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Relative Effects of Human and Feral Hog Disturbance on a Wet Forest in Hawaii

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ABSTRACT

The effects of 20 months of intensive disturbance by humans, as well as the presence of feral hogs Sus scrofa, *was measured on vegetation. Both forms of disturbance have been thought severely to affect Hawaiian rain forests by reduction of plant cover and allowing the proliferation of exotic plants. Despite much human use throughout the study area, the only significant ($P \leq 0{\cdot}05$) effects were within 2 m of a trail. This disturbance was limited to vegetation < 10 cm in height. No change in canopy cover or in incidence of exotic plants was noted. Feral hog usage was approximately three times higher in the study area than outside, and caused a great deal of damage to the vegetation. The direct impact of humans is relatively minor, being restricted to < 5% of the area. The greater frequency of hogs in the study area could have an undetermined but possibly serious effect on the vegetation.*

INTRODUCTION

The preservation of forested areas in natural reserves and parks requires that land managers balance benefits derived from human use with possible effects on the resources (Burden & Randerson, 1972). In ecosystems with slow growth, shallow soils, and species sensitive to disturbance, even moderate use can result in some alteration of the

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habitat (Liddle & Greig-Smith, 1975). The mid-elevation (1500–2500 m) wet forests in Hawaii are thought to be such an ecosystem. It was our purpose to assess the impact of regular human use on one such forest. We also document the effects of feral hogs *Sus scrofa* in the area. Other studies have documented the profound effects of feral hogs on an ecosystem (e.g., Bratton, 1975).

VEGETATION OF THE STUDY SITE

The study site was in the Kilauea Forest Reserve, located on the east slope of Mauna Loa, on the island of Hawaii. The site is in an area of reasonably level terrain. The vegetation can be classified as an *Acacia-Metrosideros-Cibotium* montane rain forest and is described in detail in Mueller-Dombois *et al.* (1981). *Acacia koa* var. *hawaiiensis* is the emergent tree at 25–35 m, and *Metrosideros polymorpha* makes up most of the canopy at 10–20 m. In a lower level, 2–5 m, tree ferns (*Cibotium* spp.) form a nearly closed canopy. This three-layered structure of the upper level vegetation is typical of this forest type. Cooray & Mueller-Dombois (1981*a*) considered this forest to be in a stable condition because species composition and structure are being maintained, with reproduction of essentially all species.

Below the mature tree ferns (<2 m high) are various ferns (*Dryopteris paleacea*, *Sadleria pallida*, and immature tree ferns) and sedges (*Uncinia uncinata* and *Carex alligata*). The other vascular plants living at these levels include tree and shrub seedlings. These most often grow on downed logs that usually develop a solid layer of moss. The most common plants on logs are: *Metrosideros polymorpha*; *Cheriodendron trigynum*; *Ilex anomala*; *Vaccinium calycinum*; and the ferns *Adenophorus* spp., *Athyrium microphyllum*, *Elaphoglossum* spp., *Grammitis hookeri*, and *Dryopteris* spp.

Five exotic species encountered were: *Rubus* spp. (not including *R. hawaiiensis*); *Hypericum mutilum*; *Microlaena stipoides*, and *Athyrium japonicum*.

METHODS

The area of human use ('study area') consisted of a 16-ha gridded area in the Kilauea Forest Reserve, 15 km north of the headquarters of Hawaii

Volcanoes National Park on the island of Hawaii. This is a wet montane site at 2000 m, with an annual rainfall of about 200 cm.

Human use

The study area had been subjected to frequent human disturbance by biologists studying bird and plant populations between April 1978 and late 1979. A circular trail and an additional diagonal trail, resulting in one continuous trail totalling about 1·3 km, had been placed in the plot (Fig. 1). This trail provided access for researchers using mist nets to

