et al. parcels are used to manage livestock and obviously affect cattle movements. At the time of the study, abundance of feral pig sign was greatest in the lower portions of all parcels. The situation was less consistent for cattle, with not much difference in upper and lower Liliuokalani, more cattle sign in middle Shipman than above or below, and dramatically less cattle sign in the lower than upper or middle Robertson et al. parcel.

Relationships of Alien Plants to Transects, Elevations, and Land Management

Percent frequencies of occurrence of weed species in vegetation types along each of the 14 transects are presented in Table 12. The occurrence of the highest cover abundance category (26-50%) for each species is designated by an asterisk in the table. It is evident that, in general, the frequencies of occurrences and cover abundances of meadow ricegrass and sweet vernal grass are least in vegetation types on the Piha and Robertson et al. transects (12-14). Frequencies of occurrence for kikuyugrass are similarly least

Table 10. Percent frequency of occurrence of feral pig and cattle sign along 14 transects in 30 vegetation types by elevation, Hakalau Forest National Wildlife Refuge, Spring 1987.

Transect	Vegetation Type	Elevation (m)	Elevation (ft)	Frequency of Occurrence (%) Feral Pigs	Cattle	n
1	C3Ac-Me,2NT(ns-xg)	1720-1780	5640-5850	0	31	39
	C3Ac-Me,2NT(xg,ns)	1800-1880	5920-6180	0	2	41
2	C3Ac-Me,2NT(ns-xg)	1790-1860	5860-6100	2	12	81
3	C3Ac-Me,2NT(ns-xg)	1740-1800	5700-6200	43	43	94
4	C3Ac-Me,2NT(ns-xg)	1740-1870	5700-6150	10	49	91
5	C3Me,Ac,2NT(ns-xg)	1750-1910	5750-6280	5	60	111
	C3Me,Ac,2NT(xg)	1920	6300	0	40	10
	O3Me,Ac,2NT(xg)	1940	6360	20	70	10
	VS3Ac,2NT(xg)	1960-1990	6420-6540	10	55	29
6	C3Ac-Me,2NT(ns-xg)	1750-1870	5730-6150	21	38	81
	O3Ac-Me,2NT(xg,ns)	1890	6200-6210	0	45	20
	VS3Ac(xg)	1920-1980	6300-6500	2	24	50
7	(xg)	1970-2010	6460-6590	0	45	20
	C3Ac-Me,2NT(ns-xg)	1770-1820	5800-5980	44	62	78
	OcMe,Ac(xg-nf)	1850	6080	0	50	10
	O3Me,Ac,2NT(xg-nf)	1830	6020	0	30	10
	VS3Ac-Me,2NT(xg)	1870-1950	6120-6410	13	78	40
8	OcMe,Ac,2NT(ns-xg)	1540-1550	5040-5080	18	34	62
	OcMe,Ac(xg-nf)	1820-1890	5960-6190	3	68	40
	VS3Ac,2NT(xg)	1980	6500	14	28	50
9	OcAc-Me,2NT(xg)	1620-1670	5300-5490	0	3	34
	VS3Ac-Me(xg)	1700-1900	5600-6230	1	61	108
	VS3Ac-Me,2NT(xg)	1690	5550	0	25	12
10	C3Ac-Me,2NT(ns,xg)	1580	5170	56	56	9
	C3Ac-Me,2NT(ns-tf,xg)	1500-1560	4920-5110	82	0	50
	OcAc-Me(xg)	1640-1680	5380-5500	4	22	49
	O3Ac-Me,2NT(xg-nf,ns)	1590-1630	5200-5340	48	18	40

Table 10, continued.

Transect	Vegetation Type	Elevation (m)	Elevation (ft)	Frequency of Occurrence (%) Feral Pigs	Frequency of Occurrence (%) Cattle	n
11	C3Ac-Me,2NT(ns)	1520-1620	4990-5300	18	7	87
	3Ac-Me,2NT(ns-mg)	1540-1550	5040-5080	17	0	12
	S3Ac-Me(xg,ns)	1630-1690	5350-5530	2	6	49
12	C3Ac-Me,2NT(ns-xg)	1510-1650	4950-5400	97	44	96
	C3Ac-Me,2NT(ns-mg)	1480-1500	4860-4920	100	0	20
	C3Ac-Me,2NT(ns-nf-xg)	1650-1800	5400-5910	86	4	28
	C3Ac-Me(xt-pm-ns)	1690-1890	5530-6190	91	2	132
	C3XT,Ac-Me(pm-ns-xg)	1500-1560	4940-5130	82	0	49
13	C3Ac-Me,2NT(ns-tf-xg-nf)	1400-1460	4580-4800	59	2	48
	O3Ac-Me,2NT(xg,ns)	1760-1800	5770-5930	10	63	30
	O3Ac-Me,2NT(xg-nf)	1880	6160	0	48	50
	O3Ac-Me,2NT(xg-nf,ns)	1570-1840	5160-6050	8	53	121
14	C3Ac-Me,2NT(ns-xg-nf)	1490-1620	4890-5300	7	3	119
	C3Ac-Me,2NT(ns-mg)	1430-1510	4690-4860	53	0	32
	O3Ac-Me,2NT(xg)	1630-1650	5340-5410	3	10	31
	O3Ac-Me,2NT(xg,ns)	1680-1750	5510-5750	6	20	50
	S3Ac-Me,2NT(xg)	1770-1900	5820-6220	4	25	69

Key:
Canopy Cover:
- C = Closed (60-80%)
- O = Open (20-60%)
- S = Scattered (5-20%)
- VS = Very Scattered (<5%)

Canopy and Secondary Species:
- Ac = Acacia koa (koa)
- Me = Metrosideros polymorpha ('ohi'a)
- XT = Alien Tree (Eucalyptus, gymnosperm, etc. plantings)

Table 10, continued.

Height:
1 = 3-5 m
2 = 5-10 m
3 = >10 m

Understory:
NT = Native Tree
XT = Alien Tree

Shrub:
ns = Native Shrub
tf = Tree Fern
ns* = Native shrub less dominant than other ground cover
pm = Passiflora mollissima

Ground:
xg = Alien Grass
mg = Mixed Grass (native sedge and alien grass)
nf = Native Fern
xg* = Alien grass less dominant than other ground cover

Dashes between 2 species or categories indicate similar percent cover. Species or categories after commas are of less cover than those before for overstory (outside parentheses) or understory (inside parentheses). Notation after Jacobi, in press.

Table 11. Distribution of feral animal sign according to fenced elevational units, Hakalau Forest National Wildlife Refuge, Spring 1987.

Parcel	% Frequency of Sign in Subparcel		Range in Elevation		Transects
	Pig	Cattle	(m)	(ft)	
Shipman					
Upper	6.49	25.54	1,795-2,010	5,880-6,590	5-9
Middle	12.29	48.33	1,725-1,920	5,660-6,300	1-9
Lower	15.85	37.56	1,615-1,885	5,300-6,180	1-9
Liliuokalani					
Upper	10.53	5.83	1,615-1,685	5,290-5,530	10-11
Lower	40.66	8.79	1,500-1,615	4,920-5,300	10-11
Robertson et. al					
Upper	3.89	36.67	1,705-1,895	5,600-6,220	13-14
Middle	5.80	35.75	1,575-1,700	5,160-5,580	13-14
Lower	44.60	0.47	1,395-1,565	4,580-5,130	13-14

Table 12. Percent frequencies of occurrence of major alien plant species along 14 transects by elevation and 30 vegetation types, Hakalau Forest National Wildlife Refuge, Spring 1987.

Transect	Vegetation Type	Elevation (m)	Elevation (ft)	Frequency of Occurrence (%) MiSt	AnOd	PeCl	PaMo	RuPe	UlEu	n
1	C3Ac-Me,2NT(ns-xg)	1720-1780	5640-5850	95	95	97				39
	C3Ac-Me,2NT(xg,ns)	1800-1880	5920-6180	98*	100	100		7		41
2	C3Ac-Me,2NT(ns-xg)	1790-1860	5860-6100	100*	98	53		9		81
3	C3Ac-Me,2NT(ns-xg)	1740-1800	5700-6200	100*	98*	40		7		94
4	C3Ac-Me,2NT(ns-xg)	1740-1870	5700-6150	100*	100	59		1		91
5	C3Me,Ac,2NT(ns-xg)	1750-1910	5750-6280	99*	95			1		111
	C3Me,Ac,2NT(xg)	1920	6300	90*	90	40				10
	O3Me,Ac,2NT(xg)	1940	6360	100	90	100*				10
	VS3Ac,2NT(xg)	1960-1990	6420-6540	14	97*	86			7	29
6	C3Ac-Me,2NT(ns-xg)	1750-1870	5730-6150	100*	100	30		7		81
	O3Ac-Me,2NT(xg,ns)	1890	6200-6210	100	90	80				20
	VS3Ac(xg)	1920-1980	6300-6500	28	100*	98				50
7	(xg)	1970-2010	6460-6590		100*	95				20
	C3Ac-Me,2NT(ns-xg)	1770-1820	5800-5980	99*	87	19				78
	OcMe,Ac(xg-nf)	1850	6080	80*	100*	30				10
	O3Me,Ac,2NT(xg-nf)	1830	6020	100*	100*	20				10
	VS3Ac-Me,2NT(xg)	1870-1950	6120-6410		100*	90				40
8	OcMe,Ac,2NT(ns-xg)	1540-1550	5040-5080	100*	100*	10		3		62
	OcMe,Ac(xg-nf)	1820-1890	5960-6190	68	100*	33				40
	VS3Ac,2NT(xg)	1980	6500	6	100*	86				50
9	OcAc-Me,2NT(xg)	1620-1670	5300-5490	100*	100*	97		15		34
	VS3Ac-Me(xg)	1700-1900	5600-6230		100*	97				108
	VS3Ac-Me,2NT(xg)	1690	5550	25	100*	100*		8		12
10	C3Ac-Me,2NT(ns,xg)	1580	5170	100*	44					9
	C3Ac-Me,2NT(ns-tf,xg)	1500-1560	4920-5110	100	18			2		50
	OcAc-Me(xg)	1640-1680	5380-5500	78	100*	33		20		49
	O3Ac-Me,2NT(xg-nf,ns)	1590-1630	5200-5340	100*	88	13		15		40
11	C3Ac-Me,2NT(ns)	1520-1620	4990-5300	86*	14	34	43	24		87
	S3Ac-Me,2NT(ns-mg)	1540-1550	5040-5080		0	92*	25			12
	S3Ac-Me(xg,ns)	1630-1690	5350-5530	45	92*	90	6	80		49

Table 12, continued.

Transect	Vegetation Type	Elevation (m)	Elevation (ft)	Frequency of Occurrence (%) MiSt	AnOd	PeCl	PaMo	RuPe	UlEu	n
12	C3Ac-Me,2NT(ns-xg)	1510-1650	4950-5400	100*	8	21	31	20		96
	C3Ac-Me,2NT(ns-mg)	1480-1500	4860-4920	93*			5	10		20
	C3Ac-Me,2NT(ns-nf-xg)	1650-1800	5400-5910	57	11		18			28
	C3Ac-Me(xt-pm-ns)	1690-1890	5530-6190		35	3	92*	4		132
	C3XT,Ac-Me(pm-ns-xg)	1500-1560	4940-5130		14		45	8		49
13	C3Ac-Me,2NT(ns-tf-xg-nf)	1400-1460	4580-4800		67					48
	O3Ac-Me,2NT(xg,ns)	1760-1800	5770-5930				100			30
	O3Ac-Me,2NT(xg-nf)	1880	6160		8		86			50
	O3Ac-Me,2NT(xg-nf,ns)	1570-1840	5160-6050		7		91			121
14	C3Ac-Me,2NT(ns-xg-nf)	1490-1620	4890-5300	8	60		33			119
	C3Ac-Me,2NT(ns-mg)	1430-1510	4690-4860		94					32
	O3Ac-Me,2NT(xg)	1630-1650	5340-5410		42		87			31
	O3Ac-Me,2NT(xg,ns)	1680-1750	5510-5750		12		94			50
	S3Ac-Me,2NT(xg)	1770-1900	5820-6220		22		91			69

*Indicates > 50% of all plots in 26-50% cover density category.

Key:

Canopy Cover:

- C = Closed (60-80%)
- O = Open (20-60%)
- S = Scattered (5-20%)
- VS = Very Scattered (<5%)

Canopy and Secondary Species:

- Ac = Acacia koa (koa)
- Me = Metrosideros polymorpha ('ohi'a)
- XT = Alien Tree (Eucalyptus, gymnosperm, etc. plantings)

Table 12, continued.

Height:
- 1 = 3-5 m
- 2 = 5-10 m
- 3 = >10 m

Understory:
- NT = Native Tree
- XT = Alien Tree

Shrub:
- ns = Native Shrub
- tf = Tree Fern
- ns* = Native shrub less dominant than other ground cover
- pm = Passiflora mollissima

Ground:
- xg = Alien Grass
- mg = Mixed Grass (native sedge and alien grass)
- nf = Native Fern
- xg* = Alien grass less dominant than other ground cover

MiSt = Microlaena stipoides
AnOd = Anthoxanthum odoratum
PeCl = Pennisetum clandestinum
PaMo = Passiflora mollissima
RuPe = Rubus penetrans
UlEu = Ulex europaeus

Dashes between 2 species or categories indicate similar percent cover. Species or categories after commas are of less cover than those before for overstory (outside parentheses) or understory (inside parentheses). Notation after Jacobi, in press.

on transects 12-14. Large percentages of these transects are in ungrazed forest. Banana poka also reached greatest frequency of occurrence on transects 12-14 in open-closed koa-ʻohiʻa forest, with native tree understory, probably also in relation to lack of cattle. Poka was absent in plots on transects 1-10. Greatest banana poka densities were obtained in closed canopy koa-ʻohiʻa without understory trees on transect 12, which sampled the State Piha Game Management Unit. The highest percent frequency of occurrence of blackberry was in scattered koa-ʻohiʻa without understory trees on transect 11, which sampled the Liliuokalani parcel. Gorse was present on transects 5 and 9 only in the very scattered koa type, but was also observed off transect in other areas (e.g., near transects 6 and 8).

An analysis of the occurrence of 6 alien plants according to elevations on Refuge lands under previous ownership in the past is presented in Table 13. Meadow ricegrass was most often encountered and was most often dense on the lower portion of all 3 parcels, possibly a reflection of shade tolerance, less competition with kikuyugrass, and preference for lower elevations. Sweet vernal grass was frequently encountered throughout the Shipman parcel but was most often dense in the upper portion. On the Liliuokalani and Robertson et al. parcels, kikuyugrass was less frequently encountered in lower pastures, perhaps because meadow ricegrass was dominant there for the reasons mentioned. Kikuyugrass was most frequent and most often dense on the upper and middle Robertson et al. pastures, perhaps a result of microclimate, less competition, more grazing pressure, and/or planting by ranchers in these areas.

Banana poka was most widespread on lower Robertson et al. and lower Liliuokalani parcels. Proximity to the Piha Area, dissemination by feral pigs, and the absence of cattle are undoubtedly factors. Blackberry was most abundant in the upper Liliuokalani Tract, and gorse on upper Shipman.

Native Plants

A checklist of vascular plants of the Hakalau Forest National Wildlife Refuge is included as Appendix E. Scientific and common names, status, and life forms of alien and native species are listed from previous sources and this study. Rare plants and alien plants of special concern are asterisked, and a short list of important references is given. Twenty-nine (29) rare plants and 9 alien plants are highlighted on the list.

Rare or vulnerable plants observed along the 14 transects in this study are listed in Table 14. Included are 1 fern, 3 mints, 2 lobelioids, 2 Cyrtandra species, and at least one species of Pelea, for a total of at least 9. (Stenogyne calaminthoides was probably more abundant than indicated because it was not consistently recorded.) As indicated previously, transects are not necessarily the best means of

Table 13. Distribution of most important alien plants according to elevation, Hakalau Forest National Wildlife Refuge, Spring 1987.

Parcel	Frequencies of Occurrence (%) MiSt	AnOd	PeCl	PaMo	RuPe	UlEu	Range in Elevation (m)	(ft)
Shipman								
Upper	12.99	99.57*	87.88			0.87	1795-2010	5880-6590
Middle	82.92*	96.88	54.38		2.50		1725-1920	5660-6300
Lower	94.15*	97.32	40.24		5.12		1615-1885	5300-6180
Liliuokalani								
Upper	66.67	100.00*	57.02		45.61		1615-1685	5290-5530
Lower	86.81*	21.98	22.53	23.63	13.74		1500-1615	4920-5300
Robertson et al.								
Upper	36.67	55.56	98.89*	15.00			1705-1895	5600-6220
Middle	34.78	91.30	96.14*	17.39	8.70		1575-1700	5160-5580
Lower	96.71*	13.15	2.82	30.05			1395-1565	4580-5130

*More than 50% of plots in unit in 25-50% cover abundance category

Key to alien plant species:
MiSt = Microlaena stipoides
AnDo = Anthoxanthum odoratum
PeCl = Pennisetum clandestinum
PaMo = Passiflora mollissima
RuPe = Rubus penetrans
UlEu = Ulex europaeus

Table 14. Sightings of rare and vulnerable plants along transects, primarily in the upper portion of Hakalau Forest National Wildlife Refuge, Spring 1987.*

Transect	Species and Notes	Location (Distance along transect)
1	Stenogyne calaminthoides (2 plants)	140 m
3	Pelea sp. (tree 10 m tall)	424 m
4	Stenogyne calaminthoides (in flower)	740 m
5	Stenogyne calaminthoides (in flower)	1,620 m
6	Stenogyne calaminthoides (large clump of plants, nibbled by cattle)	off transect
7	Stenogyne calaminthoides	1,900 m, 1,920 m, 1,960 m
10	Clermontia lindseyana (epiphyte, flowering and fruiting)	1,280 m
	Stenogyne calaminthoides	1,640 m
11	Clermontia lindseyana	2,600 m
12	Stenogyne calaminthoides	440 m
	Stenogyne macrantha	2,900 m
13	Cyanea pilosa	off transect in gulch near 5,900 m
	Cyrtandra paludosa	5,000 m
	Marattia douglasii	5,740 m, gulch
14	Cyrtandra platyphylla	4,750 m

*Plants found on and off established alien plant and ungulate activity transects. Many areas have not been adequately surveyed, especially in the heavily grazed areas of transects 1-9. The gulches that dissect the Refuge and heavily forested areas on transects 10-14 should be explored further.

sampling for rare plants. Further reconnaissance of gulches throughout the Refuge and heavily forested areas, especially on the lower parts of transects 10-14 on Liliuokalani, Piha, and Robertson et al. lands, should be done. Rare plants which may exist on the Refuge, including those especially vulnerable to ungulates and alien plants, are listed in Table 15. This list includes species known to have occurred at Hakalau in the past and species recently sighted on lands near Hakalau Refuge.

Permanent Vegetation Plots

As indicated previously (Table 2, p. 7), 6 plots were established to facilitate quantitative monitoring of the effects of management. Three (plots 1, 3, and 5) are in heavily grazed areas on transects 5, 10, and 13. In plot 1, where cattle were recently excluded, Dryopteris seems to be slowly recovering, but monitoring should be continued. The 3 lightly grazed plots were located below an old fence and thus have been protected from cattle for quite some time. One plot (no. 2) is located in an area with fairly high pig density on transect 13; plot 6, on transect 5, is in a nearly intact area with a high percentage of native ferns and tree and shrub seedlings. In general, the vegetation of higher elevation, heavily grazed plots (1, 3, and 5) was more open with alien grasses, and the lower elevation plots contained more ferns and woody plants.

The plots that have been heavily grazed by cattle (1, 3, 5) showed high alien grass cover (63.2-91.8%), little native shrub cover in the 1-2 m layer (0-3.5%), and a low percentage of exposed soil (0-1.1%) (Table 16; see Appendix F for species breakdown). Plot 5 is the least disturbed of the 3, with higher bryophyte (5.2%), lichen (3.6%), and litter (8.1%), as well as lower alien grass (63.2%) and higher native shrub cover (3.4 and 3.5%) than the others. Plot 4 is similar to plot 5 in most respects, except that native shrub cover in the <1 m stratum (9.6%) and 1-2 m stratum (20.2%) is higher than the same categories in plot 5.

Plot 2, chosen because pig activity in the area is high and cattle activity low (as well as for potential problems with Microlaena and Passiflora), showed the highest percentage of exposed soil (36.2%) of all plots. Native fern cover was higher in the <1 m stratum (20.1%) than in plots heavily grazed by cattle, and also higher in the 1-2 m stratum (11.2%). Native shrub cover in the 1-2 m stratum (12.4%) was much higher, and alien grass cover (17.5%) was lower than on plots heavily grazed by cattle.

Plot 6, as indicated, has high native fern cover (35.7%), a higher percentage of native shrubs in the 1-2 m stratum (15.2%) than most other plots, and the lowest percentage of alien grasses (8.2%) of the 6 plots. The high percentage of litter (45.5%) is indicative of lack of disturbance by pigs and cattle there.

Table 15. Rare and vulnerable plants not found during the present survey that may occur on Hakalau Forest National Wildlife Refuge, Hawai'i.*

FERNS

LYCOPODIACEAE
- Lycopodium erubescens Brack.
- Lycopodium mannii (Hbd.) Skottsb.

JOINVILLEACEAE
- Joinvillea ascendens Brongn. & Gris.

MONCOTS

IRIDACEAE
- Sisyrinchium acre Mann

ORCHIDACEAE
- Anoectochilus sandvicensis Lindl.
- Liparis hawaiensis Mann

PALMAE
- Pritchardia beccariana Rock

DICOTS

GESNERIACEAE
- Cyrtandra lysiosepala (Gray) C. B. Clarke

LABIATAE
- Phyllostegia floribunda Benth.
- Phyllostegia vestita Benth.
- Stenogyne scrophularioides Benth. var. scrophularioides

LOBELIACEAE
- Clermontia peleana Rock
- Clermontia parviflora Gaud. ex Gray
- Clermontia pyrularia Hbd.
- Cyanea fernaldii Rock
- Cyanea longipedunculata Rock
- Cyanea shipmannii Rock
- Cyanea tritomantha Gray
- Trematolobelia grandifolia (Rock) Deg.

MYRSINACEAE
- Embelia pacifica Hbd.

RUTACEAE
- Pelea grandifolia (Hbd.) St. John & Hume
- Platydesma remyi (Sherff) Deg.
- Platydesma spathulata (Gray) Deg. Sherff & Stone

Table 15, continued.

RUBIACEAE
Gouldia terminalis (H. & A.) Hbd. var. *quadrangularis* Fosb.
SOLANACEAE
Nothocestrum longifolium Gray var. *rufipilosum* B. C. Stone
THEACEAE
Eurya sandwicensis Gray

*Includes plants that were listed as Candidates for Endangered Species status (U.S. Fish and Wildlife Service, 1985). Also listed are plants which are considered vulnerable to feral animals and alien plants. Some of these plants may occur at lower elevations on Liliuokalani and Robertson et al. tracts.

Table 16. Percent cover (from line intercept transects) in 2 vertical strata on 6 20- x 20-m semi-permanent plots, Hakalau Forest National Wildlife Refuge, Spring 1987 (species breakdown in Appendix F).

	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6	
Category	<1 m	1-2 m	<1 m	1-2 m	<1 m	1-2 m	<1 m	1-2 m	<1 m	1-2 m	<1 m	1-2 m
Native Ferns	8.6		20.0	11.2	3.3		6.3		7.3		35.7	
Native Shrubs			1.0	12.4	3.1	1.0	9.6	20.2	3.4	3.5	2.4	15.2
Bryophytes	0.6		12.6		3.6		4.8		5.2		5.0	
Alien Grasses	86.2		17.5		91.8		68.7		63.2		8.2	
Alien Herbs			0.2						1.8			
Alien Shrubs					0.2							
Logs	4.2		0.2						6.3		0.4	
Lichen									3.6			
Litter	0.4		12.3				9.2		8.1		45.5	
Soil			36.2				1.4		1.1		2.8	
	100.0	0.00	100.0	23.6	100.0	1.0	100.0	20.2	100.0	3.5	100.0	15.2

Plot 1: Heavily grazed, thick alien grass cover.
Plot 2: Forested area, cattle densities reduced because of fences.
Plot 3: Heavily grazed.
Plot 4: Forested area, cattle densities reduced because of fences.
Plot 5: Heavily grazed.
Plot 6: Forested area, cattle densities reduced because of fences.

Table 17. Densities of native and alien woody species in basal diameter classes <20 cm in 6 20- x 20-m semi-permanent plots, Hakalau Forest National Wildlife Refuge, Spring 1987.*

	NUMBER OF INDIVIDUALS																			
	Plot 2 (cm)				Plot 3 (cm)				Plot 4 (cm)				Plot 5 (cm)				Plot 6 (cm)			
SPECIES	<1	1-5	6-10	11-20	<1	1-5	6-10	11-20	<1	1-5	6-10	11-20	<1	1-5	6-10	11-20	<1	1-5	6-10	11-20
Koa	1				1				4	1										
ʻOhiʻa	99	121	22	12	82	65	4	2	105	96	3	8	23	17	3	10	10	74	30	11
ʻOlapa	20	14	13	10	3	1		1	42	2	1	2					3	1		1
Kolea									2	4	1			3			10	6	4	2
Pukiawe	26	15			36	12	1		62	46	3		1	1			83	28	16	8
Tree ʻohelo	53	34	3		144	10			497	31			67	13			150	65	9	3
ʻAkala	20	16			4												6	9	1	
Hapuʻu		1		1						3										
Blackberry					2								1							

* Woody plants ≤ 20 cm diameter absent on Plot 1.

Counts of woody plants <20 cm basal diameter according to size category in each of the 5 plots (plot 1 had no woody plants ≤20 cm basal diameter) indicated that in plots heavily grazed by cattle (3 and 5), larger plants were scarce or absent (Table 17). Smaller diameter (1-5 cm) trees were also less numerous compared with less disturbed plots. Tree 'ohelo (Vaccinium calycinum) and 'ohi'a were the most abundant species in the <1 m size class, but far less so in larger size categories. Seedlings initially may have responded to open conditions caused by grazing. Plot 2 showed similar data to heavily grazed plots, although woody plant diversity in the larger size categories appeared somewhat greater than in plots heavily grazed by cattle. Plot 4 showed high native shrub cover and a high density of shrub seedlings. This may be partly a function of site as well as comparatively low cattle impact. Plot 6, chosen for native fern cover and woody plant reproduction, showed the highest numbers of woody plants in larger size categories of all plots. Graphs of percent cover and woody plant density for the 6 plots are presented in Appendices G and H, and Braun-Blanquet cover values for all species in each plot are given in Appendix I.

Gallinaceous Birds and Raptors

Two short-eared owls or pueo (Asio flammeus), 3 Hawaii hawks or 'io (Buteo solitarius), 4 turkeys (Meleagris gallopavo), and 21 kalij pheasants (Lophura leucomelana) were observed along transects (Table 18). The 2 pueo were seen together in closed canopy koa-'ohi'a forest. One pair of 'io and a single bird were seen in open koa-'ohi'a. Turkeys were observed in groups of 2, 4, 4, and 3, and one single bird. The observations of more than 2 birds at a time and the single bird were in open to very scattered koa or koa-'ohi'a. The two-bird observation was in closed canopy koa-'ohi'a. Of the 14 observations of 21 kalij peasants, 3 observations were of paired birds, and one was of a group of 5 birds. Nine observations were of single birds, and an additional one hen with chicks was seen. Eleven of the birds were seen in closed canopy koa-'ohi'a, including the hen with chicks. Eight birds were observed in open canopy koa-'ohi'a or koa, and the remaining 2 birds were seen in scattered koa-'ohi'a. Although sample sizes are small and observations were undoubtedly biased by variations in openness of forests and topography, it seems likely that there are more turkeys in open to scattered vegetation and more kalij pheasants in closed canopy vegetation types in spring on the Refuge.

DISCUSSION AND RECOMMENDATIONS

Hakalau Forest National Wildlife Refuge harbors substantial populations of 3 endangered bird species ('akepa, akiapola'au, and Hawaii creeper) and significant numbers of non-endangered native forest birds including 'omao, 'elepaio, 'i'iwi, and 'apapane. The koloa or Hawaiian duck (Anas wyvilliana) is also present. In addition, small numbers of the endangered 'io are resident, and the endangered 'o'u may

Table 18. Sightings of gallinaceous birds and raptors by transect, vegetation type, and elevation, Hakalau Forest National Wildlife Refuge, Spring 1987. (Vegetation types after Jacobi, in press.)

Transect	Vegetation Type	Elevation (m)	Elevation (ft)	Species and Numbers Seen*
1	C3Ac-Me,2NT(ns-xg)	1720-1780	5640-5850	2 Pueo
3	C3Ac-Me,2NT(ns-xg)	1740-1800	5700-6200	1 Kalij; 1 Kalij
4	C3Ac-Me,2NT(ns-xg)	1740-1870	5700-6150	2 Turkeys
5	C3Me,Ac,2NT(ns-xg)	1750-1910	5750-6280	1 Kalij; 2 Kalij
6	O3Ac-Me,2NT(xg,ns)	1890	6200-6210	5 Kalij
8	OcMe,Ac(xg-nf)	1820-1890	5960-6190	1 Kalij
	VS3Ac,2NT(xg)	1980	6500	4 Turkeys
11	C3Ac-Me,2NT(ns)	1520-1620	4990-5300	1 Kalij; 1 Kalij; 1 Kalij; 1 Kalij
12	C3Ac-Me,2NT(ns-xg)	1510-1650	4950-5400	1 Kalij
	C3Ac-Me(xt-pm-ns)	1690-1890	5530-6190	1 Kalij with chicks
13	O3Ac-Me,2NT(xg,ns)	1760-1800	5770-5930	4 Turkeys
	O3Ac-Me,2NT(xg-nf)	1880	6160	2 'Io
	O3Ac-Me,2NT(xg-nf,ns)	1570-1840	5160-6050	1 'Io
14	O3Ac-Me,2NT(xg,ns)	1680-1750	5510-5750	3 Turkeys; 1 Turkey; 2 Kalij
	S3Ac-Me,2NT(xg)	1770-1900	5820-6220	2 Kalij
Total				40 birds

*Individual observations are listed, so social relationships may be seen.

also be present. Large areas of relatively intact plant communities exist below the grazed upper refuge lands, and the status of various rare plants has not been determined. Scott et al. (1985) suggested removal of alien plants and animals to improve habitat of all endangered avian species in Hawai'i. Results of their studies and those of other investigators (e.g., see Stone and Scott 1985) suggested that forest birds and plants in general are adversely affected by alien plants and animals in a number of ways.

The Refuge cannot support native birds over the long term if forests are not allowed to regenerate. Koa reproduction can be completely suppressed by cattle (Baldwin and Fagerlund 1943; Cuddihy 1984; Scott et al. 1986), and cattle have converted large tracts of forest to open pasture throughout Hawai'i. Feral pigs also degrade forests, affecting birds such as the 'elepaio and 'omao, that feed in understory (Scott et al. 1986), but eventually changing conditions for all native species. Pigs also disperse alien plants such as banana poka (Warshauer et al. 1983), as do kalij pheasants (Lewin and Lewin 1984) and probably wild turkeys (Scott et al. 1986).

Banana poka can smother large tracts of native forest, and 'omao, 'elepaio, and Hawai'i creeper densities may be lower in infested areas (Scott et al. 1986). Alien grass species prevent regeneration of native woody plants including forest dominants such as koa and 'ohi'a and ultimately prevent forest regeneration vital to future forest bird habitat.

Ungulate Management

Cattle--Cattle should be removed from the Refuge as soon as possible in order to allow forest regeneration to begin. As noted by Cuddihy (1984), removal of cattle does not necessarily result in reduction of alien plants. Elimination of animals from lower elevations and from the northern portions of the Refuge (Liliuokalani Trust, Robertson et al., and The Nature Conservancy parcels) should be given priority because these areas are not dominated by alien understory as much as upper elevations and sites on the southern portion of the Refuge. Closed canopy forests which have the potential for shading out some alien grasses and blackberry (which will increase as cattle are removed), should also be emphasized. Continued grazing will result in increased expense in meeting Refuge objectives for forest bird management in the future.

Feral pigs--Feral pig management should also begin as soon as possible on the Refuge. As with cattle foraging, continual disturbance by pigs will result in continued degradation of the understory and inhibition of native plant reproduction. Because cattle have helped to open many areas, hunting of pigs with dogs is now facilitated. As cattle are removed, understory vegetation will increase and hunting will become more difficult.

Eradication of feral pigs in large areas is only possible when management units surrounded by pig-proof fences are established. In rain forest habitat, the size of such management units (where systematic hunting with dogs is the control method) has generally been 400-1,200 ha (1,000-3,000 a). Eradication is necessary because the high reproductive potential of feral pigs can result in rapid repopulation of an area, even when just a few pigs remain. The cost of monitoring management areas for ingress will be a continual emphasis where sustained yield management of pigs for hunting is practiced on surrounding lands. Monitoring of fences for integrity and management areas for pig ingress from surrounding areas should be part of the management plan and budgeted for. Fencing with 102-cm (40-in) woven wire fence in rain forests costs on the order of $24,000/km in Hawai'i plus survey costs. All fences should be checked at least once per month by crews prepared for on-site repair.

We recommend that 11 units, ranging from about 700 to about 2,100 a in size, be established (Fig. 3 and Appendix J). Four management units (nos. 8-11) should be created through fencing on the north end of the Refuge on Robertson et al. and The Nature Conservancy parcels. Three units (nos. 5-7) could be established on Liliuokalani Trust land (with partial use of existing fences) and 4 (1-4) on the Shipman area (using existing fences). Emphasis should be placed on establishing makai units (on Liliuokalani Trust and The Nature Conservancy parcels especially) where forest integrity and reclamation potential are highest. Even if populations of native forest birds are now greatest in some mauka units, the future of the Refuge for birds depends upon regeneration of dominants and native forest. This is most readily accomplished in least modified areas. It is desirable to actively manage all parts of the Refuge if funds allow, of course, but prioritization will undoubtedly be necessary.

Feral pig management within management units should take advantage of a number of approaches. Systematic hunting with dogs is likely to be the most cost effective method of pig control, but a distinction must be made between <u>public</u> hunting and <u>systematic</u> hunting. Public hunting sometimes reduces feral pigs in accessible areas and temporarily near human access points. It is also a good public relations tool. However, it should not be used instead of an effective, long-term, pig population reduction or eradication program. Long-term reduction and eradication can be achieved only by systematic hunting in which dogs and hunters are required to return to hard-to-hunt areas and continue to reduce pig populations. Public hunters normally go to new areas once hunting becomes difficult and/or wait for pig numbers to increase to ensure individual hunter success. Public hunters sometimes castrate and/or release small pigs for future hunts, and emphasis is not placed on killing all animals encountered. In addition, hunters who are not part of a systematic program normally spend a great deal of time

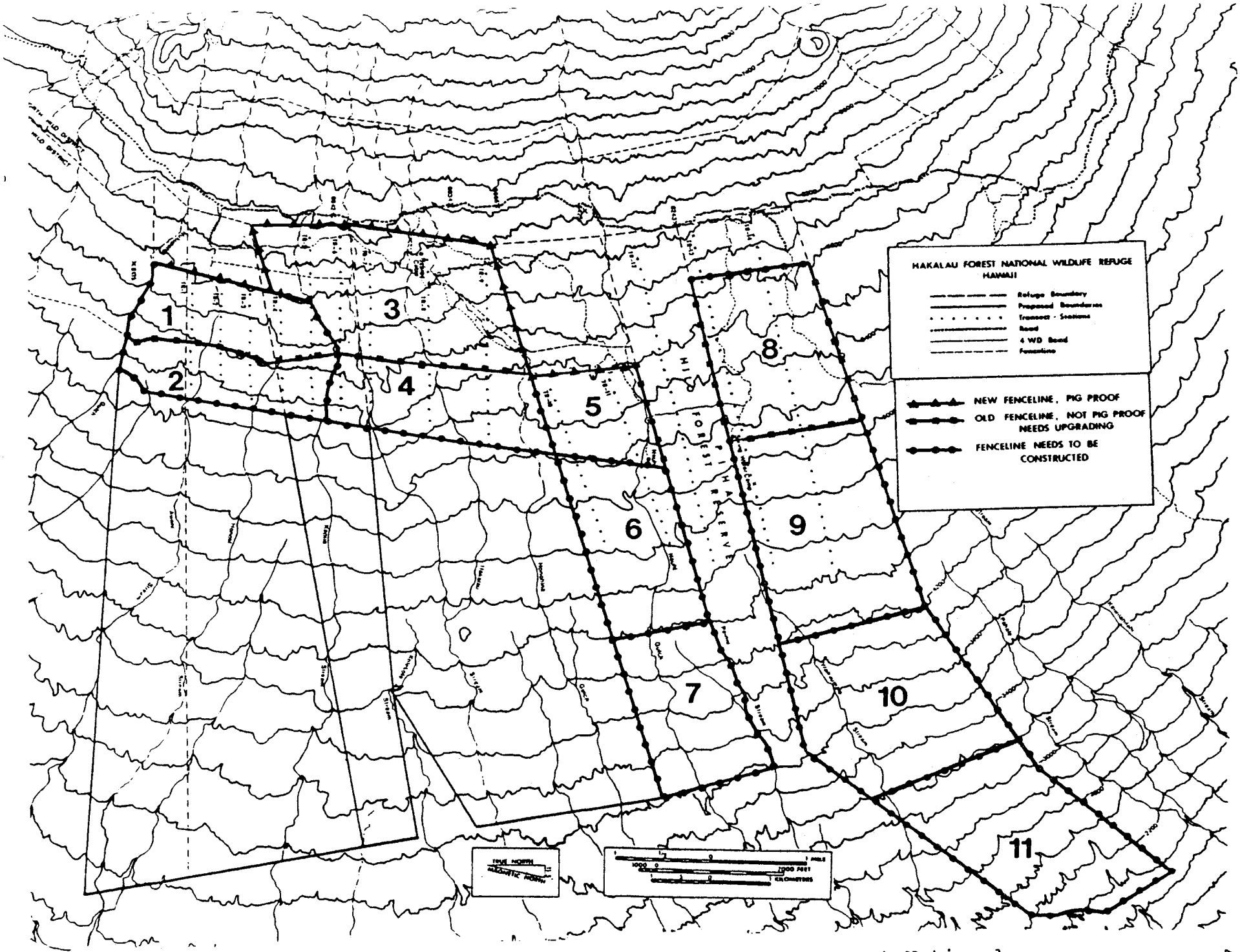

Figure 3. Suggested management units, Hakalau Forest National Wildlife Refuge.

field-dressing and removing animal carcasses. In systematic control programs, use of animals for food or trophy is not a primary objective.