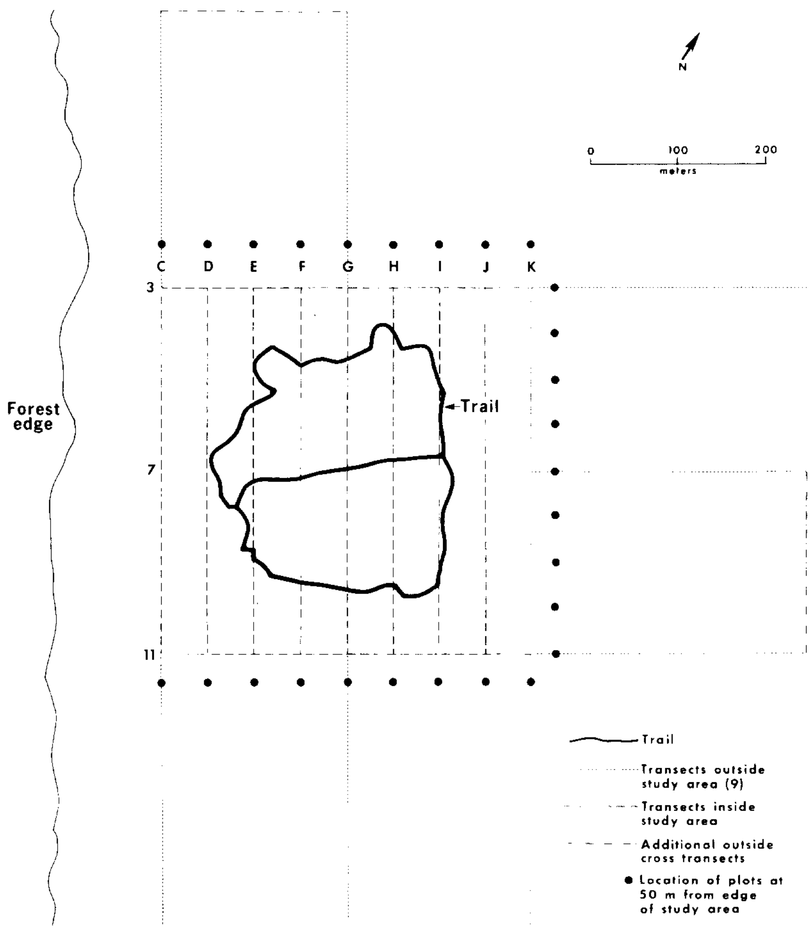

Fig. 1. Map of study area with the trail, study transects, and study plots shown. Letters and numbers indicate designations of transects.

capture birds, and other activities. The trail was laid out as nearly as possible to form a circle with a diagonal across it, but avoided large tangles of downed trees. The only clearing done was the very occasional removal of small branches obstructing the trail itself. The trail averaged less than 0·4 m wide, and generally was so inconspicuous that surveyors' flagging was necessary to mark it. The trail received about 76 person-h km^{-1} $month^{-1}$. An additional 200 person-h $month^{-1}$ was distributed more or less evenly within the study area. This is about 12·5 person-h ha^{-1} $month^{-1}$ over the entire 16-ha area. Human disturbance outside of the study area was <1 person-h ha^{-1} $month^{-1}$.

Vegetation (1 m^2) plots

The vegetation was sampled in November and December 1979. Starting at a randomly selected point along the trail (Fig. 1), we established 53 stations at 25-m intervals. At each station, we sampled vegetation in three 1-m^2 plots, one edging on the centre of the trail, another 2 m from centre, and another 5 m from centre. We alternately placed plots at left and right sides of the trail. Fifty metres outside the study area periphery we established 81 additional 1-m^2 plots at 27 stations (Fig. 1). We also measured 45 plots at 50-m intervals along 9 transects 100 m to 300 m outside the study area (Fig. 1).

Within each m^2 plot, we estimated the percent cover of all species of plants <2 m high, bare soil, rocks, logs, and hog disturbance (as evidenced by recently turned soil). We measured the diameter of all plants taller than 2 m at 1 m above the ground, or, in the case of tree ferns, just below the point where the fronds emerge. We identified all plants, insofar as was possible, to species (Table 1).

Volume of vegetation was estimated by multiplying the height of each plant by the area it covered (in cm^2). Plants were grouped for the analysis into those that were <2 m, <1 m, <25 cm, and <10 cm high. We estimated canopy cover of dominant plants by the percent of sky obscured by vegetation directly over each plot. We also recorded the species of plant obscuring the largest percentage of each plot as viewed from the ground.