A systematic approach to feral pig removal within fenced management units requires that population reduction methods be varied, responsive to progress in the program, and innovative. Snaring, trapping, baiting, use of exit gates or ramps, wing fences, and other methods of reducing numbers are often necessary. Data collection and analysis provide necessary feedback to evaluate progress. Scouting of management areas for recent pig activity is part of the process. Collection of data on pig activity along systematically established transects (with additional transects in key areas) at 2-4 mo intervals is essential. Determination of population characteristics (from killed animals) as control proceeds, and knowledge of removal rates are useful in detecting population responses to control efforts. The Refuge program should include a systematic and thorough approach so that management progress can be monitored and success in reducing animals achieved.

As pig numbers become very low in a management unit, knowledge of the habits of individual pigs is sometimes needed; a great deal of effort and money may be used to remove one animal. Patience is necessary, methods of control must be varied, and monitoring must be intensified. It is important to be able to determine from monitoring whether reproduction (or ingress) is occurring more rapidly than removal. If so, the population will likely build up again, unless control efforts and efficiency are increased.

Alien Birds

Although reduction of kalij pheasants and wild turkeys in natural areas has not yet been attempted in Hawai'i, these birds should be viewed as distributors of banana poka and possibly other alien plants rather than as game species. A study of their food habits could be made on the Refuge, and in the process the alien bird populations should be reduced to some degree. While it is unlikely that eradication can be achieved, even in small areas, reduction should be considered for these species in the more intact management units, at least sometime in the future.

Alien Plants

Systematically established transects monitored for ungulates within management units can also be used to monitor alien plant ingress and spread. Additional transects could be established in some vegetation types and units (for example where large numbers of gorse plants are near the Shipman parcel boundary). Monitoring of alien plant and ungulate occurrence could be combined with fence checks. Roads and other points of ingress to the Refuge should also be checked periodically for alien plant introductions. In addition to gorse, potential threats to the Refuge include fountaingrass

(Pennisetum setaceum), fire tree (Myrica faya), clidemia (Clidemia hirta), strawberry guava (Psidium cattleianum), and mullein (Verbascum thapsus); these species are not yet present but capable of invading. Additional surveys of gulches for rare plants should be combined with checking for alien plant foci. Some on-site research on the effect on native woody plant regeneration of removing alien grasses with herbicides should be initiated.

Control of alien plants should emphasize outlying or new populations within management units, rather than central infestations. In some locations, removal of ungulates and the shading that occurs from native woody plant recruitment after ungulates are removed will eventually reduce alien plants ecologically. However, some plants such as banana poka, blackberry, and gorse should be aggressively attacked within management units with existing manual and chemical methods. P. Motooka, University of Hawai'i College of Tropical Agriculture, Captain Cook, is a good source of chemical methodology; current research on banana poka and blackberry is also in progress in Hawai'i Volcanoes National Park (G.L. Santos and L.W. Cuddihy). Sources of plant and feral pig management expertise include T. Tunison, L. Katahira, and D. Taylor (Hawai'i Volcanoes National Park). Authorities on biological control research for some of the species of concern include G. Markin (U.S. Forest Service) and D. Gardner and C.W. Smith (National Park Service, Honolulu, and University of Hawai'i/Manoa).

The upper Liliuokalani parcel should be especially monitored for increase in blackberry and banana poka subsequent to cattle removal. This species is already abundant there. Use of ROUNDUP has proven moderately effective in blackberry control in Hawai'i Volcanoes National Park (Santos et al. 1986).

The effect of native tree plantings on alien grasses and other species should also be watched in this area. In any propagation efforts, it is important to use seed from Hakalau or the immediate vicinity, as the varieties and subspecies of the dominant tree species of Hakalau Refuge (Metrosideros polymorpha, Acacia koa, Sophora chrysophylla) may differ from those elsewhere on the Island (or on other islands). Because banana poka is very abundant in the State Piha Game Management Unit and the shape of the Unit creates considerable edge for banana poka to spread further into the Refuge, increased monitoring and control along Piha borders will be necessary. High feral pig numbers in the Piha area also pose a threat to Refuge ecosystems and present a conflict in land management goals which is not easy to resolve. The present situation seems difficult for both hunters and Refuge personnel. Should the opportunity arise to trade Piha for other lands or to change State management goals so that they will be more compatible with preserving the biological heritage of a larger area, it would ease potential conflicts.

Facilities and Personnel

Existing roads on the Refuge should be improved for more dependable access in wet weather. No new roads should be constructed unless absolutely necessary, especially not in the more intact parts of the Refuge. Vehicles and people should be monitored for alien plant propagules, especially when coming from nearby areas with fountaingrass and gorse infestations.

The new shelter at 1,920 m (6,300 ft) should be completed and expanded to accommodate more personnel. A water catchment system is still needed. (G.L. Santos has recently designed an inexpensive system for use at several shelters in Kipahulu Valley, Haleakala National Park.) Nauhi Camp shelter could be improved to serve as a base camp for management and research, but the road will need to be capable of supporting consistent access. No new shelters should be constructed until land acquisition is complete and management needs, emphases, and support can be better determined.

Visiting managers, researchers, administrators, and dignitaries should be made aware of the threats of introducing new alien plant species to the Refuge. Educational materials should be developed to explain Refuge problems and programs as well as significant natural resources. The Hawai'i Research Station (USFWS) and/or University of Hawai'i personnel should be involved in future management-oriented research and monitoring, especially long-term efforts. The Animal and Plant Health Inspection Service (APHIS) in Honolulu and on the Big Island handles animal damage problems on contract and is currently developing a feral pig management plan for the Hawai'i Natural Area Reserves System (NARS). This agency is a possible source of active and administrative help, should Refuge staffing be inadequate for a time. The Hawaii Volcanoes National Park Service research and management staff will be pleased to cooperate where possible in the future.

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APPENDIX A

Locations and azimuths of transects used
in survey of feral ungulates and alien and native plants,
Hakalau Forest National Wildlife Refuge, Spring 1987*

Transect No.*	Azimuth	Distance from Fenceline to First Station	Distance from cabin junction to start of transect
1	64	*	
2	64	*	
3	64	*	
4	64	*	
5	64	stn 33, 254 m from fenceline	
6	64	stn 133, 243 m from fenceline	
7	64	stn 55, 231 m from fenceline	
8	64	stn 78, 233 m from fenceline**	
9	64	stn 100, 314 m from fenceline	0.8 mi
10	64	***. Stn 122, 78 m from fenceline	
11	64	***. Stn 138, 130 m from fenceline	
12	75	stn 189, 267 m from fenceline	2.6 mi
13	75	stn 218, 275 m from fenceline	3.2 mi
14	75	stn 249, 232 m from fenceline	3.95 mi

*NOTE: Transects 1-4 are best accessed from Transect 5, station 38. From stn 38 follow the azimuth of 334. Tr 4, stn 163 is 500 m from stn 38. Tr 3, stn 17 is 500 m from stn 163. Tr 2, stn 154 is 500 m from stn 17. Tr 1 stn 1 is 500 m from stn 154.

**Access to TR 8 is 200 m north of cattle gate and corral at entrance to Hakalau Cabin.

***Access to Transects 10-11 is from the upper south boundary corner of Liliuokalani Tract land. Follow the fenceline for 500 m to the start of Tr 10. From Tr 10 go another 1000 m along fenceline to Tr 11.

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APPENDIX B

Criteria for determining age of feral pig and cattle sign on Hakalau Forest National Wildlife Refuge, Spring 1987.

A. Digging

Fresh - fluffy soil, small soil clumps on rootlets; fresh dung or well-defined tracks near; litter distribution uneven or different from surroundings; dug area moist (variable with weather).

Intermediate - no seedlings sprouted or with cotyledons only; scattered litter. Intermediate tracks or dung near.

Old - seedlings emerging in area; litter cover uniform and/or accumulating in pits; dug up plants dry, not green unless rerooting.

Pigs often dig more deeply, seek rhizomes or earthworms, and cover a larger area than cattle.

B. Trails

Fresh - green and broken vegetation, fresh dung or tracks near. Pig odor sometimes apparent.

Intermediate - dead vegetation, trampled, broken, or beat. No obvious sign or intermediate sign.

Old - untrampled look, seedlings emerging, vegetation growing again.

Pig trails often narrower, more surrounding vegetation, go under logs, etc. Cattle trails often deep, obvious through pasture areas especially. Obvious differences between small, narrow pig tracks and large, rounded cattle tracks.

C. Plant Feeding

Fresh - moist surfaces evident, vegetation not brown; fresh tracks or dung near. Visible tooth marks. Pig odor sometimes evident.

Intermediate - discolored surfaces, partly dried areas of plants. No other sign or intermediate sign.

Old - dried plants, regrowth, algae or litter on surface in some cases. Area not disturbed around feeding site. No other sign or old sign.

Pigs feed on hapu'u, fruits, tender shoots of koa, and fern rhizomes and orchid and lily bulbs. Cattle prefer grasses, sedges, herbs, but also take young woody plants. Look for other sign if in doubt.

Appendix B, continued.

D. Dung

Fresh - odor evident, steaming (depends on temperature), small flies in clouds around pile, other insects. Fresh tracks or feeding or digging near. Mucous or shiny appearance (depends on weather too).

Intermediate - little or no insect activity. Squishable with foot, centers (of cow pies) often soft. Intermediate or no sign nearby. Thin crust forms over cow pies; undersurface often very moist.

Old - hardened, not moist, eroded and fragmented. Seedlings or grass shoots emerging from pile or under it. Dung beetles. Not squishable (except partly in moist weather). Can throw a long distance without adverse results.

Large cattle "pies" typically fresh to intermediate, "chips" when older. Pigs and small calves have partially segmented feces. Look for additional sign nearby and composition of dung. Cattle often much more grass or finely divided material (prolonged digestion in 4 stomachs). Pig dung coarser.

APPENDIX C

Forms used in survey of alien plants and animals on Hakalau Forest National Wildlife Refuge, Spring 1987

HAKALAU FOREST NWR
ANIMAL ACTIVITY TRANSECTS
(Pig and Cattle Activity)

DATE:_____
LOCATION:_____
OBSERVERS:_____
WEATHER:_____

METER	Digging (F-I-O)	Trail (F-I-O)	Hapu'u (F-I-O)	Other Plants (F-O)	Scats (F-O)	Miscellaneous (Fresh) (sight, sound beds, rubs, wallows, etc.)

HAKALAU FOREST NWR
ALIEN PLANT TRANSECTS (FOREST AREA)

c = in canopy
fl = flowering
fr = fruiting

COVER-ABUNDANCE
<5% cover - few indiv.
5-50% cover - common
25-50% cover - numerous, abundant

DATE:_____
LOCATION:_____
OBSERVERS:_____
WEATHER:_____

METERS	DRY COR	ERE VAL	EUP ADE	HOL LAN	HYP RAD	JUN EFF	MIC STI	OXA COR	PAS MOL	PEN CLA	POL PUN	RUB PEN	RUM ACE	YOU JAP	NOTES

HAKALAU FOREST NWR
ALIEN PLANT TRANSECTS (PASTURE AREA)

c = in canopy
fl = flowering
fr = fruiting

COVER-ABUNDANCE
<5% cover - few indiv.
5-50% cover - common
25-50% cover - numerous, abundant

DATE:_____
LOCATION:_____
OBSERVERS:_____
WEATHER:_____

METERS	ANT ODO	HOL LAN	HYP RAD	LYR MAR	MIC STI	PAS MOL	PEN CLA	RUB PEN	RUM ACE	SAC IND	SPO AFR	VER PLE	VER SER	YOU JAP	NOTES

HAKALAU FOREST NWR
VULNERABLE AND RARE PLANT TRANSECTS

c = in canopy
fl = flowering
fr = fruiting

COVER-ABUNDANCE
<5% cover - few indiv.
5-50% cover - common
25-50% cover - numerous, abundant

DATE:_____
LOCATION:_____
OBSERVERS:_____
WEATHER:_____

METERS	ANO SAN	CLE PEL	CLE LIN	CLE PYR	CYA LON	CYA TRI	EMB PAC	JOI ASC	LIP HAW	NOT LON	PHY RAC	PHY VES	PLA REM	PLA SPA	STE SCO

NOTES AND ADDITIONS:_____

HAKALAU FOREST NWR
20 x 20 m PLOT, CHECKLIST, AND BRAUN-BLANQUET COVER ABUNDANCE SCALE

DATE:_____
LOCATION:_____
DISTANCE ON TR:_____
OBSERVERS:_____
ELEVATION:_____
WEATHER:_____

LAYER	SPECIES	B-B COVER VALUE

HAKALAU FOREST NWR
20 x 20 m PLOT, 50 m LINE-INTERCEPT TRANSECTS

DATE:_____
LOCATION:_____
DISTANCE ON TR:_____
OBSERVERS:_____
ELEVATION:_____
WEATHER:_____

SPECIES	DISTANCE ALONG TRANSECT <1 m ht	1-2 m ht	% COVER lower layer	upper layer

HAKALAU FOREST NWR DENSITY PLOTS

DATE:_____
LOCATION:_____
DISTANCE ON TR:_____
OBSERVERS:_____
ELEVATION:_____
WEATHER:_____

	BASAL DIAMETER <1 cm		BASAL DIAMETER >1 cm.								
	Height		Basal Diameter								
SPECIES	<10	>10	1-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80

APPENDIX D

Alien plants found on pig activity and alien plant transects, Hakalau Forest National Wildlife Refuge, Spring 1987.

	TRANSECT													
SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ageratina riparia				*							*	*	*	*
Agrostis alba							*							
Anthoxanthum odoratum	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Axonopus affinis	*	*	*		*	*	*	*	*	*	*		*	*
Cardamine flexuosa				*								*	*	*
Casuarina sp.												*		
Chamaecyparis lawsoniana												*		
Cirsium vulgare							*		*			*	*	*
Crassocephalum crepidioides													*	
Cryptomeria japonica												*		
Cuphea carthagenensis										*		*		*
Dactylis glomerata										*				
Eleocharis radicans													*	
Eragrostis brownei					*	*		*						
Erechtites valerianaefolia											*	*	*	*
Eucalyptus sp.												*		
Fraxinus uhdei												*		
Fuchsia magellanica												*		
Geranium carolinianum	*					*			*	*	*	*	*	*
Holcus lanatus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydrocotyle sibthorpioides											*		*	*
Hydrocotyle verticillata	*	*	*	*	*		*		*	*	*		*	
Hypericum sp.													*	
Hypericum degeneri													*	
Hypericum mutilum	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hypochoeris radicata	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Juncus effusus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Juncus planifolius													*	
Juncus tenius		*	*	*	*	*	*	*	*	*	*	*	*	*

Appendix D, continued.

	TRANSECT													
SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lonicera japonica											*			
Lotus angustissimus													*	
Lotus corniculatus								*						
Lotus uliginosus													*	
Ludwigia palustris						*			*				*	*
Lythrum maritimum														*
Microlaena stipoides	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Modiola caroliniana									*					
Nasturtium microphyllum											*			
Oxalis corniculata							*		*			*		*
Paspalum urvillei							*						*	
Passiflora mollissima											*	*		*
Pennisetum clandestinum	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Plantago lanceolata													*	
Plantago virginica											*		*	
Platanus sp.												*		
Poa annua	*	*	*	*	*	*	*	*		*	*	*	*	*
Poa pratensis								*					*	
Polygonum punctatum		*	*	*	*	*			*	*	*	*	*	*
Prunella vulgaris		*				*				*	*			*
Prunus cerasus												*		
Prunus sp.												*		
Ranunculus muricatus											*	*	*	
Rosaceae (unknown)											*	*		
Rubus penetrans		*	*	*	*	*	*	*	*	*	*	*	*	*
Rubus rosaefolius	*	*	*	*	*	*				*	*	*	*	*
Rumex acetosella		*	*	*	*	*	*	*	*	*	*	*	*	*
Rumex crispus				*								*	*	*
Senecio sylvaticus												*	*	*
Solanum nigrum														*
Solanum tuberosum													*	
Sporobolus africanus													*	

Appendix D, continued.

	TRANSECT													
SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Stellaria media														*
Trifolium repens					*	*	*	*	*				*	
Ulex europaea					*				*					
Verbena litoralis													*	
Veronica arvensis													*	
Veronica plebeia	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Veronica serpyllifolia	*	*	*	*	*	*	*	*	*	*	*	*	*	*

APPENDIX E

VASCULAR PLANTS OF HAKALAU FOREST NATIONAL WILDLIFE REFUGE, HAWAII

This is a preliminary plant checklist of vascular plants in the Hakalau Forest National Wildlife Refuge as of Spring 1987. Some of the information is from a list compiled by F.R. Warshauer in 1979, from field data collected by the U.S. Fish and Wildlife Service (USFWS) Forest Bird Survey. Additional information has been gathered from USFWS and others. Those taxa observed during the current survey (Spring 1987) are designated with an X.

For each of the taxa listed, the following categories have been included:

STATUS (S)
- E = Endemic
- I = Indigenous
- P = Polynesian introduction (pre 1778)
- A = Alien, Historical introduction (post 1778)

COMMON NAME (CN)
- Hawaiian or English name is given

LIFE FORM (LF)
- f = fern or fern-like
- h = herb
- g = grass-like (includes grasses, sedges, rushes)
- s = shrub
- t = tree
- l = liana, vine

PLANTS OF INTEREST OR CONCERN (*, **)
- * = rare, vulnerable, or Federally listed Threatened, Endangered, and Candidate Endangered plants that have been found in or near the Preserve.
- ** = alien plant species that should be of concern to the preserve manager and workers.

NOTE: For information on these plants see references below and in Literature Cited. Fern nomenclature follows C.H. Lamoureux (unpubl.) and other sources. Flowering plant and gymnosperm nomenclature largely follows St. John (1973). For information on Forestry plantings in the Hakalau and Piha areas, see R.G. Skolmen 1979, Plantings on the Forest Reserves of Hawaii 1910-1960. Institute of Pacific Islands Forestry, U.S. Forest Service, Honolulu, Hawaii.

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
PSILOPHYTA				
PSILOTACEAE: Psilotum Family				
Psilotum complanatum Sw.	moa	I	f	X
Psilotum nudum (L.) Beauv.	moa, pipi	I	f	X
LYCOPHYTA				
LYCOPODIACEAE: Club Moss Family				
Lycopodium cernuum L.	wawae-'iole	I	f	x
Lycopodium erubescens Brack.		E	f	
Lycopodium serratum Thunb.		E	f	
SELAGINELLACEAE: Small Club Moss Family				
Selaginella arbuscula (Kaulf.) Spring	lepelepe-a-moa	E	f	X
PTERIDOPHYTA				
ADIANTACEAE: Maidenhair Fern Family				
Adiantum capillus-veneris L.	'iwa'iwa	I	f	
Adiantum cuneatum Langsd. & Fischer	maidenhair fern	A	f	
ASPIDIACEAE: Shield Fern Family				
Arachniodes carvifolia (Kunze) Ching		I	f	X
Ctenitis rubiginosa (Brack.) Copel.		E	f	X
Dryopteris fusco-atra (Hbd.) Rob.		E	f	X
Dryopteris glabra (Brack.) O. Kuntze	kilau	E	f	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
Dryopteris hawaiiensis (Hbd.) Rob.		E	f	X
Dryopteris wallichiana (Spreng.) Hyl. Alston	lau-kahi	I	f	X
Dryopteris unidentata (Hook. & Arn.) C. Chr.	ʻakole	E	f	X
Polystichum hillebrandii Carruthers	papaʻoi	E	f	
ASPLENIACEAE : Spleenwort Family				
Asplenium contiguum Kaulf.		E	f	X
Asplenium lobulatum Mett.	piʻipiʻi-lau manamanaʻanaliʻi	I	f	X
Asplenium macraei Hook. & Grev.		E	f	X
Asplenium normale Don		I	f	X
Asplenium polyodon Forst. W.		?	f	X
Asplenium rhipidoneuron Rob.	ʻiwaʻiwa-a-kane	I	f	
Asplenium schizophyllum C. Chr.		E	f	X
Asplenium unilaterale Lam.	pamoho	I	f	
ATHYRIACEAE: Lady Fern Family				
Athyrium microphyllum (Sm.) Alston	ʻakolea	E	f	X
Diplazium sandwichianum (Presl) Diels	hoʻiʻo	E	f	X
BLECHNACEAE: Blechnum Family				
Sadleria cyatheoides Kaulf.	ʻamaʻu, ʻamaʻumaʻu	E	f	X
Sadleria pallida Hook. & Arn.	ʻamaʻu, ʻamaʻumaʻu	E	f	X
Sadleria souleyetiana (Gaud.) Moore	ʻamaʻu, ʻamaʻumaʻu	E	f	X
Sadleria squarrosa (Gaud.) Moore	ʻamaʻu	E	f	
DENNSTAEDTIACEAE				
Microlepia strigosa (Thunb.) Presl	palapalai, palai	I	f	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
DICKSONIACEAE: Dicksonia Family				
Cibotium chamissoi Kaulf.	hapu'u'i'i, i'i	E	f	X
Cibotium glaucum (J. Sm.) Hook. & Arn.	hapu'u pulu	E	f	X
Cibotium hawaiense Nakai & Ogura	meu	E	f	
ELAPHOGLOSSACEAE:				
Elaphoglossum alatum Gaud. var. parvisquamium (Skottsb.) Anderson & Crosby	'ekaha	E	f	X
Elaphoglossum crassifolium (Gaud.) Anderson & Crosby	'ekaha	E	f	X
Elaphoglossum hirtum (Sw.) C. Chr. var. micans (Mett.) C. Chr.	'ekaha	E	f	X
Elaphoglossum wawrae (Luerss.) C. Chr.	'ekaha	E	f	X
GLEICHENIACEAE: Uluhe Family				
Dicranopteris linearis (Burm.) Underw.	uluhe	I	f	X
Diplopterygium pinnata (Kunze) Nakai	uluhe-lau-nui	I	f	X
Sticherus owhyhensis (Hook.) Ching	uluhe	E	f	X
GRAMMITIDACEAE: Grammitis Family				
Adenophorus hymenophylloides (Kaulf.) Hook. & Grev.	pai, palai-la'au	E	f	X
Adenophorus pinnatifidus Gaud.	kihi, kihe	E	f	X
Adenophorus tamariscinus (Kaulf.) Hook. & Grev.	wahine-noho-mauna	E	f	X
Adenophorus tripinnatifidus Gaud.	wahine-noho-mauna	E	f	X
Grammitis hookeri (Brack.) Copel.	maku'e-lau-li'i	E	f	X
Grammitis tenella Kaulf.	kolokolo	E	f	X
Xiphopteris saffordii (Maxon) Copel.	mahine-lua	E	f	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
HEMIONITIDACEAE:				
Coniogramme pilosa (Brack.) Hieron.	lo'ulu	E	f	X
HYMENOPHYLLACEAE: Filmy Fern Family				
Mecodium recurvum (Gaud.) Copel.	'ohia ku	E	f	X
Sphaerocionium lanceolatum (Hook. & Arn.) Copel.	palaihinahina	E	f	X
Sphaerocionium obtusum (Hook. & Arn.) Copel	palai-lau-li'i	E	f	
Vandenboschia davallioides (Gaud.) Copel.	kilau, kalau, palahihi	E	f	X
HYPOLEPIDACEAE				
Hypolepis punctata (Thunb.) Mett.	olua	I	f	X
Pteridium aquilinum (L.) Kuhn var. decompositum (Gaud.) Tryon	kilau-a-pueo, brackenfern	E	f	X
LINDSAECEAE: Lindsaea Family				
Sphenomeris chinensis (L.) Maxon	pala'a	I	f	X
MARATTIACEAE: Marattia Family				
* Marattia douglasii (Presl) Baker	pala	I	f	X
NEPHROLEPIDACEAE: Swordfern Family				
Nephrolepis cordifolia (L.) Presl	ni'ani'au	I	f	X
POLYPODIACEAE: Polypody Family				
Pleopeltis thunbergiana Kaulf.	'ekaha-'akole, pakahakaha	I	f	X
Polypodium pellucidum Kaulf. var. pellucidum	'ae	E	f	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
PTERIDACEAE				
Pteris cretica L.	owali'i	I	f	X
Pteris excelsa Gaud.	waimaka-nui, iwa	E	f	X
Pteris irregularis Kaulf.	mana	E	f	
THELYPTERIDACEAE: Thelypteris Family				
Amauropelta globulifera (Brack.) Holtt.	palapalai-a-kama-pua'a	E	f	X
Christella cyatheoides (Kaulf.) Holtt.	kikawaio, pakikawaio kupukupu-makali'i	E	f	
Pseudophegopteris keraudreniana (Gaud.) Holtt.	waimaka-nui	E	f	X
Pneumatopteris sandwicensis (Brack.) Holtt.	ho'i'o-kula	E	f	X
GYMNOSPERMAE				
CUPRESSACEAE: Cypress Family				
Chamaecyparis lawsoniana	Port Orford cedar	A	t	X
TAXODIACEAE: Taxopdium Family				
Cryptomeria japonica (L.f.) D. Don	sugi, tsugi	A	t	X
Cunninghamia lanceolata (Lamb.) Hook.	China fir	A	t	X
Sequoia sempervirens (D. Don in Lamb.) Endl.	coast redwood	A	t	X
MONOCOTYLEDONAE				
ARACEAE: Arum Family				
Zantedeschia aethiopica (L.) Spreng.	calla lily	A	h	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
COMMELINACEAE: Spiderwort Family				
Commelina diffusa Burm.	day flower	A	h	
CYPERACEAE: Sedge Family				
Carex alligata F. Boott		E	g	X
Carex macloviana D'Urv.	St. Malo's sedge	I	g	X
Carex wahuensis C.A. Mey. var. rubiginosa R. W. Krauss		E	g	X
Cyperus brevifolius (Rottb.) Hassk.	kyllinga	A	g	
Cyperus haspan L.		A	g	X
Eleocharis obtusa (Willd.) Schult.	pipi wai, kohekohe	I	g	X
Eleocharis radicans (Poir.) Kunth		A	g	X
Machaerina angustifolia (Gaud.) Koyama	'uki	I	g	X
Uncinia uncinata (L. f.) Kuek.		I	g	X
GRAMINEAE: Grass Family				
Agrostis alba L.	red top grass	A	g	X
Agrostis avenacea Gmel.		A	g	X
Andropogon virginicus L.	broomsedge	A	g	
Anthoxanthum odoratum L.	sweet vernal grass	A	g	X
Avena fatua L.	wild oat	A	g	X
Axonopus affinis Chase	narrow-leaved carpetgrass	A	g	X
Dactylis glomerata L.	orchardgrass	A	g	X
Deschampsia australis Nees ex Steud.		E	g	X
Eragrostis brownei (Kunth) Nees in Hook. & Arn.	Brown's lovegrass	A	g	X
Holcus lanatus L.	velvetgrass	A	g	X
Isachne distichophylla Munro ex Hbd.	ohe	E	g	

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
**Microlaena stipoides (Labill.) R. Br.	meadow ricegrass	A	g	X
Paspalum dilatatum Poir.	dallis grass	A	g	X
Paspalum urvillei Steud.	vaseygrass	A	g	X
**Pennisetum clandestinum Hochst. ex Chiov.	kikuyugrass	A	g	X
Poa annua L.	annual bluegrass	A	g	X
Poa pratensis L.	Kentucky bluegrass	A	g	X
Sacciolepis indica (L.) Chase	Glenwoodgrass	A	g	X
Setaria geniculata (Poir.) Beauv.	perennial foxtail	A	g	X
Sporobolus africanus (Poir.) Robyns & Tournay	African dropseed	A	g	X
JOINVILLEACEAE: Joinvillea Family				
* Joinvillea ascendens Brongn. & Gris. subsp. ascendens	'ohe	E	g	
JUNCACEAE: Rush Family				
Juncus effusus L.	bog rush	A	g	X
Juncus planifolius R. Br.		A	g	X
Juncus tenuis Willd.	slender rush	A	g	X
Luzula hawaiiensis Buch.		E	g	X
LILIACEAE: Lily Family				
Astelia menziesiana Sm.	pa'iniu	E	h	X
Smilax sandwicensis Kunth	hoi-kuahiwi	E	l	X
ORCHIDACEAE: Orchid Family				
Arundina bambusaefolia (Roxb.) Lindl.	bamboo orchid	A	h	X
* Liparis hawaiensis Mann	'awapuhi-a-kanaloa	E	h	

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
PALMAE: Palm Family				
* Pritchardia beccariana Rock	loulu	E	t	
PANDANACEAE: Screw-pine Family				
Freycinetia arborea Gaud.	ie'ie	E	l	X
DICOTYLEDONAE				
AMARANTACEAE: Amaranth Family				
Charpentiera obovata Gaud.	papala	E	s,t	
APOCYNACEAE: Periwinkle Family				
Alyxia olivaeformis Gaud.	maile	E	l	X
AQUIFOLIACEAE: Holly Family				
Ilex anomala Hook. & Arn.	kawa'u	E	t	X
Ilex aquifolium L.	English holly	A	s,t	X
ARALIACEAE: Ginseng Family				
Cheirodendron trigynum (Gaud.) Heller	'olapa	E	t	X
Tetraplasandra melandra (Hbd.) Harms	'ohe	E	t	
CAPRIFOLIACEAE: Honeysuckle Family				
Lonicera japonica Thunb.	honeysuckle	A	l	X
CARYOPHYLLACEAE: Pink Family				
Cerastium vulgatum L.	larger mouse ear, chickweed	A	h	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
Drymaria cordata (L.) Willd. ex R.& S.	drymaria	A	h	X
Polycarpon tetraphyllum (L.) L.	allseed	A	h	X
Stellaria media (L.) Villars	common chickweed	A	h	X
CASUARINACEAE: Casuarina Family				
**Casuarina sp.	common ironwood	A	t	X
CELASTRACEAE: Bittersweet Family				
Perrottetia sandwicensis Gray	olomea	E	t	X
COMPOSITAE: Sunflower Family				
Ageratum conyzoides L.	ageratum	A	h	X
Ageratina riparia K. & R.	spreading mist flower	A	h	X
Bidens pilosa L. var. pilosa	Spanish needle	A	h	X
Chrysanthemum leucanthemum L.	white daisy	A	h	X
Cirsium vulgare (Savi) Tenore	bull thistle	A	h	X
Cirsium sp.		A	h	X
Crassocephalum crepidioides (Benth.) S. Moore		A	h	X
Dubautia scabra (DC.) Keck	na'ena'e	E	s	X
Erechtites valerianaefolia (Wolf) DC.	valerian-leaved fireweed	A	h	X
Erigeron bonariensis L.	hairy horseweed	A	h	X
Erigeron canadensis L.	Canada fleabane	A	h	X
Gnaphalium japonicum Thunb.	cudweed	A	h	X
Hypochoeris radicata L.	hairy cats-ear, gosmore	A	h	X
Senecio sylvaticus L.	wood groundsel	A	h	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
Sonchus oleraceus L.	sow thistle	A	h	X
Taraxacum officinale (L.) Weber in Wiggers	dandelion	A	h	X
Youngia japonica (L.) DC.	oriental hawksbeard	A	h	X
CORYNOCARPACEAE: Karaka Family				
Corynocarpus laevigata J.R. & G. Forst	karaka tree	A	t	X
CRUCIFERAE: Mustard Family				
Cardamine flexuosa With. f. umbrosa (Gren. & Godr.) O.E. Schulz		A	h	X
Nasturtium microphyllum Boenn. ex Reichenb.	watercress	A	h	X
CUCURBITACEAE: Squash Family				
Sicyos sp.	kupala	E	l	
EPACRIDACEAE: Epacris Family				
Styphelia tameiameiae (Cham.) F. Muell.	pukiawe	I	s	X
ERICACEAE: Heath Family				
Rhododendrum x hybridium Ker	rhododendron	A	s	X
Vaccinium calycinum Sm. f. fauriei (Levl.) Skottsb.	ʻohelo-kau-laʻau	E	s,t	X
Vaccinium pahalae Skottsb.	ʻohelo	E	s	X
Vaccinium reticulatum Sm.	ʻohelo	E	s	X
FAGACEAE: Beech Family				
Castanea dentata (Marsh.) Borkh.	American chestnut	A	t	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
GERANIACEAE: Geranium Family				
Erodium cicutarium (L.) L'Her. ex Ait.	filaree	A	h	X
Geranium carolinianum L. var. australe (Benth.) Fosb.	Carolina crane's bill	A	h	X
GESNERIACEAE: Gloxinia Family				
* Cyrtandra lysiosepala (A. Gray) C.B. Clarke	kanawao-ke'oke'o	E	s	
* Cyrtandra lysiosepala x C. platyphylla	kanawao-ke'oke'o	E	s	
* Cyrtandra paludosa Gaud.	kanawao-ke'oke'o	E	s	X
* Cyrtandra platyphylla Gray	kanawao-ke'oke'o	E	s	X
GUTTIFERAE: Mangosteen Family				
Hypericum degeneri Fosb.		A	h	X
Hypericum mutilum L.	St. Johnswort	A	h	X
LABIATAE: Mint Family				
* Phyllostegia floribunda Benth.		E	s	
* Phyllostegia racemosa Benth. var. racemosa	kiponapona	E	h	X
* Phyllostegia vestita Benth.		E	l	
Prunella vulgaris L.	self-heal	A	h	X
Stenogyne calaminthoides Gray		E	l	X
* Stenogyne macrantha Benth.		E	l	X
* Stenogyne scrophularioides Benth. var. biflora Sherff	mohihi	E	l	
* Stenogyne scrophularioides Benth. var. remyi Sherff	mohihi	E	l	

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
LEGUMINOSAE: Pea Family				
Acacia koa Gray	koa	E	t	X
Lotus angustissimus L.		A	h	X
Lotus corniculatus L.	bird's foot trefoil	A	h	X
Lotus uliginosus Schk.		A	h	X
Medicago polymorpha L.	burr clover	A	h	X
Sophora chrysophylla (Salisb.) Seem. var. chrysophylla	mamane	E	t	X
Trifolium repens L.	white clover	A	h	X
**Ulex europaeus L.	gorse	A	s	X
LOBELIACEAE: Lobelia Family				
* Clermontia lindseyana Rock		E	s	X
* Clermontia parviflora Gaud. ex Gray	ʻoha-wai	E	s,t	
* Clermontia peleana Rock	ʻoha-wai	E	s,t	
* Clermontia pyrularia Hbd.		E	s	
Clermontia sp.		E	s	X
* Cyanea fernaldii Rock		E	s	
* Cyanea longipedunculata Rock		E	s	
* Cyanea pilosa Gray		E	s	X
* Cyanea shipmannii Rock		E	s	
* Cyanea tritomantha Gray	ʻaku	E	s	
* Trematolobelia sp. Deg. & Deg.	koliʻi	E	s	
LOGANIACEAE: Strychnine Family				
Labordia hedyosmifolia Baill. var. grayana (Hbd.) Sherff	kamakahala	E	s	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
LORANTHACEAE: Mistletoe Family				
Korthalsella complanata (v. Tiegh.) Engler	hulumoa	E	h	X
Korthalsella cylindrica (v. Tiegh.) Engler		E	h	
LYTHRACEAE: Loosestrife Family				
Cuphea carthagenensis (Jacq.) Macbride	tarweed	A	h	X
Lythrum maritimum HBK.		A	h,s	X
MAGNOLIACEAE: Magnolia Family				
Magnolia grandiflora L.	southern magnolia	A	t	X
MALVACEAE: Mallow Family				
Modiola caroliniana (L.) G. Don	modiola	A	h	X
MYOPORACEAE: Naio Family				
Myoporum sandwicense Gray	naio	E	t	X
MYRSINACEAE: Myrsine Family				
* Embelia pacifica Hbd.	kili'oe	E	l	
Myrsine lessertiana A. DC.	kolea-lau-nui	E	t	X
Myrsine sandwicensis A. DC.	kolea-lau-li'i	E	s,t	X
MYRTACEAE: Myrtle Family				
**Eucalyptus sp.		A	t	X
**Eucalyptus robusta Sm.	swamp mahogony	A	t	X
Metrosideros polymorpha Gaud. var.	'ohi'a-lehua	E	s,t	X
**Psidium cattleianum Sabine	strawberry guava	A	t	