Feral hog use

We determined the amount of feral hog disturbance inside and outside the study area by faecal counts on 360 plots within and 310 plots outside the

TABLE 1
Frequency of Occurrence of Various Species in 1313 1-m^2 Study Plots

Growth form[a]	*Origin*[b]	*Species*	*Frequency*
t	n	*Acacia koa*	24
f	n	*Adenophorus* spp?	47
v	n	*Alyxia olivaeformis*	2
f	n	*Asplenium contiguum*	1
f	n	*A. lobulatum*	3
h	n	*Astelia menziesiana*	1
f	ex	*Athyrium japonicum*	2
f	n	*A. microphyllum*	47
s	n	*Broussaisia arguta*	21
g	n	*Carex alligata*	49
s	n	*Cheirodendron trigynum*	90
f	n	*Cibotium chamissoi*	13
f	n	*C. glaucum*	350
s	n	*Coprosma* spp?	14
f	n	*Dryopteris nuda*	5
f	n	*D. paleacea*	36
f	n	*D.* spp?	51
f	n	*Elaphoglossum altum*	2
f	n	*E. hirtum*	9
f	n	*Grammitis hookeri*	21
h	ex	*Hypericum mutilum*	76
s	n	*Ilex anomala*	2
f	n	*Lycopodium serratum*	2
t	n	*Metrosideros polymorpha*	174
g	ex	*Microlaena stipoides*	6
s	n	*Myrsine lessertiana*	6
t	n	*Myoporum sandwicense*	4
g	ex	*Paspalum* spp?	2
h	n	*Peperomia* spp?	23
f	n	*Pleopeltis thumbergiana*	5
s	n	*Rubus hawaiiensis*	11
s	ex	*R. penetrans*	1
s	ex	*R.* spp?	6
f	n	*Sadleria pallida*	15
f	n	*Sphenomeris chusana*	2
v	n	*Stenogenyne calaminthoides*	1
g	n	*Uncinia* spp?	82
s	n	*Vaccinium calycinum*	95
h	ex	*Veronica plebea*	2
h	ex	*V. serpyllifolia*	2
f	n	*Xiphopteris saffordii*	4

[a] t, tree; f, fern; v, vine; h, herb; g, grass or sedge; s, shrub.
[b] n, native; ex, exotic.

study area. Plots inside the study area were set along nine 400-m transects (C, D, E, . . ., K in Fig. 1). Hog droppings were counted along the entire transect and divided into 40 plots 10 m long and 2 m wide. Outside the study area, similar measurements were taken along the nine extended transects (C, G, K, 3, 7, and 11 in Fig. 1) and across the ends of two of these transects. In addition, all along the transects above, evidence of hog rooting was tallied as a percent of ground area disturbed in 1-m^2 plots located every 20 m.

RESULTS

Vegetation changes

Overall changes

Significant destruction of flora resulted from the use of the trail (Table 2), but the effect was significant only within 2 m of the trail centre. Between 0–1 m (centred on the trail) and 2–3 m, bare soil decreased an average of 2368 $cm^2\,m^{-2}$ ($P \leq 0{\cdot}001$). Leaf litter increased slightly (by 1017 cm^2, $P \leq 0{\cdot}05$), and moss cover more than doubled ($P \leq 0{\cdot}01$). At 5–6 m from the trail, vegetation and soil cover were the same as in undisturbed forest. There was also no significant difference between comparisons 5 m from the trail inside the study area, and plots outside the study area (Table 2).

Changes in volume

Volume of vegetation was little affected by the trail or by generalized disturbance in the study area (Table 3). Vegetation below 2 m, below 1 m, and below 25 cm each showed no significant ($P > 0{\cdot}05$) volume change from disturbance, either in comparisons of plots at varying distances from the trail, or of plots outside the study area. However, volume of vegetation < 10 cm in height was significantly less ($P \leq 0{\cdot}01$) on the trail (33 $cm^3\,m^{-2}$) than at 2 m from the trail (67 $cm^3\,m^{-2}$). No other comparisons in this group were significant (Table 3).

Tree canopy cover

There was no significant change in canopy cover (Table 2) at increasing distances from the trail. The canopy directly over the plots was predominately the tree fern *Cibotium* (Table 4). In virtually all cases, this was overtopped by *Acacia* or *Metrosideros*.

TABLE 2

Changes in Ground Cover on 1-m^2 Plots at Varying Distances from a Trail in a Wet Hawaiian Forest

Substrate	*Average cover ($cm^2\ m^{-2}$)*[a]								
	Inside area—distance from trail						*Outside area—distance from edge*		
	0–1 m	*P*	*2–3 m*	*P*	*5–6 m*	*P*	*50 m*	*P*	*100–300 m*
Bare log	129	NS	145	NS	319	NS	168	NS	147
Bare rock	58	*	15	NS	28	NS	23	NS	4
Bare soil[b]	4 153	***	1 785	NS	1 464	NS	1 116	NS	1 716
Leaf litter	4 443	*	5 460	NS	6 387	NS	6 624	NS	6 100
Moss	1 222	***	2 570	NS	1 819	NS	2 013	NS	1 978
Hog disturbance[c]	49	***	749	NS	919	NS	472	NS	380
Percent canopy cover	0·58	NS	0·66	NS	0·65	NS	0·66	NS	0·71
Number of plots	53		53		53		81	NS	45

[a] Difference between values across rows is significant as follows: NS, Not significant; * = $P \leqslant 0{\cdot}05$; *** = $P \leqslant 0{\cdot}001$.