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
OLEACEAE: Olive Family				
Fraxinus uhdei (Wenzig) Lingelsh	tropical ash	A	t	X
ONAGRACEAE: Evening primrose Family				
Epilobium cinereum A. Rich	willow herb	A	h	X
Fuchsia magellanica Lam.	fucshia	A	s	X
Ludwigia palustris (L.) Ell.	water purslane	A	h	X
OXALIDACEAE: Wood sorrel Family				
Oxalis corniculata L. var. corniculata	lady's sorrel	A	h	X
PASSIFLORACEAE: Passion flower Family				
**Passiflora mollissima (HBK.) Bailey	banana poka	A	l	X
PHYTOLACCACEAE: Pokeberry Family				
Phytolacca sandwicensis Endl.	popolo-ku-mai	E	s	X
PIPERACEAE: Pepper Family				
Peperomia cookiana C. DC.	'ala'ala-wai-nui	E	h	X
Peperomia expallescens C. DC.	'ala'ala-wai-nui	E	h	X
Peperomia hawaiensis C. DC.	'ala'ala-wai-nui	E	h	X
Peperomia hypoleuca Miq.	'ala'ala-wai-nui	E	h	X
Peperomia leptostachya H. & A.	'ala'ala-wai-nui	I	h	X
Peperomia ligustrina Hbd.	'ala'ala-wai-nui	E	h	
Peperomia lilifolia C. DC.	'ala'ala-wai-nui	E	h	X
Peperomia macreana C. DC.	'ala'ala-wai-nui	E	h	
Peperomia tetraphylla (Forst. f.) H. & A. var. parvifolia (C. DC.) Deg. & Deg.	'ala'ala-wai-nui	I	h	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
PLANTAGINACEAE:: Plantain Family				
Plantago australis Lam.	plantain	A	h	X
Plantago lanceolata L.	narrow-leaved plantain	A	h	X
Plantago major L.	common plantain	A	h	X
PLATANACEAE: Plane-tree Family				
Platanus sp.	plane tree	A	t	X
POLYGONACEAE: Buckwheat Family				
Polygonum punctatum Ell.	water smartweed	A	h	X
Rumex acetosella L.	sheep sorrel	A	h	X
Rumex crispus L.	yellow dock	A	h	X
Rumex giganteus Ait.	pawale	E	s,l	X
PRIMULACEAE: Primrose Family				
Anagallis arvensis L. var. arvensis	scarlet pimpernel	A	h	X
RANUNCULACEAE: Buttercup Family				
Ranunculus plebeius R. Br. ex DC.	common Australian buttercup	A	h	X
Ranunculus repens L.	creeping buttercup	A	h	X
ROSACEAE: Rose Family				
Fragaria vesca L. f. alba (Ehrh.) Rydb.	European strawberry	A	h	X
Prunus cerasus L.	sour cherry	A	t	X
Prunus persica (L.) Batsch.	peach	A	s,t	X
Pyrus malus L.	apple	A	t	
Rosa sp.	rose	A	s	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
Rubus hawaiiensis A. Gray	ʻakala	E	s	X
**Rubus penetrans Bailey	prickly Florida blackberry	A	s	X
Rubus rosaefolius Sm.	thimbleberry	A	s	X
Unknown		A	s	X
RUBIACEAE: Coffee Family				
Coprosma ochracea Oliver	pilo	E	t	X
Coprosma rhynchocarpa Gray	pilo	E	s,t	
Gouldia hillebrandii Fosb.	manono	E	t	X
Gouldia terminalis (H. & A.) Hbd.	manono	E	t	X
* Gouldia terminalis (H. & A.) Hbd. var. quadrangularis Fosb.	manono	E	t	
Nertera granadensis (L. f.) Druce var. insularis Skottsb.	makole	I	h	X
Psychotria hawaiiensis (Gray) Fosb. var. hawaiiensis	kopiko	E	s,t	X
RUTACEAE: Citrus Family				
Pelea clusiaefolia Gray	alani	E	s,t	X
* Pelea grandifolia (Hbd.) St. John & Hume	alani	E	t	X
Pelea pseudoanisata Rock	alani	E	s,t	X
* Platydesma remyi (Sherff) Deg. Deg. Sherff & Stone	Remy's pilo-kea	E	t	
Platydesma spathulata (Gray) Stone	pilo-kea	E	s,t	
SAPINDACEAE: Soapberry Family				
Dodonaea viscosa L.	ʻaʻaliʻi	E	s	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
SAXIFRAGACEAE: Saxifrage Family				
Broussaisia arguta Gaud. var. arguta forma ternata Forbes ex Skottsb.	pu'aha-nui, kanawao	E	s	X
Hydrangea macrophylla (Thunb.) Ser	hydrangea	A	s	X
SCROPHULARIACEAE: Figwort Family				
Castilleja arvensis Schlecht. & Cham.	Indian paintbrush	A	h	X
Veronica arvensis L.	corn speedwell	A	h	X
Veronica plebeia R. Br.	common speedwell	A	h	X
Veronica serpyllifolia L.	thyme-leaved speedwell	A	h	X
SOLANACEAE: Nightshade Family				
Physalis peruviana L.	cape gooseberry	A	h	X
Solanum nigrum L.	popolo, black nightshade	I ?	s	X
Solanum tuberosum L.	potato	A	h	X
THEACEAE:				
* Eurya sandwicensis Gray	anini	E	t	
THYMELAEACEAE: 'Akia Family				
Wikstroemia sp.	'akia	E	s	
UMBELLIFERAE: Carrot Family				
Hydrocotyle sibthorpioides Lam. var. oedipoda Deg. & Greenw.	marsh pennywort	A	h	X
Hydrocotyle verticillata Thunb.	whorled marsh pennywort	A	h	X

Appendix E, continued.

Taxon	Hawaiian Name (natives only)	Status	Life Form	Observed Spring '87
URTICACEAE: Nettle Family				
Pilea peploides (Gaud.) Hook. & Arn.		I	h	X
Pipturus albidus (H.& A.) Gray in Mann	mamaki	E	s,t	X
Touchardia latifolia Gaud.	olona	E	s	
Urera sandvicensis Wedd.	opuhe	E	t	
VERBENACEAE: Verbena Family				
Verbena litoralis HBK.	weed verbena	A	h	X

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APPENDIX F

Percent cover values for plant species and other categories from line intercept data in 6 permanent plots, Hakalau Forest National Wildlife Refuge, Spring 1987

	Percent Cover <1 m	1-2 m
PLOT 1		
Native Ferns	8.6	
Dryopteris hawaiiensis	0.4	
D. wallichiana	8.2	
Alien Grasses	86.2	
Pennisetum clandestinum	86.2	
Bryophytes*	0.6	
Logs**	4.2	
Litter	0.4	
TOTAL	100.0	
PLOT 2		
Native Ferns	20.0	11.2
Asplenium sp.	0.6	
Athyrium microphyllum	2.5	
Cibotium glaucum		1.2
Dryopteris glabra		0.4
D. wallichiana	16.9	9.6
Native Woody Plants	1.0	12.4
Metrosideros polymorpha	0.2	2.6
Rubus hawaiiensis	0.8	3.6
Vaccinium calycinum		6.2
Alien Grasses	17.5	
Holcus lanatus	1.8	
Microlaena stipoides	15.7	
Alien Herbs	0.2	
Veronica serpyllifolia	0.2	
Bryophytes*	12.6	
Logs**	0.2	
Litter	12.3	
Soil	36.2	
TOTAL	100.0	23.6
PLOT 3		
Native Ferns	3.3	
Cibotium glaucum	1.1	
Dryopteris wallichiana	1.9	
Elaphoglossum wawrae	0.3	
Native Woody Plants	3.1	1.0
Metrosideros polymorpha	2.7	1.0
Styphelia tameiameiae	0.4	
Alien Grasses	91.8	
Anthoxanthum odoratum	65.3	
Juncus effusus	3.8	

Appendix F, continued.

	Percent Cover	
	<1 m	1-2 m
Microlaena stipoides	19.1	
Paspalum urvillei	3.6	
Alien Shrubs	0.2	
Rubus penetrans	0.2	
Bryophytes*	3.6	
TOTAL	100.0	2.0
PLOT 4		
Native Ferns	6.3	
Asplenium sp.	0.6	
Athyrium microphyllum	0.4	
Cibotium glaucum	1.0	
Dryopteris glabra	3.7	
D. wallichiana	0.6	
Native Woody Plants	9.6	20.2
Metrosideros polymorpha	5.6	6.6
Styphelia tameiameiae	2.4	4.0
Vaccinium calycinum	1.6	9.6
Alien Grasses	68.7	
Anthoxanthum odoratum	0.6	
Juncus effusus	17.7	
J. tenuis	0.6	
Microlaena stipoides	49.8	
Bryophytes*	4.8	
Litter	9.2	
Soil	1.4	
TOTAL	100.0	20.2
PLOT 5		
Native Ferns	7.3	
Dryopteris glabra	7.3	
Native Woody Plants	3.4	3.5
Metrosideros polymorpha	3.4	3.5
Alien Grasses	63.2	
Anthoxanthum odoratum	25.4	
Juncus effusus	1.2	
Microlaena stipoides	36.6	
Alien Herbs	1.8	
Veronica plebeia	0.4	
V. serpyllifolia	1.4	
Bryophytes*	5.2	
Lichens	3.6	
Litter	8.1	
Logs**	6.3	
Soil	1.1	
TOTAL	100.0	3.5

Appendix F, continued.

	Percent Cover	
	<1 m	1-2 m
PLOT 6		
Native Ferns	35.7	
Dryopteris glabra	24.9	
D. wallichiana	0.1	
Elaphoglossum wawrae	9.8	
Native Woody Plants	2.4	15.2
Metrosideros polymorpha	1.0	1.4
Rubus hawaiiensis	0.4	0.8
Styphelia tameaiameiae	0.2	12.0
Vaccinium calycinum	0.8	1.0
Alien Grasses	8.2	
Microlaena stipoides	8.2	
Bryophytes*	5.0	
Logs **	0.4	
Litter	45.5	
Soil	2.8	
TOTAL	100.0	15.2

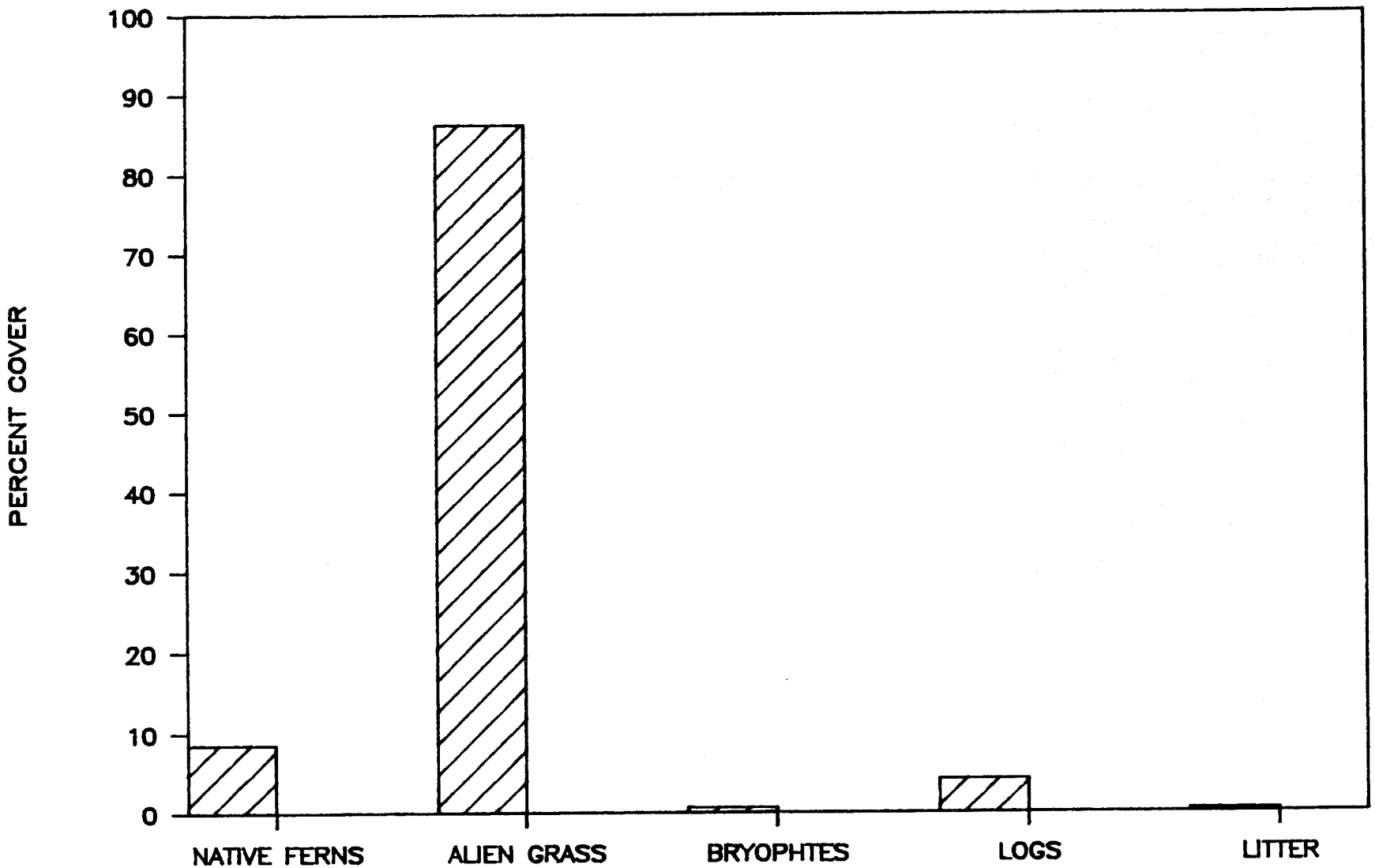
*Liverworts and mosses on ground and tree trunks.
**Fallen trees.

APPENDIX G

Percent cover from line intercept data in 6 permanent plots, Hakalau Forest National Wildlife Refuge, Spring 1987

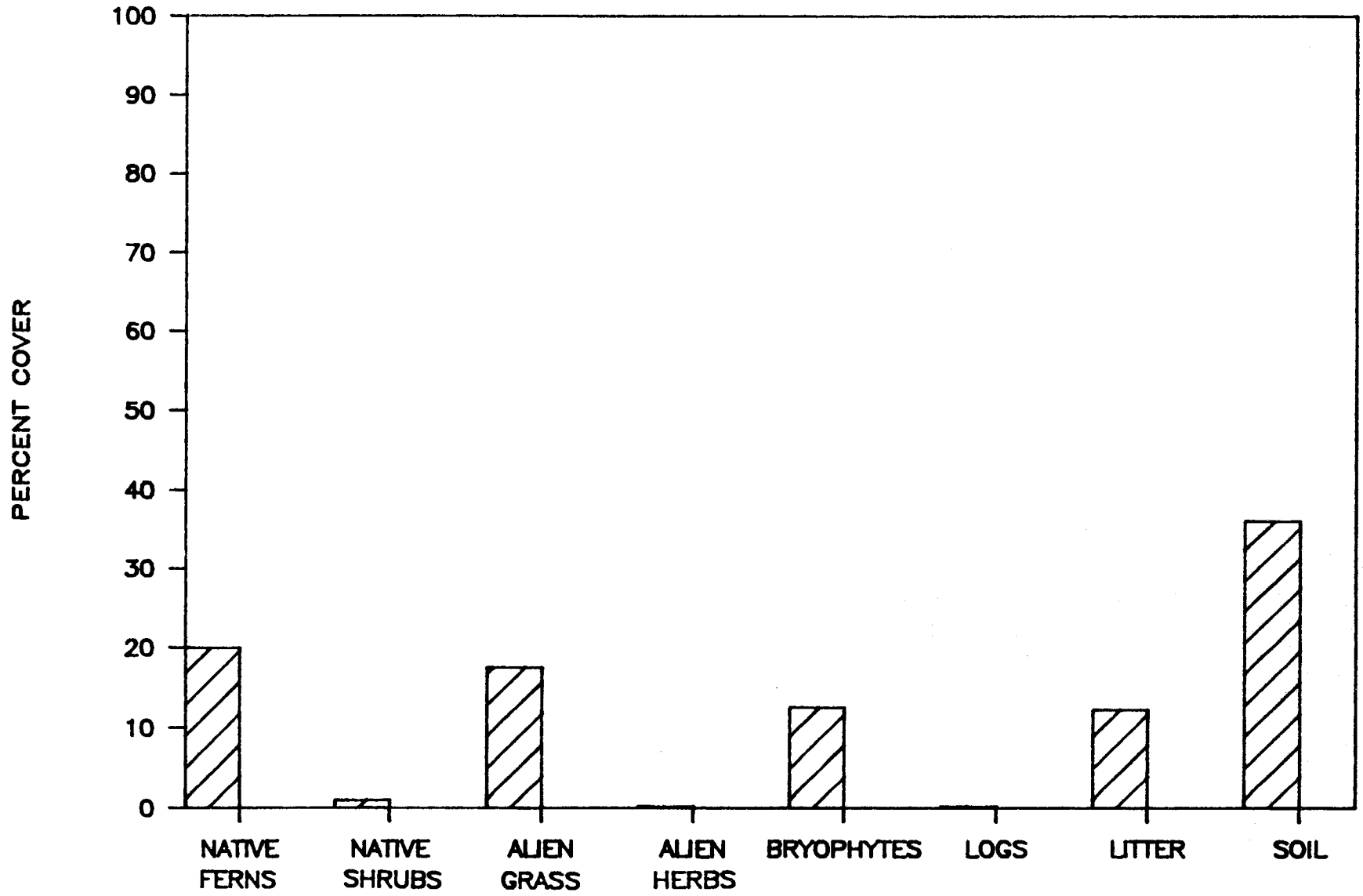
HAKALAU VEGETATION PLOT 1

LINE INTERCEPT TRANSECT



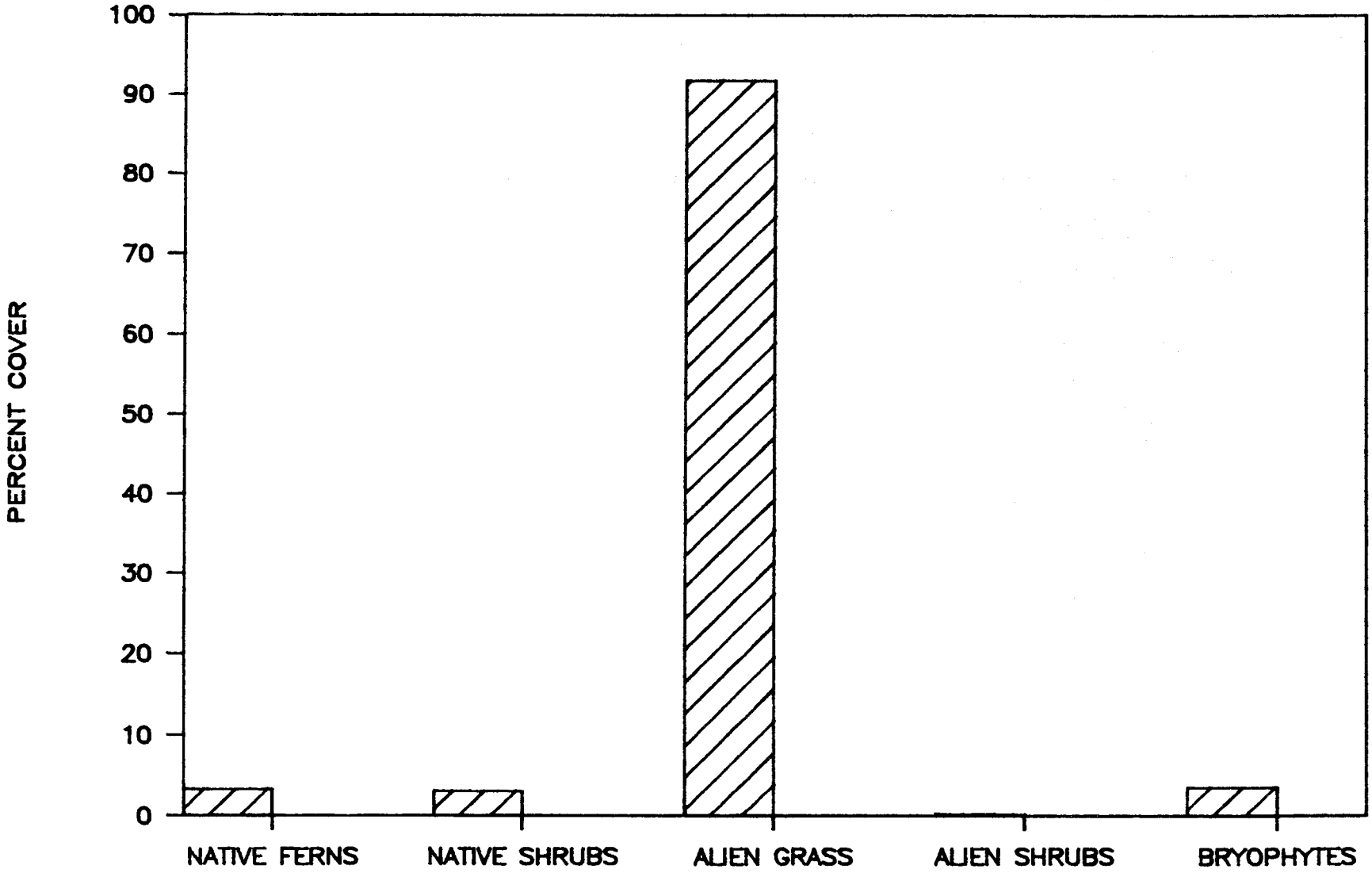
HAKALAU VEGETATION PLOT 2

LINE INTERCEPT TRANSECT



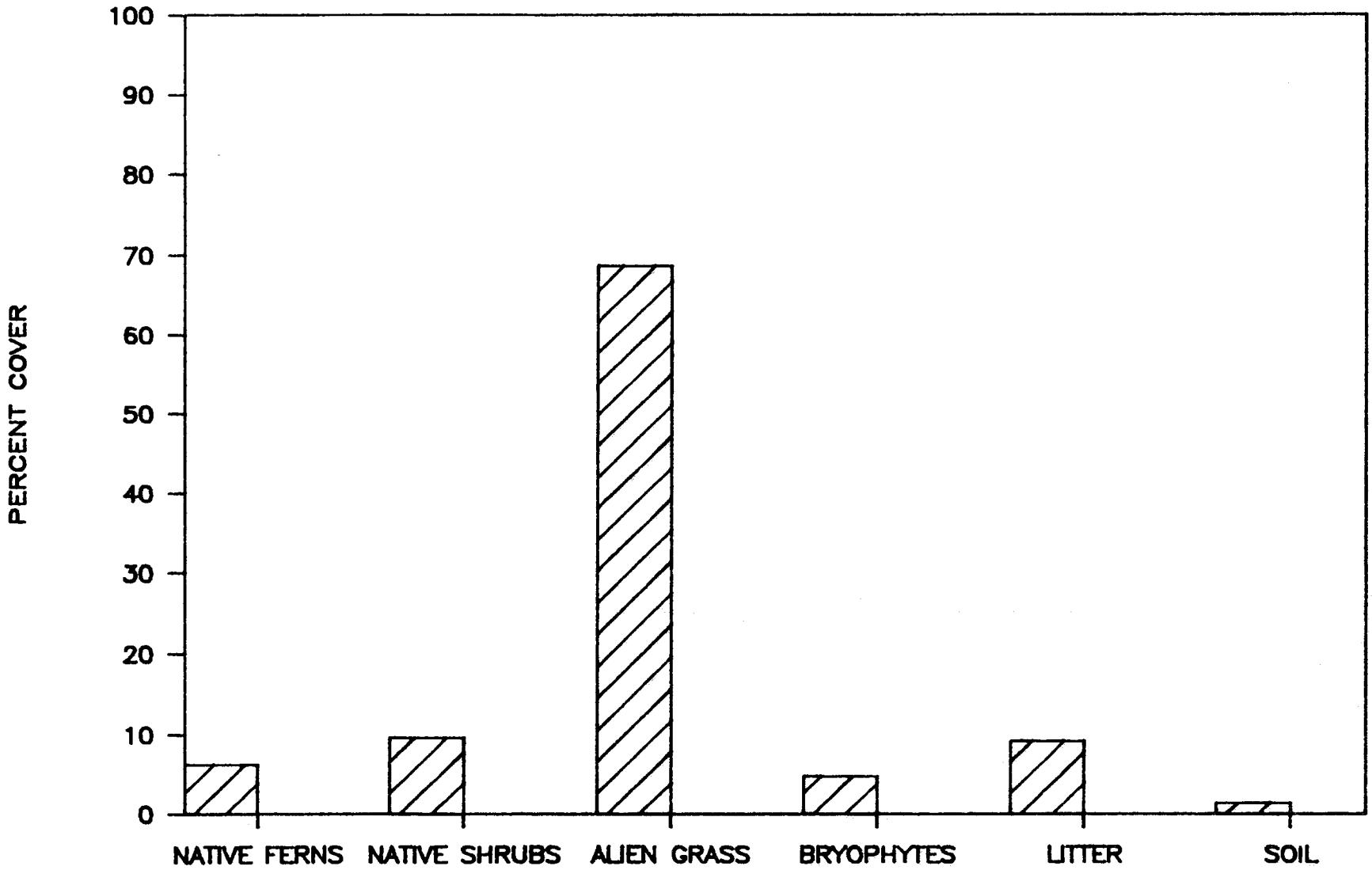
HAKALAU VEGETATION PLOT 3

LINE INTERCEPT TRANSECT



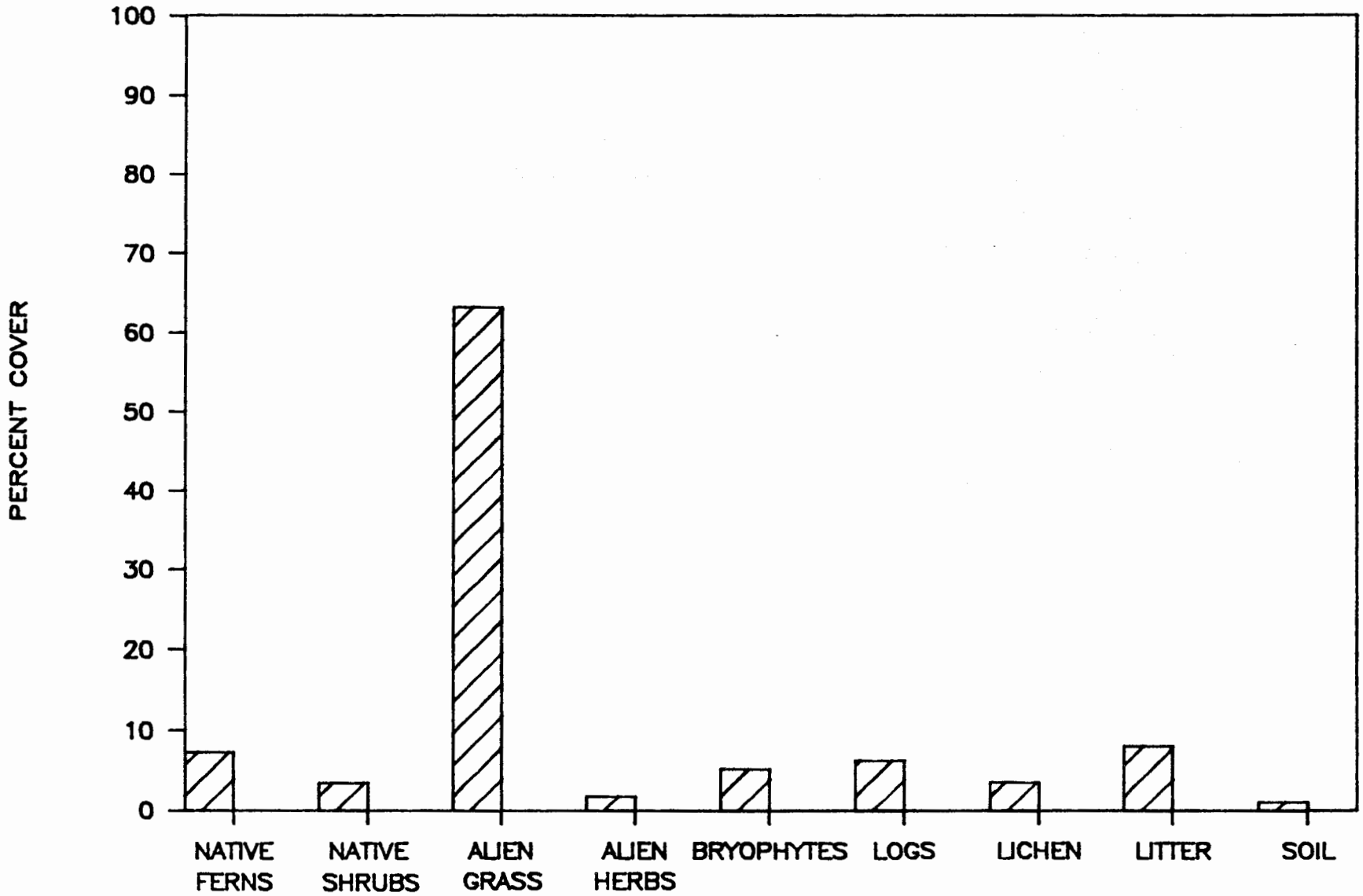
HAKALAU VEGETATION PLOT 4

LINE INTERCEPT TRANSECT



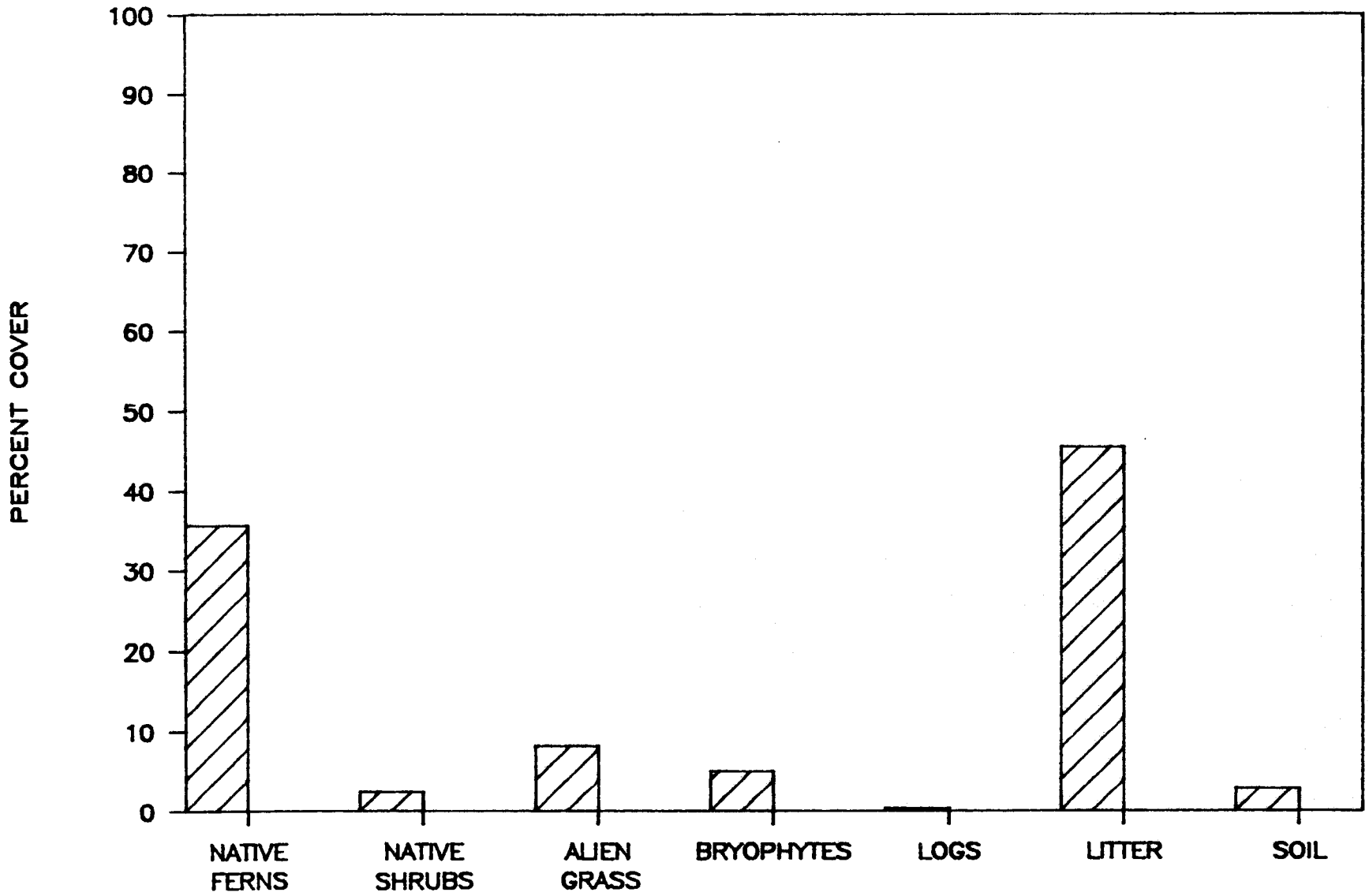
HAKALAU VEGETATION PLOT 5

LINE INTERCEPT TRANSECT



HAKALAU VEGETATION PLOT 6

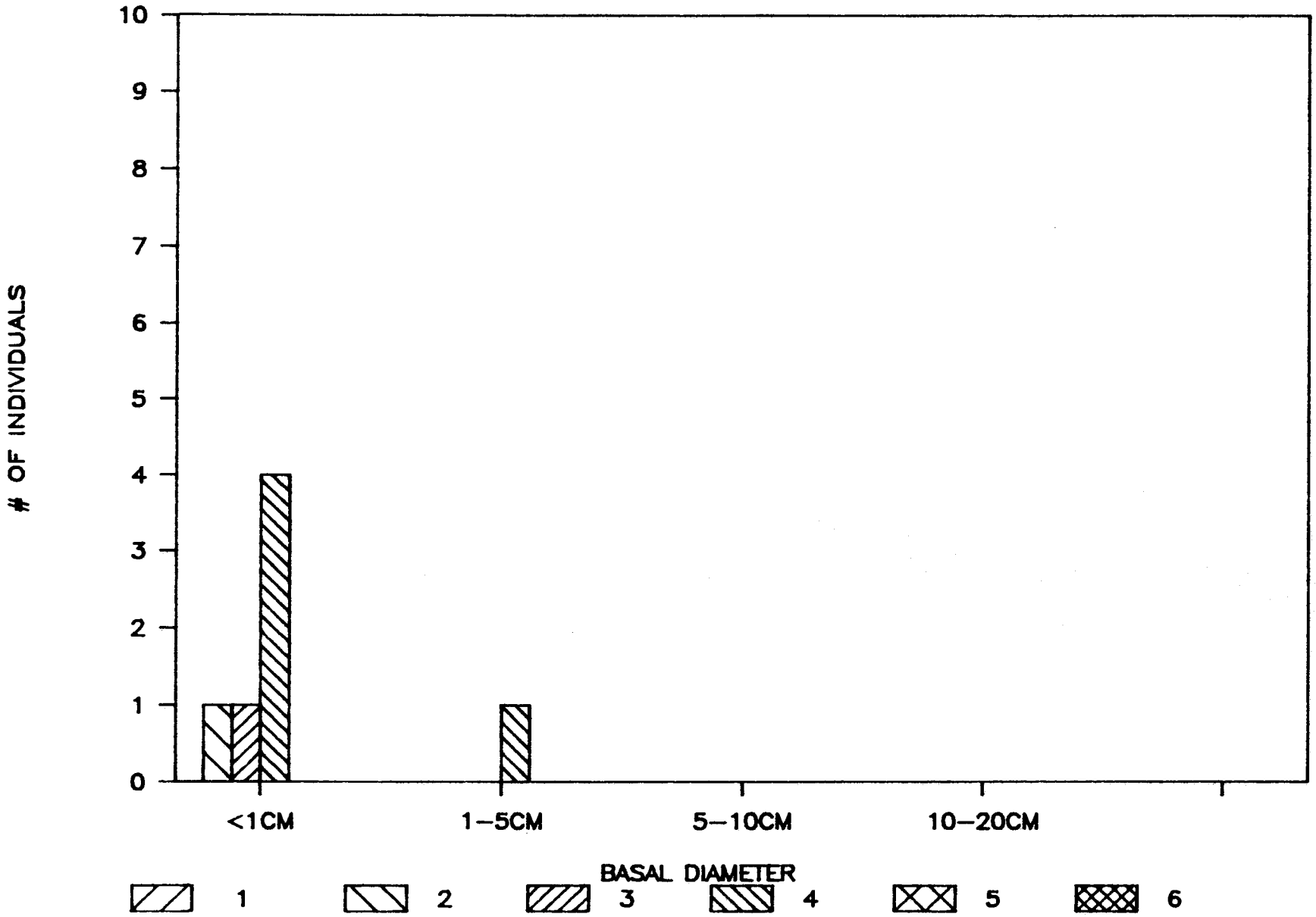
LINE INTERCEPT TRANSECT



APPENDIX H

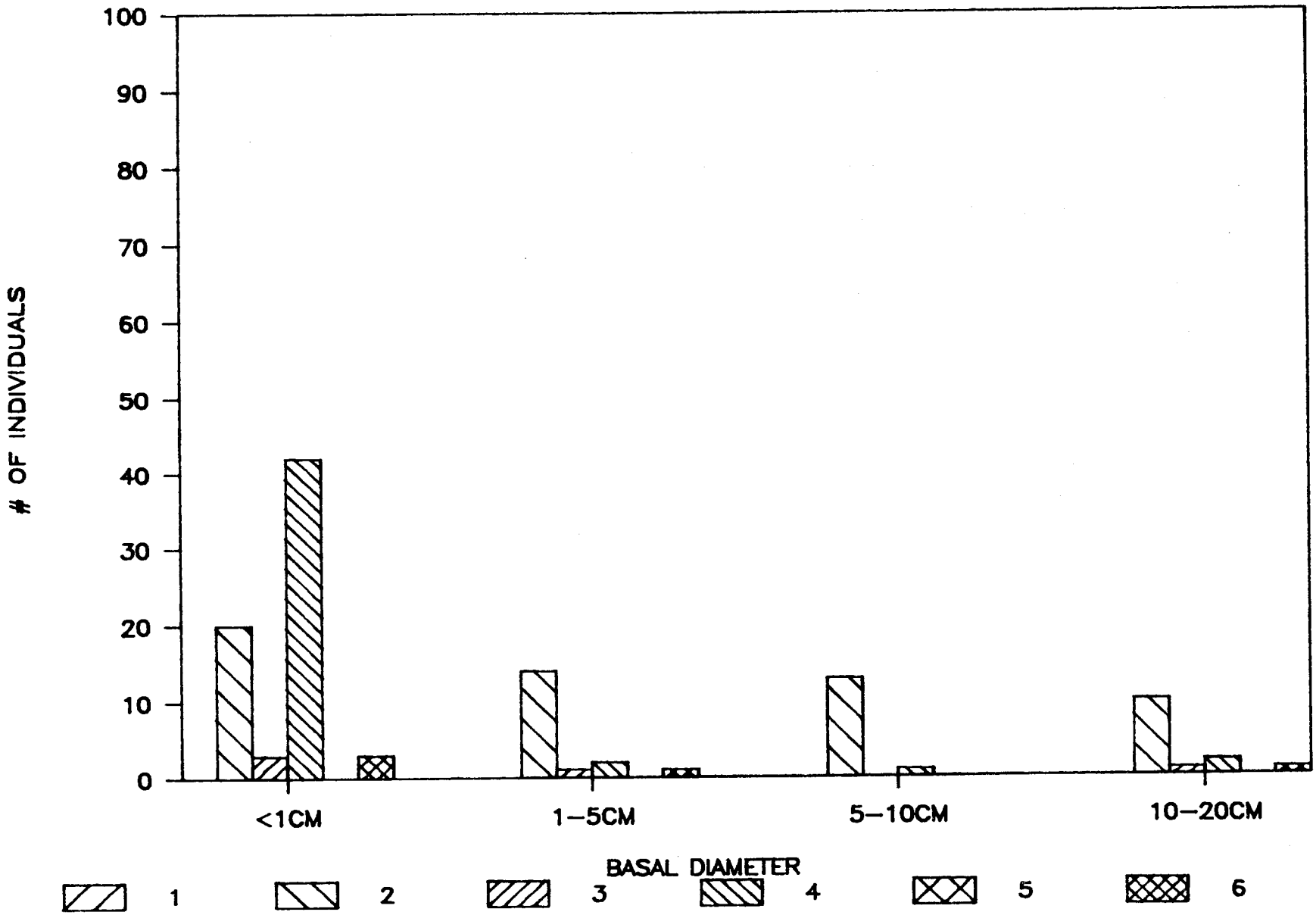
Woody plant counts in 6, 20- x 20-m permanent plots, Hakalau Forest National Wildlife Refuge, Spring 1987