[b] No evidence of disturbance and lacking litter or moss.

[c] As evidenced by recently turned soil.

TABLE 3

Changes in Volume of Vegetation on Plots at Varying Distances from a Forest Trail in a Hawaiian Rain Forest

Plant height (cm)	*Average volume ($cm^3\,m^{-2}$)*								
	Inside area—distance from trail						*Outside area—distance from edge*		
	0 m	*P*[a]	*2 m*	*P*	*5 m*	*P*	*50 m*	*P*	*100–300 m*
0–200	576	NS	734	NS	475	NS	794	NS	399
0–100	402	NS	266	NS	383	NS	298	NS	258
0–25	61	NS	73	NS	62	NS	66	NS	74
0–10	33	**	67	NS	48	NS	52	NS	53
Number of plots	53		53		53		81		45

[a] NS, Not significant; ** = $P \leq 0{\cdot}01$.

TABLE 4
Canopy Cover of Vegetation by Percent in Kilauea Forest Reserve, Hawaii

Species	*Plots*		
	Inside area	*50 m outside area*	*100–300 m outside area*
Cibotium glaucum	79·1	78·6	87·9
Metrosideros collina	10·7	6·2	9·4
Acacia koa	4·7	6·1	0·0
Cheriodendron trigynum	3·8	3·8	2·7
Coprosma spp.	0·0	3·0	0·0
Other spp.	1·7	2·3	0·0
	100·0	100·0	100·0
Number of plots	159	81	45

Exotic plants
Non-native plants were slightly more common within 1 m of the trail than at a greater distance (5·4 % of total compared with 1·2–2·9 %), but this difference was not statistically significant (Table 5).

Feral hog disturbance

Evidence of recent rooting by hogs was scarce on the trail (Table 2), averaging $49\,cm^2\,m^{-2}$, probably because much of the soil on the trail

TABLE 5
Abundance of Non-Native (Exotic) and Native Plants in 1-m^2 Plots at Varying Distances from a Forest Trail in Kilauea Forest Reserve, Hawaii

Species origin	*Inside area—distance from trail*			*Outside area—distance from edge*	
	0–1 m	*2–3 m*	*5–6 m*	*50 m*	*100–300 m*
Native (%)	420 (94·6)	487 (98·8)	394 (97·1)	795 (97·9)	412 (97·6)
Exotic (%)	24 (5·4)	6 (1·2)	12 (2·9)	17 (2·1)	10 (2·4)
Total	444	493	406	812	422
Number of plots	53	53	53	81	45

TABLE 6

Average Number (and SE) of Hog Droppings, and Average Area of Ground Disturbance from Rooting of Feral Hogs, in Plots Outside and Inside the Study Area in Kilauea Forest Reserve, Hawaii

Plot location	*Droppings per 20-m² plot*	*Number of plots*	*Hog rooting area cm² per m² plot*	*Number of plots*
Inside	1·65 (0·14)	360	1 132 (105)	369
Outside				
to north	0·56 (0·10)***[a]	110	606 (154)**	91
to east	0·51 (0·11)***	110	772 (155) NS	91
to south	0·47 (0·12)***	90	802 (215) NS	72
Total outside	0·52 (0·06)***	310	721 (99)**	254

[a] Value is significantly different from that for plots inside study area (NS, Not significant; ** = $P \leq 0{\cdot}01$; *** = $P \leq 0{\cdot}001$).

itself was bare and compacted, and human use quickly covered hog disturbances. The amount of hog rooting increased significantly ($P \leq 0{\cdot}001$) at 2–3 m and 5–6 m from the trail. Rooting was less common outside than inside the study area, but the difference was not statistically significant (Table 2) on these small 1-m² plots.

Analysis of the larger 20-m² plots (Table 6), showed that within the 40-ha study area there was 57% more hog rooting than outside the area ($P \leq 0{\cdot}01$). Although the amount of rooting was less in all directions (Table 6), it was significantly less only to the north.