ACACIA DENSITY HAKALAU SITE 1 – 6



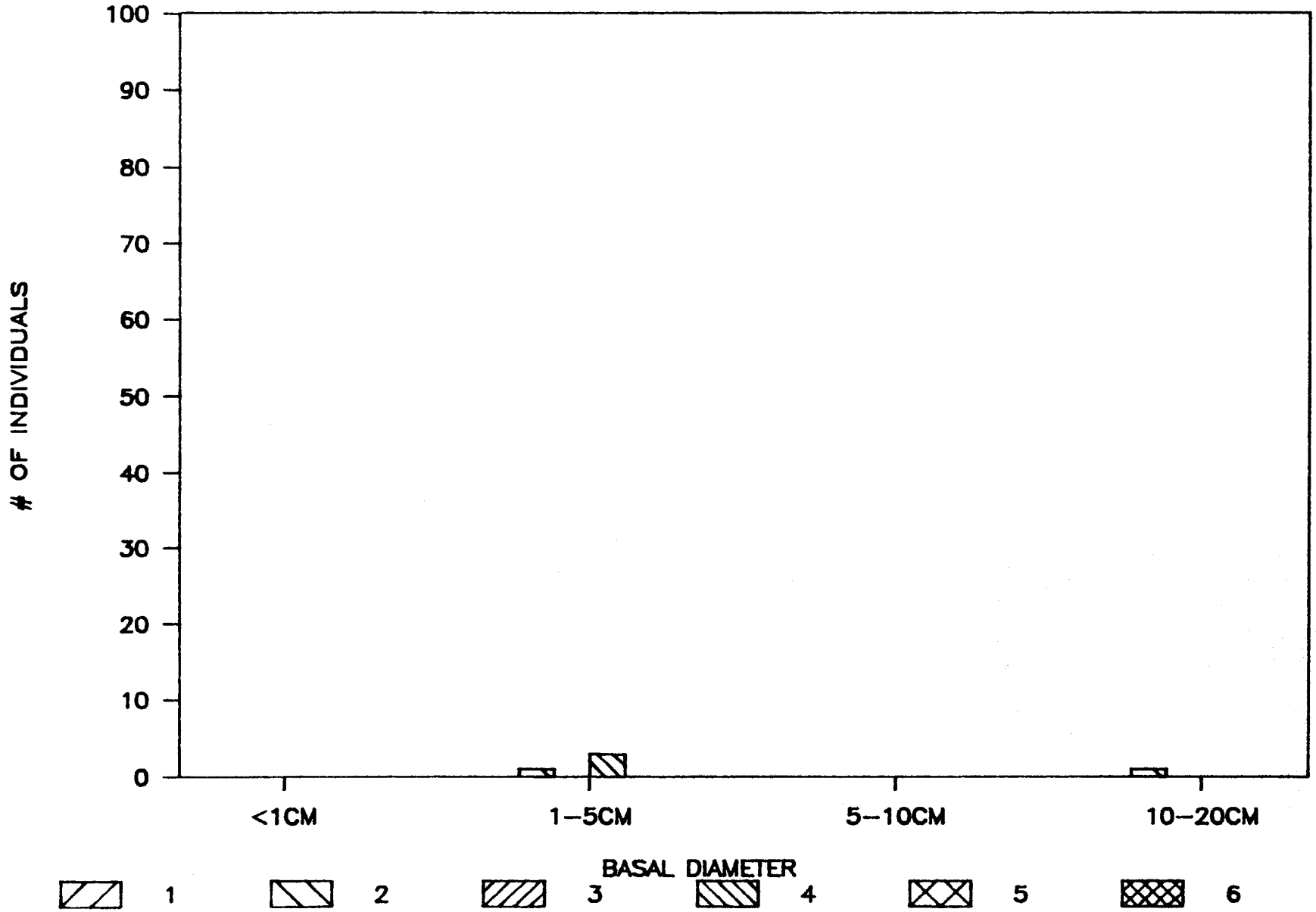
CHEIRODENDRON DENSITY

HAKALAU SITE 1 – 6

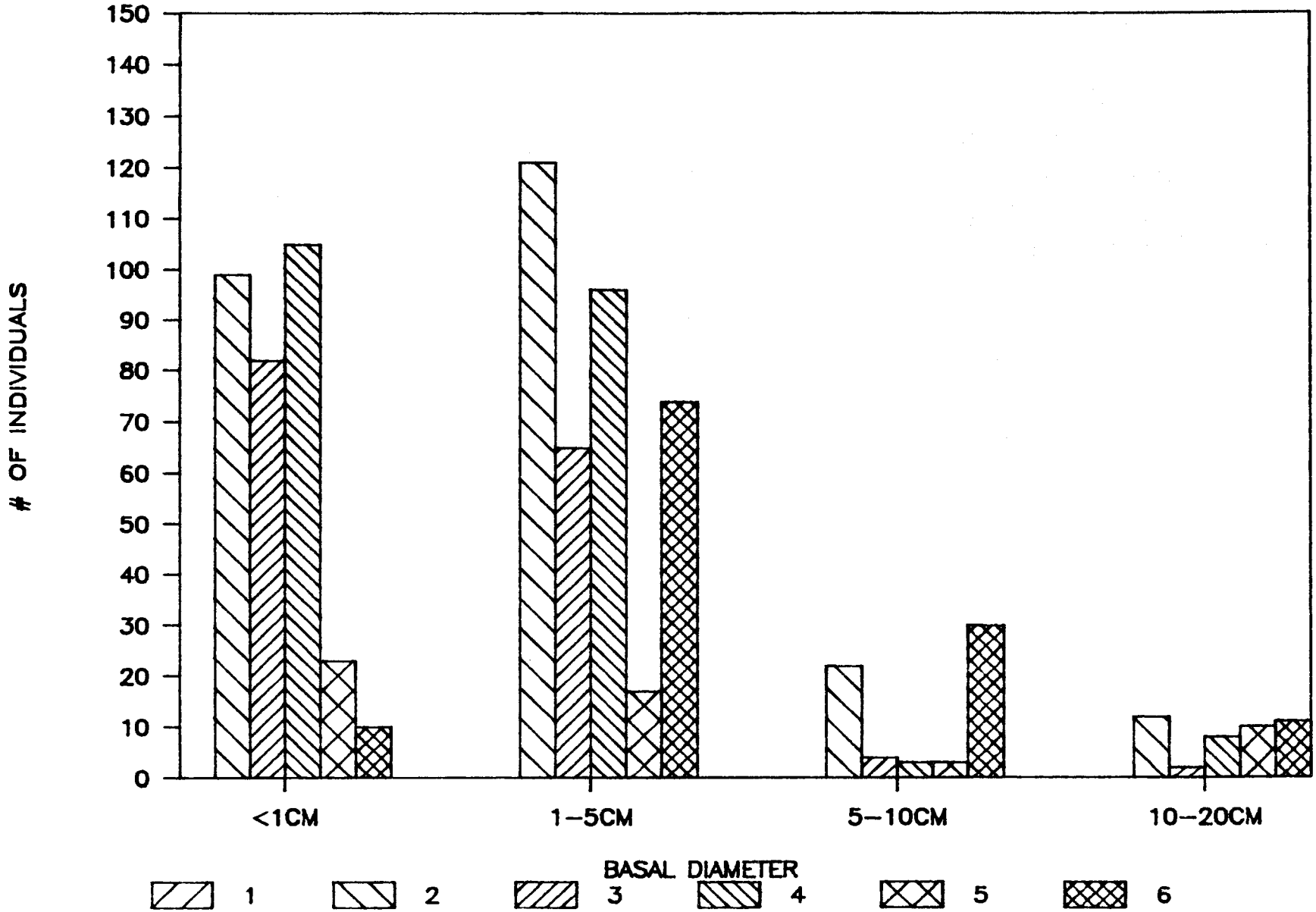


CIBOTIUM GLAUCUM DENSITY

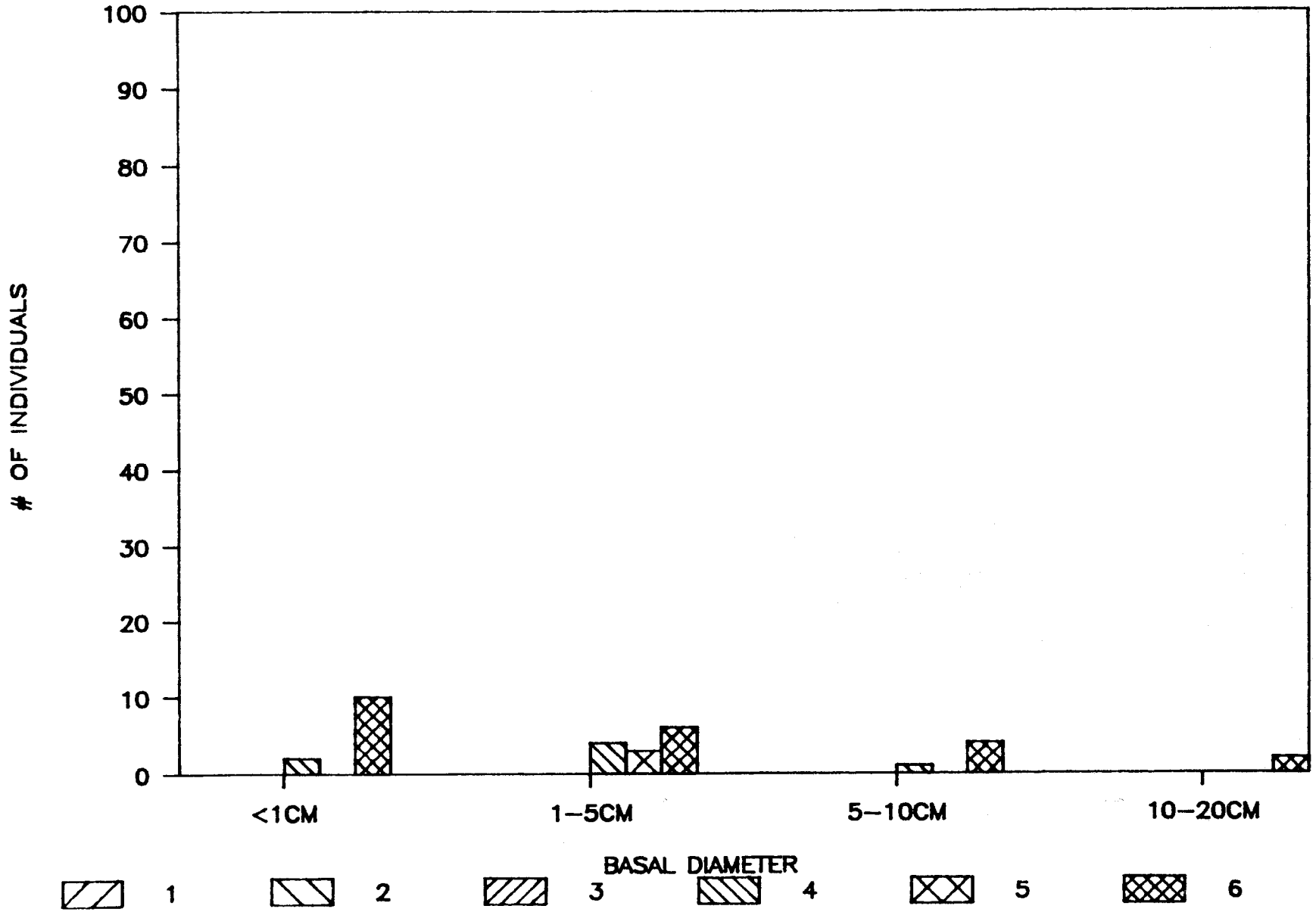
HAKALAU SITE 1 – 6



METROSIDEROS DENSITY HAKALAU SITE 1 – 6

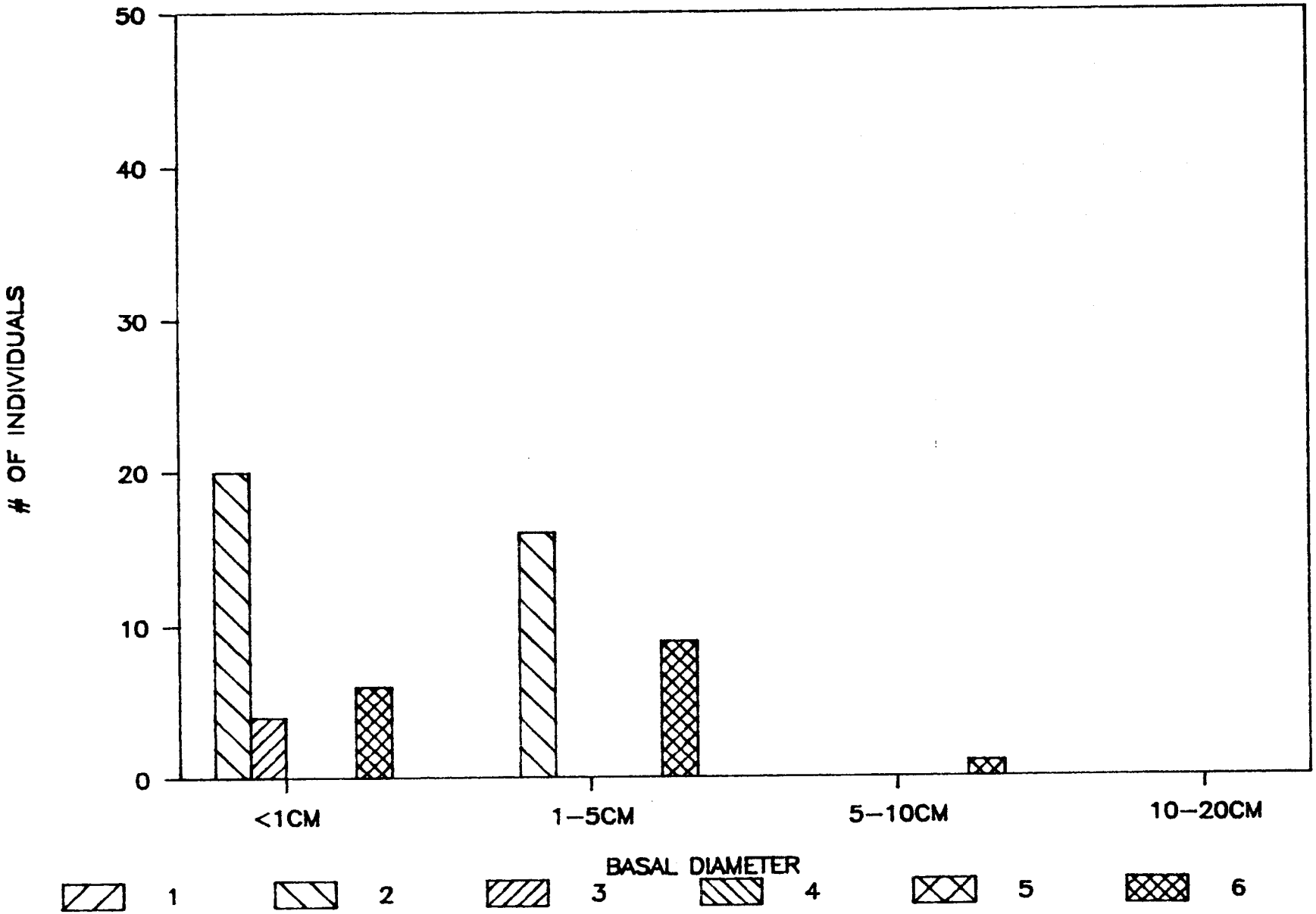


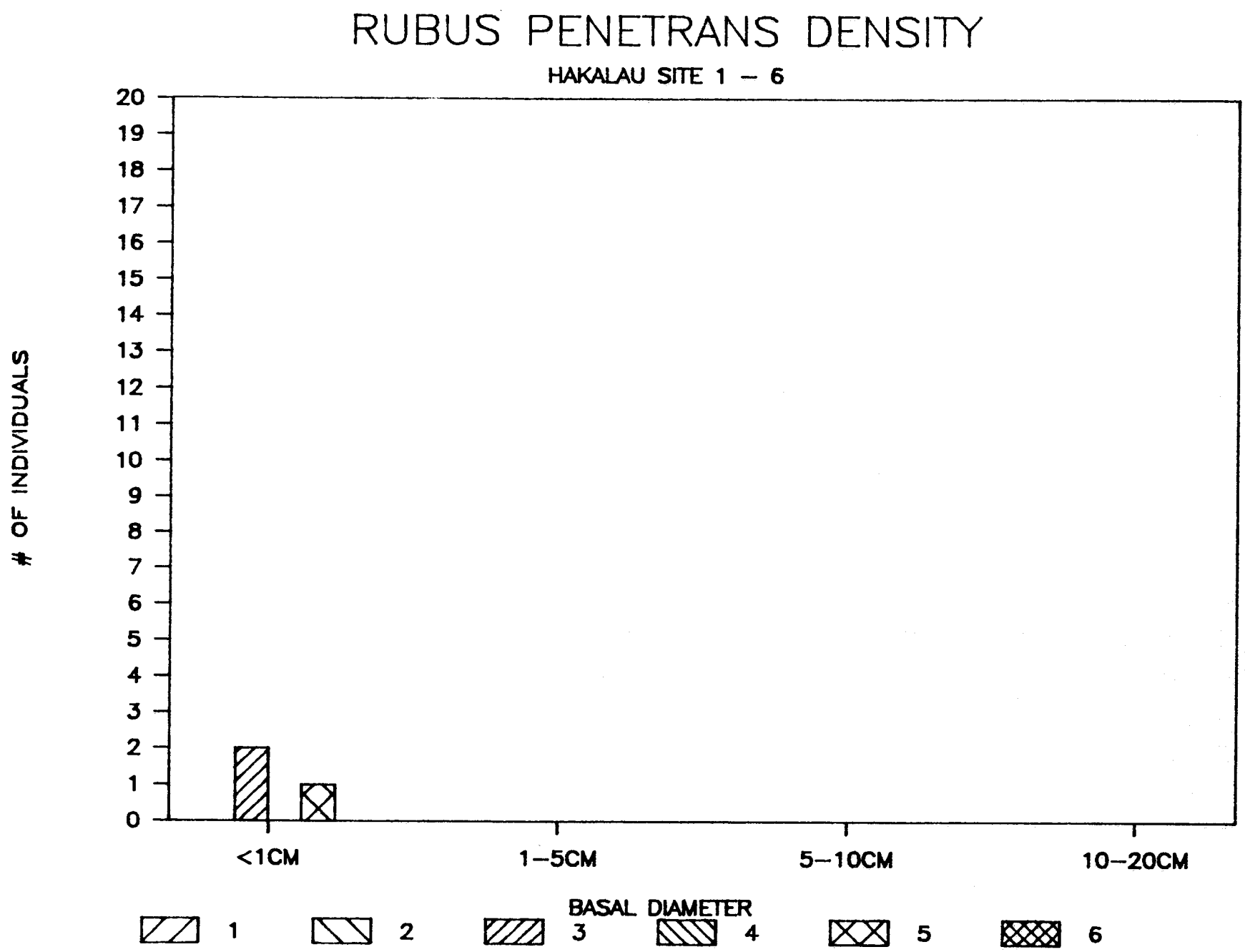
MYRSINE DENSITY HAKALAU SITE 1 – 6

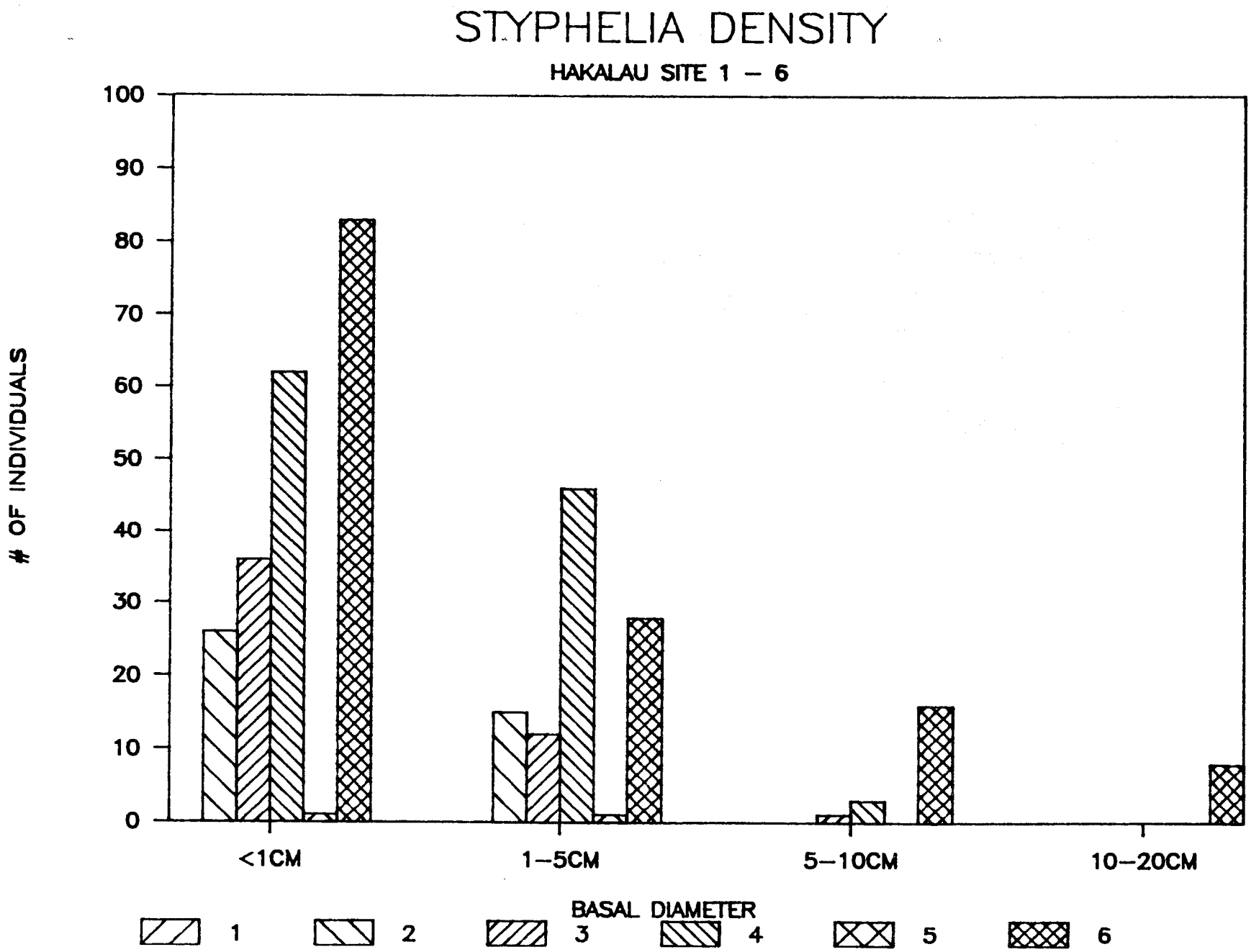


RUBUS HAWAIIENSIS DENSITY

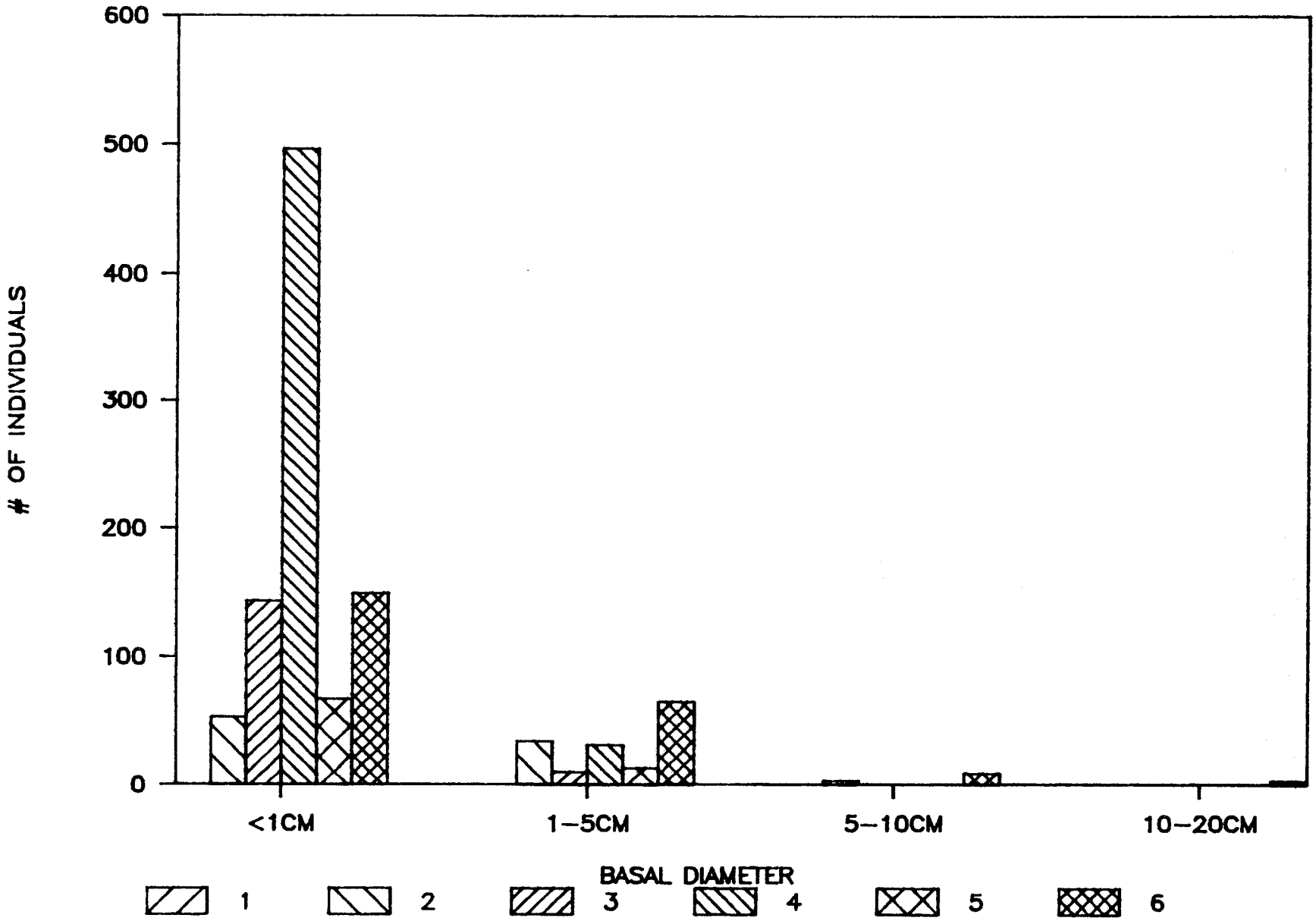
HAKALAU SITE 1 – 6




RUBUS PENETRANS DENSITY
HAKALAU SITE 1 – 6
OF INDIVIDUALS
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
<1CM
1–5CM
5–10CM
10–20CM
BASAL DIAMETER
1
2
3
4
5
6


STYPHELIA DENSITY
HAKALAU SITE 1 – 6
OF INDIVIDUALS
100
90
80
70
60
50
40
30
20
10
0
<1CM
1–5CM
5–10CM
10–20CM
BASAL DIAMETER
1
2
3
4
5
6

VACCINIUM DENSITY HAKALAU SITE 1 – 6



APPENDIX I

BRAUN-BLANQUET COVER VALUES IN 6 PERMANENT PLOTS,
HAKALAU FOREST NATIONAL REFUGE, SPRING 1987

SPECIES	STATUS	STRATUM	PLOT 1	2	3	4	5	6
		Canopy (>10 m)						
Acacia koa	E		1	2		2	2	2
Metrosideros polymorpha	E		3	3	2	4	3	3
Passiflora mollissima	A			+				
		Subcanopy (2-10 m						
Cheirodendron trigynum	E		+	3	+	1		+
Ilex anomala	E						1	
Metrosideros polymorpha	E		1	3	2	2	2	3
Myrsine lessertiana	E					+		+
Passiflora mollissima	A			1				
Vaccinium calycinum	E		+					
		Shrub 1 (1-2 m)						
Cheirodendron trigynum	E			2				
Cibotium chamissoi	E					1		
Cibotium glaucum	E			+	t			
Coprosma sp.	E							+
Ilex anomala	E							+
Metrosideros polymorpha	E			1	+	+	+	1
Myrsine lessertiana	E							+
Rubus hawaiiensis	E			2				2
Styphelia tameiameiae	I			+	+	1		2
Vaccinium calycinum	E			+	+	+	+	1

Appendix I, continued.

SPECIES	STATUS	STRATUM	PLOT 1	2	3	4	5	6
		Shrub 2 (0.5-1m)						
Acacia koa	E			+				
Cheirodendron trigynum	E					+		
Cibotium glaucum	E			+		r		
Metrosideros polymorpha	E			1		1		2
Myrsine lessertiana	E					+		+
Rubus hawaiiensis	E			2				+
Styphelia tameiameiae	I			+		2		3
Vaccinium calycinum	E			1		+		2
		Herb 1 (0.2-0.5m)						
Asplenium lobulatum	E			1				
Asplenium polyodon	E			+				
Athyrium microphyllum	E			1	+			+
Carex alligata	E			+				
Cheirodendron trigynum	E					+		
Cibotium glaucum	E			+	+			
Coprosma sp.	E			+				
Diplazium sandwichianum	E			+	+			+
Dryopteris glabra	E		+	1	+	1	2	3
Dryopteris hawaiiensis	E		+				+	
Dryopteris wallichiana	I		3	2	2	+	+	1
Juncus effusus	A				1	+	1	+
Metrosideros polymorpha	E			+	1	2	+	
Myrsine lessertiana	E						+	
Phytolacca sandwicensis	E			+				
Rubus hawaiiensis	E			1				+

Appendix I, continued.

SPECIES	STATUS	STRATUM	PLOT 1	2	3	4	5	6
Sadleria pallida	E				+			
Sticherus owhyhensis	E							+
Styphelia tameiameiae	I			+	+	1		+
Vaccinium calycinum	E				+	1	+	+
		Herb (<0.2m)						
Adenophorus tamariscinus	E					+		
Anthoxanthum odoratum	A		1		3		2	
Asplenium normale	I			+		+		
Asplenium polyodon						+		
Asplenium sp.	E				+			
Athyrium microphyllum	E				+			+
Axonopus affinis	A					+		+
Bryophyte	E		+				+	1
Cardamine flexuosa	A			+				
Cheirodendron trigynum	E				+	+		
Cibotium glaucum	E			1	1			+
Coprosma sp.	E				+			
Diplazium sandwichianum	E		+		+			+
Dryopteris glabra	E				+	+	1	1
Dryopteris hawaiiensis	E				+		+	
Dryopteris wallichiana	I			+	+	+	+	+
Elaphoglossum wawrae	E				+			1
Geranium carolinianum	A		+		+			
Holcus lanatus	A		+		+			
Juncus effusus	A			+		+	+	
Juncus tenuis	A				+			
Lycopodium cernuum	I				+			
Metrosideros polymorpha	E				+	+		

Appendix I, continued.

SPECIES	STATUS	STRATUM	PLOT 1	2	3	4	5	6
Microlaena stipoides	A		+	2	4	5	4	2
Nertera granadensis	I			+				
Poa annua	A					+	+	
Passiflora mollissima	A		r					
Pennisetum clandestinum	A		5					
Phytolacca sandwicensis	E		r	+				
Polygonum punctatum	A				+			
Polypodium pellucidum	E			1				
Rubus hawaiiensis	E		+	+	+			+
Rubus penetrans	A		+		+			
Rubus rosaefolius	A						+	
Rumex acetosella	A		+		+		+	
Sphenomeris chinensis	I				+			
Styphelia tameiameiae	I				+	+		
Vaccinium calycinum	E				+	1		
Veronica plebeia	A		+		+	+	+	+
Veronica serpyllifolia	A		+				+	+
		Ground						
Litter			+			1	+	3
Logs					+			
Rock			+					
Scats (Cattle)					+	+	+	+
(Pig)						+		+
Soil				3		1	+	2

APPENDIX J

Preliminary Fencing Information for Proposed Management Units, Hakalau Forest National Wildlife Refuge

Unit 1 .. 949 acres. Existing fences can be used. Some fences may need repair and reinforcing.

Unit 2 .. 843 acres. World Union boundary fence needs fixing. Some fences need reinforcement. Existing fences.

Unit 3 .. 2,056 acres. Use existing fences but some need reinforcing.

Unit 4 .. 1,154 acres. World Union boundary fence needs fixing. Some fences need reinforcement. Existing fences.

Unit 5 .. 706 acres. Piha boundary fence needs fixing. North boundary fence needs construction. East boundary fence below Nauhi camp in unknown condition. Use existing fences.

Unit 6 .. 1,176 acres. All fences to be constructed.

Unit 7 .. 1,257 acres. All fences to be constructed.

Unit 8 . 1,482 acres. West fence to be constructed. Piha boundary east and south fences need fixing.

Unit 9 .. 2,111 acres. West fence needs fixing. All other boundary fences to be constructed.

Unit 10 .. 2,031 acres. All boundary fences to be constructed.

Unit 11 .. 1,894 acres. All boundary fences to be constructed.