Feral hog abundance

There were approximately three times more hog droppings in the 20-m² plots than outside the study area ($P \leq 0{\cdot}0001$). This difference was found in all directions (Table 6) from the study area, and indicates that hogs were three times more abundant within the study area than outside. Hog droppings remain intact in such a forest usually for no more than two weeks (C. H. Diong, pers. comm.); therefore, this measure represents recent hog activity, certainly within the previous month.

DISCUSSION

Land managers in Hawaii, as well as in other wet forest areas, have been concerned with the effect of human trampling on these forests. We calculate that a single trail would probably result in the loss of $<1\%$ of the vegetative cover in a comparable area. Assuming that the effect of the trail extends 2 m on each side from the centre of the trail, we can calculate the total immediate effect of the 15 months of frequent trampling of the forest floor. (In fact, the assumption overestimates the disturbance, since the effects are greatly reduced even at a distance of 1 m from the centre of the trail.) The 1·3 km trail, if one assumes disturbance within 2 m on either side, occupies about 5200 m^2, or about 3·2 % of the entire 16-ha study area. Within this disturbed band, there was at most a 50 % loss of vegetation near the ground. Therefore, overall loss of vegetation in the study area would be about 1·6 %. A circular trail in the study area results in more disturbance than a single trail traversing the area.

Within the area there was 2–3 times as much hog rooting and three times the hog density (as estimated by recent hog droppings) as in the surrounding forest. Although not conclusive, these results suggest that hog damage may increase in areas of high human use. Possibly hogs were attracted by the access afforded by the human trail. However, there was no significant increase in rooting close to the trail (≤ 5 m), compared with the 20-m^2 plot samples taken throughout the study area. Where land access is more open (hunters were actively excluded by the land owners in the Forest Reserve), we would expect the trail to result in *lower* populations of hogs.

The hogs within the study area were more destructive of the ecosystem than were humans. Recent hog rooting occupied more than 10 % of the study area (6–8 % outside), much more than the area disturbed by humans. The amount of hog rooting is somewhat lower than the values obtained by Cooray & Mueller-Dombois (1981*b*), whose results in the same area ranged from 10·2 %–27·2 % in 4 annual samples taken between 1971 and 1976. (We adjusted their values for a difference in sampling technique.) The presence of hogs probably has more lasting effects beyond the relatively transitory rooting. Rooting prevents regeneration of young plants and could, therefore, modify the future structure and composition of the forest.

Since hog rooting was higher inside the study area, the amount of bare soil might also be expected to be greater than it actually was, as rooting sites become compacted. However, bare soil ranged from 12 to 17 %, both outside and inside the study area. This would indicate that hog rooting had not significantly increased the amount of bare soil, other than the rooting area itself. Thus it appears to be a delay in the effect of the higher hog densities inside the study area. Possibly hogs prefer to root in places where they have done so in the past. Since a favorite hog food available in this area is earthworms (C. H. Diong, pers. comm.), the freshly-turned areas are perhaps most productive of this resource. However, probably most of their food is vegetative material, as has been found here (Cooray & Mueller-Dombois, 1981*b*) and in other areas (Barrett, 1978).

Cooray & Mueller-Dombois (1981*b*) found an average of 62–112 hog droppings ha^{-1}, as contrasted with our values of 260–825 droppings ha^{-1}. No statistical tests were possible, but it seems clear by this measure that there has been a marked increase in hog density since their 1971–76 study. This probably reflects the change in hunting pressure since that period. During 1977–1981 we also noted a marked increase in hog density in another study site 3 km to the west of the Kilauea study site. No evidence of hogs was present at the beginning of the study, but by 1980 freshly turned earth was common throughout the area.

CONCLUSIONS

The presence and moderate human use of a trail and the adjacent forest resulted in vegetative loss of only 2·5% of the cover of small understorey plants. Each forest area will differ, but in most wet forests the loss of vegetation due to a trail will be $<5\%$ at the same level of use. Vegetation taller than 10 cm apparently was not affected. Losses would undoubtedly be higher in bogs and other areas more sensitive to disturbance, and be related to how well use was confined to a trail. It is for the land manager to decide if this relatively minor loss of ground plants is offset by benefits resulting from human use of the forest.

An apparently more destructive factor in our study area was rooting by feral hogs. If further research confirms our hypothesis that hogs are attracted to areas of human activity, controlled hog hunting in these areas could reduce this impact. The presence of well marked and maintained trails may increase hunter access and decrease the effect of these animals, not only near the trails, but at some distance from them.

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